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International VLBI Service for Geodesy and Astrometry 2019+2020 Biennial Report

Dirk Behrend, Kyla L. Armstrong, and Karen D. Baver

October 2021

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Foreword

Since its creation in 1999, the International VLBI Service for Geodesy and Astrometry (IVS) has documented its progress and current status in the form of annual or biennial reports. The first sixteen years were recorded in the form of annual reports, while starting with the years 2015+2016 the rhythm was changed to two years. Hence, the 2019+2020 Biennial Report constitutes the third installment of the two-yearly reporting scheme, documenting the work of the IVS components for the calendar years 2019 and 2020.

As a testament to its usefulness, the general structure of the reporting has remained stable over the years: the individual components of the IVS contributed short reports describing their numerous activities, progress, and future plans. Without the continued input from the VLBI groups of the international geodetic and astrometric community, this publication could not be compiled and the IVS itself would not be able to flourish. So, once again many thanks to all IVS components who contributed to this Biennial Report.

We continue to publish the Biennial Reports in electronic form only. The last Biennial Report with a corresonding printed version was the publication for 2015+2016. Hence, all IVS publications (Biennial Reports, General Meeting Proceedings, and IVS Newsletter) are available online only. The contents of this report appear on the IVS Web site at

`https://ivscc.gsfc.nasa.gov/publications/br2019+2020`

The contents of the report are organized as follows:

- The initial section holds a special report. On July 17, 2020, the IVS Directing Board approved a strategic paper called the "IVS Infrastructure Development Plan 2030" as a planning document for further contributions from IVS components as well as possible new players. How this document came into being is described in the front page article of the August 2020 issue of the IVS Newsletter.
- The next seven sections hold the reports from the Coordinators (including the Chair) and the reports from the IVS Permanent Components: Network Stations, Operation Centers, Correlators, Data Centers, Analysis Centers, and Technology Development Centers.
- The final section provides reference information about IVS. Following the current (May 24, 2019) version of the IVS Terms of Reference, a reference table is provided with links to the IVS Member and Affiliated organizations, the IVS Associate Members, and the IVS Permanent Components.

In its online location, the Biennial Report is part of the IVS website, which contains information concerning the IVS organization. For that, we consider it unnecessary to reproduce this information in the report itself. Hence, we would like to ask our readers to make use of the online tools to look up the most recent lists of IVS components, its member organizations as well as affiliated organizations, and Directing Board Members. The information can be found through the "About IVS" button, which is accessible from most IVS website pages. Useful links are also compiled in the closing section of this report.

During the report period, the IVS consisted of

- 32 Network Stations, acquiring high performance VLBI data,
- three Operation Centers, coordinating the activities of a network of Network Stations,

- seven Correlators, processing the acquired data, providing feedback to the stations and providing processed data to analysts,
- five Data Centers, distributing products to users and providing storage and archiving functions,
- 31 Analysis Centers, analyzing the data and producing the results and products,
- seven Technology Development Centers, developing new VLBI technology,
- an Office for Outreach and Communications, promoting knowledge about the VLBI technique, and
- a Coordinating Center, coordinating daily and long-term activities.

There were altogether

- 87 Permanent Components, representing 43 institutions in 22 countries, and
- about 340 Associate Members.

This report contains contributions from the NICT space-geodesy group at Kashima for a last time; the group will be disbanded at the end of March 2021. With the deconstruction of the 11-m and 34-m antennas, an era is coming to an end. In addition to the telescopes, the Kashima group also supported a Technology Development Center, a Correlator, a Data Center, and an Analysis Center. All these activities will be discontinued. NICT will continue to support the station at Koganei. Please appreciate their reports in this volume and join us in thanking NICT for the strong support of the IVS thus far as well as for future contributions from Koganei station. Arigato!

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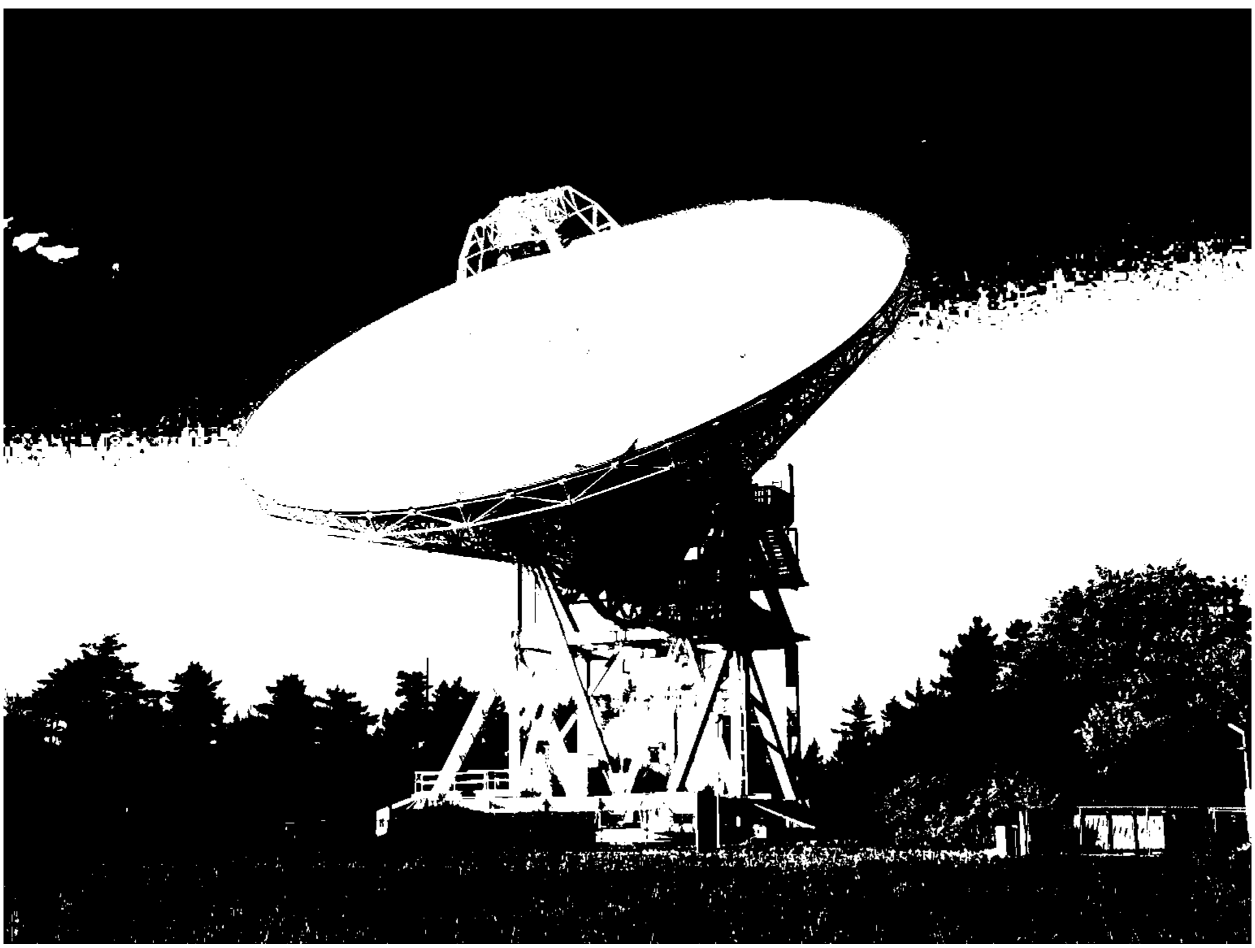
SPECIAL REPORT



IVS Infrastructure Development Plan 2030

2020-09-28

Axel Nothnagel, James Anderson, Dirk Behrend, Johannes Böhm, Patrick Charlot, Francisco Colomer, Aletha de Witt, John Gipson, Rüdiger Haas, David Hall, Hayo Hase, Ed Himwich, Nancy Wolfe Kotary, Jinling Li, Evgeny Nosov, Chester Ruszczyk, Gino Tuccari
(IVS Directing Board)

Executive Summary

The International VLBI Service for Geodesy and Astrometry (IVS) is a collaboration of organizations performing globally organized Very Long Baseline Interferometry (VLBI) observations primarily for the determination of Earth orientation parameters (EOP) as well as for terrestrial and celestial reference frames. All products of the IVS are disseminated to the users directly or through other institutions such as the International Earth Rotation and Reference Systems Service (IERS), and they are essential for the realization of the Global Geodetic Reference Frame (GGRF) for sustainable development as stressed by the United Nations General Assembly Resolution 69/266. The IVS operates in a service environment because more than 80% of the member institutions of the IVS see their predominant involvement in the IVS triggered by service interests of their institutions.

Over the course of its existence, the IVS has made possible the generation of state-of-the-art results in many areas of geodetic and astrometric VLBI through a well-working organizational structure. For this reason, we strive to develop the IVS further by fostering progress in all aspects of its operations. To provide a basis for a discussion with its stakeholders, in this document the IVS Directing Board expresses its views of the current status and the foreseen future path of developments.

It is common knowledge that the highly variable Earth's phase of rotation, UT1-UTC, is needed for a variety of important societal applications of positioning, navigation and environmental monitoring, preferably in real-time. Since the VLBI technique is the only one to determine this parameter with sufficient accuracy and due to the need for low latency results, the regular UT1-UTC determinations have the highest priority in the IVS's endeavors and justify the maintenance of global critical infrastructure. However, all other components of EOP as well as those of terrestrial and celestial reference frames, though with different latency requirements, are equally essential for numerous applications in services of general interest. At the same time, all products are highly correlated with each other and need to be monitored diligently with the same level of energy.

Starting from its current level of operations, the IVS embarks on organizing IVS observing networks in operation for 24 hours, seven days a week and on producing products with reasonable accuracies and latencies. Within these observing sessions, it will be warranted that all products, i.e., the complete set of EOP components including UT1-UTC as well as terrestrial and celestial reference frames, are produced with the same level of quality.

The IVS relies on voluntary contributions of national agencies and institutions acting in a global context. The workload is large and the investments are costly. At present, not all of the resources needed for the targets named above, such as coordination, data transfer and *Level 1 Data Analysis*, have been committed in full or even in part. For this reason, much of the progress to be seen in the next ten years will heavily depend on increased commitments and investments of active and new IVS contributors.

Preamble

The International VLBI Service for Geodesy and Astrometry (IVS) is a collaboration of organizations performing globally organized Very Long Baseline Interferometry (VLBI) observations primarily for the determination of Earth orientation parameters and geodetic reference frames in a service environment on a non-profit basis. It is a service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU). More than 80% of the IVS member institutions see their mandate in supporting operational activities for regularly providing geodetic and astrometric information.

It is common knowledge that only a global approach of VLBI activities implicitly guarantees the ultimate geometric sensitivity in terms of accuracy which is needed for optimal state-of-the-art determinations of these parameters. With this mission and due to its global nature, the IVS guarantees synergies for sustainable technological developments as well as standardization for the intrinsically necessary compatibility of equipment and procedures. Individual institutions or even nations are not able to achieve this alone.

Geodetic VLBI is the only technique to observe the phase of Earth rotation, UT1-UTC, which is needed for the operations of Global Navigation Satellite Systems (GNSS) such as GPS, GLONASS, Beidou and Galileo, and the IVS provides the infrastructure to sustainably maintain delivery of this product. Furthermore, VLBI observations are the only means for tying the global terrestrial reference frame (TRF) to the celestial reference frame (CRF) by the full set of Earth orientation parameters (EOP) which includes polar motion, UT1-UTC, and two celestial pole offsets. It should be emphasized here that CRF, EOP and TRF are mutually dependent in this entire geometric triple with VLBI being the only technique to determine the CRF in the radio frequency domain.

The TRF, besides results from other space-geodetic observing techniques, consists of precise coordinates and velocities of IVS radio telescopes. Here, the IVS strives for 1 mm position accuracy and the respective long term stability as set by the Global Geodetic Observing System (GGOS) Project of the International Association of Geodesy (IAG), which includes IVS operations, to provide the needed information for Global Change studies in general and for monitoring global sea level change in particular. Beyond providing positions and velocities of individual sites, the IVS TRF is one of two backbone techniques for determining the scale parameter of the International Terrestrial Reference Frame (ITRF) which is the basis for many global and regional applications. In the same vein, Resolution 69/266 of the United Nations pursues an identical goal when calling its member states to contribute to “A global geodetic reference frame for sustainable development”, to be realized as the Global Geodetic Reference Frame (GGRF). This also includes highly accurate coordinates of radio telescopes maintained within the IVS.

Concerning the CRF, the fundamental reference system for astronomical applications, according to Resolution B2 of the International Astronomical Union (IAU) General Assembly 1997, is realized as the International Celestial Reference Frame (ICRF), a space-fixed frame based on high accuracy radio positions of extragalactic sources measured by VLBI and using observational data from the IVS.

The radio telescopes of the VLBI Global Observing System (VGOS) as the currently expanding global infrastructure of the IVS, but also the many stations maintaining legacy S/X band equipment, are essential for all these applications. Their operations have to be developed and organized in a structured way according to the voluntary capabilities of the member institutions and the needs for the individual products.

For any nation, the need for investments in the IVS arises from the fact that in any region of the world there are applications making use explicitly or implicitly of the fundamentals provided by the IVS. In the context of this document, it has to be emphasized that the southern hemisphere is greatly under-represented compared to the northern hemisphere and that more investments in the southern hemisphere are necessary. Only when global endeavors are performed with every country contributing its share according to its grand-national product, the benefits for each nation can be guaranteed with the necessary results freely available anywhere and at any time.

For the last twenty years, the IVS has been a well-working collaboration with an effective organizational structure and with many institutions contributing a great share of resources for the benefit of general interests. With this, the IVS has made possible the generation of state-of-the-art results in many areas of geodetic and astrometric VLBI. For this reason, we will continue to develop the IVS further for fostering progress in all aspects of its operations and the quality of its results. However, it cannot be ignored that the IVS is operating on a best-effort basis. To provide a basis for a discussion with its stakeholders, the IVS Directing Board expresses in this document its views of the current status and the planned future path of developments.

A. Vision for the next 10 years

The following sections summarize the views of the IVS Directing Board on products and infrastructure in a tabulated form to define the mandate of the IVS and to give some guidance for imminent developments. The envisaged accuracies heavily depend on accepted latencies and it is assumed that the IVS will always endeavor to provide the best results achievable. As set forth in the *Strategic Plan of the IVS for the Period 2016 – 2025* (https://ivscc.gsfc.nasa.gov/about/strategic/index.html), the IVS strives for accuracies of 1 µs for UT1-UTC, 15 µs for polar motion and nutation, and of 3 mm for telescope positions for one observing session of 24 hours in a weighted root mean squared (WRMS) sense as the final product after an acceptable latency of seven days until 2025. The goal then is to improve by a factor of about three by the end of the decade.

A.1. Core products and observing sessions

	Product / Purpose	Sessions	Latency of results	Comments
a	UT1-UTC	Twice daily 1h, (730 x 1 h)	12 h	Ultra-rapid extraction, transfer, processing and analysis of observation data from VGOS network as in b. * More details below
b	EOP/TRF	daily 24 h (365 x 24 h)	96 h	16 VGOS stations each out of global VGOS pool, [0h – 0h under discussion]
c	CRF/Source characterization	50 x 24 h		16 telescopes each, ~½ of the sessions legacy and ~½ VGOS
d	Research and development	16 x 24 h		** see details below
e	Frame ties to navigation satellites	16 x 24 h		*** see details below

*) Rapid observations of UT1-UTC are inherently embedded in 24 h network sessions. The data to be extracted in an ultra-rapid fashion are prepared by suitable scheduling methods. Parallel sub-sessions/baselines are needed for increased robustness.

**) 16 sessions (4 per quarter) on a proposal basis with deadlines 6 months before the respective quarter, telescope allocation according to justified needs. Purposes need to be in the interests of the IVS. Includes legacy and VGOS telescope usage. Correlator resources are provided by IVS. *Level 1 Data Analysis* (for definitions see Appendix 1) to be performed by proposers if non-standard. *Level 2 Data Analysis* limited solely to proposers only for 6 months after correlation. A report to the OPC is due 6 months after correlation.

***) 16 sessions (4 per quarter) on a proposal basis with deadlines 6 months before the respective quarter. VGOS telescopes only. Telescope allocation according to justified needs. Purposes need to be in the interests of the IVS. If needed, correlator resources are provided by IVS. Setups of *Level 0 Data Analysis* (see Appendix 1) as well as *Level 1 Data Analysis* to be performed by proposers. *Level 2 Data Analysis* limited solely to proposers only for 6 months after IVS correlation. A report to the OPC is due 6 months after correlation.

A.2. Required infrastructure

To be able to achieve the above goals in cadence and accuracy, the IVS will require the following list of infrastructure components. The majority of these components is also necessary to even maintain the status quo.

- 1 Coordination center (3 Full time equivalent staff [FTE])
- 1 Network Coordinator (1 FTE)
- 1 Analysis Coordinator (1 FTE)
- 1 Technology Coordinator (1 FTE)
- 1 Frequency monitoring, defense and allocation manager (1 FTE)
- 7 Operations centers (at least one for every weekday)
- 3 Data centers (mirrored for permanent availability)
- Pool of 40 globally distributed VGOS telescopes (twin telescopes at locations with next telescope at > 2500 km) for observing session types a) - e)
- Pool of 30 globally distributed legacy telescopes, for observing session type c) and d)
- 1 Correlation center (CorC) with a capacity of 2 daily sessions of 1 h each every day, including respective Internet network capabilities (7 days a week sustainable) [called *CorC type 1*]
- 7 Correlation centers (at least one for every weekday) with a capacity of 60 – 65 24 h sessions per year each including respective Internet network capabilities [called *CorC type 2*]
- 5 Hardware development centers
- 7 Analysis Centers (AC) for 1 h UT1-UTC sessions (3 h latency 7 days a week sustainable) [called *AC type 1*]
- 7 Analysis Centers for 24 h EOP sessions (12 h latency 7 days a week sustainable) [called *AC type 2*]
- 5 Analysis Centers for session types c) and e) [called *AC type 3*]

- 1 Combination Center (ComC) for UT1-UTC sessions (3 h latency 7 days a week sustainable) [called *ComC type 1*]
- 1 Combination Center for 24h EOP/TRF sessions (6 h latency 7 days a week sustainable) [called *ComC type 2*]
- 1 Office for Outreach and Communications

Comments:

The numbers quoted for the individual components are minimum requirements, e.g., for guaranteeing correlation every day of the week. It is highly desirable that more units of each component be established and maintained for guaranteeing uninterrupted operations and cross-validation of results.

Correlation centers can possibly also perform distributed correlations (setups, monitoring and export under the responsibility of 1 correlation center) instead of one entire session per correlation center.

Number of required analysis centers should be considered as those with independent software packages.

All components require redundancy in personnel for sickness, vacation, and other absences. Where possible, all components should ideally be labeled as critical infrastructure to safeguard their operations at adverse environmental and global health conditions.

Analysis and combination centers can/should explore automatic processing to guarantee 24/7.

B. Current realization 2020 (operational aspects only)

At present, the IVS operates with the following cadence of sessions and the infrastructure listed below.

B.1. Core products and observing sessions

a) UT1-UTC, 1 hour every day, selected legacy stations, product latency ~24 h

b) EOP/TRF, product latency 14 d, ~3 sessions per week, up to 12 legacy stations each, start times depending on working hours

c) CRF/Source characterization: several 24 h sessions per year

d) 10 – 14 R&D sessions, telescopes and dates allocated in previous year

e) Frame ties to navigation satellites: none

B.2. Available infrastructure

- 1 Coordination center (2 FTE)
- 1 Network Coordinator (fraction of 1 FTE)
- 1 Analysis Coordinator (fraction of 1 FTE)
- 1 Technology Coordinator (fraction of 1 FTE)
- 3 Operations centers

- 3 Data centers
- Pool of 35 globally distributed legacy telescopes (~1570 station days)
- 10 VGOS telescopes (~240 station days in 2021)
- 5 Correlation centers with a total capacity of 400 1 h INT and ~150 24 h network sessions
- 5 Analysis Centers for 1 h UT1-UTC sessions
- 7 Analysis Centers for 24 h EOP sessions
- Analysis Centers for session types c)
- 1 Combination Center for 24 h EOP/TRF sessions
- 1 Office for Outreach and Communications

C. Components needed to reach the IVS goals (operational aspects only)

C.1. Core products and observing sessions

All session series and product lines as listed in Section A.1 need to be ramped up in a structured way.

C.2. IVS components needed

The IVS requires upgrades of the following components:

- Increase in Coordination Center (CC) resources

  To perform the increased duties of the CC as set forth in the IVS Terms of Reference (ToR) #1.7, the CC needs an increase in staff by at least 1 FTE.

- Increase in Network Coordinator (NC) resources

  To perform the increased duties of the NC as set forth in the IVS Terms of Reference (ToR) #3.1, the NC position needs to be equipped with an equivalent of 1 FTE which is considerably more than the 0.2 FTE available today.

- Increase in Analysis Coordinator (AC) resources

  To perform the increased duties of the AC as set forth in the IVS Terms of Reference (ToR) #3.2, the AC position needs to be equipped with an equivalent of 1 FTE which is considerably more than the 0.1 – 0.2 FTE available today.

- Increase in Technology Coordinator (TC) resources

  To perform the increased duties of the TC as set forth in the IVS Terms of Reference (ToR) #3.3, the TC needs to be equipped with an equivalent of 1 FTE which is considerably more than the 0.1 – 0.2 FTE available today.

- Establishment and funding of a new component of a Frequency (monitoring, defense and allocation) Manager for VGOS (1 FTE,)

  The Frequency Manager is a new position due to the VGOS broadband feed capabilities and needed for the following functions:

  - works on the defense of the VGOS observation spectrum at spectrum management conferences in the 3 ITU-regions
  - maintains contact with ITU, IUCAF, CRAF, CORF, RAFCAP and national/regional spectrum authorities
  - coordinates frequency friends at observatories for common actions on the national/supranational level
  - authors reports and conducts compatibility studies for working parties and study groups
  - reports to the IVS-DB

- Increase in number and resources of the IVS Operations Centers (OCs)

  To perform the increased duties of the OCs as set forth in the IVS Terms of Reference (ToR) #2.2, the number of OCs needs to be increased from 3 to 7. Each OC needs to be equipped with equivalents of 0.5 FTE each. For the existing OCs, this is considerably more than the 0.1 FTE per OC available today.

- Increase in resources of the 3 Data Centers (DC)

  To cope with the increased requirements of the VGOS operations, the higher demand for data exchanged and the increased security precautions, the IVS Data Centers need to be augmented with additional staff and modern storage architecture.

- Increase in number of VGOS telescopes

  To allow for continuous operations of a 16-telescope network in variable configurations at least 40 VGOS telescope are needed worldwide. In particular in South America, Africa, the South Pacific and South Asia regions additional telescopes are needed for strengthening the geometry of the IVS network. This is an increase of 30 from currently about ten. If the next telescope is at a distance > 2500 km, the establishment and operation of twin telescopes is advisable to guarantee uninterrupted observations.

- Maintaining continued operations of 30 globally distributed legacy telescopes

  For observing session type c) and d) it is essential that highly sensitive telescopes (20 m diameter and larger) are kept operational through investments in personnel, upgrades and spare parts. New telescopes of larger diameters for primarily astronomical applications but also with S/X band capabilities are always welcome to join the IVS network for these types of observations.

- Establishment and operations of one correlation center CorC type 1

  For correlations and *Level 1 Data Analysis* of 2 daily sessions of 1 h each every day sustainable, a correlation center type 1 needs to be established and operated. This includes availability of the respective network capabilities, also sustainable on a daily basis. This can also be realized through shared agreements.

- Establishment and operations of seven correlation centers CorC type 2

  The operation of the VGOS network 24 hours seven days a week with processing by seven correlation centers requires that two new correlation centers are established and the existing five centers are augmented. All of these correlator centers should have a capacity of 60 – 65 24 h sessions per year each including the respective network and storage capabilities.

- Hardware development

  Making use of progressing hardware developments, the IVS should maintain VLBI hardware development centers for all types of hardware needed in VLBI observations, such as feed horns, receivers, digital backends, system delay monitoring, data transfer, recording etc. Since each of these parts need special expertise, at least five different hardware development centers are required.

- 7 Analysis Centers [type 1]

  The 1 h UT1-UTC sessions, which are observed twice a day, need to be analyzed and results be disseminated within 3 h after correlation has been completed. This needs to be guaranteed seven days around the clock. Different analysis software packages should be used to warrant independency of the analyses.

- 7 Analysis Centers [type 2]

  The 24 h EOP sessions, which are observed every day, need to be analyzed and results be disseminated within 12 h after correlation has been completed. This needs to be guaranteed seven days a week around the clock. Different analysis software packages should be used to warrant independency of the analyses.

- 5 Analysis Centers [type 3]

  The session types c) ICRF and e) frame tie GNSS, which are observed in regular intervals, should be analyzed and results be disseminated within three months after correlation has been completed. Different analysis software packages should be used to warrant independency of the analyses.

- 1 Combination Center [type 1]

  For the results of the UT1-UTC sessions from different analysis centers, combination needs to be performed for final integrity control. This needs to be guaranteed 7 days a week with 3 h latency sustainable.

- 1 Combination Center [type 2]

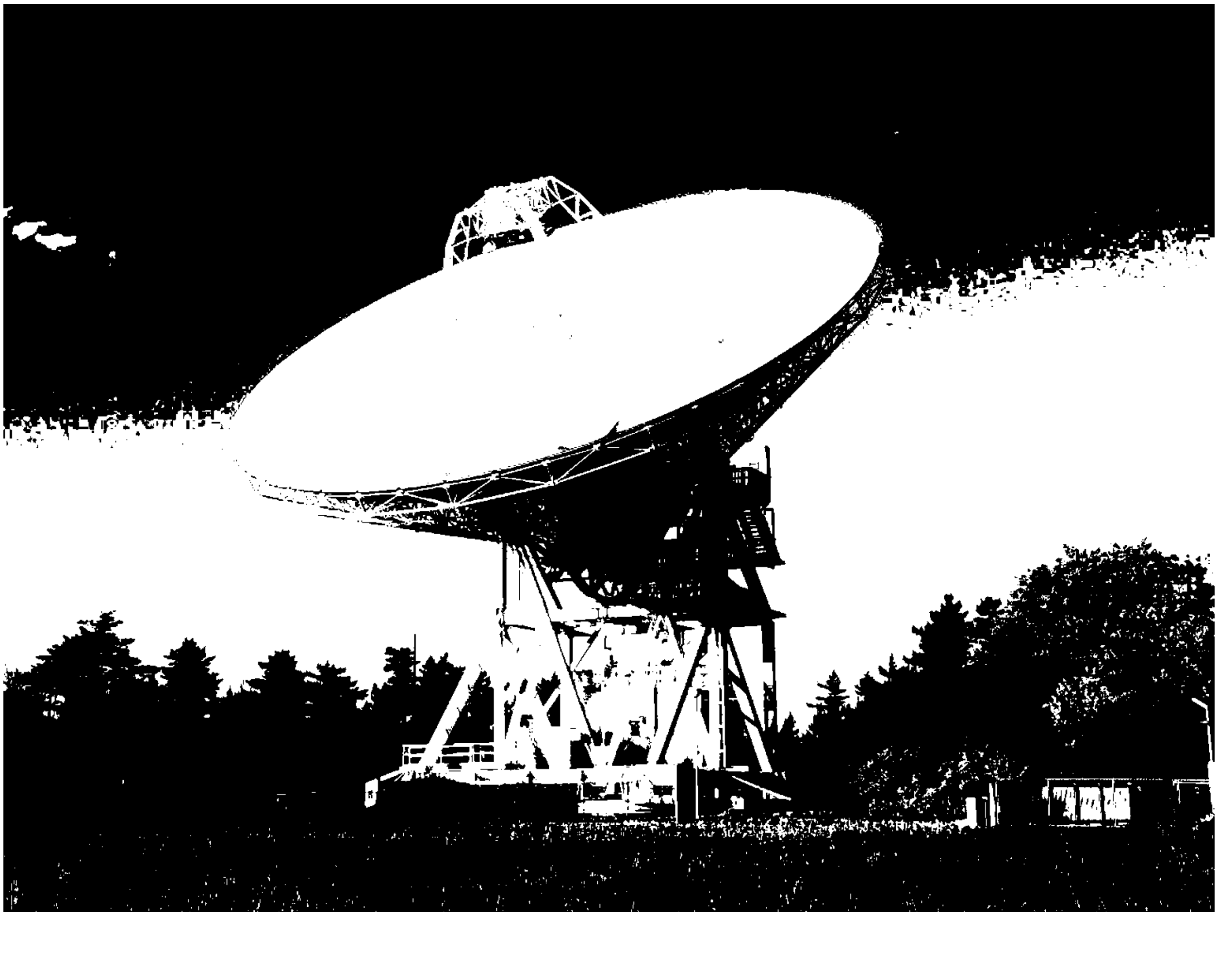
  For the results of the EOP/TRF sessions from different analysis centers, combination needs to be performed for final integrity control. This needs to be guaranteed 7 days a week with 6 h latency sustainable.

Appendix 1

Nomenclature for data types and analysis steps

The IVS Directing Board proposes to use a conventional nomenclature for data types and analysis steps for proper unambiguous referencing. This nomenclature consists of the following dividers: *Level 0 Data* is the raw digitized noise gathered at the radio telescopes. Consequently, the correlation process falls under *Level 0 Data Analysis*. The output of this processing step are the fringe visibilities, subsumed as *Level 1 Data*. The analysis steps needed to produce the observables phase and group delays as well as their time derivatives, such as polarization combination and fringe fitting of the visibilities including any other necessary analysis steps at this stage be called *Level 1 Data Analysis*. The output is the *Level 2 Data*. The analysis steps working with phase and group delays and their rates and resulting in geodetic parameters be called *Level 2 Data Analysis*. This also includes work on source imaging and source structure effects. The results of this are geodetic and astrometric parameters forming *Level 3 Data*. The final combination work of several *Level 3 Data*, e.g., from different analysis centers, is *Level 3 Data Analysis*.

IVS COORDINATION



IVS Chair's Report

Axel Nothnagel

While the year 2019 seems to have ended in the same fashion as it started—with no serious impact on all kinds of human activities including those of the IVS—, the year 2020 was extraordinary in so many aspects of our lives that we may easily have lost track of the developments within the IVS. The preparations of the IVS Biennial Report (BR) 2019–2020 may have forced some of us to contemplate the developments in a broader perspective. When published, this BR will again help the IVS community to find references of the IVS activities and the changes they have brought about, in a positive sense but, unfortunately, also in a few negative developments.

In this Chair's Report, I would like to emphasize a few items of general importance to the IVS community in the last two years. You may often also find more details in this BR. Of course everybody has on their mind the fatal COVID-19 pandemic, which caught us by surprise. I hope and wish that all of you and your families stayed (and will stay) healthy and have been affected only in a moderate way by these adverse circumstances. From an IVS Chair's point of view, I am very glad that all of you helped to bring the many operational procedures to the hygienic standards requested by the authorities. Fortunately, we were able to keep up operational readiness for most of the IVS components for the delivery of our products as our customers expect them. Sometimes this even required official letters by the IVS Chair. In any case, this situation has forced a severe re-consideration of the importance of critical infrastructure and the need for the respective documentation with the authorities in each country.

When the discussions started in 2019 about what preparations had to be taken for CONT20, the IVS Observing Program Committee (OPC) together with the IVS Coordinating Center at NASA Goddard Space Flight Center went one step back and once again debated the pros and cons of uninterrupted 15-day observing sessions. It is unchallenged that they served their purpose in the past. However, in the discussions it turned out that extended IVS legacy observing networks are now in a state in which their results may well be able to stand up against the quality of polar motion results from GNSS observations. However, this needed to be proven and extending the current IVS-R1 network in a selected set of R1 sessions by a few more telescopes, i.e., from 8–10 to at least 14 telescopes, seemed to be the right approach. As a working acronym, this project was called R1-2020 and it was approved by the Directing Board (DB) to replace CONT20.

Prepared by the OPC, the second important decision of the DB in 2020 was to make two of the regular IVS-T2 sessions very special ones called T2Plus. Here, as many telescopes as possible should participate, but all should be able to observe the 512 Mbit/s recording mode with 720/140 MHz spanned bandwidth for high sensitivity. So far, up to 28 IVS telescopes are able to observe in this mode and we will see in 2021 what the quality of the results will be.

In the last two years, considerable progress was made in achieving operational readiness of the next-generation VLBI system, the VLBI Global Observing System (VGOS). Series of 24-hour VGOS test and operational as well as *Intensive* sessions were observed in regular intervals. Finally, the correlation and Level-1 data analysis has been developed and tested

Technische Universität Wien, Department für Geodäsie und Geoinformation

Chair

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by the Haystack Observatory colleagues to a stage where cookbook procedures could be disseminated to the other correlators. In parallel to this, the EU-VGOS cooperation has developed a competing polarization combination procedure and it will be interesting to see how the two approaches compare. By now, a network of 7–8 stations has matured enough to make the observations available on the IVS Data Centers and the analyses of these are in full swing.

The volume of correlation still needs to be ramped up for meeting the expected projection. The same applies to the capabilities of data transmission via the Internet which is needed for regular VGOS operations. However, I am convinced that the many individual activities of colleagues at their ends of the pipeline will lead to a success story in the end. At the same time we are very keen to see many other VGOS telescopes become operational, which are in the construction phase at the moment. Their contributions will make the VGOS network more robust and more sensitive to the geodetically interesting parameters.

In the domain of data analysis, the preparations for and the actual computations of the IVS input to the International Terrestrial Reference Frame 2020 (ITRF2020) has taken quite some energy for the IVS Analysis Centers (AC) and, in particular, for the IVS Analysis Coordinator. The heavy coordination work is necessary to guarantee consistent processing approaches of the ACs in terms of geophysical modeling and parameterization. With the computations of the ACs being almost finished at the time of writing, the last and equally important work now lies with the IVS Combination Center. Although the final submission of the combined IVS solution is still a few days ahead, I am sure that the IVS will have produced a data set which underpins the importance of the VLBI technique for the scale of the ITRF and for precise coordinates of many reference points on the Earth's surface as well as for precise positions of radio sources in the celestial reference frame. Let me thank all IVS associates for their invaluable contributions to these results. This is not only for the analysts but more so for the staff at the observatories and the correlators as well as for the many individuals working in the field of coordination and other background services.

Due to the COVID-19 pandemic, the reporting period has only seen first-class IVS-related meetings in 2019. In conjunction with the 24th Working Meeting of the EVGA, the 3rd VLBI Training School of the IVS Committee on Training and Education took place at Las Palmas de Gran Canaria, Spain, from March 14 to March 16, 2019. The purpose of this school, as of the previous two, was to help to prepare the next generation of researchers to understand VLBI systems and inspire them in their future careers. The event attracted some 50 participants from all over the world. In the same week, also the 20th IVS Analysis Workshop provided a good forum for extensive discussions. From May 5 to May 9, 2019, the 10th IVS Technical Operations Workshop took place at Haystack Observatory, Westford, MA, USA. The 8th International VLBI Technology Workshop from November 18 to November 20, 2019, was hosted by CSIRO Radiophysics Laboratory in Sydney, Australia.

And then the pandemic hit. Had we first hoped that the 11th IVS General Meeting could still take place at Annapolis MD, USA, from March 22 to March 28, 2020, we had to learn the hard way that a pandemic can really also stop worldwide travel. Eventually, the meeting had to be cancelled, and I am really sad for having missed this opportunity of a fruitful personal exchange. Even more sorry am I for the organizers from NVI, Inc., who went through a vast load of organizational issues to finally be stopped abruptly with the decision to cancel the meeting entirely without the option for postponement. And let's not forget all of the work for unwinding all of the arrangements made already. We are all very glad that the organizers found ways to get compensated for at least some of the financial burdens. "The GM which never happened" will keep its place in the annals of the IVS. The next IVS GM is planned for early 2022 in Helsinki, Finland.

Before COVID-19, the IVS Directing Board met in person two times: on March 21, 2019 in Las Palmas de Gran Canaria, Spain, and on September 30, 2019 in Bonn, Germany. All subsequent DB meetings had to take place remotely. The 42nd DB meeting was split into two parts, one on March 26, 2020 (ersatz #1) and a second on June 25, 2020 (ersatz #2); likewise, the 43rd meeting was held on September 25, 2020 (ersatz #1) and on December 17, 2020 (ersatz #2).

Even though we only met in front of computer screens, many issues were discussed and a number of important decisions were made. On June 25, 2020, the new IVS Network Coordinator (NC), Stuart Weston of the Institute for Radio Astronomy & Space Research (IRASR), Auckland University of Technology, New Zealand, attended his first board meeting after he

Table 1 Former IVS Directing Board members of the past two years.

Ed Himwich	NVI, Inc./NASA Goddard Space Flight Center, USA	Network Coordinator	(until June 2020)
Laura La Porta	IGG-B, Reichert GmbH, Max-Planck-Institut für Radioastronomie, Bonn, Germany	Correlators and Operation Centers Representative	Feb 2019 – Apr 2019
Oleg Titov	Geoscience Australia, Australia	IAG Representative	Aug 2015 – Jul 2019

had been elected by the DB in a competitive election. The long-term NC, Ed Himwich, relinquished his position in early 2020 after performing these duties since the foundation of the IVS in 1999. Ed, thank you very much once again for your continuous and successful efforts. On September 25, 2020, the DB approved the proposal of ETH Zurich to become an IVS Associate Analysis Center.

A very prominent decision of the DB is the adoption of the "IVS Infrastructure Development Plan 2030" (this volume). In this document the IVS Directing Board expresses its views of the current status of the IVS and the foreseen future path of developments to document the background of its decisions and to provide a basis for discussions with its stakeholders.

Another item is that the IVS DB has established a mechanism for IVS Resolutions. The Directing Board adopts resolutions to guide the IVS community and to address issues in a formalized way. The IVS Resolutions give the Associates as well as others a proper means as reference for actions.

Unfortunately, there are also less pleasant issues for the Chair to report. In late 2020, the Kashima 34-m telescope of NICT was dismantled after it had been in operation since 1988. This is a severe loss to the IVS legacy telescope network. On September 30, 2020, also the VLBI group at the Institute of Geodesy and Geoinformation of the University of Bonn closed down its VLBI research activities and its IVS operations for good after more than 40 years of existence. In the natural course of new elections but also for some unexpected resignations, the IVS DB said farewell to a few members over the last two years (Table 1). We are grateful for their service to the IVS and to the DB.

The last item to report is that this is the last Chair's report for which I have to take responsibility, because my term as chair ends on February 28, 2021. I was part of the Steering Committee establishing the IVS in 1999, served as the IVS Analysis Coordinator for almost 14 years, and chaired the IVS DB for the last eight years. It has always been an honor for me to be the IVS Analysis Coordinator and to chair the IVS through its directing board. The latter task brought with it the responsibility for representation both to the inside and to the outside, such as to our parent organizations IAG and IAU as well as to the IERS and the other IAG services. The tasks have been challenging but also rewarding. I believe that the IVS bears my footprint, but whether this has a positive attribute remains for others to decide.

When this Biennial Report will be published, the new IVS DB Chairperson will have been elected. I wish him or her a successful and fulfilling future with many big steps forward.

Coordinating Center Report

Dirk Behrend

Abstract This report summarizes the activities of the IVS Coordinating Center during the calendar years 2019 and 2020 and provides an outlook on activities planned for the next two years.

1 Coordinating Center Operation

The IVS Coordinating Center is based at the Goddard Space Flight Center and is operated by NEOS (National Earth Orientation Service), a joint effort for VLBI by the U.S. Naval Observatory and the NASA Goddard Space Flight Center.

The mission of the Coordinating Center is to provide communications and information for the IVS community and the greater scientific community and to coordinate the day-to-day and long-term activities of IVS.

The Web server for the Coordinating Center is provided by Goddard. The address is

`https://ivscc.gsfc.nasa.gov`.

2 Activities during 2019 and 2020

During the period from January 2019 through December 2020, the Coordinating Center supported the following IVS activities:

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- **Directing Board support:** Coordinated, with local committees, two in-person IVS Directing Board meetings: Las Palmas de Gran Canaria, Spain (March 2019) and Bonn, Germany (September 2019). Due to the coronavirus pandemic, no in-person meeting was held in 2020; in its place four shorter ersatz meetings were organized in the form of Zoom video teleconferences (March, June, September, and December 2020). Notes from each meeting were published on the IVS website.
- **Observing Program Committee (OPC):** Coordinated meetings of the OPC to monitor the observing program, review problems and issues, and discuss changes.
- **Master Schedules for 2019 and 2020:** Generated and maintained the Master Observing Schedules for 2019 and 2020. Coordinated VLBI resources for observing time, correlator usage, and disk modules. Coordinated the usage of Mark 5 and Mark 6 systems at IVS stations and efficient deployment of disk modules.
- **2021 Master Schedule:** Generated the proposed Master Schedule for 2021 and received approval from the Observing Program Committee.
- **VGOS:** Supported the activities for establishing the VLBI Global Observing System (VGOS) through participation in the VGOS Technical Committee (VTC) and organizing meetings of the VGOS Operations and Resources group and the VGOS Correlators.
- **Communications support:** Maintained the Web pages, e-mail lists, and Web-based mail archive files. The mailing lists are slated to be migrated to a new host organization within NASA as well as upgraded to the newest list manager in the beginning of 2021. It is anticipated that all membership

information and list options will be rolled over and that the list names will remain unchanged. The mail archives and web interface will no longer be accessible to the general public (i.e., non-NASA users). Maintained the 24-hour and Intensive session Web pages including the data acquisition, correlation, analysis, and performance summaries.

- **Publications:** Published the 2017+2018 Biennial Report in fall 2019/2020. Published six editions of the IVS Newsletter in the months of April, August, and December of 2019 and 2020. All publications are available in electronic form only.
- **Meetings:** Coordinated, with the Local Committee, the tenth IVS Technical Operations Workshop, held at Haystack Observatory in May 2019, and chaired the Program Committee.

Fig. 1 Logo of the tenth IVS Technical Operations Workshop.

Fig. 2 Participants of the tenth IVS Technical Operations Workshop at MIT Haystack Observatory in May 2019.

The eleventh IVS General Meeting plus several splinter meetings were planned for the last week of March 2020. The meetings were canceled two weeks prior to commencement due to the onset of the coronavirus pandemic with travel bans and lockdowns. Extensive discussions were undertaken about whether the event could be organized in a virtual setting or postponed to a later date. Eventually it was decided to cancel outright the General Meeting proper but hold part of the splinter meetings virtually.

Fig. 3 Logo of the eleventh IVS General Meeting originally planned to be held in Annapolis, MD, USA. The event was canceled because of the onset of the coronavirus pandemic.

Fig. 4 Planned venue of the eleventh IVS General Meeting (Historic Inns of Annapolis).

- **Continuous VLBI Campaign 2017 (CONT17):** Wrote a paper on the organization of the campaign as part of the special issue on CONT17 in the Journal of Geodesy. The paper was published in October 2020: D. Behrend, C. Thomas, J. Gipson, E. Himwich, K. Le Bail, "On the organization of CONT17", J. Geod., 94:100, 2020, doi:10.1007/s00190-020-01436-x, `https://rdcu.be/b8q0I`. More information about CONT17 can be found on the IVS website under the URL `https://ivscc.gsfc.nasa.gov/program/cont17`.

- **Data Center ingest software:** Worked with Data Center personnel from CDDIS, BKG, and OPAR on new ingest software for the Data Centers. As the VLBI data and product ingest software at the CDDIS has to be integrated into a larger suite that supports all geodetic techniques, it is not feasible to create a software suite that can be ported in its entirety to BKG and OPAR. However, pieces can be used as building blocks for a second suite that basically replicates features of the CDDIS software at BKG and OPAR. The new software suites are written in Python3. In addition to the filename check, which was already done with the original software, the new ingest software added a validation step (QC) into the processing chain. That means that the data type of every submitted file is validated prior to the addition of the file to the data repository. If a submitted file fails the name check or the validation check, it is rejected. The validation routines and the accompanying data description files (DDFs) form the modular pieces that are exchanged between the Data Centers. The CDDIS has started to use the new suite, while BKG and OPAR will make the transition in 2021.

3 Staff

The staff of the Coordinating Center is drawn from individuals who work at Goddard. The staff and their responsibilities during 2019 – 2020 are listed in Table 1.

Table 1 IVS Coordinating Center staff.

Name	Title	Responsibilities
Dirk Behrend	Director	Web site and e-mail system maintenance, Directing Board support, meetings, publications, session Web page monitoring
Cynthia Thomas	Operation Manager	Master Schedules (current year), resource management and monitoring, meeting and travel support, special sessions
Mario Bérubé	Offsite Consultant	Session processing scripts, Data Center support
Karen Baver	General Programmer and Editor	Publication processing programs, LaTeX support and editing, Data Center support
Kyla Armstrong	Data Technician and Editor	Publications support and Web site support

4 Plans for 2021 and 2022

The Coordinating Center plans for 2021 and 2022 include the following:

- Maintain the IVS Web site and e-mail system. Monitor the transition of the e-mail system to the new host and list manager.
- Publish the 2019+2020 Biennial Report (this volume).
- Coordinate the eleventh IVS Technical Operations Workshop together with MIT Haystack Observatory as a virtual meeting in May 2021.
- Coordinate, with the local committee, the twelfth IVS General Meeting to be held in Helsinki, Finland in March 2022. This meeting may be organized as a hybrid event (in-person and virtual attendance).
- Implement the new ingest software at all three Data Centers and work on a clean-up of the data holdings. Ensure that the mirroring among the Data Centers works properly.
- Publish the Proceedings volume of the twelfth IVS General Meeting.
- Support Directing Board meetings in 2021 and 2022.
- Coordinate the 2021 and 2022 Master Observing Schedules and IVS resources.
- Publish Newsletter issues in April, August, and December of 2021 and 2022.
- Support the VGOS activities within the VTC, the VGOS Operations and Resources group, and the VGOS Correlators.

2019–2020 Analysis Coordinator Report

John Gipson

Abstract I summarize some of the important issues related to IVS Analysis over the last two years.

1 Conclusion of the Transition to vgosDB

In the spring of 2018 a computer failure at the Bonn correlator precipitated the sudden transition to the vgosDB format. Because not all of the pieces were in place and fully tested, many things were initially done on an ad-hoc basis. For example, at the end of 2018 none of the IVS Data Centers was able to automatically process vgosDB and, because of this, the data was uploaded to CDDIS manually. Two years later I am happy to report that the transition to vgosDB is complete.

2 ITRF2020

Much of the focus the last two years was related to preparation for and participation in the IVS submission for ITRF2020. Eleven Analysis Centers using seven software packages submitted SINEX files (Table 1).

The IVS 2020 submission differed from the 2014 submisison in several key ways, mostly modeling changes:

1. ITRFF2014 used a model from 1996 for High-Frequency EOP. This model had begun to show its age, and the IERS recommended use of a new model due to Desai-Shailen-Egbert based on Topex data.
2. The IVS also adopted the new IERS pole-tide model.
3. This submission included the effects of galactic aberration using the model recommended by IVS Working 8 on Galactic Aberration. (See A&A Volume 630, A93, 2019, `https://www.aanda.org/articles/aa/abs/2019/10/aa35379-19/aa35379-19.html`).
4. This submission included models for the effects of gravitational deformation for six antennas: EFLSBERG, GILCREEK, MEDICINA, NOTO, ONSALA60, and YEBES40M. Unfortunately we were not able to include the model for NYALES20 which became available too late.
5. Unlike previous submissions, this submission included the effect of pressure loading. In order to be able to combine the results with other techniques that do not routinely apply pressure loading effects,

Table 1 Analysis Centers and software packages involved in the IVS contribution to ITRF2020.

Analysis Center	Software Package
ASI CGS	Calc/Solve
BGK	Calc/Solve
DGFI-TUM	DOGS-RI
GFZ Potsdam	PORT
IAA	Quasar
GSFC	Calc/Solve
NMA	Where
Paris Observatory	Calc/Solve
Onsala	ASCOT
TU Wien	VieVS
USNO	Calc/Solve

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the SINEX files were modified so that pressure loading could be backed up.

6. Source positions. The IVS contribution to ITRF2020 included source coordinates.

A fuller discussion of ITRF2020 can be found in the December 2020 issue of the IVS Newsletter (Issue #58), available at `https://ivscc.gsfc.nasa.gov/publications/newsletter/issue58.pdf`).

3 Automated Scheduling of VLBI Sessions

One of the most interesting recent developments is VieSched++, developed by Matthias Schartner as part of his PhD. VieSched++ can automatically generate hundreds or thousands of schedules for a given session and choose the session with the ‘best’ properties. Here ‘best’ is determined by the goals of the session. VieSched++ is widely used in Europe and Australia, although sked is still used by GSFC and USNO to schedule the R1 and R4 sessions, and by Haystack to schedule the VGOS sessions.

4 VGOS Moves from R&D to Operational

In January 2020, the VGOS network was officially declared operational (and vgosDB files were made available on the Data Centers for sessions from January 2019 onward). The goal was to schedule 24-hour VGOS sessions every two weeks. This goal was largely successful with 26 sessions scheduled and correlated in 2019. These sessions generally involved all of the VGOS antennas which were available at a given time. Although we continued to observe at roughly a bi-weekly cadence during 2020 there was a backup in correlating sessions due to COVID-19. The IVS is still working through the backlog.

One of the obstacles to making VGOS operational was that Haystack was the only correlator that had the expertise to correlate them. Recognizing this, there was a correlator workshop held at Haystack Observatory in conjunction with the 2019 Technical Operations Workshop. Following this, several correlators processed first an Intensive session and then a 24-hour session and compared their results with Haystack. Currently there are several correlators that can process VGOS sessions.

In the spring of 2019, the NASA VLBI group began a pilot project to schedule VGOS Intensives. Initially this was a proof-of-concept demonstration, and the stations used depended on what was available. In the fall of 2019, the IVS began regular VGOS Intensives using the Kokee–Wettzell baseline.

In addition, the European VGOS consortium scheduled a series of regular EU-VGOS sessions and EU-VGOS Intensives involving European stations and Ishioka. As we move into 2021 the number of VGOS sessions continues to increase. The major roadblocks are media/data storage and data transmission.

5 IVS Analysis Centers and Analysis Software

The number of IVS Analysis Centers continues to increase. There are currently over 30 IVS Analysis Centers with the most recent one being at ETH Zurich in Switzerland. The number of analysis packages also continues to increase. Friendly competition between Analysis Centers is the surest way to improve the VLBI technique.

Network Coordinator Report

Stuart Weston[1], Mario Bérubé[2], Ed Himwich[2]

Abstract This report includes an assessment of the S/X network performance in terms of lost observing time for calendar years 2019 and 2020. It also presents some new initiatives being taken to improve the IVS service. For this period, the observing losses were 18.6% in 2019 and 21.6% for 2020; these statistics are very similar to the prior 2017–2018 period. Various tables are presented to break down the relative performance of the network and the incidence of problems with various sub-systems.

1 Introduction

During 2020 we had a transition of the Network Coordinator role from Ed Himwich [1] to Stuart Weston of AUT University, New Zealand [2]. This transition was made more challenging by events during 2020 eliminating international travel.

This report covers three items :

- Observing Network
- Network Performance
- New Initiatives

concluding with a summary. The item "New Initiatives" is a departure from previous reports and aims to highlight initiatives being taken by the Network Coordinator in cooperation with others in enhancing the IVS service.

1. Institute for Radio Astronomy and Space Research, Auckland University of Technology
2. NVI, Inc./NASA Goddard Space Flight Center

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2 Observing Network

The S/X station network for 2019–2020, consisting of 51 stations in total, is shown in Figure 1. The VGOS network has not been included in this report, as the legacy S/X network remained the production system. The network consists of 37 IVS Network Stations as official member components of the IVS as well as several cooperating sites that contribute to the IVS observing program, in particular the ten VLBA stations and four NASA DSN stations.

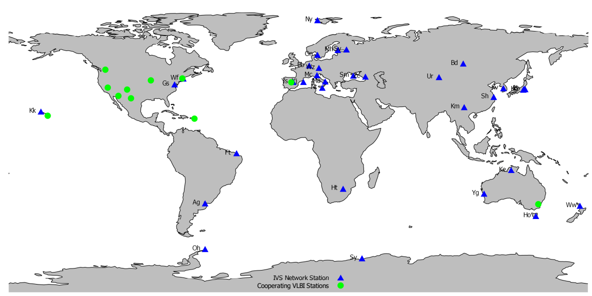

Fig. 1: Network map showing stations that participated in IVS Master Schedule sessions during 2019–2020 marked with blue triangles; other cooperating stations are marked with green circles. This uses the station coordinates from the associated SKD files.

3 Network Performance

The network performance is expressed in terms of lost observing time, or data loss. This is straightforward in cases where the loss occurred because operations were interrupted or missed. But, in other cases, it is more complicated to calculate. To handle this, a non-observing time loss is typically converted into an equivalent lost observing time by expressing it as an approximate equivalent number of recorded bits lost. As an example, a warm receiver will greatly reduce the sensitivity of a telescope. The resulting performance will be in some sense equivalent to the station having a cold receiver but observing for (typically) only one third of the nominal time and therefore recording the equivalent of only one-third of the expected bits. In a similar fashion, poor pointing can be converted into an equivalent lost sensitivity and then equivalent fraction of lost bits. Poor recordings are simply expressed as the fraction of total recorded bits lost.

Using correlator reports, an attempt was made to determine how much observing time was lost at each station and why. This was not always straightforward to do. Sometimes the correlator notes do not indicate that a station had a particular problem, while the quality code summary indicates a significant loss. Reconstructing which station or stations had problems—and why—in these circumstances does not always yield accurate results. Another problem was that it is hard to determine how much RFI affected the data, unless one or more channels were removed and that eliminated the problem. It can also be difficult to distinguish between BBC and RFI problems. For individual station days, the results should probably not be assumed to be accurate at better than the 5% level.

The results here should not be viewed as an absolute evaluation of the quality of each station's performance. As mentioned above, the results themselves are only approximate. In addition, some problems such as weather and power failures are beyond the control of the station. Instead the results should be viewed in aggregate as an overall evaluation of what percentage of the observing time the network is collecting data successfully. Development of the overall result is organized around individual station performance, but the results for individual stations do not necessarily reflect the quality of operations at that station.

The overall network performance for 2019–2020 is very similar to the prior 2017–2018 period as shown in Figure 2. The results of this report are based on correlator and analysis reports for 341 24-hour correlated sessions. The examined data set includes 2,315,499 dual-frequency observations. Approximately 75% of these observations were successfully correlated, and over 66% were used in the final IVS Analysis Reports for 2019 and 2020. These numbers are slightly down

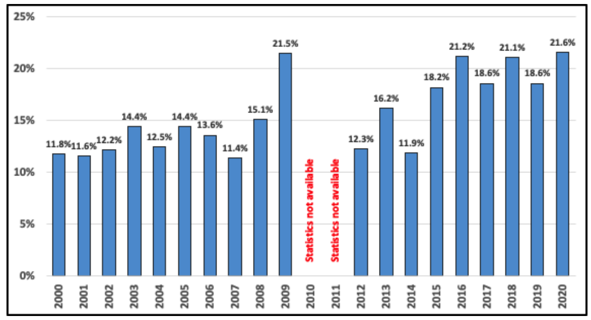

Fig. 2: The historical data loss since 2000.

from the prior 2017–2018 period. Sessions correlated at the VLBA were also included when data analysis reports provided relevant information about reasons for data loss.

Table 1: Data sets used for the 2019–2020 network performance report.

Year	Sessions	Station days	Observations	Correlated	Used
2019	182	1,875 (1,780)	1,276,954	76%	67%
2020	159	1,520 (1,388)	1,038,545	74%	66%

Table 1 summarizes the data set used for the 2019–2020 network performance report. The data in parentheses represent the station days processed by the correlators. The table also includes the percentage of successfully correlated and used observations. We see a decrease in sessions from the previous 2017–2018 period; the decrease was 10% in 2019 compared to 2017 and 9% for 2020, resulting in a corresponding drop in station days and observations. The percentage correlated was comparable to the previous period but with a drop in the percentage used (from 71% in 2017 and 68% in 2018); this decrease in the percentage used warrants further investigation. The average number of stations per session is 10.3 in 2019 and 9.6 in 2020 compared to 10.1 in 2018.

More than 349 station days (18.6%) were lost in 2019, and 328 (21.6%) days were lost in 2020. The observing time loss for 2019–2020 has been affected by stations that did not observe and were not removed from the master schedule. This loss accounted for 227 station days, or 7%.

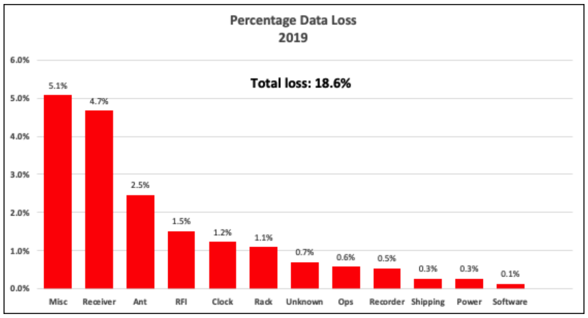

Fig. 3: Percentage of data loss for each sub-sytem in 2019.

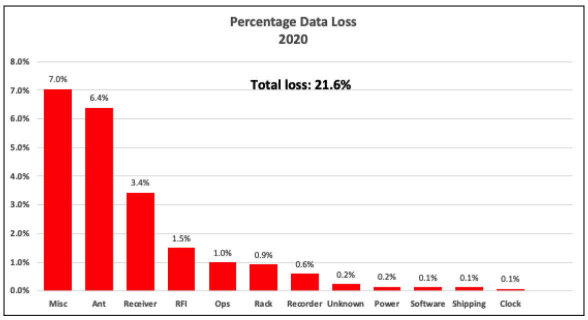

Fig. 4: Percentage of data loss for each sub-sytem in 2020.

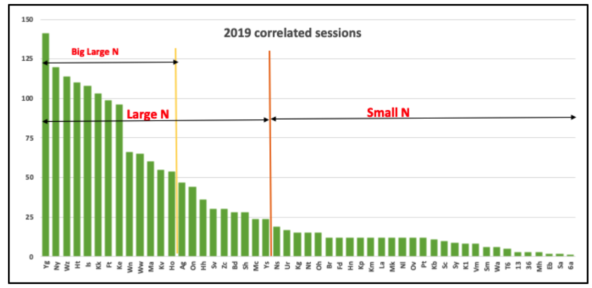

Fig. 5: The number of 24-hour sessions correlated in 2019.

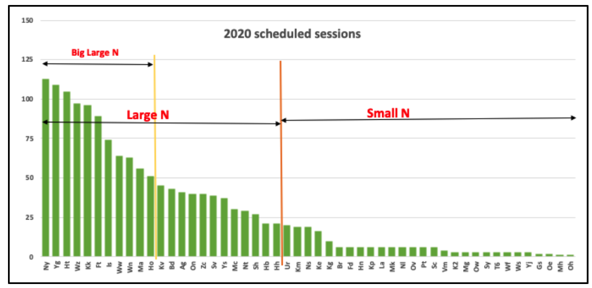

Fig. 6: The number of 24-hour sessions correlated in 2020.

In 2019 the network lost over 18.6% of its data as shown in Figure 3, a slight improvement over the previous period. But for 2020, shown in Figure 4, the loss was 21.6% and is a 3% increase in data loss. This appears to be a repeat of the prior 2017–2018 period. To analyze this global performance, the network has been analyzed by groups: Figure 5 shows 2019, and Figure 6 shows 2020. Tables 2 and 3 provide information on the three groups: **Big Large N** (stations that were used in 51 or more sessions), **Large N** (stations that were used in 21 or more sessions), and **Small N** (stations that were used in 20 or fewer sessions). The distinction between these groups was made on the assumption that results will be more meaningful for the stations with more sessions. The **Big Large N** group is a subset of **Large N** and is used to show the performance of the busiest IVS stations.

The categories in Table 4 are rather broad and require some explanation, which is given below.

Antenna This category includes all antenna problems, including mis-pointing, antenna control computer failures, non-operation due to wind through 2013, and mechanical breakdowns of the antenna. It also includes scheduled antenna maintenance.Wind stows have been moved to Miscellaneous starting in 2014.

Clock This category includes situations in which correlation was impossible because the clock offset either was not provided or was wrong, leading to "no fringes." Maser problems and coherence problems that could be attributed to the Maser are also included in this category. Phase instabilities reported for Kokee are included in this category. DBBC clock errors are included in this category.

Miscellaneous This category includes problems that do not fit into other categories, mostly problems beyond the control of the stations, such as power (only prior to 2012), (non-wind) weather through 2013, wind stows (moved here from the Antenna category starting in 2014), cables, scheduling conflicts at the stations, and errors in the observing schedules provided by the Operation Centers. For 2006 and 2007, this category also includes errors due to tape operations at the stations that were forced to use tape because either they did not have a disk recording

Table 2: Group analysis for 2019.

Category	Number stations	Station-days	Average	Median	>92%	<70%
Big Large N (>50)	14	1319	18.0%	19.8%	3	4
Large N (≥21)	23	1595	17.4%	17.0%	6	5
Small N (<21)	28	280	25.3%	19.9%	10	9
Full network	51	1875	18.6%	19.0%	16	14

Table 3: Group analysis for 2020.

Category	Number stations	Station-days	Average	Median	>92%	<70%
Big Large N (>50)	11	917	17.7%	14.4%	5	3
Large N (≥21)	23	1330	21.5%	16.6%	7	8
Small N (<21)	28	178	24.3%	4.1%	17	7
Full network	51	1508	21.8%	8.6%	24	15

Table 4: Percentages of data loss by sub-system. Percentages for 2010 and 2011 were not calculated.

Sub-System	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**
Miscellaneous	7.1	5.1	8.6	6.5	3.3	4.7	4.2	1.5	0.8	3.3	1.9	0.9	2.4	1.2	1.0	0.9
Antenna	6.4	2.5	5.2	3.6	9.2	3.6	1.8	6.4	2.2	6.3	2.9	3.9	2.6	3.5	4.1	2.6
Receiver	3.5	4.7	2.8	1.5	0.6	1.8	1.7	1.2	1.4	4.0	2.1	1.7	2.8	3.5	2.3	3.6
RFI	1.5	1.5	1.8	2.3	2.3	1.6	1.6	1.0	1.5	1.3	2.2	1.2	1.6	0.9	0.6	1.3
Operations	1.0	0.6	0.6	0.6	0.5	1.1	0.5	0.4	0.2	0.3	0.3	0.0	0.3	0.7	0.8	0.5
Rack	0.9	1.1	0.9	0.9	0.6	2.3	1.4	3.2	2.7	1.4	1.3	1.3	2.2	0.7	0.9	0.7
Recorder	0.6	0.5	0.5	0.5	0.5	1.2	0.5	0.5	0.7	0.6	0.6	0.5	0.4	1.3	1.4	1.6
Unknown	0.2	0.7	0.5	0.9	1.0	1.1	0.2	0.9	1.7	3.1	2.7	1.7	0.5	0.5	1.3	1.8
Power	0.2	0.3	0.2	0.9	0.4	0.2	0.0	0.3								
Software	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Shipping	0.1	0.3	0.3	0.4	0.3	0.2	0.0	0.1	0.4	0.9	0.8	0.1	0.0	0.0	0.2	0.9
Clock	0.1	1.2	0.0	0.5	2.3	0.2	0.0	0.6	0.2	0.4	0.1	0.0	0.7	2.1	0.1	0.5

system or they did not have enough media. All tape operations have since ceased. This category is dominated by weather and scheduling conflict issues.

Operations This category includes all operational errors, such as DRUDG-ing the wrong schedule, starting late because of shift problems, operator (as opposed to equipment) problems changing recording media, and other problems.

Power This category includes data lost due to power failures at the sites. Prior to 2012, losses due to power failures were included in the Miscellaneous category.

Rack This category includes all failures that could be attributed to the rack (DAS), including the formatter and BBCs. There is some difficulty in distinguishing BBC and RFI problems in the correlator reports, so some losses are probably mis-assigned between the Rack category and the RFI category.

Receiver This category includes all problems related to the receiver, including outright failure, loss of sensitivity because the cryogenics failed, design problems that impact the sensitivity, LO failure, and loss of coherence that was due to LO problems. In addition, for lack of a more clearly accurate choice, loss of sensitivity due to upper X-band Tsys and roll-off problems are assigned to this category.

Recorder This category includes problems associated with data recording systems. Starting with 2006, no problems associated with tape operations are included in this category.

RFI This category includes all losses directly attributable to interference, including all cases of amplitude variations in individual channels, particularly at S-band. There is some difficulty in distinguishing BBC and RFI problems in the correlator reports, so some losses are probably mis-assigned between the Rack category and the RFI category.

Shipping This category includes all observing time lost because the media were lost in shipping or held up in customs or because problems with electronic

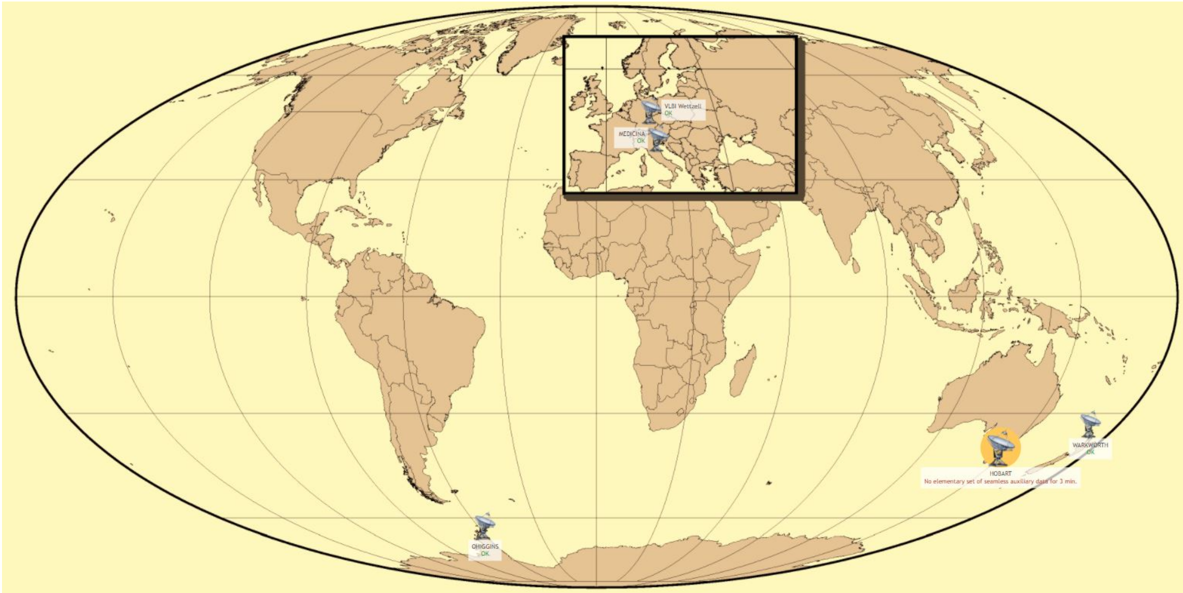

Fig. 7: IVS Auxiliary Data Archive world map with current participating stations.

transfer prevented the data from being correlated with the rest of the session's data.

Software This category includes all instances of software problems causing observing time to be lost. This includes crashes of the Field System, crashes of the local station software, and errors in files generated by DRUDG.

Unknown This category is a special category for cases where the correlator did not state the cause of the loss and it was not possible to determine the cause with a reasonable amount of effort.

An assessment of each station's performance is not provided in this report. While individual station information was presented in some of the previous years, this practice seemed to be counter-productive. Although many caveats were provided to discourage people from assigning too much significance to the results, there was feedback that suggested that the results were being over-interpreted. Additionally, some stations reported that their funding could be placed in jeopardy if their performance appeared bad, even if it was for reasons beyond their control. Last and least, there seemed to be some interest in attempting to "game" the analysis methods to apparently improve individual station results. Consequently, only summary results have been presented here.

Some detailed comments on the most significant issues for this year's data loss are given below.

- The two largest sources of data loss for 2019–2020 are Miscellaneous and Antenna. The high values of Miscellaneous are highly affected by stations having other commitments and bad weather. Many hours were lost by antennas being stowed due to high winds, snow, hurricanes, thunderstorms, or typhoons. The Antenna sub-system loss is mainly due to repairs at antennas that were delayed by months waiting for replacement parts.
- The Receiver sub-system is mainly due to a few stations observing a total of 122 station days with warm receivers while waiting for replacement parts.
- Operator performance is very good with less than 0.8% of data loss.
- RFI due to commercial systems continues to be an important factor of data loss mostly in S-band given that correlators dropped over 1.5% of the recorded channels. RFI is mainly evaluated from dropped channels at correlation, but there are some difficulties in distinguishing BBC and RFI problems. Some stations were contacted to confirm RFI presence at their site.

4 New Initiatives

In IVS Newsletter 58 [3] Alexander Neidhardt and Stuart Weston introduced the initiative “Data Unlimited – The IVS Seamless Auxiliary Data Archive.” As of early 2021, there are five stations shown in Figure 7 sending data to this archive; these are Wettzell, Medicina, O’Higgins, Hobart, and Warkworth. Currently the following data points are archived: meteorological values, clock offsets, and cable calibrations. We would like to encourage more stations to adopt this; Alexander and Stuart are very happy to assist stations in setting this up. At the March 2021 IVS Directing Board meeting this was adopted as a resolution for stations to try to adopt and contribute to the service.

In addition, there is an initiative from Eskil Varenius (Onsala Space Observatory) in cooperation with and supported by the Network Coordinator for stations to log and record their SEFD/T_{sys}. Eskil Varenius kindly presented a seminar on Station Amplitude Calibration, which he recorded; the slides and video from the seminar are available on the Web [4]. This will help with scheduling for the future, as IVS will have accurate and up-to-date SEFD/T_{sys} measurements for stations. In addition this will assist with investigating source structure in more detail, again leading to improved scheduling. We also envisage a spin-off benefit in that IVS will build a catalog and archive of time monitored source flux density for the sources; this may provide other astronomical discoveries.

Metrics need to be designed and monitored to track and report on the performance of the VGOS network. These metrics also need to allow for possible mixed-mode S/X and VGOS sessions as the two systems run in parallel.

5 Summary

Estimating station data losses could be subjective and some times approximative, but this is a useful tool for evaluating the health of the S/X IVS network over the years. A station yielding over 80% of data is considered very good, and the statistics of the Large N group show that stations have been doing well in 2019–2020. In addition it is hoped that the new initiatives will be generally adopted by stations and help to improve further the IVS scheduling and service. The VGOS network is not the production system of the IVS yet and has not been included in this report but will be included in future reports.

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IVS Technology Coordinator Report

Gino Tuccari

Abstract The main activities of the IVS Technology Coordinator can be summarized as follows: organization and support of VTC teleconferences, technical support of IVS stations, maintaining the VGOS Equipment Tables for improving technical compatibility, distributed correlation, and communication with the EVN. The report relates to the period 2019–2020 which was affected by the Coronavirus pandemic in the last year; in spite of this, a number of initiatives have been carried out.

1 Organization of VTC Teleconferences

The organization and support of VGOS Technical Committee (VTC) teleconferences occupied a large part of the Technology Coordinator activities. Indeed, due to the pandemic, it was felt useful to concentrate the efforts of many colleagues forced to operate from home on those elements for too long a time expected but, often due to the lack of time, not actually put on the bench to be taken to an operative level.

The nominally monthly teleconferences have been based on the Zoom platform, which allows talking and seeing a large number of interested colleagues. This simplified the communication and hopefully improved the level of collaboration.

The main tasks in the agenda have been a short report about the activities and status in the main VGOS components, including stations, correlators, and development teams, as well as different themes which were of general interest. It is worth mentioning the two most prominent items that were discussed, as demonstrated by the large audience, and resulted in the creation of two working sub-groups:

a) the study of shorter integration periods, and thus scans, from 30 seconds to 10 seconds (proposer and sub-group leader B. Petrachenko), and
b) the effects of source structure and possible correction (proposer J. Anderson, sub-group leader P. Charlot).

Recently an additional item was considered (proposed by H. Hase): starting from the need to protect frequency slots in the full VGOS band dedicated to the radioastronomy service stimulated the evaluation of new observing frequency schemes. Moreover, a number of additional items of general interest are to be introduced at the proper time in order to promote any possible useful actions to study and implement improvements to achieve the IVS goals.

2 IVS Station Support

One of the most relevant items for the Technology Coordinator is considered to be the support of the IVS stations. In this respect, a frequent communication has been maintained with those stations that were asking for assistance, for instance, with new stations to be implemented or with existing quasi-operative or operative stations.

The coordinator visited in person the Kashima and Ishioka teams in 2019 and discussed the implementation of VGOS observations at the Ishioka station.

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A particular consideration was the RFI estimation to define the observing band as well as possible mitigation methods. Ishioka additionally asked for support with the realization of a digital linear-to-circular-polarization converter. This task became part of the DBBC3 development and could be adopted by interested stations making use of this backend.

A second in-person visit was made to the Irbene station, where more radio astronomy activities are underway. In particular, the Irbene team showed interest in contributing VGOS observations using their RT-16, which is a fast antenna at present under consideration for a BRAND receiver (which includes the entire VGOS broadband).

In 2020, no visit was possible due to the pandemic. A planned visit to the VGOS Shanghai station had to be cancelled.

3 VGOS Equipment Tables

The VGOS tables compile detailed information about relevant equipment of existing VGOS stations and those that are under construction. This is relevant for promoting compatibility within the IVS network and as a guide for new and upcoming stations. The great amount of information and the format formerly used, and represented as an EXCEL spreadsheet, proved to be inappropriate for a fast consultation and in particular for an easy and useful comparison.

A study was undertaken with the help of a student to compare different methods of database management and visualization. This topic was planned to be completed in 2020; but, again due to the pandemic, the work was greatly slowed down, and it is not expected to be completed before the summer of 2021.

An important functionality when consulting the database would be the possibility of implementing an advanced search capability in order to be able to select a number of parameters and stations to view and then to compare them. Such a functionality is, in principle, rather complex to be performed under a web site belonging to a research institution, for many reasons, where the most important is web site security. So a dedicated server was envisaged to be appropriate, with then links indicated in relevant web pages where this information needs to be easily found.

As soon as it will be proven valid, the database will be placed in the dedicated Technology Coordinator web pages. The next step is now to collect the most recent data from the VGOS stations, widely modified in the last years.

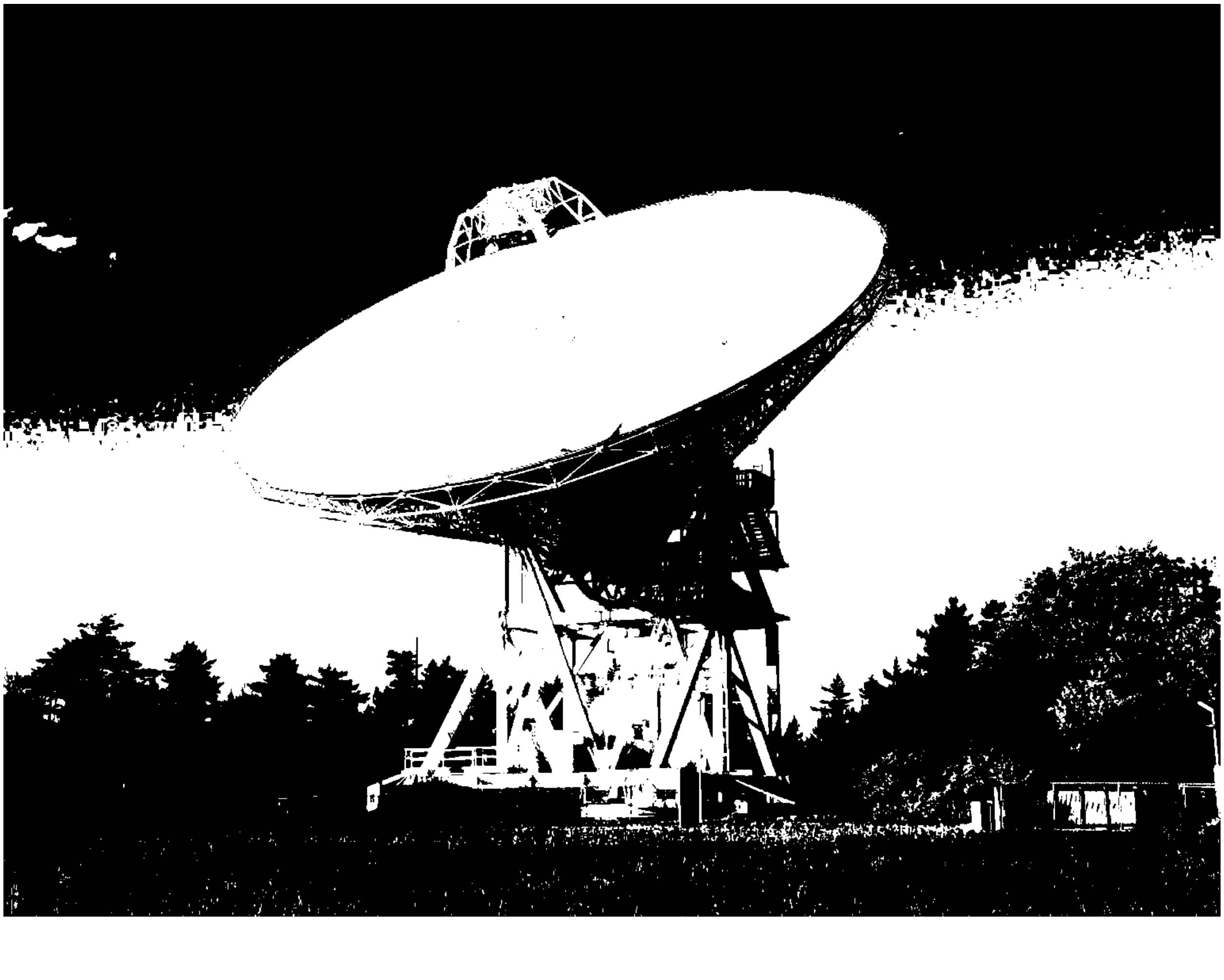
4 Distributed Correlation

Distributed correlation is considered an important task to be explored in the perspective of having an always increasing amount of data to be correlated. A couple of tests have been organized involving a number of small and big correlators. A new test run has to be performed inviting all the correlators interested to join the experiment, which now is under the coordination of the Bonn VLBI correlator team. The correlators involved in this effort so far are Bonn (S. Bernhart), Onsala (R. Haas), Warkworth (S. Weston), Vienna (J. Gruber), Hobart (J. McCallum), and Shanghai (F. Shu). It is expected that a meeting will be held to evaluate possible future experiments.

5 Liaison with the EVN

Periodic meetings have been performed on a regular basis with the European VLBI Network (EVN) chairman, in order to maintain an exchange of information about any technical element worth being shared between the two networks. Furthermore, it was possible to have an almost regular informal exchange with the current lead of the EVN Technical and Operations Group (TOG) Uwe Bach.

NETWORK STATIONS



Argentinean-German Geodetic Observatory

AGGO-VLBI Network Station Report

Hayo Hase[1], Federico Salguero[2], José Vera[2], Augusto Cassino[2], Alfredo Pasquaré[2]

Abstract The Argentinean-German Geodetic Observatory (AGGO) contributed to the observation programs of the IVS and of Wettzell. This report summarizes the experiences of the regular provision of VLBI data during 2019–2020.

1 General Information

The Argentinean-German Geodetic Observatory (AGGO) is a joint effort of the Argentinean National Scientific and Technical Research Council (CONICET) and the German Federal Agency of Cartography and Geodesy (BKG) to support the Global Geodetic Observing System (GGOS) by contributing to it a geodetic fundamental station located in South America [1].

The selected site is a plot of land, owned by the science department of the provincial government of the Province of Buenos Aires approximately 25 km from the center of its capital town of La Plata (and approximately 50 km from the city of Buenos Aires), adjacent to the Pereyra Iraola natural park and next to the Argentinean Institute of Radio Astronomy (IAR) [2].

The project is based on the bilateral scientific-technical cooperation between Argentina and Germany. While Germany via BKG provides the measuring devices and two staff members, CONICET provides the infrastructure and the AGGO staff (currently nine persons) and is responsible for providing operators.

1. Bundesamt für Kartographie und Geodäsie (BKG)
2. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)

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Table 1 Useful data about the VLBI reference point at AGGO and VLBI equipment.

Parameter	Value
DOMES No.	41596S002
CDP No.	7641 (axis intersection)
four-char code	AGGV
IVS two-char id	Ag
approx. longitude	W 58.51398°
approx. latitude	S 34.8739°
approx. height	35.8 m
data acquisition	VLBA5
data recorder	Mk5B+
max. e-transfer bandwidth	400 Mbps
FS-version	9.11.19 (2019), 9.13.2 (2020)
webcam: https://www.aggo-conicet.gob.ar/liveview.php	

2 Activities during the Past Years 2019–2020

2.1 Operators

By the end of 2018 AGGO demonstrated its readiness for regular operations. In order to execute observation programs of the IVS, CONICET decided to start a joint venture with the Argentinean Ministry of Defense in order to receive military staff as operators for the observation shifts. The agreement between both parties was signed on February 5, 2019. The first group consisted of one civil coordinator and six soldiers—three

Fig. 1 The 6-m primary focus offset radio telescope for VLBI observations of AGGO became 25 years old in 2020.

from the army, two from the navy, and one from the air force.

Fig. 2 The first group of operators provided by the Ministry of Defense to the AGGO project. From left to right, top: Rodrigo Duarte, Jorge Gonzalez, David Baldonado, and coordinator Dr. Ánibal Aguirre; bottom: Alejandra Beribei, Luis Correa, and Héctor Huanca. The photo was taken on the occasion of the ceremony of the signature of the agreement between the Ministry of Defense and CONICET. In 2020 Pablo Dario replaced Jorge Gonzalez.

The operators received training on a) geodesy and VLBI, b) the Linux operating system, c) VLBI hardware and monitoring tools, and d) the VLBI Field System, and they were certificated by the end of 2019 after their first year of duty. The training program was elaborated and executed by the AGGO staff. A "VLBI Operator's Manual" was written in order to have a written reference (currently 71 pages) available. This manual is periodically adjusted if changes in the operational procedures require it. It contains a *Checklist* with references to the Operator's Manual, so that a cookbook-like operation of a VLBI session from start to end became possible. The training of the operators continued as training on-the-job, in which the operators were supervised on their shifts during the setup of a session and at the finalization. During the time span while the session was running, the operators monitored the automated processes on their own. A 24-hour session is typically a 27-hour duty for a team of two operators. The operators start two hours before the session with the setup and have one hour after the session to finish their duties. In case of a major technical problem (BBC unlock, receiver temperatures, vacuum, cryo-circuit, power outage), a telephone hotline to AGGO staff is provided for limited remote guidance. The operators are present at AGGO only for the observation sessions.

2.2 AGGO Staff

The AGGO staff is keeping the instruments in operation so that the operators are excluded from maintenance tasks. Recurring duties were to keep the receiver in operational condition, that is to keep it cryogenically cooled and keep a good vacuum, hence keeping a low system temperature. But, frequent power interruptions, high summer temperatures, and aging equipment are causing reoccurring problems. The power supply was modified several times, as the consumption exceeded the limits of the backup batteries. This is being addressed by a new energy backup infrastructure to be installed in 2021/22. The ambient temperature dependence of the receiving system is being addressed by the design of a new receiver box with more cooling elements. This box is currently being installed. Problems with aging equipment, namely with the Baseband Converters, were addressed by adding some resistances in the electronic circuits to compensate for the aging effect. This might be a temporary cure. A further action is on its way: the replacement of analog BBCs by the DBBC2. The number of tasks is larger than the number of staff members, which delays the work on system improvements. The programmed sessions of AGGO limit the access time to work on the existing problems, and the supervision of operators is still an issue.

2.3 COVID-19 Impact

With the occurrence of the COVID-19 pandemic, operations at AGGO had to stop on March 23, 2020, when a lockdown was declared by the Argentinean President. Strict rules were applied, and it was not possible to move around freely, e.g., to the AGGO workplace. Only essential persons, such as military staff, were allowed to follow their duties. The AGGO contingency plan during COVID-19 could not be executed by AGGO staff as they were not considered to be essential. Fortunately, the Operator Coordinator from the Ministry of Defense carried out volunteer daily visits at AGGO and made sure that the minimum infrastructure was kept running (frequency normals, air conditions, cryogenic circuits). Beginning at the end of May 2020, the two-hour VLBI sessions could be observed by one person coming to the station. During the lockdown, the Field System had been upgraded to enable remote control operation, and a new webcam had been installed (Table 1). Later on, operations resumed with less staff possible at the station in accordance with a sanitary protocol and keeping distances among the staff members. The year 2020 ended with a reduced presence of staff at the station and therefore less productivity of the operations because manual intervention was still necessary. But, even under unusual circumstances, a significant number of VLBI sessions could be executed, and AGGO-VLBI data is available for the ITRF2020 calculations. Hence, AGGO may become a new ITRF VLBI network station!

2.4 Sessions

Table 2 gives an overview about the data yield from AGGO and its performance. The loss of sessions is related mainly to technical failures during vacation periods without operators in the summer months in 2019 and due to technical failures and the COVID-19 lockdown restrictions on going to AGGO during 2020.

3 Current Status

The status as of the end of 2020 is that AGGO-VLBI is operational. The availability of operators upon request challenges the AGGO staff to have the VLBI equipment and infrastructure in operational conditions for the scheduled sessions. AGGO is still affected by uncontrolled power outages by the energy provider. The improvement of the horizon mask for the radio telescope by cutting the limiting trees could not be achieved yet. The radio frequency interference situation at S-band became worse, and rare interference of unknown origin (ship radars on the La Plata river?) at X-band could be observed.

As a fundamental station for geodesy, AGGO owns also an SLR station, the overhaul of which suffered further delays due to the COVID-19 crisis. Other instruments are kept working:

- time and frequency laboratory with two H-masers, three Cs normals, one GNSS receiver, and one NTP-server,
- VLBI radio telescope,
- GNSS receiver (IGS),
- absolute gravity meter and super conducting gravity meter (IGFS),
- hydrological sensors,
- meteorological sensors.

Internet provision is available by a 1 Gbps optical fiber.

The power supply is still characterized by frequent interruptions due to the lack of pruning of the vegetation along the route of the line, the adverse weather conditions, and the lack of maintenance of the power line by the supplier.

The construction of a new office building for the staff of AGGO has been initiated and has been delayed by more than two years. Once it has been finished, space in the operation building will be released to move the operations from the containers to the operation building.

The current VLBI staff situation is presented in Table 3.

Table 2 AGGO-VLBI session performance in 2019–2020. The column “Correlated” also contains observed sessions which are still in backlogs at the correlators. “Lost” sessions are those which had to be canceled or were eliminated from the correlation process due to a poor quantity or quality of observations. The “Corona-year” 2020 shows lost sessions due to the lockdown, during which AGGO staff were not allowed to go for work to AGGO for a couple of months. Nevertheless an effort was made to provide as much data as possible.

Year	Session	Duration	Scheduled	Correlated	Lost	Performance
2019	R1	24	45	31	14	0.69
	R4	24	4	3	1	0.75
	T2	24	6	3	3	0.50
	OHIG	24	5	4	1	0.80
	WC	2	32	28	4	0.88
Total			92	69	23	0.72
2020	R1	24	36	22	14	0.61
	R4	24	4	1	3	0.25
	T2	24	5	3	2	0.60
	CRD	24	5	2	3	0.40
	OHIG	24	4	2	2	0.50
	WD	2	48	35	13	0.73
Total			103	65	37	0.63

Table 3 AGGO staff linked with VLBI in 2020.

Name	Background	Tasks	E-mail
Federico Salguero	electronic engineer	VLBI hardware	fsalguero@aggo-conicet.gob.ar
José Vera	electronic engnieer	VLBI software and system administrator	jvera@aggo-conicet.gob.ar
Alfredo Pasquaré	electronic engineer	time and frequency lab, GNSS	apasquare@aggo-conicet.gob.ar
Augusto Cassino	electrical engineer	head of infrastructure and construction	acassino@aggo-conicet.gob.ar
Hayo Hase	geodesist	head of operations	hayo.hase@bkg.bund.de
six operators	soldiers	VLBI operation	

4 Future Plans

The receiver box is being enlarged to host more cooling peltier elements in order to keep the ambient temperatures of the dewar lower and to better resist high ambient temperatures during the summer season.

The plan to move the operations from the containers to the operation building will coincide with putting into operation a new backend for VLBI: the DBBC and a Flexbuff system to replace the VLBA5 and Mk5B equipment. The new equipment is scheduled to arrive in 2021.

The servo cabinet and the antenna control unit will follow later on. For this operation, a renewal of the cables between the receiver and control room is being considered.

An uninterruptible power supply for the entire observatory has been requested and will be realized. With an enhanced reliability of the power supply, a return to full and reliable operations is envisaged.

Complementary instruments to VLBI such as a water vapor radiometer are being considered for being put into operation during the near future.

Concerning the mid-term future, a new VGOS radio telescope has been specified, and such a desired project is waiting for its execution. But it depends on a renewed agreement on the cooperation between BKG and CONICET. This agreement is under negotiation and targets a time span of more than ten years during which a sustainable operation of AGGO for the Global Geodetic Reference Frame will be assured.

Acknowledgements

The authors acknowledge the support received from the Argentinean Ministry of Defense with the provision of operators, and they are especially grateful to its coordinator Dr. Ánibal Aguirre, who checked on AGGO daily during the COVID-19 lockdown period.

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Effelsberg Radio Observatory 2019–2020 Report

Uwe Bach, Alex Kraus

Abstract The 100-m radio telescope of the Max-Planck-Institut für Radioastronomie (MPIfR) is one of the largest fully steerable single-dish radio telescopes in the world, and a unique high-frequency radio telescope in Europe. The telescope can be used to observe radio emissions from celestial objects in a wavelength range from 90 cm (300 MHz) down to 3.5 mm (90 GHz).

1 General Information

The Effelsberg radio telescope was inaugurated in 1971 and was (for almost 30 years) the largest fully steerable single-dish radio telescope in the world. It is situated in a protected valley near Bad Münstereifel (about 40 km southwest of Bonn) and operated by the Max-Planck-Institut für Radioastronomie (MPIfR) on behalf of the Max-Planck-Society (MPG). To this day, it is the largest radio telescope in Europe and is mostly used for astronomical observations.

This extremely versatile and flexible instrument can be used to observe radio emissions from celestial objects in a wavelength range from about 1 m (corresponding to a frequency of 300 MHz) down to 3.5 mm (90 GHz). The combination of the high surface accuracy of the reflector (the mean deviation from the ideal parabolic form is ∼0.5 mm rms) and the construction principle of 'homologous distortion' (i.e., the reflector in any tilted position has a parabolic shape with a well-defined, but shifted, focal point) enables very sensitive observations to be made at high frequencies (i.e., ν >10 GHz).

The wide variety of observations with the 100-m radio telescope is made possible by the good angular resolution, the high sensitivity, and a large number of receivers which are located either in the primary or in the secondary focus. Together with a number of distinct backends dedicated to different observing modes, this provides excellent observing conditions for spectroscopic observations (atomic and molecular transitions in a wide frequency range), high time-resolution (pulsar observations), mapping of extended areas of the sky, and participation in a number of interferometric networks (e.g., IVS, mm-VLBI, EVN, and Global VLBI).

Max-Planck-Institut für Radioastronomie, Bonn, Germany

Effelsberg Network Station

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Table 1 Telescope properties.

Name	Effelsberg
Coordinates	6°53′01.0″ E, +50°31′29.4″ N
Mount	azimuthal
Telescope type	Gregorian (receivers in primary and secondary focus)
Diameter of main reflector	100 m
Focal length of prime focus	30 m
Focal length of secondary focus	387.7 m
Surface accuracy	0.55mm rms
Slew rates	Azi: 25 deg/min, Elv: 16 deg/min
Receivers for Geodetic observations	3.6 cm/13 cm secondary-focus (coaxial)
T_{sys} (3.6 cm/13 cm)	25 K, 200 K
Sensitivity (3.6 cm/13 cm)	1.4 K/Jy, 0.5 K/Jy
HPBW (3.6 cm/13 cm)	81 arcsec, 350 arcsec
Tracking accuracy	∼ 2 arcsec

Fig. 1 Aerial image of the Effelsberg radio observatory. Shown are the 100-m Effelsberg antenna and the institute's building (left of the antenna).

2 Staff

The staff at Effelsberg consists of about 40 people, including telescope operators, technical personnel for receivers, electronics, and mechanics, scientists, and administrative personnel. Involved in IVS activities are, beside the telescope operators, **Dr. Alexander Kraus** as station manager and scheduler for the 100-m Effelsberg telescope, and **Dr. Uwe Bach** as support scientist and VLBI friend. Two of the telescope operators, **Marcus Keseberg** and **Peter Vogt** are also involved in the preparation of schedules and disk management and shipping.

3 Activities during the Past Years

Effelsberg has participated regularly in the EUROPE IVS sessions since 1991. In 2019 and 2020, the T2132, T2135, T2138, T2142, and T2P144 experiments were observed. About 30% of the observing time of the Effelsberg antenna is used for VLBI observations. Most of them are astronomical observations for the European VLBI Network (EVN), High Sensitivity Array (HSA), Global MM VLBI Array (GMVA), or other global networks, but also geodetic VLBI observations within the IVS are performed.

In late 2019 Effelsberg started commissioning the new DBBC3 backend. In preparation of higher recording rates (up to 32 Gbps), wideband C-band observations at 4 Gbps were observed with the new DBBC3 backends at Yebes, Onsala, and Effelsberg. Yebes and Onsala used their VGOS antennas and Effelsberg used the linear polarization broadband C-band receiver. The fringe test was successful, but further tests got delayed due to required firmware developments and upgrades of the DBBC3 hardware.

Despite the restrictions caused by the worldwide Covid-19 pandemic in 2020, the Effelsberg observatory did not have to close completely. Due to suitable

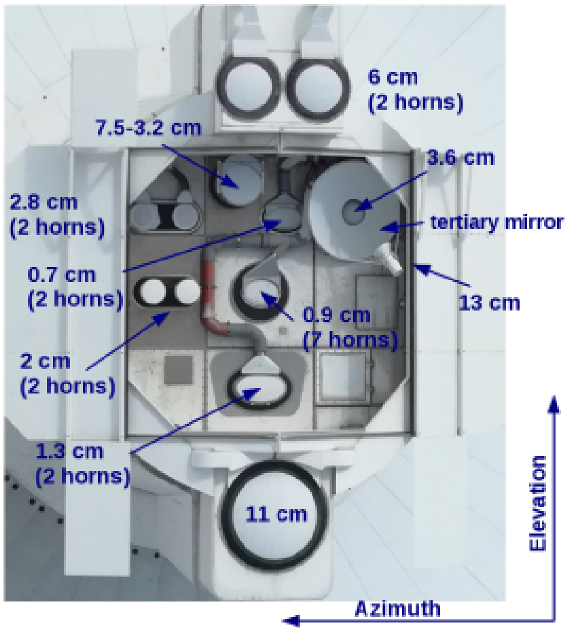

Fig. 2 Picture of the secondary focus cabin with several astronomical receivers, e.g., the new Ku-band with two horns, the geodetic S/X system with the 3.6-cm horn, and the tertiary mirror for the 13-cm horn.

safety measures, operations of the 100-m telescope were not interrupted.

In 2019, a new Ku-band receiver covering 12 to 18 GHz was installed in the secondary focus, providing an IF bandwidth of up to 4 GHz. Although not an IVS/EVN band, the receiver is regularly used for observations together with the VLBA.

4 Current Status

Effelsberg uses the DBBC2, Fila10G, and a Mark 6 recorder for all EVN, global, and geodetic VLBI observations. The Mark 6 recorders provide 390 TB of storage capacity and most of the recorded data is e-transferred to the correlators in Bonn and JIVE. The modules in one of the recorders are mounted as Raids, and each module of eight disks forms a tpye 5 Raid. One disk can fail without data loss. One slot is currently kept for modules that can be shipped.

In addition to the DBBC2, there are two NRAO RDBEs connected to one of the Mark 6 recorders that are used for observations with the VLBA and HSA. Mark 6 modules for Socorro are still being shipped. Both VLBI backends and their recorders are controlled by the Field System (current release FS-9.13.2). The observatory is connected via a 10 GE optical fiber to the e-VLBI network and can do real time e-VLBI observations (performed about monthly within the EVN) and e-transfers.

5 Future Plans

The DBBC3 for Effelsberg is in the lab in Bonn and is being upgraded for the use with the BRAND receiver. It will be equipped with more and new boards and optical Ethernet inputs for the BRAND signals. The same hardware can be used for other receivers as well. The installation is delayed because the labs were closed for some time because of the pandemic restrictions.

Plans for a direct digitalization of the RF signals from the receivers in Effelsberg are becoming more concrete. The same digitizers that are used for Meerkat digitize up to 3 GHz at the receiver and the full band at 12 or 14 bit is streamed over 40 Gbps Ethernet using the Speed protocol to the software backend. The digital lab is developing a software backend on a GPU cluster. It currently supports single dish continuum and spectroscopy observations in full Stokes and pulsar observations. A basic support for VLBI VDIF is implemented and a first zero baseline test to the DBBC2 yielded fringes.

To use the down conversion capabilities of the DBBC3, it is planned to send the digitized band from the GPU cluster directly into the DBBC3 for further processing. This should provide the best compatibility with the current VLBI operation.

Fortaleza Station Report for 2019 and 2020

Adeildo Sombra da Silva[1], A. Macilio Pereira de Lucena[2], Jean-Pierre Raulin[1]

Abstract This is a brief report about the activities carried out at the Fortaleza geodetic VLBI station (ROEN: Rádio Observatório Espacial do Nordeste), located in Eusébio, CE, Brazil, during the period from January 2019 until December 2020. The total observed experiments consisted of 174 VLBI sessions and continuous GPS monitoring recordings. All VLBI recorded data was transmitted through high-speed network.

1 General Information

The Rádio Observatório Espacial do Nordeste, ROEN, located at INPE facilities in Eusébio, nearly 30 km east of Fortaleza, Ceará State, Brazil, began operations in 1993. Geodetic VLBI and GPS observations are carried out regularly, as contributions to international programs and networks. ROEN is part of the Brazilian space geodesy program, which was initially conducted by CRAAE (a consortium of the Brazilian institutions Mackenzie, INPE, USP, and UNICAMP) in the early 1990s. The program began with antenna and instrumental facilities erected, with activities sponsored by the U.S. agency NOAA and the Brazilian Ministry of Science and Technology's FINEP agency.

ROEN is currently coordinated by CRAAM, Center of Radio Astronomy and Astrophysics, Engineering School, Mackenzie Presbyterian University, São Paulo, in agreement with the National Institute for Space Research INPE. The activities are currently carried out under an Agreement of Cooperation which was signed between NASA—representing research interests of NOAA and USNO—and the Brazilian Space Agency, AEB, which was extended until 2021. Under the auspices of the NASA-AEB Agreement, a contract was signed between NASA and CRAAM, Mackenzie Presbyterian Institute and University to partially support the activities at ROEN. In 2019, the contract was renewed for five more years.

The counterpart of the operational costs, staff, and support of infrastructure are provided by INPE and by Mackenzie.

2 Main Instruments

The largest instrument at ROEN is the 14.2-m radio telescope on an alt-azimuth positioner. It is operated at S- and X-bands, using cryogenic radiometers. The system is controlled by the Field System, Version 9.11.19. Observations are recorded with a Mark 5A system and transmitted through a high-speed network either to the correlators in the U.S. (WACO and Haystack), to Bonn in Germany, or to SHAO in China at rates of about 220 Mbps.

For this, a 1-Gbps link has been available since 2007. It is integrated into and sponsored by the Brazilian Research Network (RNP).

One Sigma-Tau hydrogen maser clock standard is operated at ROEN. GPS monitoring is performed within a cooperative program with NOAA (USA). There is a Leica System 1200 installed at the station that operates continuously. The collected data are provided to the NOAA/IGS center and to the Brazilian

1. Universidade Presbiteriana Mackenzie, CRAAM and INPE, Rádio Observatório Espacial do Nordeste, ROEN
2. Instituto Nacional de Pesquisas Espaciais, INPE

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Fig. 1 The 14.2-m radio telescope at Fortaleza Station.

IBGE center. ROEN has all basic infrastructures for mechanical, electrical, and electronic maintenance of the instrumental facilities.

3 Staff

Dr. Raulin Jean-Pierre is the current coordinator of the space-geodesy program. The coordination receives support from the São Paulo office at CRAAM/Instituto and Universidade Presbiteriana Mackenzie, with administrative support from Valdomiro M. S. Pereira and Lucíola Russi. The Fortaleza Station facilities and geodetic VLBI and GPS operations are managed on site by Dr. Antonio Macilio Pereira de Lucena (CRAAM / INPE), assisted by Eng. Adeildo Sombra da Silva (CRAAM / Mackenzie), and the technicians Emerson Costa (CRAAM / Mackenzie), Kelvin de Oliveira (CRAAM / Mackenzie), and Francisco Renato Holanda de Abreu (CRAAM / Mackenzie).

4 Current Status and Activities

4.1 VLBI Observations

In 2019 and 2020, Fortaleza participated in the geodetic VLBI sessions described in Table 1.

Table 1 Fortaleza's VLBI session participation in 2019 and 2020.

Experiment	Number of Sessions
IVS-R1	60
IVS-R4	81
IVS-T2	6
R&D	16
OHIG	11

4.2 Operational and Maintenance Activities

A summary of activities performed in the report period is listed below:

1. The main bearing of the antenna failed at the end of 2020. Staff effort is important to collect all necessary info to figure out the best alternative to repair the antenna in terms of quality of material, services, and cost.
2. Repair and maintenance of the following equipments: cryogenic system, Mark IV acquisition system, Mark 5A recorder, antenna mechanical and electrical systems, angle encoders system, receiver telemetry, and the receiver thermoelectric temperature control system.
3. Repair of electrical motors.
4. Operation and maintenance of geodetic GPS (NOAA within the scope of NASA contract).
5. Operation and maintenance of power supply equipment at the observatory (main and diesel driven standby).
6. Transferring of recorded data through high-speed network.

4.3 GPS Operations

The IGS network's GPS receiver operated regularly at all times during 2019 and 2020. Data was collected and uploaded to an IGS/NOAA server.

5 Future Plans

Discussions have already started among the Brazilian groups and with international partners to raise funds for a new VGOS-compatible system to be installed at the Fortaleza VLBI station facilities.

Goddard Geophysical and Astronomical Observatory

Katie Pazamickas, Chris Szwec, Jason Laing

Abstract This report summarizes the technical parameters of the Very Long Baseline Interferometry (VLBI) systems at the Goddard Geophysical and Astronomical Observatory (GGAO), provides an overview of the activities that occurred in 2019–2020, provides the outlook for 2021, and lists the outstanding tasks to improve performance.

1 Location

The Goddard Geophysical and Astronomical Observatory (GGAO) consists of a 12-meter radio telescope for VGOS development, a 1-meter reference antenna for microwave holography development, an SLR site that includes MOBLAS-7, the next generation Space Geodesy Satellite Laser Ranging (SGSLR) system, a 48″ telescope for developmental two-color Satellite Laser Ranging, a GPS timing and development lab, a DORIS system, meteorological sensors, and a hydrogen maser. The 5-meter radio telescope for VLBI is no longer in service. In addition, the site is a fiducial IGS site with several IGS/IGSX receivers.

GGAO is located on the east coast of the United States in Maryland. It is approximately 15 miles NNE of Washington, D.C. in Greenbelt, Maryland.

- Longitude: 76.4935
- Latitude: 39.0118
- MV3
- Code 61A
- Goddard Space Flight Center (GSFC)
- Greenbelt, Maryland 20771
- https://cddis.nasa.gov/ggao/

Peraton

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2 Technical Parameters

In October of 2010, construction of the new 12-meter VGOS developmental antenna was completed. This antenna features all-electric drives and a Cassegrain feed system. The antenna has a VGOS broadband receiver and associated subsystems. The technical parameters of the 12-m radio telescope are summarized in Table 1.

Table 1 Technical parameters for GGAO.

Parameter	12-m Antenna
Owner and Operating agency	NASA
Year of construction	2010
Diameter of main reflector	12 m
Azimuth range	±270 deg
Azimuth velocity	5 deg/sec
Azimuth acceleration	1.3 deg/sec/sec
Elevation range	5–88 deg
Elevation velocity	1.25 deg/sec
Elevation acceleration	1.3 deg/sec/sec
Focus	Cassegrain
Receive Frequency	2–14 GHz
Bandwidth	512 MHz, four bands
VLBI terminal type	VGOS
Recording media	Mark 6

3 Staff of the VLBI Facility at GGAO

GGAO is a NASA research and development and data collection facility. The VLBI facility at GGAO is operated under the Space Exploration Network Services and Evolution (SENSE) contract by Peraton. The Peraton staff includes Katie Pazamickas (Station Manager) and Jay Redmond (Station Engineer) conducting VLBI operations and maintenance at GGAO with the support of the sustaining engineering Peraton team.

4 Mission Support

Having ceased VLBI operations in May 2007, the MV3 5-m antenna is retired due to issues with the obsolete controller. The 12-m VGOS antenna has participated in many VLBI Global Observing System (VGOS) 24-hour experiments, including CONT17, VGOS Trial, and VGOS Intensive observations. The antenna currently observes VGOS-O observations on a regular twice a month basis.

5 Recent Activities

Much of the 2019 and 2020 activities at GGAO have been focused on experiments using the VGOS 12-m antenna. Other activities worth noting include:

- Conducted IVS observations using the Mark 6 recorders to demonstrate the VGOS capabilities on a regular twice a month schedule
- Participated in 46 VGOS-O sessions in 2019 and 2020
- Participated in 13 VGOS Intensive sessions in 2020
- Participated in two mixed-mode sessions in 2020
- Obtained regular cable delay measurements to use along with the observation data
- Replaced primary azimuth gearbox with site spare after a failure
- Participated in mixed-mode test observations
- Supported developmental testing for the VLBI site at MGO
- Started e-transferring entire VGOS Intensive sessions to the correlator

6 Outlook

GGAO will continue to support VGOS, e-VLBI, and other developmental observations and activities during the upcoming year. Tentative plans for 2021 include:

- Conduct IVS observations using the Mark 6 recorders to demonstrate the VGOS capabilities on a regular at least twice a month schedule. In mid-2021 GGAO will begin supporting weekly VGOS-O sessions
- Continue to investigate how and why the cables are degrading in the azimuth wrap
- Continue taking cable delay measurements for observation data correlation
- Support testing and implementation of MIT signal chain upgrade efforts at GGAO
- Upgrade the VLBI facility's network infrastructure as part of a larger site modernization effort
- Complete the replacement of the jackscrew, elevation gearbox, and brake assembly.

Hartebeesthoek Radio Astronomy Observatory (HartRAO)

Marisa Nickola, Aletha de Witt, Jonathan Quick, Roelf Botha, Philip Mey

Abstract HartRAO is the only fiducial geodetic site on the African continent and participates in global networks for VLBI, GNSS, SLR, and DORIS. This report provides an overview of geodetic VLBI activities at HartRAO during 2019+2020, including progress with the VGOS antenna and continued operations under COVID-19 restrictions.

1 Geodetic VLBI at HartRAO

The Hartebeesthoek Radio Astronomy Observatory (HartRAO) forms part of the larger South African Radio Astronomy Observatory (SARAO). The Hartebeesthoek site is located 65 km northwest of Johannesburg, just inside the provincial boundary of Gauteng, South Africa. HartRAO is located 32 km away from the nearest town, Krugersdorp. The telescopes are situated in an isolated valley which affords some protection from terrestrial radio frequency interference. HartRAO currently operates 13.2-m, 15-m, and 26-m radio telescopes. The 13.2-m VGOS radio telescope is not fully operational yet, but funding has been made available to equip it with a broadband VGOS receiver and DBBC3 backend. It should achieve operational status in the first half of 2022. The 26-m is an equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961. The telescope was part of the NASA deep space tracking network until 1974 when the facility was converted to an astronomical observatory. The 15-m is an Az-El radio telescope built as a Square Kilometre Array (SKA) prototype during 2007 and converted to an operational geodetic VLBI antenna during 2012. The telescopes are co-located with an ILRS SLR station (MOBLAS-6), a Russian satellite laser and radio ranging system «Sazhen-TM+OWS», two IGS GNSS stations (HRAO and HRAG00ZAF), a seismic vault, and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. SARAO is also a full member of the EVN.

Fig. 1 The HartRAO trio (from left to right): the VGOS, 26-m, and 15-m antennas. The newly installed VGOS backup generator is visible next to the shadow of the VGOS antenna.

SARAO

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2 Technical Parameters of the 15-m, 26-m, and VGOS Telescopes at HartRAO

Table 1 contains the technical parameters of the HartRAO 15-m, 26-m, and VGOS radio telescopes, while Table 2 and Table 3 contain technical parameters of the HartRAO 15-m and 26-m receivers, respectively. The current data acquisition systems consist of a DBBC terminal and a Mark 5B+ recorder for both the 15-m and the 26-m antennas. A Mark 5B and a Mark 5C recorder are used for e-transfer of data and conditioning and testing of disk packs. Internal power-wiring upgrades to the DBBC2s and commissioning of a new Flexbuff recording system for geodetic use, have been delayed due to COVID-19 restrictions. A 258-TB Flexbuff recording system is already available for astronomical VLBI use.

Currently the hydrogen maser, iMaser 72, is being used for VLBI on both the 15-m and 26-m antennas. The EFOS-28 hydrogen maser, previously employed for VLBI on the 15-m antenna, developed an internal heater fault and has been taken out of service. It is not reliable but still usable. A heater controller replacement on EFOS-28 is also pending, again due to COVID-19 restrictions. The older EFOS-6 hydrogen maser is completely down at the moment and attempts to restart it following recent repairs have so far failed.

Table 1 Antenna parameters.

Parameter	Hart15	Hart26	HartVGOS
Owner and operating agency	NRF	NRF	NRF
Year of construction	2007	1961	2017
Mount type	Offset Az-El	Offset equatorial	Az-El
Receiving feed	Prime focus	Cassegrain	Ring-focus
Diameter of main reflector d	15 m	25.914 m	13.2 m
Focal length f	7.5 m	10.886 m	3.7 m
Focal ratio f/d	0.5	0.42	0.4
Surface error of reflector (RMS)	1.6 mm	0.5 mm	0.1894 mm
Short wavelength limit	3 cm	1.3 cm	3 mm
Pointing resolution	0.001°	0.001°	0.0001°
Pointing repeatability	0.004°	0.004°	(unknown)
Slew rate on each axis	Az: 2° s^{-1} El: 1° s^{-1}	HA: 0.5° s^{-1} Dec: 0.5° s^{-1}	Az: 12° s^{-1} El: 6° s^{-1}

Table 2 Parameters of the 15-m co-axial receiver.

Parameter	X-band	S-band
Feeds	stepped horn	wide-angle corrugated horn
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	40	42
S_{SEFD} (Jy)	1400	1050
PSS (Jy/K)	35	25
3 dB beamwidth (°)	0.16	0.57

Table 3 Parameters of the 26-m receiver (degraded performance due to dichroic reflector being used for simultaneous S/X VLBI).

Parameter	X-band	S-band
Feeds	dual CP conical	dual CP conical
Amplifier type	cryo HEMT	cryo HEMT
T_{sys} (K)	52	40
S_{SEFD} (Jy)	849	1190
PSS (Jy/K)	16.3	29.8
3 dB beamwidth (°)	0.096	0.418

3 Current Status

During 2019 and 2020, the 15-m antenna participated in 111 and 117 geodetic/astrometric IVS sessions, respectively (see Figure 2). The 26-m antenna participated in 37 and 30 sessions during 2019 and 2020, respectively (see Figure 3). In 2019, the antennas observed together in two T2 sessions and in 2020 in only one T2 session. Whilst the 15-m antenna's maser was offset in frequency to prevent PCAL cross-correlation during the first dual T2 of 2019, the antennas were run off the same maser for the other two dual T2 sessions. During June, July, and August 2020 the 26-m antenna partcipated in three mixed-mode RD sessions aimed at tying the S/X and VGOS frames together in support of ITRF2020. The 26-m antenna served as one of three southern stations used to orient the S/X and VGOS frames. Astrometric single-baseline VLBI sessions in collaboration with Hobart (UTAS) to further improve the K-band reference frame in the South, as included in the ICRF-3, continued to be observed on the 26-m antenna. All sessions from 19 March 2020 onwards were run under remote control due to COVID-19 restrictions. VLBI data for all sessions was e-transferred to the correlators.

The 15-m antenna's cable wrap mechanism caused damage to various cables during 2019 which led to an upgrade of the azimuth wrap cabling later that year. During 2019 and 2020, problems with the 15-m an-

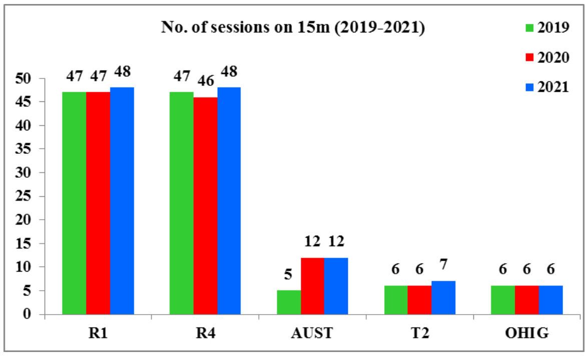

Fig. 2 HartRAO 15-m IVS sessions observed during 2019 and 2020, as well as planned for 2021.

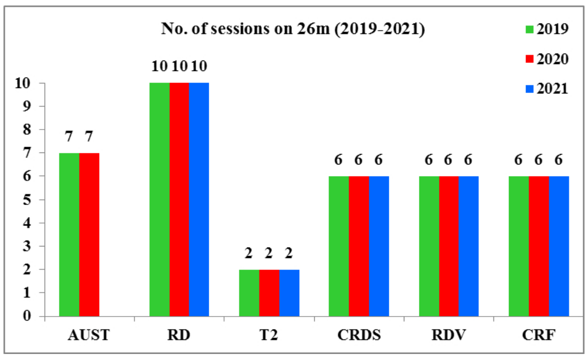

Fig. 3 HartRAO 26-m IVS sessions observed during 2019 and 2020, as well as planned for 2021.

tenna's cryogenic dewar caused several sessions to be observed with a warm or partially cooled receiver. The receiver has been operating since inception and is due for a full service once a gap becomes available in the observing schedule.

The 26-m antenna's encoders continued to be unreliable during 2019–2020, failing and misreading intermittently. In 2019, it was also discovered that the 26-m antenna's west declination shaft bearing had failed. This failure has delayed the installation of new higher resolution Heidenhain absolute encoders (see Figure 4). Fault finding on the current, aged encoders revealed that the power supply to the encoders was marginal. Increasing the value of the supply voltage and some software improvements seems to have solved the reliability issues. An unexpected consequence of the encoder misreadings is that the antenna engaged the brakes every time the encoders misread and, as a result, when it was finally thought to be fixed, the antenna failed to drive because of a catastrophic failure in the brake pads on the declination motors. With these

Fig. 4 One of the new HEIDENHAIN 26-bit absolute encoders awaiting installation after bearing replacement.

problems addressed, the reliability of the encoders are again at a level that allows for the continuous use of the 26-m antenna, while planning for the declination bearing replacement.

4 Personnel

Table 4 lists the HartRAO station staff involved in geodetic VLBI. Jonathan Quick (VLBI friend) handles all local telescope scheduling issues, provides technical support for the Field System as well as support for hardware problems. During the COVID-19 lockdown, from the 19th of March onwards, Jon has been running all geodetic VLBI sessions under remote control.

Table 4 Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
Aletha de Witt	Operations Scheduling	Fundamental Astronomy
Jonathan Quick	Hardware/ Software	Astronomy
Sayan Basu	Operator	Student
Siphelele Blose	Operator	Technical
Jacques Grobler	Operator	Technical
Philip Mey	Operator	Technical
Ronnie Myataza	Operator	Technical
Marisa Nickola	Logistics/ Operations	Fundamental Astronomy
Pieter Stronkhorst	Operator	Technical

Operations astronomer, Aletha de Witt, provides support for astrometric VLBI. Alet is the principal investigator for some of the IVS Southern Hemisphere astrometric and geodetic VLBI sessions as well as for the K-band celestial reference frame project. In 2019, Alet was elected as secretary of the IAU astrometry commission A1. She is also the chair of the newly established IVS CRF Committee. Alet was re-elected to the IVS Directing Board in December 2020.

Since the retirement of Keith Jones at the end of August 2019, the VGOS project manager, Philip Mey, has been given the added responsibility of heading up the Engineering department at HartRAO. In May 2019, Philip and electronics technician, Siphelele Blose, attended the 10th IVS TOW held at MIT Haystack Observatory in Westford, Massachusetts, USA. Siphelele joined the HartRAO geodetic VLBI operator team in 2019.

Antenna systems technician and geodetic VLBI operator, Jacques Grobler (see Figure 5), has left a huge gap with his departure from HartRAO at the end of February 2020 for the shores of the Black Sea.

Fig. 5 Jacques Grobler greasing the 15-m antena's gears.

5 New Developments

Although 2020 COVID-19 lockdown restrictions disrupted the supply chain, causing several projects to be delayed or to be put on hold, remote operations allowed HartRAO to continue supporting geodetic VLBI sessions on the 15-m and 26-m antennas in full. The Space Geodesy programme was recognized as an essential service and staff obtained permits to perform essential duties on-site. This allowed for site visits during which inspection, repairs, and maintenance could be performed. It also allowed for installation/removal of the necessary dichroic reflector system on the 26-m antenna.

A backup generator for the VGOS antenna was installed in 2019 (see Figures 1 and 6) and a four-bank Mark 6 recorder was acquired in 2020. A fully VGOS-capable DBBC3 terminal was ordered from Hat-Lab during the early part of 2020 with expected delivery in the first half of 2021. Yebes Observatory was recently appointed to build a complete wide-band VGOS receiver system to match, with delivery of the latter expected in early 2022.

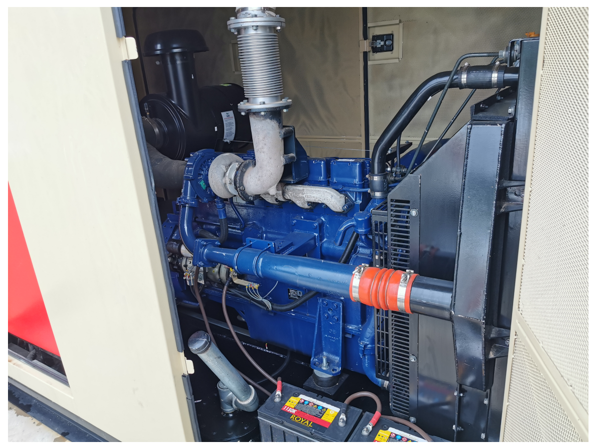

Fig. 6 Inside the housing of the VGOS antenna's backup generator.

We are also currently soliciting bids for possible replacement of the 26-m declination shaft bearings, which would probably involve some significant period of down-time at some yet to be determined date.

During 2019 and 2020, plans were put in place and preparation started to improve the performance and enhance the reliability of the 15-m and 26-m antenna systems. This includes an upgrade to electronic equipment to better find and quickly address problems as they arise; migrating communications to use fiber optics; removing obsolete equipment and connections; and upgrading noise diode controllers to name a few. Work towards this end is continuously in progress and refined as required.

Since the start of 2020, the 15-m antenna has been particpating in Southern Intensive (SI) test sessions in order to compare southern dUT1 results with that from the north. During 2020, these hour-long test sessions were observed monthly on Ht-Hb-Yg baselines during the AUA sessions at the same time as the regular IVS Intensives. From June 2020, SI test sessions were also added to run prior to the weekly R1 sessions, with a total of 35 SI sessions having been observed during 2020.

A further 24-hour VLBI–GNSS session, comprising VLBI observations of GNSS satellites, was run on 23 June 2019 in collaboration with Onsala, Badary, Svetloe, and Zelenchukskaya.

From December 2019 until December 2020, local interferometer sessions between the HartRAO 26-m legacy antenna and the co-located 15-m antenna have been conducted on a regular basis. During these monthly short baseline experiments of four-hour duration (22:00 UT to 02:00 UT the next day), the two antennas simultaneously observe ICRF2/ICRF3 defining sources covering the full range of azimuth, elevation, and cable wrap. Not only do these sessions allow for determining the local tie between the antennas, but it also affords the opportunity to test HartRAO's ability to meet the GGOS requirement of 1-mm accuracy in station coordinates and global baselines.

In August 2020, a request by the IVS Network Coordinator for updated information regarding station meteorological data prompted the condition of HartRAO meteorological sensors to come under scrutiny. Sensors have not been upgraded or calibrated for at least ten years. We are currently utilizing a new MET4 unit as a calibrator for comparative analysis of historical and current meteorological data from HartRAO sensors towards potential reprocessing of historical data sets.

6 Future Plans

Of the 149 geodetic VLBI sessions scheduled for 2021, 119 sessions are allocated to the 15-m antenna, 28 sessions to the 26-m antenna, and two T2P sessions will be run on both antennas.

Progress with the local automated site tie system for continuous monitoring of vector ties was slow due to several factors, but the preparation of various hardware items is near completion with initial measurements and tests to commence in 2021 (see Figure 7).

Fig. 7 Site tie: multi-prism pillar being installed co-axially on the 26-m telescope's shaft.

Work is still under way on an in-house cryogenic receiver that will be used to test the VGOS antenna and resolve possible interface/control issues before arrival of the broadband VGOS receiver. Preliminary participation in VGOS obervations is only expected to begin in the second half of 2022.

Funds were allocated for a complete renewal of onsite meteorological sensors supporting VLBI activities. The MET4 unit is to be installed at the reference height of the 15-m antenna, while two highly accurate pressure sensors will be mounted at the reference heights of the 26-m and VGOS antennas, respectively. Additionally, we plan to obtain a Laboratory Pressure Standard to enable in-house calibration of our pressure sensors.

Acknowledgements

HartRAO forms part of SARAO which is a National facility operating under the auspices of the National Research Foundation (NRF), South Africa. The Space Geodesy Programme is an integrated programme, combining VLBI, SLR, and GNSS, and it is active in several collaborative projects with DLR, ESA, GFZ (Potsdam), GSFC, ILRS, JPL, «Roscosmos» as well as numerous local institutes. General information as well as news and progress on geodesy and related activities can be found at `http://geodesy.hartrao.ac.za/`.

AuScope VLBI Array and Hobart 26-m Antenna

Lucia McCallum, Jamie McCallum, Lim Chin Chuan, Warren Hankey, Ahmad Jaradat, Tiege McCarthy, Guifré Molera Calvés, Brett Reid, Simin Salarpour

Abstract This is a report on the activities carried out at the University of Tasmania in support of the three AuScope VLBI observatories and the Hobart 26-m antenna in 2019 and 2020. Our current and completed research programs are outlined as well as our planned developments of the array.

1 General Information

The Australian AuScope VLBI array consists of 12-m VLBI telescopes located in Hobart, Tasmania (Hb), Katherine, Northern Territory (Ke), and Yarragadee, Western Australia (Yg). In addition, this contribution covers the Hobart 26-m telescope (Ho). While owned and operated by the University of Tasmania, AuScope VLBI observations are contracted through Geoscience Australia. Thanks to the Australian Government *Positioning Australia* initiative, operations and staff are now on medium-term funding cycles allowing improved planning into the future.

2 Component Description

The AuScope VLBI array was initially designed as three identical telescopes with the technical specifications for legacy operations detailed in [1]. Since then, several improvements as well as the gradual VGOS upgrade has resulted in slightly unequal technical situations at the three sites, which are summarized below:

University of Tasmania, Australia

UTAS, AuScope, Hb, Ho, Ke, Yg, Network Stations

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2.1 Hobart 12-m Antenna

A Callisto wide-band feed has been installed since August 2017, operating across the 2.2–14 GHz frequency range. Frequencies below 3 GHz are sent over coaxial cable using a pre-existing S-band local oscillator for downconversion, while the 3–14 GHz RF is transmitted using RF over fiber links to the control room. The output is bandpass filtered to provide three 4-GHz input bands to the DBBC3 sampler (3–7 GHz, 6–10 GHz, and 9.5–13.5 GHz) The existing DBBC2 is used to sample the S-band signal in mixed-mode configuration. A phasecal unit is installed, operating with a 10-MHz spacing together with a noise diode for Tsys calibration. Recording is carried out by a 36-disk Flexbuff system, populated with 8-TB drives for a total data volume of 288 TB. The observatory is connected via a 10-Gbps link to the University and then over a shared multi-Gbps link to the Australian Research Network (AARNet) on the mainland and wider Internet. While variable, typical performances are on the order of hundreds to thousands Mbps, both inwards and outwards.

2.2 Katherine 12-m Antenna

A Callisto wide-band feed was installed in August 2019 using the same RF configuration as at Hobart. Until the end of 2020, the existing DBBC2 was used to sample the S-band signals in mixed-mode configuration until it suffered an equipment failure. A new arrangement has been developed where the DBBC3 is used for the S-band data through recabling. A phasecal unit is installed, operating with a 10-MHz spacing together with a noise diode for Tsys calibration. The recording is carried out using a 36-disk Flexbuff system typically populated with 8-TB drives for a total data volume of 288 TB. The Internet connection is sufficient for basic remote operations and suitable for high-latency transfers of small test data. Peak traffic rates are approximately 10 Mbps.

2.3 Yarragadee 12-m Antenna

Largely unchanged. A new cable wrap system and an air conditioning unit in the hub were installed in early 2019. In late 2019, a Fila10G was installed in the DBBC2 together with a 36-Disk Flexbuff unit as an alternative recording system. The Internet connection is sufficient for basic remote operations and suitable for high-latency transfers of small test data. Peak rates are approximately 10 Mbps.

2.4 Hobart 26-m Antenna

The Mark IV rack has been officially decommissioned and all recordings are now using the DBBC2 and Mark 5B+ system, previously in use for the Hobart 12-m. The phasecal unit previously used on the Hb 12-m is planned to be restored to the 26-m telescope. There have been a number of ongoing issues with front-end electronics and cryogenic systems which have affected the reliability and sensitivity of this telescope throughout the period. In 2019–2020, the Hobart 26-m increased its participation in the IVS observing program, partly to compensate for the removal of the Hobart 12-m from S/X operations. However, the telescope is currently also experiencing increased demand from other projects.

3 Staff

Routine operations, maintenance, and development are undertaken by a few staff at the University of Tasmania, while experiment monitoring is usually carried out by PhD students. Table 1 summarizes the current staff and their responsibilities.

4 Current Status and Activities

The AuScope array of telescopes has been participating in the regular IVS experiments, aiming to observe whenever it is possible and useful to do so. In 2019 and 2020 the AuScope and Hobart 26-m antennas participated in 158 and 151 IVS sessions, respectively. The slight decrease from ∼170 in 2017–2018 is largely due to the removal of Katherine from the S/X network.

The main activities in 2019 and 2020 were efforts into maintaining current operations, planning, managing, and implementing the VGOS upgrades. While at the start of this reporting period we were very low on staffing, we have worked on recruiting and training towards a critical number of staff for sustainable operations and critical research. For the first time, we have a geodetic VLBI research group at the University of Tasmania, with regular meetings and 5+ members.

A brief discussion of significant projects undertaken over the last two years is given below.

- **VGOS upgrade:** Early in 2018 the final adjustments were made to the Hobart 12-m optical arrangements which considerably improved the performance of the system. With the design finalized and the arrival of the DBBC3s, it was possible to undertake the upgrade of the Katherine telescope in mid-2019. The upgrade to the Yarragadee station is contingent on the ability of the array to contribute to global VLBI and thus on the performance of the Hobart12 and Katherine stations. Unfortunately, we have not been able to carry out fully compatible observations with the existing VGOS network. With our current design having three bandpasses (and corresponding DBBC3 samplers) we are currently limited to observing three out of four bands at a time (using eight BBCs).
  While it would be possible to observe a wider subset of the lower bands through mixed USB/LSB channels, this would require some additional configuration of the correlator, together with non-trivial modifications to the post-processing system. Some test observations with Ishioka (correlated in Hobart) resulted in fringes but have

Table 1 Staff

Name	Role	Topics
Jamie McCallum	AuScope array manager	Operations & Development
Warren Hankey	Technical support	Technical support and data transfers
Brett Reid	Observatory manager	Maintenance, repairs, and implementation of new systems
Amirsadra Falahati	Technical Assistant	Maintenance and repairs, part-time
Eric Baynes	Technical support	Electronics specialist, part-time
Peter McCulloch	Technical support	VGOS RF-design, part-time
Jim Lovell		Project work, casual
David Horsley		Project work, casual
Lucia McCallum	Post-doc	research, part-time / extended leave periods
Guifré Molera Calvés	Post-doc	systems development, AOV secretary
Tiege McCarthy	Post-doc	project work, feed-back system
Simin Salarpour	PhD student	research, source structure
Lim Chin Chuan	PhD student	research, dynamic observing
Ahmad Jaradat	PhD student	research, AuScope VGOS
AuScope observers		about 10 regular observers

not been fully post-processed. An upgrade of the DBBC3 to support the latest firmware, which can generate up to 16 BBC per IF and should make it possible to carry out fully compatible ovservations, is being carried out in stages, with the first unit currently being in Bonn. We hope that all three DBBC systems will be available by the end of 2021 and that we will be able to join the global VGOS observations with Hobart12 and Katherine somewhat earlier.

- **AUM sessions:** With the upgrade of the Hobart12 telescope to the wideband backend in 2017, it became unavailable as an S/X station. With the difficulties in the beginning VGOS operations, we investigated the potential for “mixed-mode” (VGOS–Legacy) observations. After some initial tests, a short series of experiments was carried out in mid-2018 using the Hobart 12-m as a VGOS station, together with Katherine and Yarragadee as S/X stations. After correlation and fringe-fitting, the results appeared promising and Hobart12 joined the ongoing AUSTRAL experiment series. With the upgrade of the Katherine telescope in mid-2019, the network now had a VGOS–VGOS baseline and a new AUM experiment series was begun to investigate the technique’s application on this baseline. Observations made in 2020 with the participation of Warkworth are currently under analysis.
- **AUV sessions:** With Katherine’s upgrade to a wideband receiver and recording system in mid-2019, it became possible to carry out single baseline observations using a wideband observing mode. With the limitations of the current system, observations made using a subset of the “standard” VGOS bands were unlikely to yield useful data due to ambiguity issues with dTEC and delay resolution. Instead, a new frequency sequence was designed around the capabilities of the DBBC3-equipped stations which utilized the wide input bandwidths available. Test observations were made in 2020 with promising results, but a full 24-hour session is yet to be successfully observed. The fringe-fitting is carried out using fourfit, following the normal VGOS procedures. This does require some modifications of the processing scripts.
- **AUA sessions:** The AUSTRAL-Astrometry experiment series in 2019 was based around the SOuthern Astrometry Project (SOAP), but has reverted to standard geodetic observations in 2020. The scheduling for the geodetic sessions has been carried out by Matthias Schartner (TUW/ETHZ), with correlation carried out by TUW during this period.
- **Southern Intensives:** Organized by TUW, a series of “Intensive”-style experiments were carried out during 2020, using the Hart15–Yarragadee baseline. Additionally, the Hobart12 joined in a number of these sessions as a way to both investigate the performance of the station in mixed-mode and hopefully as a comparison with the Hart15–Yarragadee baseline. Over 30 sessions were observed and correlated in Vienna. An analysis of the results is pending.

- **Data transfers:** As part of the upgrade to the wideband observing system, the Mark 5B systems were decommissioned for Hobart12 and Katherine. Without a high-speed network link available at Katherine, it was necessary to develop a method for transferring the large data volumes generated in mixed-mode or VGOS-style observations. The solution has been to use the removable drive caddies from the flexbuff chassis, shipping these as needed. For local correlation, the correlator nodes have matching interfaces and can directly mount the drives. Alternatively, the nodes can act as temporary storage for data transfers to overseas correlators.
- **Station upgrades:** We have conducted several upgrades on the instrumentation and computation infrastructure in order to keep up-to-date and modernize the Auscope VLBI array. New NASA Field System (FS) computers were built and installed with the latest version of the FSL 10.0.0. The new FS machines were installed and tested successfully at the three geodetic locations of Yarragadee, Katherine, and Hobart. We can now operate the antenna, the recorder, and both DBBC3 and DBBC2 from the FS without any external scripts.
  During these two years we also have worked on adapting the DBBC3 to the needs of the AuScope sessions. At the moment, Katherine and Hobart operate with the DBBC3 for broadband sessions and a combination of DBBC2 and DBBC3 for the mixed-mode sessions. Yg still uses the DBBC2 with its S/X receiver.
  In 2020 we also redesigned the monitoring and analytics platform to supervise the correct functioning of the array with Grafana. We set up the system as suggested in the NASA VLBI Station Monitoring and Archival System (MAS) Guide. All data are collected from the nodes using Telegraf and transferred to the Web server. Data are collected and archived using the influxdB database. Finally, the metrics stored in the database is displayed using Grafana and it can be accessed via our Web site by operators and observers. The development is a work in progress (as seen in Figure 1).
- **Feedback loop:** An automated system for processing correlation and analysis reports to monitor the performance on the UTAS operated telescopes was developed in 2020 and is currently in operation. The aim is to ensure better performance from the array.
- **Dynamic observing:** This research focuses on improving the efficiency of the three 12-meter AuScope VLBI telescopes by streamlining the operational processes through more dynamism and automation. This work also includes the improvement of the agreement between the actual and scheduled signal-to-noise ratio through improved source selection and better determined antenna sensitivities. A discrepancy between the source flux on the global network with the Australian network is also under investigation.
- **Source structure:** As part of a PhD project, source structure and its effects on VLBI observations is an active research topic at UTAS: We have studied different structure index (SI) characteristics in a statistical sense on a large sample. We have investigated SI time series of 8,000 images (186 sources) over a 25-year period and the impact of different X-band observing modes on these values. We have also compared the median structure delay calculated in different VGOS observing networks with nominal SI. In another investigation, we have constructed source models for a group of quasars (176 sources) by fitting two/multiple Gaussian components to their available X-band images at various epochs using an automated script. We have applied these models to generate simulated broad bandwidth observations with the Vienna VLBI Software (VieVS). Using this approach and simulated VGOS networks, we aim to quantify the number of observations that may be affected by variable source structure.
- **Satellite observations:** Funded by the Australian Research Council (ARC), we continue investigations of VLBI observations to satellites, aiming for improved space ties. In a benchmarking study [2], we designed an observing setup to use VLBI radio telescopes as bright reflectors for InSAR satellite imagery. With regular observations ongoing, the aim is to use these observations for improved georeferencing of the InSAR images. Alternatively, precise information about relative height-changes of the radio telescope may be useful for VLBI local ties.
- **AuScope VLBI performance:** In late 2020, a new PhD project was commenced with the aims to quantify the recent performance of the AuScope VLBI

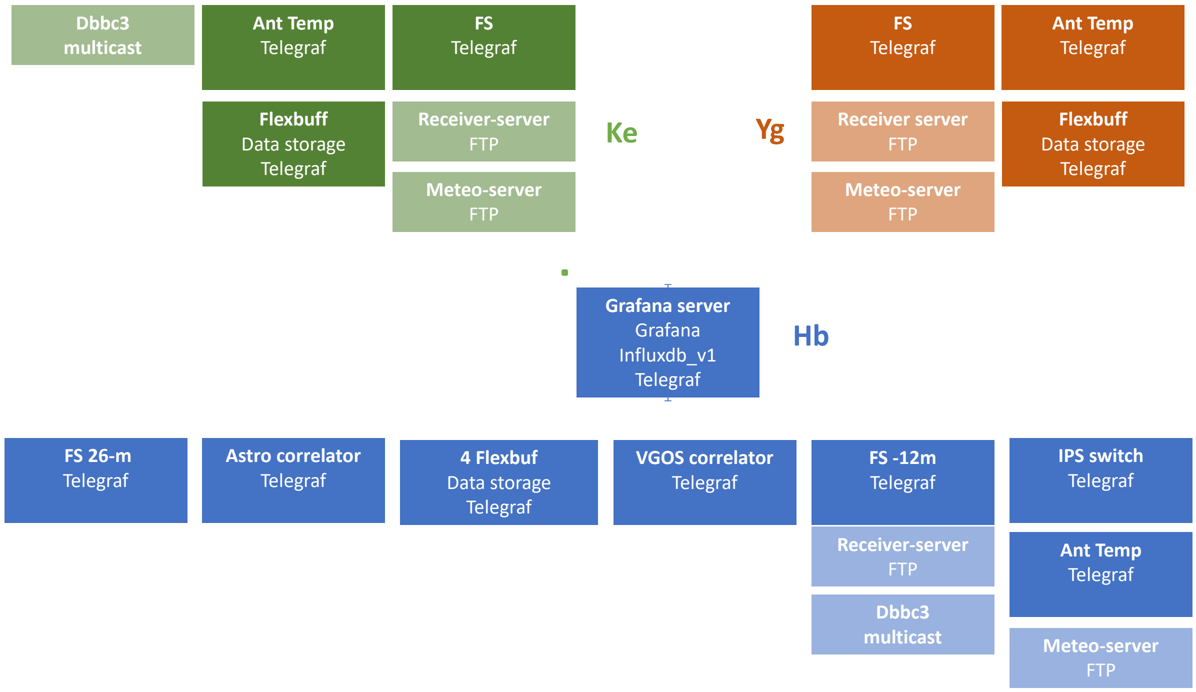

Fig. 1 Newly implemented Grafana setup.

array and to design observations in order to create useful AuScope VLBI VGOS results.

5 Future Plans

We are currently looking forward to being able to make use of the upgraded DBBC3s and to begin the process of joining the global VGOS experiment. With the continued importance of the S/X program, we aim to continue our mixed-mode campaign and the associated observing programs.

Acknowledgements

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Ishioka Geodetic Observing Station – 13.2-m Radio Telescope

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Abstract The Ishioka Geodetic Observing Station is operated by the Geospatial Information Authority of Japan (GSI). The Ishioka 13.2-m radio telescope at this station contributed to regular S/X and VGOS observations during 2019 and 2020. During a five-months period in 2020, the station could not participate in international observations because of antenna trouble. This is a report on activities of the Ishioka station during 2019 and 2020.

1 General Information

The Ishioka Geodetic Observing Station (Figure 1, hereafter called Ishioka station) is located at about 70 km northeast of Tokyo and 17 km northeast of the Geospatial Information Authority of Japan (GSI) headquarters in Tsukuba (Figure 2) and operated by GSI. Ishioka station has a 13.2-m radio telescope, which was designed by MT Mechatronics (MTM) to fulfill the VGOS requirements.

The Ishioka 13.2-m radio telescope started observation in 2016 as the successor of the Tsukuba 32-m radio telescope, which was located in Tsukuba, and has participated in S/X sessions coordinated by IVS. Furthermore, it has also participated in the VGOS sessions as a VGOS station.

1. Geospatial Information Authority of Japan
2. Advanced Engineering Service Co., Ltd.

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Fig. 1 Ishioka 13.2-m radio telescope in the Ishioka Geodetic Observing Station.

2 Component Description

The specifications of the Ishioka 13.2-m radio telescope are summarized in Table 1. Ishioka station has two types of feeds: a tri-band feed and a QRFH feed. We use these two feeds depending on the types of observation: a tri-band feed for legacy S/X observation and a QRFH feed for broadband observation. It takes about one week to switch the feeds and adjust the equipment.

The signal is recorded in the following way for both observations. First, radio waves received with the antenna are converted to radio signals at the feed. Then, the signal is amplified and converted to an optical signal to be transferred to the observation building. In the building, it is again converted to RF and then to IF signal by frequency conversion. Finally, it is digitalized and recorded. Field System ver. 9.10.5 (FS9) is used to control the antenna and surrounding devices.

Table 1 Specifications of the Ishioka 13.2-m radio telescope.

Parameter	Ishioka 13.2-m radio telescope
Owner and operating agency	GSI
Latitude	N36°12′33″
Longitude	E140°13′08″
Altitude	112.8 m
Year of construction	2014
Radio telescope mount type	Az-El
Antenna optics	Ring focus
Diameter of main reflector	13.2 m
Azimuth range	180° ± 250°
Elevation range	0–100°
Azimuth drive velocity	12°/sec
Elevation drive velocity	6°/sec
Tsys at zenith (X/S)	50 K / 300 K
Tsys at zenith (Broadband)	H-pol: [*1] 216 K (3-GHz band) 138 K (5-GHz band) 139 K (6-Hz band) 243 K (10-GHz band) V-pol: N/A[*2]
SEFD (X/S)	1500 Jy / 2200 Jy
SEFD (Broadband)	H-pol: [*1] 4,040 Jy (3-GHz band) 3,854 Jy (5-GHz band) 3,900 Jy (6-GHz band) 9,368 Jy (10-GHz band) V-pol: N/A[*2]
RF range (X)	8,192–9,104 MHz
RF range (S with BPF)	2,170–2,425 MHz
RF range (Broadband with BPF)	2–14 GHz
Recording terminal	ADS3000+ sampler & K5/VSI data recording terminals
Data capacity	89 TB
Hydrogen maser	VCH-1003M (VREMYA-CH)

[1] The average value in observing frequency band for VGOS observation (3-GHz band: 3,000.4–3,480.4 MHz, 5-GHz band: 5,240.4–5,720.4 MHz, 6-GHz band: 6,360.4–6,840.4 MHz, 10-GHz band: 10,200.4–10,680.4 MHz).
[2] V-polarization of broadband is very noisy (described in section 4.2.3). Tsys and SEFD could not be measured as of January 22, 2021.

Fig. 2 Location of Ishioka station.

3 Staff

Ishioka station is operated by eight members and a contract operation staff member belonging to the VLBI group of GSI as of December 2020. The member list is shown in Table 2.

Table 2 Member list of the VLBI group of GSI (as of December 2020).

Name	Main Function	Remarks
Tomokazu Kobayashi	Supervisor	Apr. 2020
Toru Yutsudo	Management	Apr. 2019
Katsuhiro Mori	Observation facility management & Co-location	Apr. 2020
Yu Takagi	Research	Apr. 2020
Kyonosuke Hayashi	Research	Apr. 2019
Haruka Ueshiba	Operation & Co-location	
Tomokazu Nakakuki	Operation & Research	Apr. 2019
Saho Matsumoto	Operation & Research	
Kentaro Nozawa	Operation (AES)	

4 Current Status

4.1 Observation

Observation is automated and basically operated remotely from GSI headquarters in Tsukuba. It is unmanned operated at night and holidays, and error e-mails are sent when problems occur. Because of the spread of COVID-19, a state of emergency was declared in Japan from April to May 2020. Although most of the staff worked from home, it did not affect operations. Note that all staff continued to be required to work from home once a week as of the end of 2020. However, Ishioka station had stopped operations for about five months due to antenna trouble (described in Section 4.3).

4.1.1 S/X Observation

Ishioka station participated in the S/X sessions from January to November 2019 and from March to June 2020 (Table 3). It participated in one-hour sessions to contribute to dUT1 and 24-hour sessions for obtaining EOP with high frequency. AOV sessions, which are designed for enhancing positioning accuracy in the Asia-Oceania region, were held once a month and GSI contributed as a scheduler in some of them. Furthermore, Ishioka participated in "AOV Mixed-mode" observations, in which S/X and VGOS stations observed at the same time, beginning in March 2020.

Ishioka station could not participate in the scheduled S/X sessions from July to September 2020 because of antenna trouble.

4.1.2 Broadband Observation

From December 2019 through February 2020 and after November 2020, Ishioka station participated in broadband observations with the QRFH feed. Ishioka station participated in the bi-weekly VGOS-O (VGOS-T before 2020) sessions. In December 2019, we started to participate in EU-VGOS sessions as the only station in Asia. In addition, VGOS Intensive sessions with Onsala (ONSA13NE (Oe) and ONSA13SW (Ow)) also started. These are one-hour sessions conducted at the same time as the S/X Intensive sessions and are conducted once a week.

We also participated in one of the mixed-mode R&D sessions, coordinated by IVS, as a VGOS station in 2020.

During the broadband observations from December 2019 to February 2020, Ishioka's antenna and QRFH feed were also used for test observations for frequency comparison conducted by the National Institute of Information and Communications Technology (NICT).

Table 3 Number of regular sessions in 2019 and 2020.

System	Sessions	2019	2020
S/X	IVS-R1	41	14
	IVS-R4	43	14
	IVS-T2	6	1
	APSG	2	2
	AOV	11	3
	IVS-CRF	2	1
	IVS-INT1	30	3
	IVS-INT2	93	29
	IVS-INT3	41	14
	Total	*269*	*81*
VGOS	VGOS-O (VGOS-T)	2	6
	EU-VGOS	2	5
	VGOS-B	4	12
	IVS-R&D	–	1
	Total	*8*	*24*
Total		**277**	**105**

4.2 Introduction of the Superconducting Filter

As mentioned in Section 2, Ishioka station participates in the S/X and VGOS sessions with a different feed. To participate in both of the sessions continuously, we started to discuss the possibility of observing with the QRFH feed without interruption. To realize this, it is required to observe S- and X-band with the QRFH feed. However, because of the strong Radio Frequency Interference (RFI) caused by the artificial noise around Ishioka station, we had to cut less than 3 GHz with the high-pass filter installed in the QRFH feed. Therefore, we considered to introduce the filter to cut only artificial noise in S-band. First, we conducted an RFI survey in July and October of 2019, and we determined the frequency to cut with the filter. According to these results, the superconducting filter was developed and installed in the QRFH feed (both H- and V-polarization) in March 2020. We adopted the superconducting filter because it has steep cut-off characteristics and is able to cut the noise avoiding the frequency needed for observation. From June to July 2020, we conducted the RFI survey to check the effect of the filters and confirmed that the filters have the expected performance. Furthermore, we conducted test observations with the cooperation of NICT, University of Tasmania (UTAS), and Shanghai Astronomical Observatory (SHAO) in July 2020. We confirmed that fringes could be detected [1].

4.3 Troubles

Some troubles had a large impact on the operation of Ishioka station.

4.3.1 Trouble in Antenna Elevation Driving System

In June 2020, the antenna suddenly stopped with errors during observation. It repeated frequently, occurring only when driving in elevation direction, and the antenna always stopped around EL 60 degrees. We asked the manufacturer to investigate this problem and we were forced to cancel almost all planned observation during that time. The cause of this trouble has not been clearly detected yet. After some treatments, Ishioka station restarted the observation at the end of November 2020 with the follow-up check by the manufacturer. Because of this trouble, we could not participate in the planned S/X and VGOS observations for five months.

4.3.2 Internal Noise in QRFH Feed

In the QRFH feed, a high-frequency noise has occurred in the V-polarization since January 2020. We investigated the cause of this noise several times and confirmed that the noise was detected at the output of the receiver LNA, so it is sure the noise is caused inside the receiver. Although this problem has not been solved yet, it is possible to detect fringes with this noisy data for VGOS observations. We will conduct further investigation to fix this problem.

4.3.3 Other Troubles

During the term of S/X observations in 2019, several sessions were missed because the antenna's emergency lock activated suddenly due to the trouble of the antenna control unit and could not be unlocked remotely. In addition, during the term of VGOS observation in 2020, some data were missed because of the trouble of the recording server. We dealt with this trouble by changing the PC-VSI (interface) board or updating the driver of the RAID controller.

4.4 Co-location Survey

At Ishioka, we also operate a GNSS Continuously Operating Reference Station (CORS) which is registered as an IGS station. To contribute to building the ITRF, we regularly conduct co-location surveys. To determine the local-tie vector between the VLBI antenna and the GNSS antenna (Figure 3), we did the first co-location survey in 2016 and have conducted further co-location surveys once a year since 2018. In 2018, we applied two methods to estimate the VLBI antenna invariant point: legacy one called *Outside method* and another one called *Inside method*. *Inside method* was expected to be more efficient and accurate than *Outside method* and it was confirmed by comparing the results for both methods [2, 3] and we adopted the *Inside method* instead of the *Outside method* in the 2019 and 2020 surveys. We are preparing to submit the results to the IERS.

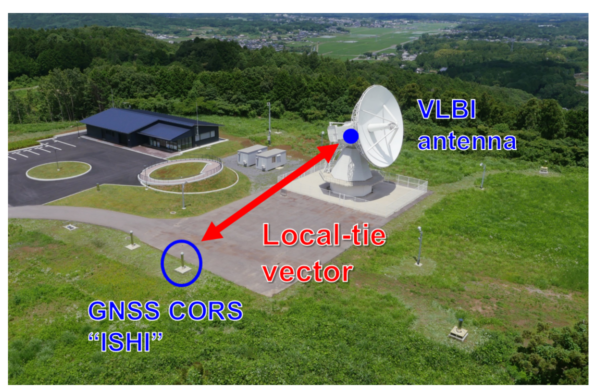

Fig. 3 VLBI–GNSS local-tie in Ishioka station.

5 Outlook

Ishioka station will continue to participate in the S/X and the VGOS observations coordinated by the IVS. In parallel with that, we will progress with the consideration for participating in both broadband and S/X observations with the QRFH feed. At the moment, the circular polarized signal is treated in S/X observation and the linear polarization signal is treated in broadband observation. To participate in S/X observations with the QRFH feed, it is required to convert the polarization from linear to circular in the process of signal from receiver to recorder. Furthermore, we are setting up the new sampler DBBC3 for our operating system. In addition, we will continue to conduct co-location surveys regularly.

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NICT Kashima 34-m Report for 2019–2020

Mamoru Sekido, Eiji Kawai

Abstract The NICT Kashima 34-m diameter radio telescope regularly participated in IVS sessions until 18 August 2019 (R1908). A strong typhoon (Faxai) passed through the east coast of Japan on 9 September 2019. It seriously damaged the elevation drive and main structure of the Kashima 34-m antenna. The antenna stopped operation since then and the decision was made to dismantle in 2020–2021.
The station was maintained by the VLBI group of Space Time Standards Laboratory of NICT. The VLBI application for precision frequency transfer is the main project of this group. In 2018–2019, a series of broadband VLBI experiments for comparison of optical frequency standards was conducted between Italy and Japan. A small diameter (2.4 m) antenna pair was deployed at Medicina Astronomical Station in Italy and at NICT headquarters at Koganei in Tokyo. The Kashima 34-m antenna participated in the experiments as a 'hub' station for boosting the SNR of VLBI observation.
In addition to the frequency transfer of VLBI projects and geodetic IVS sessions, the antenna participated in astronomical VLBI observations of the Japan VLBI network (JVN).

1 General Information

The VLBI activities are operated by a group of the Space-Time Standards Laboratory (STSL) of the National Instate of Information and Communications Technology (NICT). The STSL is keeping Japan Standard Time (JST) at Koganei headquarters in Tokyo, and the development of optical lattice clocks is a part of its activity. The VLBI group is working at the Kashima Space Technology Center, where two radio telescopes, Kashima 34 m and Kashima 11 m, are located. The future redefinition of the 'second' using optical frequency standards, instead of the current cesium atom, has been discussed in the metrological community [1]. Based on the requirement of the accurate comparison of optical frequency standards toward redefinition of 'second', NICT has conducted developments of a broadband VLBI system as a tool for long-distance frequency transfer.

NICT Kashima Space Technology Center

Kashima 34-m Network Station

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2 Activities during the Past Year

A transportable broadband VLBI station (MARBLE) was installed at the Medicina radio astronomical station in 2018. Broadband VLBI experiments were then intensively conducted with the network of two small VLBI stations and the Kashima 34-m antenna.

Our broadband VLBI system [2] is capable to observe a wide frequency range (3.2–14 GHz), which is similar to that of the VGOS specifications [3]. Unique features in our data acquisition system are full digital signal processing and utilizing virtual delay via the Node-Hub style (NHS) VLBI scheme. The radio frequency signal is directly digitized by 16-GHz sampling, and the desired frequency bands are then extracted via digital signal processing without analog frequency conversion. The NHS is a scheme that utilizes the virtual delay observable derived by linear combinations of two baselines from three stations forming a

Fig. 1 Picture of the Kashima 34-m antenna taken on 16 June 2019.

triangle. It enables VLBI observations between a small diameter antenna pair with a high sensitivity hub station. We have successfully applied this technique for geodesy and frequency transfer VLBI [4]. Please refer to [2] for more technical details.

Table 1 shows experiment codes of VLBI sessions in which the Kashima 34-m antenna participated in 2019–2020. Broadband VLBI experiments were conducted as the main mission of our group. There observations were made by the network of two 2.4-m antennas at Medicina and Koganei and the 34-m antenna at Kashima.

In addition to participation in IVS sessions, the Kashima 34-m antenna has been supporting domestic astronomical VLBI observations conducted by University collaboration with JVN [5].

The typhoon 'Faxai' with strong winds passed through the east coast of Japan on 9 September 2019. The elevation drive system and part of the antenna structure were seriously damaged. By taking into account its deterioration, dismantlement of the antenna was decided. R1908 of IVS-R1 performed on 21 August 2019 was the last IVS observation for the Kashima 34-m antenna.

Table 1 VLBI experiments of the Kashima 34-m antenna during 2019–2020.

IVS and AOV sessions

Session code	Length [h]
rd1901 rd1902 rd1903 r1899 aov034 aov036 r1902 r1906 r1908 crf112 t2133	24

Broadband VLBI experiments

Session code	Length [h]
gv9015 gv9025 gv9035 gv9045	29–36
gv9091 gv9095 gv9137 gv9146	52–78
gv9150 gv9163 gv9184 gv9199	108–168
gv9212	40.5

Astronomical VLBI obseravtions

Session code	Length [h]
u9083 u9084 u9085 u9086 u9087 u9088 u9089 u9090 u19052 u19191 u19192 u19206 u19207 u19208 u19219 u19220 u19221	1.4–10.3

Table 2 Parameters of the receiver system of the Kashima 34-m antenna. Letters in 6th column ‘L’ and ‘R’ represent left- and right-hand circular polarizations (LHCP and RHCP), respectively. ‘V’ and ‘H’ represents linear polarization in vertical and horizontal directions. Tsys with ‘*’ indicates effective system temperature measured by R-Sky Y-factor measurement.

Band	Freq [GHz]	Tsys [K]	Efficiency [%]	SEFD [Jy]	Polarization	Trolley Group	Note
L	1.405–1.440, 1.600–1.720	80	68	200	L/R	1	Superconductor filter
S	2.193–2.35	72	65	340	L/R	2	
Wide	3.2–14	150*	20–40	1k–2k	V/H	3	Room temperature LNA
X	8.18–9.08	50	65	270	L/R	2	
K	22.0–24.0	141	50	850	L(R)	4	
Q	42.3–44.9	350	20	3500	L(R)	4	

3 Brief History

The Kashima VLBI group of NICT has a long history in VLBI technology development. It started from a TELEX received from NASA/GSFC in 1971 for invitation of collaboration. Proving plate tectonics by the first detection of contraction of the baseline between Kashima and Hawaii was accepted as big news in Japan. The understanding of crustal deformation around the Japanese islands gave citizens a hope for potential prediction of an earthquake. Based on those great achievements by the Kashima 26-m, the Kashima 34-m antenna was constructed as the first VLBI-dedicated antenna in Japan in 1988 [6]. The antenna was manufactured by TIW Systems Inc. of USA, and it has quite similar structure as the 34-m antenna at Goldstone and Canberra of NASA’s deep space network. The Kashima 34-m was designed not only for geodesy (S/X-band), but also had the capability for radio astronomical observations (L-, K-, and Q-band) in its scope.

Fig. 2 Broadband ‘NINJA’ feed mounted on the Kashima 34-m antenna.

The originally designed wideband ‘NINJA’ feed [7] (Figure 2) was installed by replacement with C-band on the trolley No.3 in 2015. The receiver parameters of the Kashima 34-m antenna are listed in Table 2. It participated in many VLBI observations and was used for a variety of technology developments. A series of VLBI observation systems (K3/K4/K5) [8, 9] and rapid UT1 determination with e-VLBI [10] contributed to the geodetic VLBI community. Please refer to [11] for achievement of the Kashima 34-m antenna.

Acknowledgements

We thank colleagues of INRiM (Davide Calonico, Marco Pizzocaro, Cecilia Clivati, et al.), INAF (Monia Negusini, Federico Perini, Giuseppe Maccaferri, Roberto Ricci, Mauro Roma, Claudio Bortolotti, Giampaolo Zacchiroli, and Juri Roda), and NICT (Nils Nemitz, Hidekazu Hachisu, and Tetsuya Ido, Jun’ichi Komuro, Kunitaka Namba, and others) for contribution to the achievement of the frequency link of optical frequency standards via intercontinental VLBI between Italy and Japan. We thank NICT members (Junichi Nakajima, Noriyuki Kurihara, Tetsuro Kondo, Yasuhiro Koyama, Ryuichi Ichikawa, Hiroshi Takaba, Yukio Takahashi, and others), staff of Advanced Engineering Services Co. Ltd. (Ryu Suzuki, Hideaki Sakuyama), and the people of the Rikei Corporation (Yasutaka Mizuno ,Yuki Watanabe, Yujiro Hirose, Shigeo Suzuki, and Makoto Koyanagi)

Fig. 3 **Left:** Bottom view of the Kashima 34-m antenna receiver room. Receivers are separated into four groups and mounted on one of four trolleys. Observing receiver is changed by exchanging the trolleys at the focal point (center). **Right:** The Kashima 34-m antenna and flowers.

for their contribution to keep the antenna operational for 30 years.

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Kokee Park Geophysical Observatory

Chris Coughlin

Abstract This report summarizes the technical parameters of the VLBI systems at the Kokee Park Geophysical Observatory and provides an overview of the activities that occurred in 2019–2020.

1 Location

The Kokee Park Geophysical Observatory (KPGO) is located in Kokee State Park on the island of Kauai in Hawaii at an elevation of 1,100 meters near the Waimea Canyon, often referred to as the Grand Canyon of the Pacific. KPGO is located on the map at longitude 159.665° W and latitude 22.126° N.

Fig. 1 KPGO site logo.

1. USNO
2. NASA GSFC

Fig. 2 KPGO site overview.

2 Technical Parameters

The 20-m receiver is of NRAO (Green Bank) design (a dual-polarization feed using cooled 15 K HEMT amplifiers). The antenna is of the same design and manufacture as those used at Green Bank and Ny-Ålesund. A Mark 5B+ recorder is currently used for all data recording.

The 12-m receiver is of MIT design. The ultra wideband receiver uses a Quadruple-Ridged Flared Horn (QRFH) and LNAs, developed at the California Institute of Technology, cooled to $\sim$15K and is dual polarization. The antenna is a prototype that was developed by InterTronic Solutions Inc. A Mark 6 recorder is currently used for all data recording.

Timing and frequency is provided by a Sigma Tau Maser with a second Sigma Tau Maser backup, and a NASA NR Maser providing a second backup. Monitoring of the station frequency standard performance is

Table 1 Technical parameters of the radio telescopes at KPGO.

Parameter	20-m	12-m
Owner and operating agency	USNO-NASA	USNO-NASA
Year of construction	1993	2015
Diameter of main reflector d	20 m	12 m
Azimuth range	$\pm 270°$	$\pm 270°$
Azimuth velocity	$2°/s$	$12°/s$
Azimuth acceleration	$1°/s^2$	$1°/s^2$
Elevation range	$\pm 90°$	$\pm 90°$
Elevation velocity	$2°/s$	$6°/s$
Elevation acceleration	$1°/s^2$	$1°/s^2$
Receiver System		
Focus	Primary Focus	Cassegrain
Receive Frequency	2.2–8.9 GHz	2–14 GHz
T_{sys}	40 K	40 K
$S_{SEFD\ Range}$	500–2000 Jy	1500–3000 Jy
G/T	40 dB/K	43 dB/K
VLBI terminal type	VLBA4	RDBE
Recording media	Mark 5B+	Mark 6
Field System version	10.0.0	10.0.0

provided by a CNS (GPS) Receiver/Computer system. The Sigma Tau performance is also monitored via the IGS Network.

3 Staff

The staff at Kokee Park consists of six full-time employees and one part-time person employed by Peraton Corporation under the SENSE contract to NASA for the operation and maintenance of the observatory. Chris Coughlin (KPGO Station Manager), Kiah Imai (KPGO Lead Engineer), Lawrence Chang, and Morgan Goodrich conduct VLBI operations and maintenance. Ben Domingo is responsible for antenna maintenance, and Amorita Yaris provides administrative and logistical support. Kelly Kim also supports VLBI operations and maintenance during 24-hour experiments and as backup support.

4 Mission Support

Kokee Park participates in many VLBI experiments for both Legacy and VGOS Networks. KPGO (Kk) participates in the R4, R1, RDV, CRF, APSG, RD, and OHIG 24-hour sessions along with the INT1 one-hour sessions. KPGO (Kk) averaged two experiments of 24-hour duration each week, with weekday Intensive experiments in 2019 and 2020. KPGO (K2) participates in the VO 24-hour sessions along with the V2 one-hour sessions. KPGO (K2) averaged one experiment of 24-hour duration each week, and two Intensive experiments per week in 2019 and 2020.

Kokee Park hosts other systems, including the following: a Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) beacon and remote control, a Quasi-Zenith Satellite System (QZSS) monitoring station, a Two-Way Satellite Time and Frequency Transfer (TWSTFT) relay station, and a Turbo-Rogue GPS receiver. Kokee Park is an IGS station.

5 Recent Activities

KPGO Staff and General Dynamics Mission Systems (GDMS) completed the refurbishment of the 20-m frontend focus system in July 2019. This refurbishment effort restored the capability to adjust the focal point for the 20-m Frontend Receiver. This ability will allow us to upgrade to the new VGOS broadband signal chain when ready.

The original 26-year-old 15-kW GenSet of the 20-m telescope, used for backup power for cryogenics and frontend electronics, was replaced with a new

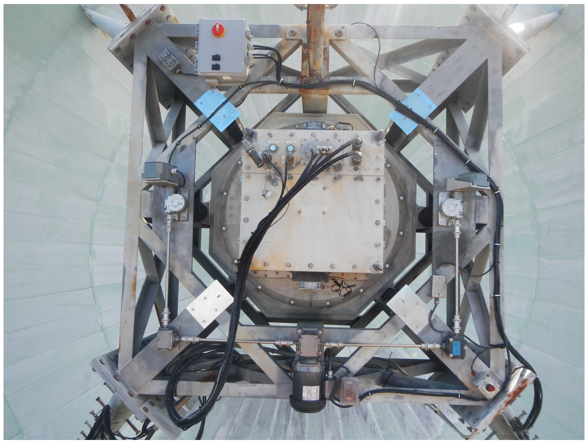

Fig. 3 New 20-m telescope prime focus frontend system.

Cummin's 60-kW GenSet in December 2019. This allowed for the newly installed M700 Helium Compressor to be on the standby power circuit, limiting warm-ups due to site power outages. This upgrade effort restored the reliability of operations for the KPGO 20-m system.

Fig. 4 New 20-m telescope 60-kW GenSet.

KPGO completed a major site network upgrade in 2019 to new compliant network configuration, hardware, and protocols. Network upgrade not only improved our overall site network performance, but also our data e-transfer speeds. KPGO e-transfer speed capabilities improved from 80 Mbps to 700 Mbps. This particular improvement from the Site Network Upgrade allows us to e-transfer the majority of our VLBI data and cut back on FedEx shipping of modules to correlator sites.

KPGO staff and ISI rebalanced the 12-m reflector counterweights in late 2019 along with a controller modification to allow more connections to the 12-m antenna controller over the network. This achieved a more desirable reflector misbalance towards zenith, and allowed us to connect our MAS system to the 12-m antenna controller for archiving of system data. Much of 2020 was limited as far as major site activities due to the COVID-19 pandemic. KPGO staff was able to report to the site and continue our mission during the pandemic achieving excellent data acquisition metrics on both 20-m and 12-m systems, and all the while staying safe and healthy. We are grateful for that!

Fig. 5 12-m telescope counterweight rebalance effort.

6 Outlook

KPGO is still planning numerous site improvements in the future. When funding is acquired, we are still planning to perform several upgrades to our 20-m system including VGOS Broad Band Signal Chain Install, New Servo System and Cabling, Reflector Backup Structure Refurbishment, Elevation Gearboxes and Gear Replacement, and Reflector RF Alignment. For the 12-m VGOS system we are planning to fine-tune our reflector counterweight balance to ensure longer life for the elevation drive train components. KPGO staff will be working on this with ISI in 2021.

NASA is working with Japan for the installation of a new QZSS system at KPGO. Install of a new QZSS system is planned for late 2021 or early 2022.

NASA is working with the French DORIS team for a visit to KPGO to upgrade the KPGO DORIS Beacon. The DORIS visit time frame is still TBD.

Peraton is working with NASA Network Engineers to optimize the speeds for our newly upgraded e-transfer circuit. We are hoping to improve the e-transfer speeds from 700 Mbps to 1.5 Gbps in the near future. This will allow us to e-transfer even our largest VGOS data sets to the correlator sites.

Kashima 11-m and Koganei 11-m VLBI Stations

Mamoru Sekido, Eiji Kawai

Abstract The Kashima 11-m and Koganei 11-m stations have participated in R1, T2, CRF, APSG, and AOV sessions conducted by the IVS and Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV)[1]. Unfortunately, serious degradation of performance was found with the Kashima 11-m antenna in July 2019. After this, the Kashima 11-m station could not return back to normal operation. Following the decision to shut down the Kashima VLBI site, Kashima 11-m antenna was dismantled in 2020. Co-location local surveys were performed for four sites of KSP (Kashima, Koganei, Miura, and Tateyama) in 1996–1999 and for the Koganei site in 2013. This local tie information was submitted to the ITRF2020 Combination Center.

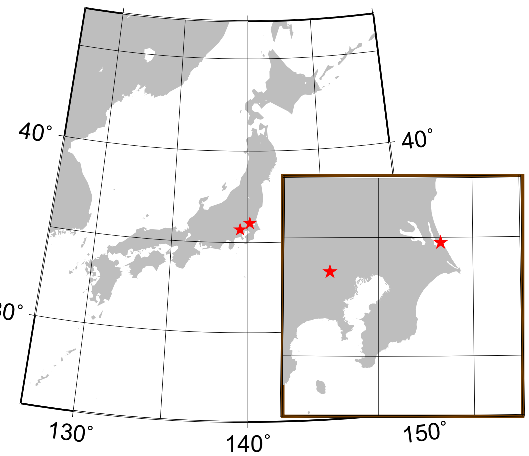

Fig. 1 Location of NICT-Koganei Headquarters and Kashima.

1 General Information

A pair of 11-m diameter antennas were operated by the VLBI group of the Space-Time Standards Laboratory (STSL) of the National Institute of Information and Communications Technology (NICT). The Kashima 11-m antenna is located at Kashima Space Technology Center (KSTC), on the east coast of the Japanese main island. The Koganei 11-m antenna is located at the NICT headquarters in Koganei, Tokyo (Figure 1). These two 11-m VLBI antennas (Figure 2) were built together with two other VLBI stations to create the Key Stone Project (hereafter referred as KSP). The aim of the KSP [1] was monitoring crustal deformation around the Tokyo metropolitan area by using multiple space-geodetic techniques: VLBI, GPS, and SLR. That project was operated in the period between 1995 and 2001. After the KSP project was terminated in 2001, two 11-m antennas at Miura and Tateyama were transferred to Gifu University and Hokkaido University and used for radio astronomy. Two antennas at Kashima and Koganei were used for geodetic observations and technology developments. Their regular participation in IVS sessions started after the "Great East Japan Earthquake" in March 2011.

NICT Kashima Space Technology Center

NICT KSP Network Station

IVS 2019+2020 Biennial Report

[1] http://auscope.phys.utas.edu.au/aov/index.html

1.1 Data Acquisition Systems

The K5/VSSP32 [2] system, which has four channels of video band signal input per unit, is deployed at both

Fig. 2 11-m VLBI antennas at Kashima (left panel) and Koganei (right panel).

stations. The data stream is recorded on a standard Linux file system in K5/VSSP32 format[2]. This software tool [3] has been used for data format conversion from K5/VSSP32 to Mark IV, VLBA, and Mark 5B.

All the VLBI data acquired by NICT were exported to Correlation Centers over the network from data servers at Kashima. Network connection at 10 Gbps was provided by the High Speed R&D Network Testbed JGN. All NICT VLBI stations (i.,e., Kashima 11-m, Koganei 11-m, and Kashima 34-m) share the same 10-Gbps network.

Table 1 VLBI sessions of the Kashima and Koganei stations in 2019–2020.

Kashima 11-m	**2019**	**2020**
IVS & AOV	aov032 aov035 apsg44 apsg45 t2130 t2131 t2132	—
Koganei 11-m	**2019**	**2020**
IVS & AOV	apsg44 apsg45 crf112 crf113 crf115 t2130 t2131 t2133 t2135 t2136 aov032 aov035 aov038 aov039 aov041 aov042	apsg46 apsg47 t2137 t2138 t2139 t2140 t2141 t2142 t2143 aov044 aov047 aov048 aov049 aov050 aov051 aov053 aov054
Freq. transfer	in001 in002	

2 Events and Activities during the Past Two Years

The two 11-m antennas participated in the IVS and AOV sessions as listed in Table 1.

2.1 Kashima 11-m antenna

In preparation of T2133 on 23 July 2019, serious degradation of sensitivity was found for the Kashima 11-m station. It was due to rainwater filled in the waveguide feed of its S/X-band receiver system that was caused by breakage of the feedome sheet of the antenna (Figure 3). Although we made tentative repair by closing the hole, additional holes were found a few weeks later. Since the feedome top is made of a strong and durable sheet, it was unlikely to be caused by the accidental hit of falling debris. Bird-repelling needles were equipped at the top of the feed cone; thus, we never had such trouble before. Though it was suspected to be caused by sharp bill such as woodpecker, we could not identify the reason. Finally, the dismantlement of the 11-m antenna together with the Kashima 34-m antenna was decided. As a consequence, T2132 on 21 May 2019 became the last VLBI observation for the Kashima 11-m antenna.

[2] https://www2.nict.go.jp/sts/stmg/K5/VSSP/vssp32_format.pdf
[3] https://www2.nict.go.jp/sts/stmg/K5/VSSP/index-e.html

Fig. 3 A hole was found in the feedome sheet of the Kashima 11-m antenna in July (left). The hole was closed by tentative repair. However, additional holes were found in August (right).

Table 2 DOMES numbers of the instruments that were part of the local tie surveys. Note that the SLR geodetic ground marker (Site reference point: SRP) is located separately from the intersection point of the azimuth/elevation axes of the SLR telescope.

DOMES Number/SLR Code	Site Name	CDP	GNSS	Description
21701S001	KASHIMA	1856		26-m VLBI antenna
21701M002	KASHIMA	7335		SLR geodetic ground marker (Site Reference Point:SRP)
21701S004	KASHIMA	1857		34-m VLBI antenna
21701S006	KASHIMA	7334		Steerable 11m Cassegrain VLBI antenna/intersection of axes
21701S007	KASHIMA		KSMV	Ashtech Z-XII with GEODETIC L1/L2 antenna/ARP
KASL(SLR)	KASHIMA			SLR telescope Az/El axis cross point at Kashima KSP
21704M001	KOGANEI	7328		SLR geodetic ground marker (Site Reference Point:SRP)
21704S002	KOGANEI	7308		SLR CRLLAS IAR
21704S004	KOGANEI	7327		Steerable 11m Cassegrain VLBI antenna/intersection of axes
21704S005	KOGANEI		KGNI	Ashtech Z-XII with GEODETIC L1/L2 antenna/ARP
KOGL(SLR)	KOGANEI			SLR telescope Az/El axis cross point at Koganei KSP
21739M001	MIURA	7337		SLR geodetic ground marker (Site Reference Point:SRP)
21739S001	MIURA	7336		Steerable 11m Cassegrain VLBI antenna/intersection of axes
MIUL(SLR)	MIURA	7337		SLR telescope Az/El axis cross point at Miura KSP
21740M001	TATEYAMA	7339		SLR geodetic ground marker (Site Reference Point:SRP)
21740S001	TATEYAMA	7338		Steerable 11-m Cassegrain VLBI antenna/intersection of axes
TATL(SLR)	TATEYAMA			SLR telescope Az/El axis cross point at Tateyama KSP

2.2 Koganei 11-m Antenna

The Koganei 11-m antenna has participated in geodetic VLBI sessions conducted by the IVS and AOV. It has been pointed out in the correlator reports that the correlation amplitude of the Koganei 11-m antenna-related baselines was smaller than expected from its SEFD values. Regarding this issue for the S-band receiver, it is already known that strong RFI coming from cell phone base stations has been sometimes saturating the first low noise amplifier (LNA) for this antenna. However, the reason for smaller correlation amplitudes at X-band is not clear yet. Detailed local investigation is required though, and visiting Koganei from Kashima was restricted due to COVID-19 in 2020; thus, studying this issue remains as a future task.

Antenna time is shared with the Space Environment Laboratory (SPEL), when the antenna is free from VLBI observation. Receiving down-link signal of the STEREO satellite[4] was performed for monitoring of solar activity.

[4] http://www.nasa.gov/mission_pages/stereo/main/index.html

2.3 Local Tie Information

The KSP was a project to monitor crustal deformation around the Tokyo metropolitan area with multiple space-geodetic techniques of VLBI, SLR, and GPS. With the aim of comparison and confirming the consistency of the different space-geodetic techniques, local surveys were conducted in the KSP during 1996–2000. In addition, another survey was conducted at the Koganei site in 2013 for the last time. It was triggered by construction of 1.5-m diameter new optical telescope at Koganei for the purpose of optical communication with satellites.

Responding to the call for participation to ITRF2020, these survey data were summarized and submitted to the ITRF Combination Center. The same data is available on the NICT website.[5] Table 2 shows the DOMES numbers of the instruments that were measured in the local tie survey at each site.

3 Future Plans

The Koganei 11-m antenna will continue to participate in VLBI sessions of the IVS and AOV in 2021 and beyond. The cause of the discrepancy between the correlation amplitude of the VLBI observation and single dish antenna sensitivity needs to be investigated.

[5] https://ksp.nict.go.jp/survey/Supplment/KSP-colloc.html

Acknowledgements

We thank the High-Speed R&D Network Testbed JGN and the Information System Section of NICT for supporting the high-speed network environment.

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Matera CGS VLBI Station Report

Giuseppe Bianco[1], Giuseppe Colucci[2], Francesco Schiavone[2]

Abstract This report presents the status of the Matera VLBI station. An overview of the station, some technical characteristics of the system, and staff email addresses are given.

1 General Information

The Matera VLBI station is located at the Italian Space Agency's 'Centro di Geodesia Spaziale G. Colombo' (CGS) near Matera, a small town in the south of Italy. The CGS came into operation in 1983 when the Satellite Laser Ranging SAO-1 System was installed. Fully integrated into the worldwide network, SAO-1 was in continuous operation from 1983 to 2000, providing high precision ranging observations of several satellites. The new Matera Laser Ranging Observatory (MLRO), one of the most advanced Satellite and Lunar Laser Ranging facilities in the world, was installed in 2002, replacing the old SLR system. CGS also hosted mobile SLR systems MTLRS (Holland/Germany) and TLRS-1 (NASA).

In May 1990, the CGS extended its capabilities to Very Long Baseline Interferometry (VLBI), installing a 20-m radio telescope. Since then, Matera has observed in 1,337 sessions up through December 2020.

In 1991 we started GPS activities, participating in the GIG 91 experiment and installing a permanent GPS Rogue receiver at Matera. In 1994, six TurboRogue SNR 8100 receivers were purchased in order to create the Italian Space Agency GPS fiducial network (IGFN). At the moment 15 stations are part of the IGFN, and all data from these stations, together with 24 other stations in Italy, are archived and made available by the CGS Web server GeoDAF (http://geodaf.mt.asi.it). Six stations are included in the IGS network, while 12 stations are included in the EUREF network.

In 2000, we started activities with an Absolute Gravimeter (FG5 Micro-G Solutions). The gravimeter operates routinely at CGS and is available for external campaigns on request.

Thanks to the co-location of all precise positioning space-based techniques (VLBI, SLR, LLR, and GPS) and the Absolute Gravimeter, CGS is one of the few "fundamental" stations in the world. With the objective of exploiting the maximum integration in the field of Earth observations, in the late 1980s ASI ex-

Table 1 Matera antenna technical specifications.

Parameter name	Value (S/X)
Input frequencies	2,210–2,450 MHz 8,180–8,980 MHz
Noise temperature at dewar flange	<20 K
IF output frequencies	190−430 MHz 100−900 MHz
IF Output Power (300 K at inp. flange)	0.0 dBm to +8.0 dBm
Gain compression	<1 dB at +8 dBm output level
Image rejection	>45 dB within the IF passband
Inter modulation products	At least 30 dB below each of two carriers at an IF output level of 0 dBm per carrier
T_{sys}	55/65 K
SEFD	800/900 Jy

1. Agenzia Spaziale Italiana
2. e-geos - an ASI/Telespazio company

Fig. 1 Matera VLBI antenna.

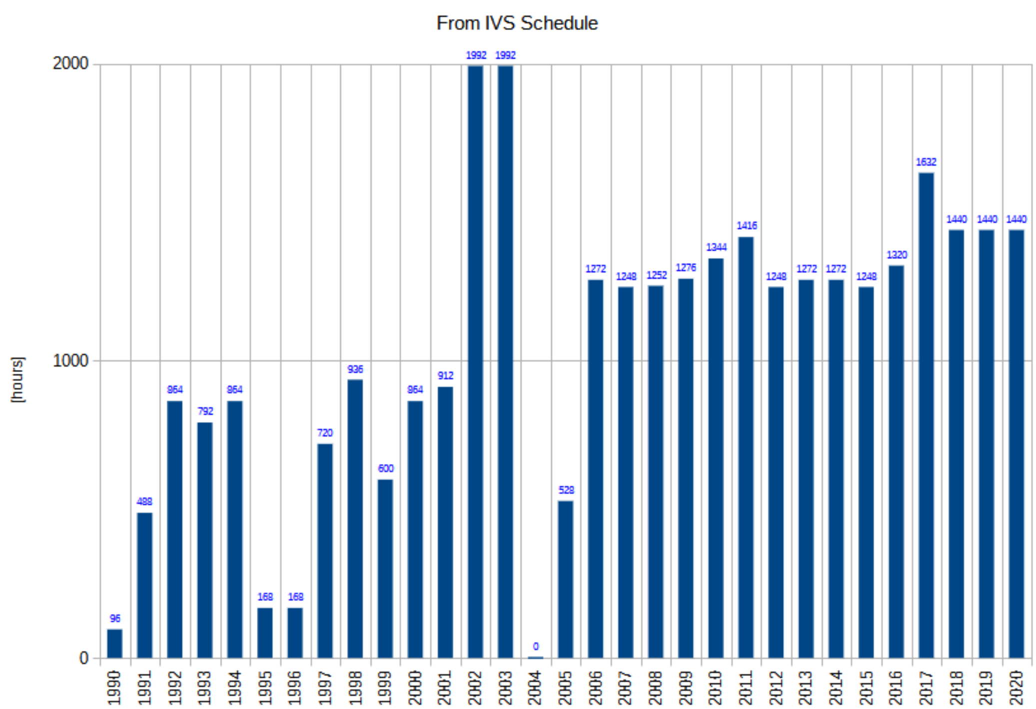

Fig. 2 Matera observation time.

tended CGS' involvement to include remote sensing activities for present and future missions (ERS-1, ERS-2, X-SAR/SIR-C, SRTM, ENVISAT, and COSMO-SkyMed).

The Matera VLBI antenna is a 20-meter dish with a Cassegrain configuration and an AZ-EL mount. The AZ axis has ±270 degrees of available motion. The slewing velocity is 2 deg/sec for both the AZ and the EL axes.

The technical parameters of the Matera VLBI antenna are summarized in Table 1.

The Matera time and frequency system consists of three frequency sources (two Cesium beam and one H-maser standard) and three independent clock chains. The iMaser 3000 H-maser from Oscilloquartz is used as a frequency source for VLBI.

2 Activities during the Past Year

The VLBI frequency standard is a T4SCIENCE iMaser 3000 installed in 2013.

Specifications for this maser can be found here: http://www.t4science.com/product/imaser_3000.

3 Current Status

In 2019 and 2020, 120 sessions were observed in total. During 2020, the COVID-19 pandemic emergency did not have significant impact on operations. Figure 2 shows a summary of the total acquisitions per year, starting in 1990.

In 2004, in order to fix the existing rail problems, a complete rail replacement was planned. In 2005, due to financial difficulties, it was instead decided that only the concrete pedestal under the existing rail would be repaired. From then on, no rail movements have been noted [1, 2, 3].

4 Future Plans

A bid to build a new VGOS system was finalized. New construction on the system should start soon.

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Medicina Station Status Report

Alessandro Orfei, Giuseppe Maccaferri

Abstract General information about the Medicina Radio Astronomy Station, the 32-m antenna status, and the VLBI observations is provided. Updates to hardware and software infrastructure have been made and are briefly described.

1 The Medicina 32-m Antenna: General Information

The Medicina 32-m antenna is located at the Medicina Radio Astronomy Station. The station is run by the Istituto di Radioastronomia and is located approximately 33 km east of Bologna. The Consiglio Nazionale delle Ricerche was the funding agency of the Istituto di Radioastronomia until the end of 2004. Since January 1, 2005, the funding agency has been the Istituto Nazionale di Astrofisica (INAF). The antenna, which was inaugurated in 1983, has regularly taken part in IVS observations since 1987 and is an element of the European VLBI Network.

A permanent GPS station (MEDI), which is a part of the IGS network, is installed in the vicinity. Another GPS system (MSEL) is installed near the VLBI telescope and is part of the EUREF network.

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2 Current Status and Activities

- **Antenna.** a) The telescope has been idle since mid-December 2019 due to a couple of mechanical issues. Two steel girders composing the reticular structure that supports the counterweights were broken. Mainly for safety reasons the antenna was stopped, and a structural investigation was done in order to make a survey of the problem over the whole antenna. Once we replaced the broken beams, we also found that a non-drive wheel showed a broken bearing. Covid-19 prevented us from quickly restarting operations, which were resumed at the end of July 2020.
  b) An active surface system for the Medicina primary mirror has been funded. The upgrade will include new aluminum panels with enhanced surface accuracy, electromechanical actuators to move panels in order to compensate for gravitational deformation, and a completely new subreflector with low RMS surface (one will be provided for Noto as well). Once completed, Medicina will be able to observe at high frequencies up to 116 GHz with good overall efficiency. The timeline for completing the project is by 2022.
- **Receivers.** In 2019 INAF was awarded a call (National Operational Program, PON) issued by the Ministry of Research. As part of this funding, our institute requested the installation on the Medicina radio telescope of a simultaneous 3-band receiver (18–26, 34–50, and 80–116 GHz). The receiver is expected to be available by 2022.
- **VLBI backend.** The DBBC firmware version is currently DDC V107, PFB v16. The Flexbuff system works with jive5ab-3.2. As part of the PON

Fig. 1 An updated image of the 32-m Medicina antenna, June 2018.

funding program (see above), the new DBBC3 systems for both Medicina and Noto are being ordered.

- **Field System.** a) We have installed a new FSL10 Debian machine, and we are running the new FS 10.0.0-beta2. b) The Continuous_cal system is working for the Cassegrain receivers (6, 5, and 1.3 cm) and from session 2/2019 is available also for the primary focus receivers, 3.6 and 18/21 cm.

3 Geodetic VLBI Observations

Despite the long maintenance periods in the years 2019 and 2020, Medicina participated in 35 (23 and 12) routine geodetic sessions: four IVS-R1, 19 IVS-R4, two IVS-T2, one IVS-CRF, two EUROPE, and seven R&D experiments.

4 Transportable NICT VLBI Antenna

Since 2018, the Observatory of Medicina has hosted a 2.4-m antenna designed and built by NICT to carry out broadband VLBI measurements with the aim of comparing optical clocks on an intercontinental basis. This technique is innovative for overcoming the obstacles imposed by current clock comparison techniques in terms of cost/feasibility. Broadband VLBI observations were carried out between October 2018 and February 2019.

Metsähovi IVS Network Station Report

Nataliya Zubko[1], Juha Kallunki[2], Joona Eskelinen[1], Niko Kareinen[1], Ulla Kallio[1], Jyri Näränen[1]

Abstract In 2019–2020, Metsähovi Radio Observatory, together with the Finnish Geospatial Research Institute (FGI), National Land Survey of Finland, has observed several IVS T2 sessions. FGI has constructed a new VGOS radio telescope in 2018. A new VGOS system is under development and commissioning. The Metsähovi Radio Observatory had renovation work in 2020, with a new radome replacing the old one.

1 General Information

The Aalto University Metsähovi Radio Observatory (MRO) and the Finnish Geospatial Research Institute (FGI) are two separate institutes which together form the Metsähovi IVS Network Station. The Metsähovi Radio Observatory operates a 13.7-meter radio telescope on the premises of Aalto University at Metsähovi, Kylmälä, Finland, about 35 km from the university campus. The Metsähovi Geodetic Research Station of FGI is in the same area, next to the Metsähovi Radio Observatory, where the VGOS 13.2-meter telescope was built. The new system is under commissioning and finalization.

IVS sessions are observed with the 13.7-meter radio telescope owned by MRO. The technical preparation and support are provided by MRO, while session preparation and operation are performed by FGI. The main purpose of the MRO telescope is astronomical observations; thus, the number of the annual geodetic sessions is very limited.

1. Finnish Geospatial Research Institute (FGI), National Land Survey of Finland
2. Aalto University Metsähovi Radio Observatory

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1.1 Metsähovi Radio Observatory

The Metsähovi Radio Observatory has been operational since 1974. MRO, together with FGI, began observing IVS T2 and EUROPE sessions in 2004. Approximately three to six sessions are observed per year. MRO is known for its long-term quasar monitoring, VLBI, and solar observations. The surface accuracy of the present telescope is 0.1 mm (rms) and the slewing speed of the Metsähovi antenna is 1.2 degrees per second. Astronomical VLBI observations are carried out with the 22-GHz, 43-GHz, and 86-GHz receivers, while the geodetic observations use the S/X narrow band receiver. The geodetic VLBI receiver uses right circular polarization and the 8.15–8.65 GHz and 2.21–2.35 GHz frequency bands.

1.2 Metsähovi Geodetic Research Station

FGI runs the Metsähovi Geodetic Research Station. Observations at the Metsähovi Geodetic Research Station started in 1978. It is a part of the IAG GGOS Core Station network. The instrumentation includes the VGOS telescope, Satellite Laser Ranging (SLR), DORIS, GNSS equipment, and absolute and superconducting gravimeters. Renewal of most of the instrumentation has been ongoing since 2013. A new VGOS-compatible radio telescope system was built at Metsähovi Geodetic Research Station during the sum-

Fig. 1 Metsähovi Geodetic Research Station and Metsähovi Radio Observatory. Photo: Jyri Näränen

mer of 2018. The telescope has a fast moving telescope dish with a diameter of the main reflector of 13.2 meters and a ring focus design. The telescope is equipped with a broadband receiver with a working frequency range of 2–14 GHz.

2 Activities during the Past Two Years

2.1 IVS Sessions

The Metsähovi Network Station observed altogether four T2 IVS sessions during 2019–2020. The EUROPE sessions were canceled; thus, the total number of the observed sessions was reduced. There were no technical issues or problems during the observations or correlations, with the exception of RFI disturbing some channels in S-band.

2.2 VGOS Project

The new FGI-owned VGOS radio telescope was commissioned in 2019. Telescope technical characteristics can be seen in Table1. It is equipped with a quad-ridge horn, a 2.1–14 GHz broadband receiver manufactured by the IGN Yebes Technology Development Center, Spain, in November 2019 (Figure 2). The signal from the receiver is divided into low (2.1–4 GHz) and high (3.6–14.1 GHz) frequency bands transmitted to the backend via RF over fiber (RFoF) links.

Table 1 Telescope technical characteristics.

Feature	Description
Antenna mount	Standard azimuth-elevation
Reflector optics	Ring focus
Diameter of the main reflector	13.2
Surf. accuracy of the main refl.	< 0.3 mm rms
Surf. accuracy of the subrefl.	< 0.1 mm rms
Antenna motion:	
Velocity in Az axis	12 deg/s
Velocity in El axis	6 deg/s
Acceleration in Az axis	2.5 deg/s^2
Acceleration in El axis	2.5 deg/s^2

The first light of the Metsähovi VGOS telescope was obtained in November 2019. During 2020 the receiver performance was investigated together with RFI conditions at the site. Substantial RFI sources were observed in the 2–3-GHz band, limiting its usability in observations. A real-time RFI monitoring system is under development. The signal chain is equipped with a DBBC3 backend; a Flexbuff recorder is under development.

2.3 Metsähovi Radio Observatory Renovation

The years 2019 and 2020 included major modernization work at the Metsähovi Radio Observatory. The observatory premises were renovated. The oldest part of the observatory, which was from the 1970s, was dismantled, and new compensatory spaces were built (Figure 3). New premises include a seminar room, flex-

Fig. 2 Receiver installation on the VGOS radio telescope. Photo: Nataliya Zubko

ible office and laboratory spaces, among others. Other older premises were renovated; for instance, building services engineering was renewed. The work started in the summer of 2019 and it was completed in December 2020. The observatory will be fully back to normal operations in the spring of 2021.

Also motors, drives, and high-speed gears of the 14-meter radio telescope were replaced. The old DC-servo drives were replaced with modern AC-drives. The telescope performance and reliability improved as a result of the overhaul. The modernization work was completed in April 2020, causing a three-week break in normal operations.

The replacement of the protective radome of the 14-meter radio telescope was carried out in June 2020. The new radome is identical to the old one, i.e., the electromagnetic performance is similar. Both radomes, the old one and the new one, were removed and installed as a whole, causing a three-hour break for observations. The whole installation project was completed within three weeks.

3 Current Status

FGI and MRO carry out participation in IVS-T2 sessions with the 13.2-meter telescope. FGI continues its work on the integration of the signal chain of the new VGOS system and finalization of the whole system. The Flexbuff recording system development is in progress as well as the automation of the RFI monitoring system.

3.1 Long Distance Frequency and Time Link

FGI has been developing a long distance frequency and time link over optical fiber. The work has been carried out together with VTT MIKES, which is responsible for maintaining the realization of UTC in Finland (UTC-MIKE). The current aim is to achieve redundancy and to test the link against the H-maser. In the future, a stable frequency link would reduce the need of a dedicated maser and allow several stations to share a common clock.

Our optical fiber uses a 55-km dark fiber and connects the Metsähovi Geodetic Research Station with the Otaniemi Campus Area, where VTT MIKES is located. Both commercially available low-jitter White-Rabbit technology (originally developed at CERN) and an in-house developed drift compensated frequency transfer system were tested. Currently we have achieved ca. 1E-14 ADEV at 100 s, with a 5–10 MHz carrier. The project continues until 2023 with the aim of achieving sufficient stability for VGOS observations.

3.2 Local Tie Measurements

National Land Survey of Finland is one of the partners in the EMPIR 18SIB01 GeoMetre project. During the project the new local tie vectors in Metsähovi will be measured between the space-geodetic instruments, including the new VLBI telescope. For this purpose, two GNSS antennas were attached on the left and right edge of the telescope dish with a new type of gimbal system in March 2020. Compensators have an improved damping system which stabilizes the movement of the rather high angular velocity of the VGOS telescope.

Several monitoring test measurements were carried out in 2020 (Figure 4). The terrestrial pillar network for local ties was also updated with new adapters for GNSS antennas and prisms enabling seamless measurements. Automatic monitoring of the VLBI telescope reference point from the network pillars were

Fig. 3 Metsähovi Radio Observatory new premises. Photo: Juha Kallunki

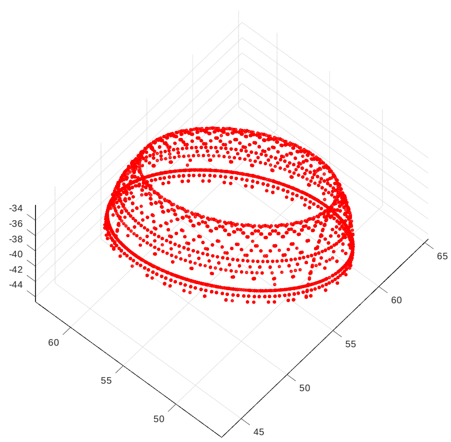

Fig. 4 Combination of the monitoring data from the MET3 GNSS antenna to the VLBI. Coordinates in the figure are coordinate differences w.r.t. MET3 in global orientation.

tested with the robot tacheometer in September simultaneously with GNSS measurements.

4 Future Plans

Tests of the entire telescope system, as well as the integration of the signal chain components are planned for 2021. A 10-Gb Internet connection will be installed at the research station in 2021 for VGOS data transfer.

To improve the thermal insulation and consequently stability of the telescope's steel pedestal, an additional insulation layer is planned to be added. This work is planned for 2021 together with the telescope manufacturer.

A new main building is planned to be build at Metsähovi Geodetic Research station in 2021–2022. It will contain office space and instrumentation rooms, including dedicated VGOS operating and server rooms.

Acknowledgements

The 18SIB01 Geometre project contributed to the measurements of the local tie network and monitoring. This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

VERA 2019 and 2020 Geodetic Activities

Takaaki Jike[1], Yoshiaki Tamura[1]

Abstract The geodetic activities of VERA in the years 2019 and 2020 are briefly described. The regular geodetic observations were carried out both in K- and S/X-bands. The frequency of regular observations is three times a month—twice for the VERA internal observations in K-band. The networks of the S/X sessions are AOV and IVS-T2. The recorders used are K5-VSSP for IVS-T2 sessions and OCTAD-OCTADISK2 for AOV sessions. The raw data of the T2 and AOV sessions are electronically transferred to the Bonn and GSI correlators via the Internet. Gravimetric observations are carried out at the VERA stations. SGs are installed at Mizusawa and Ishigakijima in order to monitor precise gravity changes, and the observations continued for two years.

Fig. 1 The front view is the Mizusawa 10-m antenna, and the back view is the VERA Mizusawa 20-m antenna.

1 General Information

VERA is a Japanese domestic VLBI network consisting of the Mizusawa, Iriki, Ogasawara, and Ishigakijima stations. Each station is equipped with a 20-m radio telescope and a VLBI backend. The VERA Mizusawa 20-m antenna is shown in Figure 1. The VERA array is controlled from the Array Operation Center (AOC) at Mizusawa via the Internet. The primary scientific goal of VERA is to reveal the structure and the dynamics of our galaxy by determining three-dimensional force fields and mass distribution. Galactic maser sources are used as dynamical probes, the positions and velocities of which can be precisely determined by phase referenced VLBI relative to extragalactic radio sources. The distance is measured as a classical annual trigonometric parallax. The observing frequency bands of VERA are the S-, C-, X-, K-, and Q-bands. Geodetic observations are made in the S/X- and K-bands. The C- and Q-bands are currently not used for geodesy. Only a single beam is used even in K-band in geodetic observations, although VERA can observe two closely separated ($0.2^\circ <$ separation angle $< 2.2^\circ$) radio sources simultaneously by using the dual-beam platforms.

General information about the VERA stations is summarized in Table 1, and the geographic locations are shown in Figure 2. The lengths of the baselines range from 1,080 km to 2,272 km. The skyline at Ogasawara station ranges from 7° to 18° because it is located at the bottom of an old volcanic depression. The

1.Mizusawa VLBI Observatory, National Astronomical Observatory of Japan

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north-east sky at Ishigakijima station is blocked by a nearby high mountain. However, the majority of the skyline is below 9°. The skylines at Mizusawa and Iriki are low enough to observe sources at low elevations. Because Ogasawara and Ishigakijima are small islands in the open sea and their climate is subtropical, the humidity in the summer is very high. This brings about high system temperatures in the summer, in particular in the K- and Q-bands. The Iriki, Ogasawara and Ishigakijima stations are frequently hit by strong typhoons. The wind speed sometimes reaches up to 60–70 m/s. Mizusawa often stops operating its antenna due to heavy snow in winter.

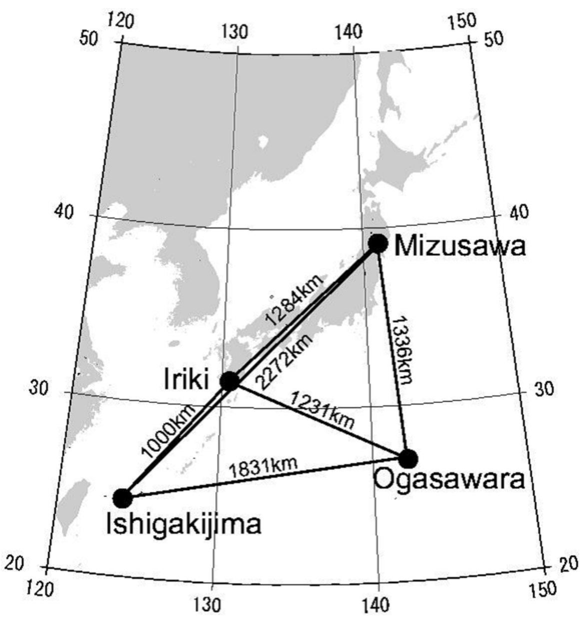

Fig. 2 Distribution of the stations in the VERA network.

Table 1 Locations of the four VERA sites.

Site name	Longitude	Latitude	Altitude
Mizusawa	141° 07′ 57″.199 E	39° 08′ 00″.726 N	75.7 m
Iriki	130° 26′ 23″.593 E	31° 44′ 52″.437 N	541.6 m
Ogasawara	142° 12′ 59″.809 E	27° 05′ 30″.487 N	223.0 m
Ishigakijima	124° 10′ 15″.578 E	24° 24′ 43″.834 N	38.5 m

2 Activities during the Past Years

The parameters of the antennas are summarized in Table 2, and the front and backends are summarized in Table 3. The actual receiver temperature in S-band is much higher than the notation in the table due to the influence of interference. Two observing modes are used for geodetic observations. One is the VERA internal observing in K-band with the recording rate of 1 Gbps or 2 Gbps using OCTADISK. The other is the conventional S/X-band observing with K5-VSSP (128 Mbps) and OCTAD-OCTADISK2 (1 Gbps and 512 Mbps) [1]. AOV, IVS-T2, and T2P sessions belong to this class. Only Mizusawa participated in these sessions.

Table 2 Antenna parameters.

Diameter of main reflector	20 m
Mount type	AZ-EL
Surface accuracy	0.2 mm (rms)
Pointing accuracy	< 12″ (rms)

	Azimuth	Elevation
Slew range	−90° – 450°	5° – 85°
Slew speed	2.1°/sec	2.1°/sec
Acceleration	2.1°/sec^2	2.1°/sec^2

	S	X	K
HPBW	1550″	400″	150″
Aperture efficiency	0.25	0.4	0.47

Table 3 Frontend and backend parameters.

Frontend parameters			
Frequency band	S	X	K
Frequency range (GHz)	2.18–2.36	8.18–9.00	21.5–24.5
Receiver temperature	>100 °K	100 °K	39±8 °K
Polarization	RHC	RHC	LHC
Receiver type	HEMT	HEMT	cooled HEMT
Feed type	Helical array		Horn

Backend parameters				
Observation type	VERA Intl.	T2	T2P	AOV
Sampling [MHz-bit]	32-2 or 1024-2	8-1	16-2	32-2
Channel	16 or 1	16	16	16
Filter	Digital	Analog	Digital	Digital
Recorder	OCD	K5	OCD2	OCD2
Rec. rate [Mbps]	1024 or 2048	128	512	1024
Deployed station	four VERA	Mizusawa		

K5:K5-VSSP, OCD: OCTADISK, OCD2: OCTADISK2

3 Current Status

VERA observes seven days a week, except for during a maintenance period from middle June to middle August. The 24-hour geodetic sessions are allocated two or three times in a month. Among these geodetic sessions, VERA internal geodetic observations in K-band are performed once or twice in a month, and Mizusawa participated in AOV and T2 sessions in the S/X-bands about eight times a year in total. The main purpose of the VERA internal geodetic observations is to determine relative positions of the VERA antennas accurate enough for astrometric requirements. The purpose of the S/X sessions is to link the VERA coordinates into the reference frame built by VLBI.

In the VERA internal geodetic sessions, the regularly used frequency changed from the S/X-bands to K-band in 2007. The reason for the shift of the observing frequency band from the S/X-bands to K-band is to avoid the strong radio interference from mobile phones in S-band, particularly at Mizusawa. The interfering signal, which has line spectra, is filtered out. But this filtering considerably degrades the system noise temperature. The interference zone is increasing, so it is likely that S-band observing will become almost impossible in the near future. On the other hand, VERA has the highest sensitivity in K-band as shown in Table 3. Thanks to the high sensitivity in this band, the maximum number of scans in K-band is 800/station/24-hours, while that in the S/X-bands is 500 at most. It has been confirmed that the K-band observations are far more precise. In fact, standard deviations of the individual determinations of the antenna positions in K-band are less than half of those in the S/X-bands.

In 2019 and 2020, a long maintenance period from the middle of June to the middle of August was allocated for each year. Except for this period, VERA carried out internal geodetic VLBI observations 36 times. Mizusawa participated in 16 T2 and AOV sessions. The final estimation of the geodetic parameters is derived by using the software developed by the VERA team.

Continuous GPS observations were carried out at each VERA station throughout the year. The superconducting gravimeter (SG) installed within the enclosure of the Mizusawa VLBI observatory, in order to accurately monitor gravity change for the purpose of monitoring height change at the VERA Mizusawa station, continued acquisition of gravity data.

An SG was installed also at the VERA Ishigakijima station, and observing started in January 2012. The observing continued also during 2019–2020. The observing aims at solving the cause of the slow slip event which occurs frequently around the Ishigakijima island.

4 Future Plans

VERA will end astrometry observations in a few years and move on to a new project. The examination of increasing the recording rate to 8 Gbps (from 1 Gbps or 2 Gbps) by using OCTAD is being carried out [2] for the purpose of improvement in parameter fitting performance, and we can get the high-precision geodetic solutions, characteristics of wide-band observations, and performance evaluation. It was held several times from 2019 to 2020, and even now, as a preliminary basic experiment for research carried out in the new VLBI project, we plan to continue this basic experiment.

5 Staff

Mareki Honma is the director of Mizusawa VLBI Observatory. The geodesy group consists of Yoshiaki Tamura (scientist) and Takaaki Jike (scientist).

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Noto Station Status Report

Pietro Cassaro, Andrea Orlati

Abstract General information about the Noto VLBI Station, the 32-m antenna status, and the VLBI observations are provided. Status of the hardware and the upgrades performed are briefly described.

1 General Information

The 32-m parabolic antenna is located near Noto in Sicily. The telescope is a facility of the INAF Istituto di Radioastronomia, and has been active since 1989 in VLBI observations. In the past the antenna was also involved in many different projects of radioscience and Space VLBI. Currently the telescope has commitments for both EVN and IVS networks, with some VLBI projects in the Italian network and some single-dish experiments being carried out.

2 Current Status and Activities

- **Antenna.** The 32-m antenna is equipped with an active surface, allowing to correct gravitational deformations of the primary mirror. The actuator network, along with moving the panels, was partially refurbished during 2020. During the past few months, damages of the mechanical structure of the antenna were found. The issues were related to two steel beams supporting the counterweights and one actuator of the subreflector servo system. The problems occurred at different epochs but clearly have a common origin, which are the stress and strain concentration were beyond the limits of the low cycle fatigue of the structure. The steel beams of the backup structure were replaced at the end of July 2020. Repair of the sub-reflector movement mechanism is still pending as the replacement of the deteriorated parts was severely delayed by the COVID-19 pandemic emergency. The replacement is scheduled for March 2021; until then, the telescope can only operate primary focus receivers.
- **Receivers.** The new L-, S-, and X-band receiver, positioned in the primary focus, was installed in June 2019 and is currently in use. Secondary focus receivers are currently not used due to the reported sub-reflector problem, which does not allow to switch the focus. After the aforementioned sub-reflector movement repair, CLow-, CHigh-, and K-band receivers will be available. A Q-band receiver has no functioning LNAs, affecting one of the circular polarizations. No repair is planned; so the receiver will be operated with the only working polarization.
- **VLBI backend.** The DBBC firmware version is currently DDC V107. The Flexbuff system of Noto has a capacity of 360 TB.

3 Geodetic VLBI Observations

Despite the long maintenance periods in the years 2019 and 2020, Noto participated in 24 (11 and 13) routine geodetic sessions: ten IVS-R1, six IVS-R4, four IVS-T2, two IVS-CRF, and two EUROPE experiments.

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Fig. 1 A recent image of the Noto antenna.

4 Future Plans

A complete refurbishment of the helium pipes to the vertex room and the cooling system of the telescope have been funded by INAF. Presently, the timeline of the task is not defined but our goal is to complete it by the end of 2021.

INAF has succeeded in a funding call (PON) issued by the Ministry of Research. As part of the PON (National Operational Program), Noto will be equipped with a simultaneous three-band receiver (18–26 GHz, 34–50 GHz, and 80–116 GHz). The receiver will output wide bandwidth IFs (K-Band: 8 GHz; Q-Band: 16 GHz; and W-Band: $16+16$ GHz), which will be converted to tunable 2-GHz bands. The receiver will be built by KASI and is planned to be available in 2022. Also the PON fundings will permit to buy a DBBC version 3. The call for tender has already been issued by INAF.

A new IF distributor is being developed to be installed in the control room. The device will automate and facilitate receiver setup, allowing for better and more reliable setup before experiments.

Ny-Ålesund Geodetic Observatory

Piotr Kupiszewski, Gro Grinde, Susana Garcia-Espada, Rubén Bolaño González

Abstract In 2019/2020 the 20-m Ny telescope in Ny-Ålesund, Svalbard, operated by the Norwegian Mapping Authority (NMA), continued regular contributions to the IVS observation schedule as the northernmost VLBI station. The Ns 13-m telescope at the new geodetic observatory (officially inaugurated in 2018) became a tag-along station and is contributing regularly to R1 and R4 sessions.

1 General Information

The Geodetic Observatory of the Norwegian Mapping Authority (NMA) is situated at 78.9° N and 11.9° E in Ny-Ålesund, Kings Fjord, on the west side of the island of Spitsbergen. This is the biggest island in the Svalbard archipelago. The Geodetic Observatory features a 20-meter Legacy VLBI radio telescope at the Rabben site (see Figure 1), as well as fast-slewing VGOS (VLBI Global Observing System) twin telescopes at the new facility at Brandal (see Figure 2). In 2019/2020, the 20-m Ny telescope at Ny-Ålesund was scheduled for 241 24-hour VLBI sessions, including R1, R4, EURO, RD, T2, and RDV sessions. But, due to the failure of the elevation encoder in November 2020, only 96 sessions were analyzed in 2020. The Ny telescope was also scheduled for 101 one-hour sessions within the Intensives program during this period. Meanwhile, the 13-m Ns telescope was scheduled in tag-along mode in 67 sessions in 2019/2020.

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Fig. 1 The geodetic observatory's Rabben site with the Ny 20-m telescope.

Fig. 2 The geodetic observatory's Brandal site with 13-m twin telescopes (Image: Bjorn-Owe Holmberg).

In addition to the 20-m VLBI telescope and the 13-m twin telescopes, the geodetic observatory has two GNSS receivers in the IGS system and a Super Conducting Gravimeter which is part of the International Geodynamics and Earth Tide Service. A second SCG is installed at the Brandal site, approximately 1.5 km away. A solar radio burst monitor is set up at Rabben, and a tide gauge is in operation at the harbor. The observatory also hosts an accelerograph from the Instituto Geográfico Nacional in Spain and a GISTM (GPS Ionospheric Scintillation and TEC Monitor) receiver which is operated in the frame of ISACCO, an Italian research project on ionospheric scintillation observations, led by the Italian Institute of Volcanology and Geophysics (INGV). Another Real-Time Ionospheric Scintillation (RTIS) Monitor has been set up and operated by the NMA since November 2012. A DORIS station is located approximately 350 m from the new geodetic observatory at Brandal and is hosted by the French-German AWIPEV research base.

2 Component Description

The radio telescope with a 20-m diameter is intended for geodetic use and receives in S- and X-band. Its design and construction are similar to those at Green Bank and Kokee Park. A DBBC2 streams the data to a Mark 5B+ recorder. Another Mark 5B+ unit is used to transfer data via network to the correlators. Timing and frequency is provided by a NASA NR maser, which is monitored by a CNS system.

The fast-slewing VGOS twin telescopes at Brandal (designated as Nn and Ns) are 13.2 m in diameter. A tri-band feed is currently installed at the Ns telescope with a DBBC2 and Flexbuff forming the backend system. At the Nn telescope a broadband receiver (2—14 GHz) is installed, with a DBBC3 and Flexbuff as the backend. A T4Science iMaser 3000 provides the frequency signal at Brandal.

3 Staff

The staff at Ny-Ålesund consists of five people employed at 75 %, with 3.75 full-time positions currently covered (see Figure 3 for an overview). Station staff are part of the Global Geodesy group at the Geodetic Institute of the Norwegian Mapping Authority, which has its main office in Hønefoss (near Oslo).

Axel Meldahl has been working as an operations engineer at the observatory since 2015, while Susana Garcia-Espada and Rubén Bolaño González joined the operations team in April 2020. Piotr Kupiszewski has been with the observatory since 2018 and is the station leader. Simon L'orange (an operations engineer since 2018) will leave Ny-Ålesund in February 2021. A new operations engineer will join the team in May 2021.

The staff at Ny-Ålesund work closely with colleagues located on the mainland at NMA's Hønefoss and Oslo offices: Ann-Silje Kirkvik (VLBI data analyst), Leif Morten Tangen (VLBI instrument responsible person), Robin Kleiven (VLBI engineer), Gro Grinde (project leader for the new geodetic observatory), and Hans Christian Munthe-Kaas (head of department) (see Table 1 for an overview).

Fig. 3 Core team: Rubén Bolaño González, Susana Garcia-Espada, Piotr Kupiszewski, Simon L'orange, Axel Meldahl (Image: Helge Markussen).

Table 1 Staff related to VLBI operations at Ny-Ålesund.

Head of department	Hans Christian Munthe-Kaas
Station Leader	Piotr Kupiszewski
Project leader (new observatory)	Gro Grinde
Operations engineer	Axel Meldahl
Operations engineer	Rubén Bolaño González
Operations engineer	Susana Garcia-Espada
Operations engineer	Simon L'orange (until February 2021)
VLBI instrument responsibility	Leif Morten Tangen
VLBI engineer	Robin Kleiven
VLBI data analyst	Ann-Silje Kirkvik

4 Current Status and Activities

A broadband receiver (2–14 GHz) was installed in September 2019 in the northern telescope (Nn) at the new geodetic observatory at Brandal, adding to the tri-band receiver already installed in the southern telescope (Ns). During the course of 2019 and 2020, work continued to run observations with the tri-band receiver and DBBC3 at the Ns antenna. Unfortunately, multiple issues were encountered with the DBBC3, and reaching stable operations proved difficult. The problems were partly caused by using the DBBC3 together with a tri-band receiver, which was not an optimal combination. A DBBC2 replaced the DBBC3 in November 2020, greatly improving the stability of operations. Ns is currently operating as a tag-along station in R1 and R4 sessions and has also contributed to RV and T2 sessions.

Work to operationalize Nn is ongoing with the aim of having Nn be able to join the IVS observation schedule as a VGOS telescope in mid-2021. The backend system for the Nn telescope was completed with the delivery of a Flexbuff in October 2020. The storage capacity of the new Flexbuff is 553 TB (72 disks of 7.68 TB each), while the expected recording rate is $\geq$ 16 Gbps.

The Legacy 20-m telescope at Rabben (Ny) was operative for most of 2019 and 2020. But, in October 2020, Ny suffered a major setback when the elevation encoder failed. The 20-m telescope has been out of operation since then, as Ny-Ålesund awaits the return of the spare BEI encoder which was sent for repair to the US in August 2020. Delivery of the repaired spare encoder is expected in March 2021. In August 2020, prior to the encoder failure, laser scanning of the gravitational deformation of the 20-m telescope at Rabben was performed together with colleagues from the RISE research institute in Sweden.

Local tie measurements were carried out at Brandal in 2019 and 2020 and, in August 2019, two new control points were set up for line-of-sight local tie measurements between the VLBI telescopes at Brandal and the DORIS beacon. In the summer of 2020 a cable duct (approximately 350 m) was dug down between Brandal and the DORIS beacon. The duct will house an RF cable providing a 5 MHz reference signal from the hydrogen maser at Brandal to the DORIS beacon and will ensure that all space geodetic techniques at Brandal use a common frequency standard.

Furthermore, several new instruments have been installed at the observatory. A solar radio burst monitor was installed at Rabben in 2019. The instrument is a passive receiver with a directional antenna and measures radio waves in the range 1.0 to 1.6 GHz. The solar radio burst monitor tracks the Sun (as long as the Sun is above the horizon) and monitors radio noise at frequencies which are relevant for aviation and GNSS systems.

In preparation for installation of the Satellite Laser Ranging (SLR) instrument an ADS-B (Automatic Dependent Surveillance–Broadcast) antenna was installed at Brandal, and subsequently a second antenna was set up at Rabben. The ADS-B instruments are used to collect information about air traffic over Ny-Ålesund and will be part of the SLR safety system.

Other activities include maintenance of the superconducting gravimeters, energy optimization work, and installation of an electronic access control system at Brandal. For both the superconducting gravimeters at Kongepunktet and Brandal, cold heads were exchanged in March 2020. At Brandal, the heating and ventilation systems were improved, e.g. by adding an outdoor cooling system to the existing ventilation system in the Data Center. A new 28-m telescopic boom lift (Manitou 280TJ) was acquired in November 2019, greatly facilitating maintenance of the VLBI telescopes.

Finally, the Internet site for the geodetic observatory received a new graphic design (see https://www.kartverket.no/en/about-kartverket/geodetic-earth-observatory).

5 Future Plans

Fully operationalizing the twin-telescopes at the new geodetic observatory remains the focus of the station staff. The Ns telescope is expected to join the IVS schedule as a fully operational station in March 2021. The Ns telescope is planned to run with the tri-band receiver, DBBC2, and Flexbuff at least until the end of 2022, when the 1.5 years of parallel observations with the 20-m Ny telescope should be completed. Subsequently, a broadband receiver and DBBC3 will be installed. Delivery of the second broadband receiver from the Instituto Geográfico Nacional is scheduled for August 2022.

Testing and configuration of the DBBC3 at the Nn telescope continues in parallel, with the aim of having the Nn telescope join the IVS schedule in mid-2021. The old 20-m telescope will undergo repair work in spring 2021. The elevation encoder will be re-installed, troubleshooting of the vacuum system will be carried out, and the leak in the helium system will be fixed. Overall, focus will increasingly shift to operations at the new geodetic observatory, and the 20-m telescope will be phased out and taken down once the period of parallel observations with Ns is completed.

Installation of the first components of the SLR is planned for 2021 with setup of the dome on the roof at Brandal and installation of the riser. The gimbal and telescope assembly will follow in 2022, and the laser system will be installed in 2024. The SLR is planned to be fully operational by 2025. The geodetic observatory is thus planned to become a fundamental station with all space geodetic techniques co-located in 2025.

German Antarctic Receiving Station (GARS) O'Higgins

Theo Bachem[1], Reiner Wojdziak[1], Thomas Klügel[1], Alexander Neidhardt[2], Christian Plötz[1], Torben Schüler[1]

Abstract The German Antarctic Receiving Station (GARS) O'Higgins contributed successfully to the IVS observing program in the years 2019 and 2020. The receiver cold-head and the compressor of the helium cooling system was replaced. A new recording system consisting of a Flexbuff server (Dell PowerEdge) and a Fila10G formatter was installed and tested. A complete integration within the automatized workflow of the observation planning system of the German Aerospace Center (DLR) allows a seamless integration of VLBI observation with the satellite operation program. A new UPS for the hydrogen masers as well as new atmospheric sensors for wind and barometric pressure measurements were installed. The frequency standard had to be switched to the backup hydrogen maser EFOS 11 after the main system, the EFOS 50, failed.

1 General Information

The Antarctic station GARS O'Higgins is jointly operated by the German Aerospace Center (DLR) and the Federal Agency for Cartography and Geodesy (BKG, belonging to the duties of the Geodetic Observatory Wettzell (GOW)). The Institute for Antarctic Research Chile (INACH) coordinates the logistics. The 9-m radio telescope at GARS O'Higgins is mainly used for downloading remote sensing data from satellites such as TanDEM-X and for the commanding and monitoring of spacecraft telemetry. DLR operating staff and a Chilean team for maintaining the infrastructure (e.g., power and freshwater generation, and technical support) are present at the station the entire year. BKG staff was on site from the end of January to mid-March 2019 and from the beginning of February until mid-March 2020. Within the report time period, the O'Higgins VLBI station was scheduled in a total of 34 IVS sessions. In addition, the O'Higgins VLBI radio telescope participated in three 24-hour BKG sessions.

The carriage of passengers and cargo by air and by ship was organized by the Chilean Antarctic Institute (INACH) in close collaboration with the Chilean Army, Navy, and Air force, and with the Brazilian Air force. All technical material and food for the entire stay are delivered from Punta Arenas via Base Frei on King George Island to O'Higgins on the Antarctic Peninsula. The conditions for landing on the glacier are strongly weather-dependent. In general, transport of staff and cargo is always a challenging task. Arrival and departure times strongly depend on the current meteorological conditions and on the logistic circumstances.

The VLBI system is continuously operational and maintenance and potential repair work is only possible when BKG staff is present. Frequent damages resulting from the rough climate conditions and strong storms have to be identified and repaired, e.g., wind sensors. Shipment of each kind of material, such as special tools, spare parts, or upgrade kits, has to be carefully prepared in advance. The most important station and system parameters are permanently remotely monitored.

1. Bundesamt für Kartographie und Geodäsie (BKG)
2. Forschungseinrichtung Satellitengeodäsie (FESG), Technische Universität München

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Fig. 1 View of the 9-m radio telescope.

2 Activities during 2019 and 2020

After more than two years of continuous operation, the cold head of the VLBI receiver as well as the associated helium compressor had to be replaced. After this maintenance, the system was able to again reach a stable cold-stage temperature of 14 Kelvin.

The 9-m radio telescope is controlled by a fully automatized observation planning system of the German Aerospace Center (DLR). Thus, in order to integrate automatically executed VLBI observations, a software for integration of the intended VLBI observations into the satellite operation program was developed. This allows the identification of available observing time slots and allocating them for VLBI observations in advance. Additionally, known satellite contacts can be included in advance to the VLBI scheduling stage as down times. Therefore, the cancellation of VLBI scans can be avoided. In summary, this allows a full automation and remote operation of the VLBI system at GARS O'Higgins.

In order to solve the frequent outages of the anemometer wind sensor due to the extreme weather conditions, this sensor was now replaced by a special ultrasonic one. The meteorologic equipment was also extended with a second barometric pressure sensor. Further enhancements were made to the VLBI recording system. We installed a new Flexbuff server with a Fila10G formatter, which is replacing the existing Mark 5B+ VLBI data recorder as the main recording system. In the time and frequency area we installed a new UPS to extend and secure the power supply of the hydrogen masers in case of a power outage. Since the main maser EFOS 50 fell out of lock in March 2020, the spare maser EFOS 11 took over this task in April 2020. The output frequency of the maser EFOS 11 had to be adjusted after the re-initialization beginning April 2020.

Fig. 2 New wind anemometer.

3 Staff

The members of staff for operation, maintenance, and upgrade of the VLBI system and other geodetic devices are summarized in Table 1. On June 30, 2020 our colleague and friend Reiner Wojdziak died very unexpectedly. He was one of the backbones for the operation of GARS O'Higgins and the most experienced team member, regularly participating in measurement and maintenance campaigns from 1994 onward (see also IVS Newsletter, Issue 57, August 2020).

4 Current Status

Besides the 9-m VLBI radio telescope, which is used for the dual purpose of receiving data from and sending commands to remote sensing satellites and performing geodetic VLBI, other geodetic-relevant instruments are also operated on site:

- currently two H-masers (EFOS 11 and EFOS 50), an atomic Cs-clock, a GPS time receiver, and a Total Accurate Clock (TAC) offer time and frequency. Due to a failure of the main EFOS 50 Maser the frequency standard had to be switched to the backup system (EFOS 11).
- two GNSS receivers OHI2 and OHI3, operating in the frame of the IGS network, while both are Galileo enabled. The receivers worked without failure.
- a meteorological station providing pressure, temperature, humidity, and wind information, as long as the temporarily extreme conditions did not disturb the sensors.
- two SAR corner reflectors, which were installed in March 2013 as part of a network to evaluate the localization accuracy of the TerraSAR-X mission.

Fig. 3 Reiner on his last O'Higgins campaign.

Table 1 Staff members. [Key: FESG = Forschungseinrichtung Satellitengeodäsie, RTW = Radio Telescope Wettzell, TTW = Twin Telescope Wettzell.]

Name	Affiliation	Function	Mainly working for
Torben Schüler	BKG	head of the GOW	GOW
Thomas Klügel	BKG	deputy head of the GOW	administration laser gyro/ local systems Wettzell
Christian Plötz	BKG	electrical engineer (chief engineer RTW)	O'Higgins, RTW, TTW
Reiner Wojdziak (†30.06.2020)	BKG	software engineer	O'Higgins, IVS Data Center Leipzig
Theo Bachem	BKG	electrical engineer	SLR Wettzell, operator O'Higgins
Swetlana Mähler	BKG	geodesist	survey, SLR Wettzell, logistics O'Higgins
Olaf Lang	BKG	electrical engineer	local systems/ SLR Wettzell, logistics O'Higgins
Alexander Neidhardt	FESG	head of the microwave group, VLBI chief	RTW, TTW
Gerhard Kronschnabl	BKG	electrical engineer (chief engineer TTW)	TTW, RTW

5 Future Plans

As the main frequency standard of the VLBI station, the EFOS 50 hydrogen maser needs to be repaired during the next campaign. The IT equipment has to be upgraded by installing new network routers. Also, the time and frequency system will be improved by the installation of new measurement equipment (counters, GNSS receiver).

References

1. D. Behrend, "Coordinating Center Report", In K. D. Baver, D. Behrend, and K. Armstrong, editors, International VLBI Service for Geodesy and Astrometry 2012 Annual Report, NASA/TP-2013-217511, pages 55–57, 2013.

Onsala Space Observatory — IVS Network Station Activities During 2019–2020

Rüdiger Haas, Eskil Varenius, Gunnar Elgered, Grzegorz Kłopotek, Periklis-Konstantinos Diamantidis, Hans-Georg Scherneck, Maxime Mouyen, Peter Forkman, Karine Le Bail

Abstract During 2019 and 2020 we participated in 88 legacy S/X sessions with the Onsala 20-m telescope. We observed almost 50 VGOS 24-hour sessions with one or both of the Onsala twin telescopes and 49 shorter VGOS sessions. We also performed local interferometry measurements at Onsala.

1 General Information

The Onsala Space Observatory is the national facility for radio astronomy in Sweden with the mission to support high-quality research in radio astronomy and geosciences. The geoscience instrumentation at Onsala includes three antennas used for geodetic VLBI, several GNSS installations, a superconducting gravimeter, a platform for visiting absolute gravimeters, several microwave radiometers for atmospheric measurements, both GNSS-based and conventional tide gauge sensors, and a seismometer. The observatory can thus be regarded as a fundamental geodetic station. The staff members associated with the IVS Network Station at Onsala are listed in Table 1.

2 Legacy S/X VLBI Observations

In total, the 20-m radio telescope (On) participated in 45 and 43 legacy S/X sessions during 2019 and 2020, respectively, see Table 2. The majority were standard IVS sessions, but two special sessions were carried out together with Italian stations. All sessions were recorded with the DBBC2/Flexbuff system, and the data were e-transferred for correlation.

Two of the planned IVS sessions were lost. RV133 was lost due to data transfer issues in January 2019. R1943, in April 2020, was not even observed due to Covid-19 issues. Several sessions are still not correlated, including two of the mixed-mode RD-sessions observed in 2020.

Chalmers University of Technology, Department of Space, Earth and Environment, Onsala Space Observatory

Onsala IVS Network Station

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3 Local Interferometry Observations

In April 2019 we started local interferometry observations at X-band with the goal of connecting the twin telescopes and the 20-m telescope, see Table 3, the so-called ONTIE sessions. These sessions were planned, scheduled, observed, correlated, fringe-fitted, and analyzed at Onsala. The majority of the sessions were 24 hours long during which typically more than 1,000 scans were observed. The corresponding vgosDb files are available at the IVS. More details about the ONTIE sessions are provided in [2].

4 VGOS Observations

For 2019 and 2020 we planned to participate in 50 international VGOS sessions of 24-hour duration, the VT and VO series. For most of these sessions both Oe and Ow were planned to observe. During March to June 2020 we had problems with the low noise amplifiers (LNAs) of the OTT, which had been damaged by ship radar. As a consequence, several of the VO sessions could not be observed. We were participating in 32 European VGOS sessions during 2019 and 2020, of 4–6 h

Table 1 Staff members associated with the IVS Network Station at Onsala. All e-mail addresses have the ending @chalmers.se, and the complete telephone numbers start with the prefix +46-31-772.

Function	Name	e-mail	telephone
Responsible P.I.s for geodetic	Rüdiger Haas	rudiger.haas	5530
VLBI observations	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
	Karine Le Bail (2020.06.15–)	karine.lebail	5556
Ph.D. students involved in geodetic VLBI	Grzegorz Kłopotek (–2020.05.31)	grzegorz.klopotek	5575
	Periklis-Konstantinos Diamantidis	periklis.diamantidis	5575
Responsible for the VLBI Field System	Michael Lindqvist	michael.lindqvist	5508
	Rüdiger Haas	rudiger.haas	5530
	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
Responsible for the VLBI equipment	Karl-Åke Johansson (–2019.04.30)	karl-ake.johansson	5571
	Magnus Dahlgren (2019.05.01–)	magnus.dahlgren	5594
	Leif Helldner	leif.helldner	5576
Responsible for the VLBI operators and	Roger Hammargren	roger.hammargren	5551
data recording and transfer equipment	Simon Casey	simon.casey	5529
	Eskil Varenius (2019.10.01–)	eskil.varenius	5558
Telescope scientist	Henrik Olofsson	henrik.olofsson	5564
Software engineer	Mikael Lerner	mikael.lerner	5581
Responsible for gravimetry	Maxime Mouyen	maxime.mouyen	5549
Responsible for tide gauge and radiometry	Gunnar Elgered	gunnar.elgered	5565
Responsible for aeronomy and radiometry	Peter Forkman	peter.forkman	5577
Observatory director	John Conway	john.conway	5503

observing time. Furthermore, we observed 17 VGOS Intensive sessions of 1-hour duration. These were primarily the VGOS-B sessions [1], but for one occasion, day 336 in 2020, the OTT participated simultaneously in a VGOS-B Intensive session (Oe) and a VGOS-V2 Intensive session (Ow).

5 Monitoring Activities

We continued monitoring activities:

Calibration of pressure sensor. Starting in September 2002 the ground pressure sensor at the observatory has been continuously monitored and regularly compared to the Vaisala PA11 "traveling barometer" in order to maintain traceability to SI. This specific type has aged and was calibrated a final time at the SMHI main office in Norrköping on December 17, 2020. The differences were < 0.05 hPa in the interval from 950 to 1050 hPa. A new traveling barometer was installed on December 22, 2020, on recommendation by SMHI. This new type will facilitate future calibrations at SMHI, and furthermore it is set up for a continuous archiving of the observations (presently one sample per minute) while operating at the observatory.

Vertical changes of the 20-m telescope tower. We continued to monitor the vertical changes of the telescope tower using the invar rod system at the 20-m telescope. The measurements are available at `http://wx.oso.chalmers.se/pisa/`.

The local geodetic network. In October 2020 a survey was performed to determine the axis intersection of the Onsala twin telescopes. These measurements were performed by colleagues from Lantmäteriet, the Swedish mapping, cadastral, and land registration authority, using a total station mounted on the geodetic survey pillars around the twin telescopes and retro-reflecting prisms mounted on the elevation cabins. A preliminary analysis performed by colleagues from the Frankfurt University of Applied Sciences, Germany, indicates that the axis offset is less than 0.2 mm for both antennas. To connect the reference points of the twin telescopes with the 20-m telescope, further measurements are necessary, including GNSS observations on the survey pillars.

Table 2 Legacy S/X geodetic VLBI observations at Onsala during 2019 and 2020. The third and sixth columns give some general remarks and information about the percentage of the scheduled Onsala (On) observations that were used in the analysis (as reported on the web pages for the IVS session analyses), compared to the station average (StAv) percentage per experiment.

Exp.	Date	Remarks	Exp.	Date	Remarks
R1875	19.01.02	OK: 70.1 % (StAv 62.5 %)	R1928	20.01.07	OK: 58.8 % (StAv 41.9 %)
RV133	19.01.07	−− 0.0 %, data transfer issues	RV139	20.01.08	OK: 84.0 % (StAv 80.8 %)
RD1901	19.01.08	Not correlated yet	R1929	20.01.13	OK: 82.6 % (StAv 71.0 %)
R1877	19.01.14	OK: 83.3 % (StAv 70.6 %)	RD2001	20.01.15	OK: 73.5 % (StAv 54.8 %)
R1879	19.01.28	OK: 67.6 % (StAv 83.3 %)	R1931	20.01.27	OK: 81.4 % (StAv 72.6 %)
T2130	19.01.29	OK: 66.7 % (StAv 57.9 %)	R1932	20.02.03	OK: 84.1 % (StAv 74.4 %)
EURD09	19.01.30	OK: 95.9 % (StAv 93.8 %)	RD2002	20.02.12	OK: 69.3 % (StAv 62.5 %)
R1880	19.02.04	OK: 93.9 % (StAv 92.8 %)	R1934	20.02.17	OK: 85.0 % (StAv 72.3 %)
RD1902	19.02.06	Not correlated yet	R1939	20.03.23	OK: 97.4 % (StAv 93.8 %)
R1881	19.02.11	OK: 92.3 % (StAv 88.7 %)	RD2003	20.03.25	OK: 43.0 % (StAv 28.0 %)
R1882	19.02.19	OK: 91.9 % (StAv 89.4 %)	R1940	20.03.30	OK: 72.1 % (StAv 55.6 %)
R1887	19.03.25	OK: 87.8 % (StAv 77.9 %)	R1942	20.04.14	OK: 85.9 % (StAv 77.1 %)
T2131	19.03.26	OK: 80.2 % (StAv 67.8 %)	R1943	20.04.20	−− 0.0 %, no observations due to Covid-19
EUR149	19.03.27	OK: 97.0 % (StAv 77.8 %)	R1945	20.05.04	OK: 82.8 % (StAv 73.6 %)
R1888	19.04.01	OK: 96.4 % (StAv 89.7 %)	RD2004	20.05.06	OK: 73.7 % (StAv 50.2 %)
R1891	19.04.23	OK: 91.5 % (StAv 77.8 %)	R1947	20.05.18	OK: 96.2 % (StAv 94.1 %)
RV134	19.04.29	OK: 84.4 % (StAv 76.4 %)	RV140	20.05.19	OK: 65.1 % (StAv 96.8 %)
EURD10	19.05.06	OK: 75.2 % (StAv 61.4 %)	R1948	20.05.26	OK: 81.4 % (StAv 72.0 %)
VI007	19.05.19	OK: N/A, Test with Italy.	RD2005	20.06.24	OK: 68.5 % (StAv 52.2 %)
R1895	19.05.20	OK: 92.3 % (StAv 89.6 %)	R1953	20.06.29	OK: 83.6 % (StAv 75.9 %)
T2132	19.05.21	OK: 79.2 % (StAv 62.1 %)	R1954	20.07.06	OK: 83.9 % (StAv 76.1 %)
RV135	19.06.24	OK: 81.4 % (StAv 72.1 %)	RV141	20.07.07	OK: 86.9 % (StAv 83.5 %)
RD1905	19.06.26	OK: 58.2 % (StAv 58.0 %)	RD2006	20.07.08	Not correlated yet
R1901	19.07.01	OK: 83.3 % (StAv 77.9 %)	R1959	20.08.11	OK: 75.6 % (StAv 77.9 %)
RV136	19.07.08	OK: 86.8 % (StAv 76.0 %)	R1960	20.08.18	OK: 88.4 % (StAv 72.6 %)
RD1906	19.07.10	OK: 78.3 % (StAv 64.2 %)	RV142	20.08.19	OK: 73.3 % (StAv 61.8 %)
R1907	19.08.12	OK: 78.7 % (StAv 72.8 %)	R1961	20.08.24	OK: 80.1 % (StAv 63.8 %)
R1908	19.08.19	OK: 75.5 % (StAv 65.1 %)	RD2007	20.08.25	Not correlated yet
R1909	19.08.26	OK: 71.1 % (StAv 53.6 %)	R1962	20.08.31	OK: 78.3 % (StAv 63.2 %)
RD1908	19.08.27	OK: 71.8 % (StAv 59.9 %)	R1963	20.09.08	OK: 76.3 % (StAv 59.9 %)
R1910	19.09.02	OK: 76.7 % (StAv 64.8 %)	RD2008	20.09.09	Not correlated yet
EURD11	19.09.03	OK: 91.1 % (StAv 85.1 %)	R1965	20.09.21	OK: 66.5 % (StAv 53.1 %)
R1911	19.09.09	OK: 72.6 % (StAv 59.5 %)	RV143	20.09.22	OK: 77.6 % (StAv 67.6 %)
RD1909	19.09.11	OK: 77.0 % (StAv 65.3 %)	R1966	20.09.28	OK: 77.5 % (StAv 65.9 %)
R1913	19.09.23	OK: 69.2 % (StAv 52.8 %)	R1972	20.11.09	OK: 112.5 % (StAv 122.7 %), extra stations joined
T2134	19.09.24	OK: 75.1 % (StAv 53.6 %)	T2142	20.11.10	Not correlated yet
RD1910	19.09.25	Not correlated yet	VI008	20.11.14	OK: N/A, Test with Italy
RV137	19.09.30	OK: 49.5 % (StAv 5.6 %)	RV144	20.11.18	OK: 75.3 % (StAv 69.7 %)
R1921	19.11.18	OK: 82.2 % (StAv 74.9 %)	RD2009	20.11.23	Not correlated yet
EUR150	19.11.20	OK: 75.5 % (StAv 58.5 %)	R1974	20.11.24	OK: 89.5 % (StAv 80.3 %)
RV138	19.11.25	OK: 75.5 % (StAv 78.4 %)	RD2010	20.12.02	Not correlated yet
R1924	19.12.09	OK: 72.9 % (StAv 58.0 %)	R1976	20.12.07	OK: 83.1 % (StAv 77.1 %)
T2136	19.12.10	OK: 73.3 % (StAv 47.8 %)	R1977	20.12.14	OK: 73.3 % (StAv 56.0 %)
EURD12	19.12.16	OK: 70.5 % (StAv 53.0 %)	R1978	20.12.21	OK: 86.7 % (StAv 79.9 %)
R1925	19.12.17	OK: 76.5 % (StAv 56.9 %)			

Superconducting gravimetry (SCG). The superconducting gravimeter operated continuously and produced a highly accurate record of gravity variations. Tide solutions were prepared on a weekly basis, and results are available on the SCG homepage (`http://holt.oso.chalmers.se/hgs/SCG/toe/toe.html`).

Table 3 2019 and 2020 local X-band interferometry observations involving On, Oe, and Ow. These sessions were planned, scheduled, observed, correlated, fringe-fitted, and analyzed at Onsala. All vgosDb files are available via the IVS Web pages. The third and sixth columns give information about the percentage of the scheduled observations that were used in the final data analysis.

Exp.	Date	Remarks	Exp.	Date	Remarks	Exp.	Date	Remarks
ON9114	19.04.24	OK: 99.0 %	ON0010	20.01.10	OK: 98.2 %	ON0178	20.06.26	OK: 98.9 %
ON9120	19.04.30	OK: 99.4 %	ON0011	20.01.11	OK: 98.2 %	ON0179	20.06.27	OK: 99.2 %
ON9120	19.04.30	OK: 99.4 %	ON0012	20.01.12	OK: 98.2 %	ON0180	20.06.28	OK: 98.9 %
ON9120	19.04.30	OK: 99.4 %	ON0079	20.03.19	OK: 98.3 %	ON0223	20.08.10	OK: 98.2 %
ON9136	19.05.16	OK: 98.9 %	ON0080	20.03.20	OK: 98.6 %	ON0227	20.08.14	OK: 97.3 %
ON9142	19.05.22	OK: 99.3 %	ON0081	20.03.21	OK: 99.1 %	ON0228	20.08.15	OK: 97.7 %
ON9323	19.11.19	OK: 98.2 %	ON0082	20.03.22	OK: 98.8 %	ON0317	20.11.12	OK: 98.8 %
ON9327	19.11.23	OK: 98.1 %	ON0177	20.06.25	OK: 99.0 %	ON0318	20.11.13	OK: 98.7 %
ON9328	19.11.24	OK: 98.4 %						

Absolute gravimetry. Lantmäteriet visited the observatory twice with their FG5 instrument. These measurement campaigns were performed once in 2019 and once in 2020.

Seismological observations. The seismometer owned by Uppsala University and the Swedish National Seismic Network (SNSN) was operated throughout the two-year period.

Water vapor radiometry. The observatory operated two radiometers at the beginning of 2019: Astrid and Konrad. Both were operating continuously until the summer, when a thunder storm hit the observatory and both radiometers failed because many components were damaged. Konrad was repaired and started operating again in early October 2019. After that, Konrad has been operating more or less continuously, but the quality of the data is now and then not satisfactory due to gain jumps. The cause of these jumps has been investigated in the lab on several occasions and was not fully understood at the end of 2020.

Astrid is still broken, and discussions are going on regarding a major upgrade of the instrument, because the data acquisition system is obsolete.

Sea level. The official Onsala tide gauge station is a part of the national observational network for sea level operated by the Swedish Meteorological and Hydrological Institute (SMHI). The data are available via SMHI web pages (open access). It has been in continuous operation since the summer of 2015. During 2020 repeated leveling campaigns have revealed an offset of the reference point on the main sensor, a Campbell CS474 radar. We plan for additional leveling measurements during 2021 in order to have an accuracy at the millimeter level, over the dynamic range of the expected sea level variations, approximately from -1 m to $+2$ m around the mean. Based on these measurements, we will, thereafter, apply a correction to all historical data.

The GNSS-R based tide gauge was operated continuously, and the recorded data were analyzed.

6 Future Plans

In the coming two years we plan to

- participate in about 50 IVS legacy S/X sessions per year with the 20-m telescope;
- participate in as many VGOS sessions as possible;
- continue the local interferometric measurements on a regular basis;
- continue the work to establish local tie vectors between the telescopes' reference points using classical geodetic observations as well as ones made with gimbal-mounted GNSS antennas on the telescopes;
- continue the monitoring activities.

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Table 4 2019/2020 international (VT, VO) and European (VGT, EV) VGOS, VGOS Intensive (B, V2), and mixed mode (RD) sessions with ONSA13NE (Oe) and/or ONSA13SW (Ow). Filled/open circles mean success/failure; dashes mean “not scheduled.”

Exp.	Date	Oe	Ow	Remarks	Exp.	Date	Oe	Ow	Remarks
VT9007	19.01.07	○	○	Oe missed 5 h, Ow missed 133 scans	B20007	20.01.07	●	●	OK
VT9022	19.01.22	●	●	Ow weak PCAL	VO0009	20.01.09	●	●	OK
VGT035	19.02.04	●	–	Ow no PCAL	EV0009	20.01.09	●	●	Not yet correlated
VT9035	19.02.04	●	–	Ow no PCAL	B20013	20.01.13	●	●	OK
VT9050	19.02.19	●	–	Ow no PCAL, Oe 12 scans missed	EV0021	20.01.21	●	●	Not yet correlated
VGT050	19.02.19	●	○	Ow clock&PCAL issue, Oe some loss	VO0021	20.01.21	●	●	OK
VT9063	19.03.04	●	–	Ow no PCAL	B20023	20.01.23	●	●	OK
VT9077	19.03.18	●	–	Ow no PCAL	B20027	20.01.27	●	●	OK
VT9091	19.04.01	●	–	Ow no PCAL	VO0034	20.02.03	●	●	OK
VT9105	19.04.15	●	–	Ow no PCAL	EV0034	20.02.03	●	●	Not yet correlated
VGT105	19.04.15	●	–	Ow no PCAL	B20037	20.02.06	●	●	OK
EV9119	19.04.29	●	○	Ow manual PCAL	B20044	20.02.13	●	●	OK
VT9119	19.04.29	●	–	Ow no PCAL	B20048	20.02.17	●	●	OK
VT9133	19.05.13	○	–	Oe lost 12 h; recorder issues	VO0051	20.02.20	●	●	OK
VT9148	19.05.28	●	○	Ow lost 21 h due to ACU	EV0051	20.02.20	●	●	Not yet correlated
EV9162	19.06.11	●	●	PCAL+CDMS issues	B20055	20.02.24	●	●	OK
VT9162	19.06.11	●	○	Ow lost 16 h due to ACU	VO0062	20.03.02	●	●	OK
VT9175	19.06.24	●	○	Ow missed 8 h due to ACU	EV0062	20.03.02	●	●	Not yet correlated
EV9175	19.06.24	●	●	OK	VO0076	20.03.16	●	●	Not yet correlated
EV9189	19.07.08	●	●	Ow missed 7 scans due to ACU	EV0076	20.03.16	●	●	Not yet correlated
VT9189	19.07.08	●	○	Ow missed 6 h due to ACU	VO0090	20.03.30	●	●	Oe and Ow LNA damage
VT9203	19.07.22	●	●	OK	VO0105	20.04.14	○	○	Oe and Ow LNA damage
EV9203	19.07.22	●	●	OK	VO0147	20.05.26	●	○	Ow LNA damaged
VT9217	19.08.05	●	●	OK	VO0160	20.06.08	○	○	Oe netwk. failure, Ow LNA damage
EV9217	19.08.05	●	●	OK	VO0174	20.06.22	●	●	Not yet correlated
VT9231	19.08.19	●	●	Oe RX+CDMS issues	RD2005	20.06.24	●	●	Too strong PCAL
EV9231	19.08.19			Cancelled	VO0188	20.07.06	●	●	Not yet correlated
VT9248	19.09.05	●	●	OK	RD2006	20.07.08	●	●	Not yet correlated
EV9259	19.09.16	●	●	Ow lost 0.5 h to bias issue	VO0202	20.07.20	●	●	Not yet correlated
VT9259	19.09.16	●	●	OK	VO0219	20.08.06	●	●	OK
VT9273	19.09.30	●	●	OK	VO0231	20.08.18	●	●	Not yet correlated
VT9290	19.10.17	●	●	17 % scans with $\geq$ 10 % data loss	RD2007	20.08.25	●	●	Not yet correlated
EV9290	19.10.17	○	●	Cancelled; station Ws failed	VO0244	20.08.31	●	●	Not yet correlated
EV9301	19.10.28			Cancelled	EV0244	20.08.31	●	●	Not yet correlated
VT9301	19.10.28	●	●	Oe lost 20 min; DBBC3 problem	EV0258	20.09.14	●	●	Not yet correlated
EV9318	19.11.14	●	●	Network switch failure; lost 0.5 h	VO0258	20.09.14	●	●	Not yet correlated
VT9318	19.11.14	●	●	Missed 9 h due to recorder issues	EV0272	20.09.28	●	●	Not yet correlated
EV9329	19.11.25	●	●	OK	VO0272	20.09.28	●	●	Not yet correlated
VT9329	19.11.25	●	●	OK	VO0287	20.10.13	●	●	OK
VT9343	19.12.09	●	●	OK	EV0287	20.10.13	●	●	Not yet correlated
EV9343	19.12.09	●	●	Not yet correlated	EV0303	20.10.29	●	●	Not yet correlated
B19344	19.12.10	●	●	OK	VO0303	20.10.29	●	●	Not yet correlated
B19351	19.12.17	●	●	OK	VO0314	20.11.09	●	●	Not yet correlated
EV9357	19.12.23	●	●	Not yet correlated	EV0314	20.11.09	●	●	Not yet correlated
B19357	19.12.23	●	●	OK	EV0328	20.11.23	●	●	Not yet correlated
VT9360	19.12.26	●	●	OK	VO0328	20.11.23	●	●	Not yet correlated
B19364	19.12.30	●	●	OK	B20329	20.11.24	●	●	Not yet correlated
					B20336	20.12.01	●	–	Not yet correlated
					V20336	20.12.01	–	●	OK
					VO0345	20.12.10	●	●	Not yet correlated
					EV0345	20.12.10	●	●	Not yet correlated
					B20349	20.12.14	●	●	Not yet correlated
					B20356	20.12.21	●	●	Not yet correlated
					VO0357	20.12.22	●	●	Not yet correlated
					EV0357	20.12.22	●	●	Not yet correlated

“Quasar” VLBI Network Stations Report

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Abstract The current status, as well as activities in 2019 and 2020, of the “Quasar” VLBI Network stations is presented.

1 General Information

The “Quasar” VLBI Network is a unique Russian astronomical instrument created at the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA RAS) [1].

The main purposes of the “Quasar” Network are to improve the celestial and terrestrial reference frames, to monitor the Earth rotation parameters, and to study data essential for understanding the Earth’s environments. The Network consists of three observatories including Svetloe in Leningrad Region, Badary in Eastern Siberia, and Zelenchukskaya in the Northern Caucasus and the Data Processing Center in St. Petersburg. The Svetloe observatory was the first to be put into operation in 1999, the next was Zelenchukskaya in 2002, and the final was Badary in 2005. The baselines of the radio interferometer vary from 2,000 to 4,400 km. Each observatory is equipped with at least three co-located instruments of different techniques: VLBI, SLR, and combined GNSS receivers [2]. In addition, the Badary observatory is equipped with the DORIS system. All observatories are linked by optical fiber lines, are equipped with identical hydrogen Time Standards, and also are equipped with Water Vapor Radiometers and meteorological stations whose data are used for all types of observations.

The basic instruments at each of the three observatories are a 32-m radio telescope (RT-32) and a VGOS radio telescope (RT-13). Figure 1 presents a view of the Badary observatory.

Fig. 1 Badary observatory.

The Legacy 32-m antennas (SVETLOE, ZELENCHK, and BADARY) provide a completely automatic process of observing the radio sources and satellites in a radiometric or radio interferometric mode. The main technical characteristics of the antennas are presented in Table 1. At SVETLOE station, there is a limitation on the maximum number of scans per 24-hour session: no more than 350 scans. Each RT-32 radio telescope is equipped with highly sensitive receivers, providing signal amplification in the K (22.02–22.52 GHz), X (8.18–9.08 GHz), C (4.6–5.5 GHz), S (2.15–2.5 GHz), and L (1.38–1.72 GHz) frequency bands in both circular polarizations. A cooled low-noise amplifier is

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Table 1 Specifications of the RT-32.

Mount	alt-azimuth
Configuration	cassegrain
Subreflector scheme	asymmetrical
Main mirror diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Azimuth speed	1.0°/sec
Elevation speed	0.5°/sec
Limits by Az	±265°
Limits by El	0° – 85°
Tracking accuracy	±10 arcsec
Surface accuracy (RMS)	0.5 mm
Frequency range	1.4–22 GHz
Polarization	LCP + RCP

used at all frequency bands in order to achieve a less than 50 K noise temperature for the radio telescope and radiometer system. We use the R1002M data acquisition system with 16 converters developed at the IAA RAS [3] and the Mark 5B recording system. During the years 2019 and 2020, observational data were transmitted to the ARK correlator [4] in the Data Processing Center at the IAA RAS, which is capable of processing the data in the Mark 5 format received simultaneously from three stations at an average rate up to 2048 Mbps.

Fig. 2 The RT-13 radio telescope at the Svetloe observatory.

In 2015 two multi-band fast rotating antennas with a mirror diameter of approximately 13.2-m (RT-13) were installed at the Zelenchukskaya and Badary stations (ZELRT13V and BADRT13V) [5]. The third RT-13 radio telescope (SVERT13V) was installed in 2018 at the Svetloe observatory (Figure 2) and commissioned on November 24, 2020.

Table 2 presents some specifications of the RT-13 antenna system, which meets all requirements of the VGOS program. Each RT-13 radio telescope is equipped with a specially designed receiver system. The main feature of this system is the cryogenic receiver unit that includes a cooled tri-band feed and low-noise amplifier. Such a design makes it possible to achieve high sensitivity and to receive weak noise signals of cosmic origin. As well, the feed design allows us to receive signals in three frequency bands: S (2.2–2.6 GHz), X (7.0–9.5 GHz), and Ka (28–34 GHz) in both circular polarizations simultaneously [6].

Table 2 Specifications of the RT-13.

Mount	alt-azimuth
Configuration	Cassegrain
Subreflector scheme	ring-focus
Main mirror diameter	13.2 m
Subreflector diameter	1.48 m
Focal length	3.7 m
Azimuth speed	1.0°/sec
Elevation speed	0.5°/sec
Limits by Az	±245°
Limits by El	6° – 109°
Operation	24h/7d
Tracking accuracy	±15 arcsec
Surface accuracy (RMS)	0.1 mm
Frequency range	2–40 GHz
Surface efficiency	> 0.7
Polarization	LCP + RCP

The RT-13 antennas at the Zelenchukskaya and Badary observatories are equipped with the Broadband Acquisition System (BRAS) [7]. The RT-13 antenna at the Svetloe observatory is equipped with the new Multifunctional Digital Backend (MDBE) [9].

Wideband intermediate frequency signals (1.024–1.536 GHz for BRAS or 1.024–2.048 GHz for MDBE) from the receiver output are digitized by BRAS or MDBE. The Digital Backend digitizes the input signals, performs signal processing, and packs the output data into 10 Gigabit Ethernet VDIF frames. The IAA RAS has been conducting observations with the RT-13 radio telescopes with the network BADRT13V–ZELRT13V–SVERT13V in test mode since March 2019 and on a regular basis since the end of 2020. During the observations, the data flow generated by the Digital Backends (up to 16 Gbps) is routed via optical fiber line to the data transfer and recording system (DTRS). The DTRS then transfers the data to the RASFX correlator in the Data Processing Center in St. Petersburg. The registration and transmission procedures take place simultaneously. The RASFX correlator, based on a hybrid-blade HPC cluster, was designed at IAA RAS in 2014 and now is used to process the wideband signals from the RT-13 radio telescopes [8].

2 Staff

The list of the staff members of the "Quasar" VLBI Network stations in 2019–2020 is given below:

- Svetloe:
  Prof. Ismail Rahimov: observatory chief;
  Vladimir Tarasov: chief engineer;
  Tatiana Andreeva: engineer;
  Alexander Isaenko: engineer.
- Zelenchukskaya:
  Andrei Dyakov: observatory chief;
  Dmitry Dzuba: FS, pointing system control;
  Anatoly Mishurinsky: front end, receiver support.
- Badary:
  Valery Olifirov: observatory chief;
  Roman Kuptsov: engineer.
- IAA Operating Center:
  Ilya Bezrukov: data transfer;
  Andrey Mihkailov: FS, observation control;
  Alexey Melnikov: skd for Domestic sessions;
  Mikhail Kharinov: planning of observations.

3 Current Status and Activities

During 2019–2020, the RT-32 and the RT-13 radio telescopes of the "Quasar" VLBI Network participated in both IVS and domestic VLBI observations. Activities of the observatories are presented in Tables 3 and 4. SVERT13V participated in the IVS-R1972 session on November 9, 2020. e-VLBI mode is used for the transfer of the domestic sessions' data.

Table 3 VLBI observations with the RT-32 radio telescopes.

	Sv		Zc		Bd	
Sessions	2019	2020	2019	2020	2019	2020
IVS-R4	18	18	20	12	16	19
IVS-R1		18		16		19
IVS-T2	5	2	2		5	2
EUROPE	1		1		1	
EUR R & D	4		4		4	
AOV		1		1		1
CRF			3	2		2
IVS-Intensive	21	20				
RuE	35	32	35	32	35	32
RI	60	72	359	311	318	326

Table 4 VLBI observations with the RT-13 radio telescopes.

	Sw		Zv		Bv	
Sessions	2019	2020	2019	2020	2019	2020
R	575	1214	1394	1227	1372	1227
RI-RT13			347		347	
24-h		1				
X (S/X/Ka)		349	328	376	328	371

During 2019–2020 the RT-13 radio telescopes participated in the following geodetic sessions:

- R: one-hour geodetic sessions in the S/X bands for UT determination—since 7/8/2020, we have observed these sessions as two-hour sessions;
- RI-RT13: sessions performed simultaneously with RI sessions at RT-32 antennas with the same schedule (RI-RT13);
- X: geodetic sessions in the S/X/Ka bands for UT determination—during the year 2019 they were 30 minutes long and during 2020 one hour long.

From the end of December 2019 until March 2020, a successful series of experimental sessions with new receivers with linear polarization [10] were held on the baseline SVERT13V–BADRT13V, a total of 170 sessions.

Table 5 presents the main types of Russian domestic sessions at the S/X frequency range. The standard

IVS designations of the stations are used in the table: Sv for Svetloe, Zc for Zelenchukskaya, and Bd for Badary for RT-32 and Bv for Badary, Zv for Zelenchukskaya, and Sw for Svetloe for RT-13. Test X sessions at the S/X/Ka frequency range have been observed as a rule once a day by the network BvZvSw (since March of the year 2020).

Table 5 Specifications of domestic sessions at the S/X frequency range.

Program	RI	RuE	R	RI(RT-13)
Stations	BdZc(Sv)	SvZcBd	ZvBvSw	ZvBv
Duration, hours	1	24	1 or 2	1
Aim	dUT1	EOP	dUT1	dUT1
Turn-around time, in hours	2	120	2–6	2–6
Scheduled	daily	weekly	3–4 times	daily
Start time, UT	20:00	Fri, 20:00	per day	20:00
Scan duration, s	22-127	60	10	22-127
Sources	150	60	156	150
set	>0.25 Jy	>0.5 Jy		>0.25 Jy
Sour.number/sess	20	50	60	20
Sampling, bit	1	1	2	1
Bandwidth, MHz	8	8	512	512
Data rate, Mbit/s	256	256	2048	2048
Scan number	25	350	120	25
Obs. number	25	1000	45–120	25
Correlator	IAA ARC	IAA ARC	RASFX	RASFX

During the years 2019–2020, we performed some significant repair and upgrade works at all observatories.

The rail track for the RT-32 radio telescope was repaired at the Zelenchukskaya observatory. In the period from July 7 to July 24 and from August 21 to September 21, 2020, work was carried out to restore two sections of the concrete foundation of the rail of the RT-32 radio telescope at the Zelenchukskaya observatory. The destruction of concrete and embedded parts in these areas caused the rail to sag by 2–3 mm. The old embedded parts were dismantled and replaced by new ones, and the concrete was dismantled to a depth of 350–400 mm and replaced by a new one. After curing, the concrete was treated with penetrating waterproofing. The rail was set to the design height.

For the aim of improving the accuracy of VLBI observations in the K frequency range, during the summer and autumn of 2020, the surface of the counter-reflectors (Figure 3) was replaced for the RT-32 antennas at all observatories.

Fig. 3 Counter-reflector of the RT-32 radio telescope at BADARY.

The new counter-reflector shields have a surface accuracy of 0.2 mm. After the first alignment, the accuracy of the counter-reflector surface reached 0.36 mm (versus 0.65 mm for the old counter-reflector). In 2021, we will continue to align.

In 2020, all observatories were equipped with two new high-performance CH1-1035 hydrogen masers designed at VREMYA-CH Russia JSC. After setting up, we are going to start using them from mid-2021.

Fig. 4 The RT-32 radio telescope at the Svetloe observatory.

16-bit and 24-bit tracking resolver-to-digital converters were installed in the new servo control system of the RT-32 radio telescope. A new version of the RT-32 antenna electric drive control system software was developed, installed, and put into operation.

4 Future Plans

During the next two years, all stations of the “Quasar” VLBI Network will continue to participate in IVS and domestic VLBI observations, upgrade existing equipment, and replace obsolete equipment.

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Sejong Station Report for 2019–2020

Sangoh Yi, Jongwan Kim, Hasoo Yoon, Sangchul Han, Sangwon Lee

Abstract This is a brief report on VLBI observational activities conducted by Sejong Observatory from 2019 to 2020. Sejong Antenna participated in 107 R1, AOV, and T2 sessions.

1 General Information

Sejong VLBI Observatory, located in Sejong City, about 120 kilometers south of Seoul, began operation in 2012. Geodetic VLBI and GNSS observations are being carried out as part of international geodetic cooperation activities. Sejong is managed by the Korea National Geographic Information Service. All operating budgets of Sejong are provided by the National Geographic Information Institute.

2 Component Description

The Sejong VLBI antenna is equipped with a receiver capable of simultaneously receiving four frequencies (2/8/22/43 GHz) with a diameter of 22 m. We are conducting geodetic and astronomical observations using receivers from all bands. With active cooperation between the KISTI and NIA institutions in South Korea, we are using three (1 Gbps, 10 Gbps, and 100 Gbps) telecommunication networks. The 10-Gbps network is used for IVS observation, and the 100-Gbps network is used for joint research with the Korea Institute of Standards and Korea Astronomy and Space Science Institute.

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3 Staff

As of 2020, a total of five employees are performing VLBI duties at Sejong Observatory. Kim Jong-wan is the manager of the center. Yi Sang-oh is responsible for managing and analyzing VLBI-related tasks, while Lee Sang-won performs VLBI observations and data transfer related tasks. Han Sang-chul performs maintenance tasks for VLBI equipment.

4 Current Status and Activities

Sejong Observatory operates VLBI, GNSS, and SLR systems by the National Geographic Information Institute and the Korea Astronomy Space Science Institute. The systems are operated for global geodetic cooperation and contribute to the ITRF2020 effort by submitting space-geodetic connection information to IERS to support ongoing global geodetic observation programs.

Sejong measured the IVP points of each system for joint measurement and measured each position relationship precisely. This became the first combined survey result of Sejong Observatory and plans to conduct regular surveys and increase the reliability of the results.

Sejong is also making efforts to increase utilization of geodetic VLBI equipment. It is also conducting research with Sejong observatory, KASI (Korea Astronomy Space Science Institute), KISTI (Korea Institute

Fig. 1 Sejong Observatory.

Science Technology Information), and KRISS (Korea Research Institute of Standards and Science) to verify the stability of optical clocks developed at KRISS. To this end, it received 100-Gbps optical communication for frequency standards provided by the KRISS and is experimenting with geodetic VLBI observations using them.

Table 1 Sessions that Sejong participated in 2019–2020.

IVS Session	Number of Participations
IVS-R1	81
IVS-T2	14
IVS-AOV	12

5 Future Plans

Sejong Station is planning to continue to participate in geodetic observation programs using S/X receivers. In order to increase utilization of Sejong VLBI equipment, it is also planning to open it to private researchers. It also plans to participate in the East Asian VLBI network and seek academic geographical and astronomical contributions.

Shanghai Station Report for 2019–2020

Bo Xia, Qinghui Liu, Zhiqiang Shen

Abstract This report summarizes the observing activities at the Sheshan station (SESHAN25) and the Tianma station (TIANMA65) in 2019 and 2020. It includes the international VLBI observations for astrometry, geodesy, and astrophysics and domestic observations for satellite tracking. We also report on updates and development of the facilities at the two stations.

1 General Information

The Sheshan station (SESHAN25) is located at Sheshan, 30 km west of Shanghai. It is hosted by Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS). A 25-meter radio telescope is in operation at 3.6/13, 5, 6, and 18 cm wavelengths. The Sheshan VLBI station is a member of the IVS and the EVN.

The Tianma station (TIANMA65) is located in the western suburbs of Shanghai, Sheshan town, Songjiang district. It is jointly funded by the Chinese Academy of Sciences (CAS), Shanghai Municipality, and the Chinese Lunar Exploration Program. The telescope construction started in early 2009, and the majority of the mechanical system was completed in October 2012. On December 2, 2013, the Tianma65 telescope passed its acceptance evaluation. By design, the Tianma telescope—with a diameter of 65 meters it is one of the largest steerable radio telescopes in the world—is a multi-function facility, conducting astrophysics, geodesy, and astrometry, as well as space science. By the end of 2014, Tianma65 was equipped with five cryogenic receiver systems (L, C, S/X, and Ku), with the expectation that another two high-frequency cryogenic receiver systems (Ka and Q) would be finished in 2015. The K band cryogenic receiver system was installed at the end of 2016. The CDAS and the DBBC2 have been installed at the Tianma 65-m telescope for the VLBI terminal.

The SESHAN25 and TIANMA65 telescopes take part in international VLBI sessions for astrometric, geodetic, and astrophysics research. Apart from its international VLBI activities, the TIANMA65 telescope spent a large amount of time on the Chinese Lunar Project, including testing before the launch of the Chang'e test satellite, as well as the tracking campaign after the launch and other single dish observations.

Shanghai Astronomical Observatory

SHAO Network Station

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2 Component Description

In 2019, the SESHAN25 telescope participated in forty-one IVS sessions (including fifteen INT2/3 Intensive sessions). TIANMA65 participated in three IVS sessions.

In 2020, the SESHAN25 telescope participated in forty-one IVS sessions (including twenty-two INT3 Intensive sessions). TIANMA65 participated in three IVS sessions.

Table 1 provides a breakdown of the various session types observed in 2019 and 2020 for both SESHAN25 (Sh) and TIANMA65 (T6).

Table 1 Statistics of sessions observed.

Session Type	2019 (Sh)	2020 (Sh)	2019 (T6)	2020 (T6)
AOV	5	5	2	3
APSG	2	1	0	0
IVS-R1	17	11	0	0
IVS-T2	1	2	0	0
IVS-R&D	1	0	1	0
IVS-INT2	5	0	0	0
IVS-INT3	10	22	0	0

3 Current Status and Activities

3.1 Antenna Maintenance at SESHAN25

From September 2019 to April 2020, we did some maintenance work on the rail track and the base of the Sheshan 25-m control room.

Fig. 1 Antenna maintenance on the SHESHAN 25-m telescope.

The Sheshan station encountered an antenna encoder problem during the R1972 session. Repairs were carried out from November to December.

3.2 Antenna Maintenance at TIANMA65

The maintenance of the Tianma radio telescope focused on eliminating the noise from the pitch axes in 2020. First, we lifted the upper structure, which is around 1,300 tons including the rational pitch mechanism, back-up structure, quadripod, and sub-reflector. Then, we welded the pitch axes, replaced bolts, and unloaded the upper load. This work lasted two months, from 15th April to 15th June. Finally, the noise disappeared, and the pointing accuracy was better. In addition, the faulty motors and reducers were replaced, and the key mechanisms were greased. The telescope is in a good running state at present.

3.3 Other Tasks

- **China Mars Probe of Tianwen-1:** From the launch of Tianwen-1 on July 23, 2020 to December 30, 2020, 85 VLBI observations were made with the participation of the Tianma telescope. The accuracy of the VLBI time delay measurement was 0.1 ns, and the time delay rate was 0.3 ps/s, which was far better than the requirements of technical indicators. The VLBI orbit determination mission of Tianmwen-1 was successfully carried out, and three orbit corrections and one deep space maneuver were supported. VLBI is an essential means of the precise orbit determination of Tianwen-1 in each measurement and control stage, especially in the cruising stage and Mars capture stage, which plays a vital role.

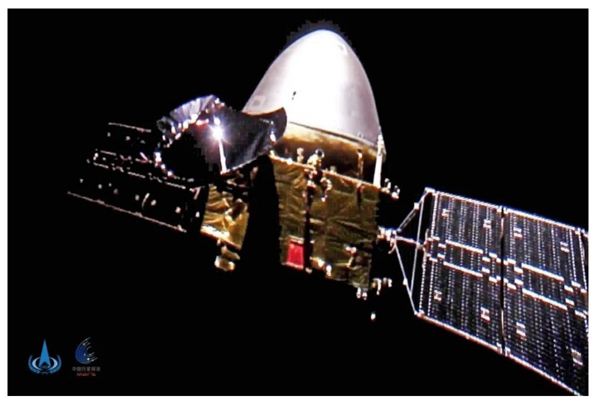

Fig. 2 Selfie of the Tianwen-1 probe, which released a small camera (2020.9.16 BJT 22:00: about 17.48 million km from Earth).

- **Chang'e-5 Lunar Probe:** On November 24, China launched the Chang'e-5 spacecraft, comprising an orbiter, a lander, an ascender, and a returner. Chang'e-5 consisted of eleven flight stages, four probes, and different assemblies, which were highly challenging for monitoring and controlling events. As an important station of the VLBI orbital sub-system of Chang'e-5, the Tianma telescope has participated in the VLBI orbital determination and lunar surface positioning missions of nine flight stages, including Earth–Moon transfer, Braking, Orbiting the Moon, Landing and Descent, Lunar Operation, Power Ascent, Rendezvous and

Docking, Orbiting the Moon, and Moon–Earth Transfer. From its arrival on November 24 to the return of the samples, Chang'e-5 has been tracked and observed for 23 consecutive days, more than 10 hours a day. Successfully completing the orbit determination and positioning tasks of each flight stage, it will continue to carry out the orbiter expansion mission.

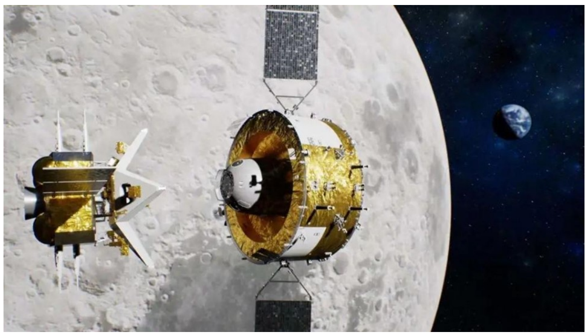

Fig. 3 Chang'e-5 orbiter and ascender rendezvous and docking (their relative positions are accurately measured using the same beam).

4 Staff of the Shanghai VLBI Station

Table 2 lists the group members at the Shanghai VLBI Station. The staff is involved in the VLBI program at the station with various responsibilities.

5 Future Plans

In 2021, the Sheshan radio telescope will take part in thirty IVS sessions. The Tianma radio telescope will take part in five IVS sessions.

The telescopes will regularly track the Chang'e-4, Chang'e-5, and Tianwen-1 satellites in their lunar orbits.

Table 2 Staff at the Shanghai VLBI station. All e-mail addresses end with `@shao.ac.cn`.

Name `E-mail`	**Background**	**Position and Duty**
Zhiqiang Shen `zshen`	Astrophysics	Deputy Director
Qinghui Liu `liuqh`	Radio Technique	Chief Engineer
Bin Li `bing`	Microwave	Technical friend, Receiver
Bo Xia `bxia`	Electronics	VLBI friend, VLBI terminal
Jinqing Wang `jwang`	Electronics	Engineer, Antenna
Lingling Wang `llwang`	Software	Engineer, Timing system
Rongbing Zhao `zhaorb`	Software	Engineer, Timing system
Li Fu `fuli`	Ant. mechanical	Engineer, Antenna
Weiye Zhong `wyzhong`	Microwave	Engineer, Receiver
Chao Zhang `zhangchao`	Microwave	Engineer, Receiver
Wei Gou `gouwei`	Electronics	Engineer
Linfeng Yu `lfyu`	Electronics	Engineer
Yongbin Jiang `jyb`	Electronics	Engineer
Yunxia Sun `sunyunxia`	HVAC	Engineer, Refrigeration
Gou Wen `gw`	Electronics	Engineer
Yongchen Jiang `yongchen`	Electronics	Engineer, Disk shipping
Zhiqiang Xu `zqxu`	Microwave	Engineer, Receiver
Zhang Zhao `zhaozhaong`	Electronics	Engineer

Working Status of Urumqi Station from 2019 to 2020

Hua Zhang, Ming Zhang

Abstract Urumqi Station is a very important VLBI station, which is responsible for a lot of VLBI joint interferometry and single-dish observation missions. The main observations include EVN, IVS, EAVN, pulsar arrival time, ammonia molecular survey, AGN variability, and so on. In order to fulfill those various tasks, we have introduced some new equipment and upgraded existing equipment in the past two years. We provide some details in this report.

1 Equipment Situation

1.1 Antenna System

The 26-meter radio telescope system is mainly composed of the antenna mechanical structure, the antenna feed sub-system, the axial angle encoding sub-system and the antenna servo sub-system. The mechanical structure of the 26-meter radio telescope adopts a modified Cassegrain antenna and a fully-steerable central symmetrical alt-azimuth wheel-rail antenna mount. The five-band feeds of Q, K, S/X, C, and L bands are distributed on the same focal plane, and the feed illumination can be changed by rotating the secondary reflector, which can be completed within one minute. The axial angle encoding sub-system adopts the shaft angle encoder to collect the position information of the antenna and the secondary reflector while it rotates to change the feed and feed it back to the antenna-control and feed-change computer through the communication board to display and compare the information in real-time. The main function of the antenna control system is to accept the antenna position control instructions given by the antenna control computer and drive the antenna to accurately point to the radio source to be observed.

The main technical specs are as follows:

- Antenna type: modified Cassegrain antenna;
- Antenna mount: wheel-rail alt-azimuth mount;
- Main surface: 26 meters in diameter, accuracy ≤ 0.40 mm (rms);
- Secondary surface: 3 meters in diameter, accuracy ≤ 0.25 mm (rms);
- Pointing accuracy: $\leq 15''$;
- Working range: azimuth $\pm 270°$ (relative to true south), elevation 5°–88° (relative to horizontal), and
- Maximum rotation speed and acceleration: azimuth 1°/s, 0.5°/s^2; elevation 0.5°/s, 0.25°/s^2.

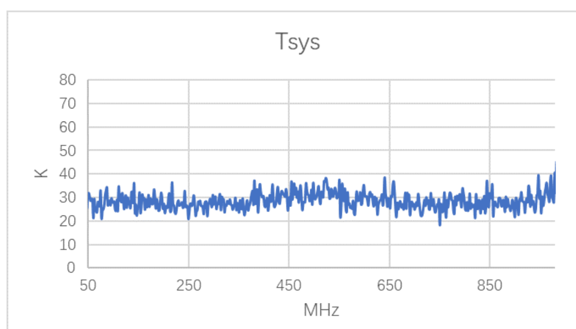

Fig. 1 X-band system temperature (right-handed circular polarization).

Xinjiang Astronomical Observatory (XAO), CAS

XAO-Nanshan Network Station

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1.2 Front-end Receiver System

At present, Urumqi Station is equipped with Q-, K-, S/X-, C-, and L-band receivers. The Q-band receiver, which is not operating at present, currently still needs to be debugged. The other band receivers are all working normally. From 2019 to 2020, the front-end receiving system has been mainly updated with the transmission line, and the optical fiber laying in the high-frequency warehouse and compressor room have been accomplished. In addition, a shielded cabinet is installed in the high-frequency warehouse to mitigate the RFI. The X-band receiver has been upgraded. Its low-temperature refrigerating unit, the normal temperature microwave frequency conversion unit, and the intelligent power supply system have also been replaced. The system temperature now is better than the temperature with the previous generation X-band receiver.

Fig. 2 The new C-band receiver.

Future plans include:

- To install a new C-band receiver, with an RF output range of 4–8 GHz, an intermediate frequency output range of 0.1–1 GHz, and the adjustable local oscillator;
- To develop a 1–2 GHz broadband L-band refrigerated receiver, with a horizontal polarization output range of 1–2 GHz and a circular polarization output range of 0.1–0.6 GHz.

1.3 VLBI Terminal System

Currently, the main equipment of the VLBI terminals at Urumqi Station includes one DBBC2, one Mark 5B+, one Mark 5B, one Mark 6, four CDAS2, and six FS control computers. Among them, the DBBC2 and Mark 5B+ are mainly used for international joint observations of EVN, EVN FRB, IVS, EAVN, and others. The CDAS2 is mainly used for domestic VLBI joint observations. The Mark 6 has not been operating yet.

Fig. 3 Unpacking and accepting the Flexbuff.

In April 2020, due to the demand for domestic VLBI observation missions, two more sets of CDAS2 and FS control computers were added at Urumqi Station. In June of the same year, the purchase contract for the DBBC3 and the Flexbuff was signed. The Flexbuff has now arrived. The delivery period of the DBBC3 is delayed due to the international COVID-19 epidemic. It is expected to arrive after June 2021. From 2019 to 2020, Urumqi Station purchased 12 sets of diskpacks for EVN observations with a total capacity of 384 TB.

Fig. 4 VLBI observation room of Urumqi Station.

1.4 Time and Frequency System

Fig. 5 Pictures of the hydrogen atomic clocks: (left) Domestic hydrogen clock 1, (right) Domestic hydrogen clock 2.

Two new hydrogen atomic clocks (see Fig. 5), both of which were made in China, were purchased in 2019 and 2020. The currently operating clocks are mainly the hydrogen atomic clocks from Shanghai Astronomical Observatory, which are H123 and H124, and the backup clock is H152.

In 2020, we re-optimized the configuration of the time-frequency system's links and its equipment to improve the output performance of the system's signal. The environment of the hydrogen atomic clock room has been modified in all aspects to improve its operating performance.

Fig. 6 The new hydrogen clock room.

2 VLBI Observations Performed at Urumqi Station from 2019 to 2020

In 2019, Urumqi Station completed 1532.8 hours of effective VLBI observations. Among them, EVN sessions were performed 91 times, and 640.5 hours of effective observation time were obtained. EVN FRB sessions were performed 24 times, and 80 hours of effective observation time were obtained. EAVN sessions were performed 32 times, and 191.5 hours of effective observation time were obtained. IVS sessions were performed 12 times, and 291 hours of effective observation time were obtained. There were 99 performances of domestic joint surveys, and the effective observation time was 330 hours. Moreover, the total single-dish observation time was 4620 hours.

Table 1 Station IVS observing session statistics (Urumqi 2019). Note: The statistical data is compiled according to the data published on the IVS (International VLBI Service) website. Other unlisted sessions were not performed. The reasons for the non-implementations are conflicts with lunar exploration and IVS' cancellation of sessions.

No.	Session epoch	Session code	Data rate (Mbps)	Data format
1	2019-031 UT 18:30	R4879	128	Mark 5B+
2	2019-078 UT 17:30	APSG44	128	Mark 5B+
3	2019-079 UT 18:00	AOV033	128	Mark 5B+
4	2019-087 UT 18:30	R4887	128	Mark 5B+
5	2019-093 UT 18:00	AOV034	128	Mark 5B+
6	2019-106 UT 17:30	APSG45	128	Mark 5B+
7	2019-107 UT 17:30	R4890	128	Mark 5B+
8	2019-129 UT 18:30	R4893	128	Mark 5B+
9	2019-220 UT 18:30	R4906	128	Mark 5B+
10	2019-253 UT 17:30	CRF113	128	Mark 5B+
11	2019-345 UT 18:00	CRF115	128	Mark 5B+
12	2019-233 UT 18:00	CZ002A	128	Mark 5B+

Table 2 Station IVS observation experiment statistics (Urumqi 2020). Note: The statistical data is compiled according to the data published on the IVS (International VLBI Service) website. Other unlisted sessions were not performed. The reasons for the non-implementations are conflicts with lunar exploration and IVS' cancellation of sessions.

No.	Session epoch	Session code	Data rate (Mbps)	Data format
1	2020-009 UT 18:30	R4928	128	Mark 5B+
2	2020-020 UT 10:00	AOV043	128	Mark 5B+
3	2020-089 UT 18:00	APSG46	128	Mark 5B+
4	2020-106 UT 17:30	CRF118	128	Mark 5B+
5	2020-134 UT 18:00	APSG47	128	Mark 5B+
6	2020-141 UT 18:00	AOV047	128	Mark 5B+
7	2020-177 UT 18:30	R4952	128	Mark 5B+
8	2020-182 UT 17:30	CRF119	128	Mark 5B+
9	2020-267 UT 18:00	AOV051	128	Mark 5B+
10	2020-281 UT 18:00	AOV052	128	Mark 5B+
11	2020-286 UT 10:00	CRF121	128	Mark 5B+
12	2020-317 UT 18:30	R4972	128	Mark 5B+

The statistics of IVS and land network observations in 2019 are compiled in Table 1. The sessions that have not been completed due to conflicts between national missions and other missions in 2019 are: AOV031, R4900, CRF112, AOV037, R4904, AOV038, and AOV040.

In 2020, Urumqi Station completed 2,051.3 hours of effective VLBI observations. Among them, EVN sessions were performed 43 times, and 296.9 hours of effective observation time were obtained. EVN FRB sessions were performed 20 times, and 131.7 hours of effective observation time were achieved. EAVN sessions were performed 36 times, and 242.4 hours of effective observation time were obtained. IVS sessions were performed 12 times, and 240 hours of effective observation time were obtained. There were 185 performances of domestic joint surveys, and the effective observation time was 1132.7 hours. The total single-dish observation time was 3957 hours.

The statistics of IVS and land network observations in 2020 are compiled in Table 2. The sessions that have not been completed due to national missions and other mission conflicts in 2020 are: R4933, AOV046, AOV048, R4964, AOV051, R4974, AOV054, and R4976.

New Zealand VLBI Station, Warkworth

Stuart Weston, Axl Rogers, Tim Natusch, Lewis Woodburn, Sergei Gulyaev

Abstract The Warkworth Radio Astronomical Observatory is operated by the Institute for Radio Astronomy and Space Research (IRASR), AUT University, Auckland, New Zealand. Here we review the characteristics of the VLBI station facilities and report on a number of activities and technical developments in 2019/20.

1 General Information

The Warkworth Radio Astronomical Observatory 12-m antenna, shown in Figure 1, is located some 60 km north of the city of Auckland, near the township of Warkworth. Specifications of the Warkworth 12-m and 30-m antennas are provided in Table 1.

The 12-m antenna is equipped with an S/X dual-band dual-circular polarization feed at the secondary focus and an L-band feed at the prime focus. Backend data digitizing is handled by a digital base band converter (DBBC) manufactured by the HAT-Lab, Catania, Italy [2].

The 30-m antenna is currently equipped with an uncooled C-band dual-circular polarization receiver and an uncooled X-band dual-circular polarization receiver. In addition, a 4.8 GHz uncooled dual-circular polarization receiver was built for RadioAstron participation. We also have a separate DBBC for backend data digitizing.

The station frequency standard is a Symmetricom Active Hydrogen Maser MHM-2010 (75001-114). We have now moved to Flexbuffs (Super-Micro servers) running jive5ab [3] for recording and data

Institute for Radio Astronomy and Space Research, Auckland University of Technology

Warkworth Network Station

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Fig. 1 Photo of the Warkworth 12-m during the southern winter of 2020 (image courtesy of Stuart Weston).

Table 1 Specifications of the Warkworth 12-m and 30-m [1] antennas.

	12-m	30-m
Antenna type	Dual-shaped Cassegrain	wheel-and-track, Cassegrain beam-waveguide
Manufacturer	Cobham/Patriot, USA	NEC, Japan
Main dish Diam.	12.1 m	30.48 m
Secondary refl. Diam.	1.8 m	2.715 m
Focal length	4.538 m	10.44 m
Surface accuracy	0.35 mm	1.2 mm
Mount	alt-azimuth	alt-azimuth
Azimuth axis range	$90^\circ \pm 270^\circ$	-179° to $+354^\circ$
Elevation axis range	7.2° to 88°	6.0° to 90.1°
Azimuth axis max speed	5°/s	0.37°/s
Elevation axis max speed	1°/s	0.36°/s

storage connected to the DBBC via fiber, which allows parallel real-time streaming and recording of data. The observatory network is directly connected to the national network provided by Research and Education Advanced Network New Zealand Ltd (REANNZ) via a 10-Gbps fiber link to the site [4].

2 Component Description

2.1 The 12-m Antenna: Progress and Issues

We are now having to replace major mechanical components on this antenna due to wear and tear. In mid-2020 the elevation gearbox was replaced, and in 2019 some of the bolts holding the turning head to the azimuth bearing were very badly corroded and had to be replaced. With the recent upgrade of the Australian AuScope antennas to VGOS receivers, the University of Tasmania very kindly passed one of their S-X Tsys/Pcal systems to us. We will look to install this hopefully in the very near future.

2.2 The 30-m Antenna: Progress and Issues

We still have to fully commission a Tsys/Pcal unit sourced from Haystack on this antenna; this is work in progress.

2.3 Warkworth Network

We have installed a CISCO 100 Gbps fiber switch, and all DBBCs and Flexbuffs are now interconnected with fiber at 100 Gbps. When we can upgrade the NREN link provided by REANNZ, we can also use this switch to provide 100 Gbps. In September 2016, the international circuits from New Zealand provided by REANNZ were upgraded to be 100 Gbps and bi-directional to the United States' west coast and to Australia. REANNZ has also acquired bandwidth on the new Hawaiki Cable, which provides redundancy for international circuits via Sydney.

We have used the Flexbuffs with the new 100-Gbps switch to create a small DiFX [5, 6] cluster, upon which we have correlated local twin dish experiments and some VLBI sessions with Australia.

3 Current Status and Activities

We have reduced the number of IVS sessions with the 12-m during the 2019/20 period by about 26% with respect to our previous report (82 in 2015 and 80 in 2016). This reduction was initiated to reduce the wear and tear on the antenna. A breakdown of IVS session types completed over this two year period is presented in Table 2.

Table 2 The 12 m IVS 2019 and 2020 session participation.

Session	Number of sessions 2019	2020
AUA	11	8
AOV	10	7
CRDS	5	4
OHIG	4	4
R1	7	7
R4	22	11
Total	59	41

In addition, both antennas are now active for Australian LBA sessions each semester, the choice of antenna being dependent on frequency. With the addition of the X-band feed to the 30-m, we would expect to see the LBA workload shift more to the 30-m antenna in the future. Also, cooperation with various space agencies for spacecraft tracking has continued using the 12-m antenna, with some interest shown in using the 30-m in the future.

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Westford Antenna 2019–2020 Biennial Report

Mike Poirier, Alex Burns

Abstract Technical information is provided about the VLBI antenna and equipment located at the Westford site of the Haystack Observatory, the off-campus location of the Massachusetts Institute of Technology (MIT) in Westford, Massachusetts. Updated information is also provided about changes to the VLBI systems since the last IVS Biennial Report.

1 Westford Antenna at Haystack Observatory

Since 1981, the Westford antenna has been one of the primary geodetic VLBI sites in the world. Located approximately 70 km northwest of Boston, Massachusetts, the antenna is part of the MIT Haystack Observatory complex.

The Westford antenna was constructed in 1961 as part of the West Ford Project by Lincoln Laboratory that demonstrated the feasibility of long-distance communication by bouncing radio signals off a spacecraft-deployed belt of copper dipoles flying at an altitude of approximately 3,600 km above the Earth's surface. The antenna was converted to geodetic use in 1981, becoming one of the first two VLBI stations of the POLARIS Project by the National Geodetic Survey. Westford has continued to perform geodetic VLBI observations on a regular basis since 1981.

In recent years, Westford has focused on and supported the technology development and operational integration of the next-generation VLBI Global Observing System (also known as VGOS; e.g., Niell et al., 2018; Merkowitz et al., 2019). As the first "prototype" VGOS station, Westford continues to provide this valuable knowledge base to all of the new VGOS operational stations as they come on line around the world.

MIT Haystack Observatory

Westford Antenna

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Fig. 1 Aerial view of the radome and facilities of the Westford antenna. (For scale the diameter of the radome is 28 m.)

Table 1 Location and addresses of the Westford antenna.

Longitude	71.49°W
Latitude	42.61°N
Height above m.s.l.	116 m
MIT Haystack Observatory 99 Millstone Rd Westford, MA 01886-1299 U.S.A.	
`https://www.haystack.mit.edu`	

2 Technical Parameters and Equipment of the Westford Antenna

The Westford antenna is enclosed in a 28-meter air-inflated radome constructed of a 1.2-mm-thick teflon fabric (Raydel R-60) (see Figure 1). The major components of the VLBI data acquisition system at Westford include a VGOS broadband cryogenically-cooled receiver, RF-over-Fiber (RFoF) Transmission links, an RF power distributor, four Up/Down converters (v2.1), four R2DBEs, and a Mark 6 recorder with expansion chassis which are all controlled by the personal computer field system (PCFS) running version 9.12.11. Westford is also equipped with an MCI system, which monitors and logs parameters for key components in the system. The primary frequency standard on site is the NR-4 Hydrogen maser.

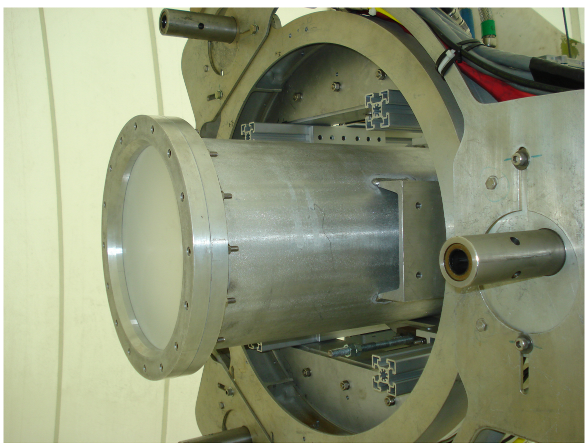

Fig. 2 View of the Westford antenna VGOS feed which is located at prime focus on the antenna.

Westford also continues to host WES2, the permanent Global Navigation Satellite System (GNSS) site of the International GNSS Service (IGS) network. The WES2 system currently consists of a Dorne-Margolin chokering antenna and a Septentrio PolaRx5 Reference Station receiver. The antenna is located on top of a tower approximately 60 meters from the VLBI antenna, and the receiver is housed within the Westford premises. These specific equipment brands and models were damaged from a severe high-voltage event in 2020 and are being replaced.

Table 2 Technical parameters of the Westford antenna for geodetic VLBI.

Parameter	**Westford**
primary reflector shape	symmetric paraboloid
primary reflector diameter	18.3 meters
primary reflector material	aluminum honeycomb
feed location	primary focus
focal length	5.5 meters
antenna mount	elevation over azimuth
antenna drives	electric (DC) motors
azimuth range	$90° - 470°$
elevation range	$4° - 87°$
azimuth slew speed	$3° \ s^{-1}$
elevation slew speed	$2° \ s^{-1}$
	Frequency range 2–14 GHz
T_{sys} at zenith	40–70 K
aperture efficiency	0.25–0.60
SEFD at zenith	1800–4500 Jy

3 Westford Staff

The personnel associated with the geodetic VLBI program at Westford, and their primary responsibilities, are:

- Alex Burns: Technician, Observer
- Pedro Elosegui: Principal Investigator
- Colin Lonsdale: Site Director
- Glenn Millson: Observer
- Arthur Niell: VLBI Science Support
- Michael Poirier: Site Manager
- Ganesh Rajagopalan: RF Engineer
- Chet Ruszczyk: VGOS Technical Manager

4 Standard Operations

From January 1, 2019, through December 31, 2020, Westford participated in 54 VGOS sessions, including 27 VGOS Tests (VT), 24 VGOS operational sessions (VO), and three S/X legacy-VGOS R&D-type 24-hr sessions. Westford also supported 18 so-called VGOS Intensive sessions (VI and/or V2), along with many short fringe tests with other worldwide stations, thus assisting in their VGOS system configuration and operational checkout.

5 Research and Development

Presently, we are running bi-weekly 24-hr sessions supporting the core VGOS network. These sessions covered a wide range of focus from engineering testing to the standardizing of operational configuration formats supporting the expanding VGOS network.

6 Outlook

Westford presently expects to continue to support the VGOS operational series of 24-hr sessions, along with supporting new development, testing, and integration of VGOS operational systems around the world.

We are in the process of replacing the GNSS hardware at WES2 with a Trimble Alloy receiver, a new Dorne-Margolin chokering antenna with dome, and a new LMR-600 cable with lightning suppressors to bring it back to continuous operations. We expect that over the next two years we will continue to upgrade our operational systems to help Westford in breaking new ground in VLBI technical development and support for the operational network of stations, along with locally running stable and consistent operations.

Acknowledgements

We would like to thank Pedro Elosegui, Arthur Niell, Ganesh Rajagopalan, and Chet Ruszczyk for their contributions to this report. Funding for geodetic VLBI research and development (R&D) as well as operations at Westford is provided by the NASA Space Geodesy Program (SGP).

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Geodetic Observatory Wettzell: 20-m Radio Telescope and Twin Radio Telescopes

Alexander Neidhardt[1], Christian Plötz[2], Gerhard Kronschnabl[2], Martin Hohlneicher[2], Torben Schüler[2]

Abstract The Geodetic Observatory Wettzell, Germany mainly contributed successfully to the IVS observing program and to some observations of the EVN in 2019 and 2020. Technical changes, improvements, upgrades, and developments were made to extend and increase the reliability of the entire VLBI observing system. While the 20-m Radio Teslcope Wettzell (RTW, Wz) and the 13.2-m Twin radio Telescope Wettzell North (TTW1, Wn) are in regular S/X sessions, the 13.2-m Twin radio Telescope Wettzell South (TTW2, Ws) is equipped with a VGOS receiving system and participated in all test and regular international and European VGOS sessions.

Fig. 1 View of the Geodetic Observatory Wettzell: in the foreground one of the two 13.2-m TWIN radio telescope antennas (Wn) and the 20-m Radio Telescope Wettzell (Wz) in the back.

1 General Information

The Geodetic Observatory Wettzell (GOW; see Figure 1) is jointly operated by the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) and the Research Facility Satellite Geodesy (Forschungseinrichtung Satellitengeodäsie, FESG) of the Technical University of Munich (TUM). The 20-m Radio Telescope in Wettzell (RTW, Wz) has been an essential component of the IVS since 1983 and produced the longest VLBI-data time series worldwide. The 13.2-m Twin radio Telescope Wettzell North (TTW1, Wn) also produces S/X-data as a regular station. The 13.2-m Twin radio Telescope Wettzell South (TTW2, Ws) participates in almost all VGOS and EU-VGOS sessions.

In addition to the VLBI, an ILRS laser ranging system, several IGS GNSS permanent stations, a large laser gyroscope G (ring laser) and the corresponding local techniques, e.g., time and frequency, meteorology, and superconducting gravity meters, are also operated. Wettzell also runs a DORIS beacon as a complete geodetic core site.

Activities to monitor atmospheric parameters use a continuously growing number of equipment, including a Nubiscope and weather balloons. A project with external contractor Menlo Systems improves the timing system with compensated fiber-optic transfers and a frequency comb which is under test in parallel to the existing timing distribution.

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Meanwhile, automation and remote control is a central part of operation. One operator monitors and controls all VLBI telescopes and also the laser ranging systems from one central control room located in the Twin operating building.

The GOW is also responsible for the AGGO system in La Plata, Argentina (which is the former station TIGO in Concepción, Chile), and the German Antarctic Research Station (GARS) O'Higgins on the Antarctic Peninsula (see separate reports).

2 Expansion Project for the GOW

The German Federal Ministry of the Interior (BMI) and BKG have agreed to a four-year project to expand the infrastructure and operations of the Geodetic Observatory Wettzell in 2018. The main objective of this project is to contribute to the 17 sustainable development goals of the United Nations (UN), such as promotion of high-tech facilities in rural areas in terms of employment and education. Furthermore, Germany intends to deepen its role of supporting European's satelite navigation system "Galileo," which will also be a major task of the observatory in Wettzell in the future.

To meet these goals, the expansion project comprises the following three topics:

- Further development of the existing geodetic infrastructure (VLBI, SLR, GNSS) to enhance availability and 24/7 real-time capabilities.
- Establishment of new systems, such as a new VLBI correlator, a Solar-Flux telescope to monitor space weather, and a Galileo monitoring station for the Public Regulated Service (PRS).
- Creation of a center of excellence for space geodesy, which will operate in the field of public relations, knowledge transfer, and student education.

A main focus of the program for VLBI is laid on 24/7 observations so that one of the three Wettzell telescopes is active for IVS sessions or domestic sessions. Domestic sessions are planned and scheduled at Wettzell and use one or more of the Wettzell telescopes, AGGO (Argentinia), and O'Higgins (Antarctica). There is also a plan to monitor selected Galileo satellites with one of the VGOS telescopes (due to their broadband feeds which covers L-Band) for quality control. The new solar flux telescope can also be used for these tasks at night, while it monitors space weather during daylight.

Fig. 2 Installation of the new correlation facility at Wettzell observatory.

All domestic sessions can be correlated with the new DiFX correlation facility, where experience is growing. The correlator increases the efficiency and real-time capabilities for VLBI sessions, but can also be used to support Galileo (e.g., EOPs) for time-critical requests. Additionally, the facility may also complement international correlation infrastructure in the future.

Technically, it is a Dell HPC Cluster with 24 compute nodes having 48 Intel® Xeon® CPUs each with 12 cores, so that 576 cores can be used in total. The storage has a volume of 834 TB. Used software is DiFX 2.6.1 with HOPS (Haystack Observatory Post-processing System). A first test correlation of INT9 sessions between Ag, Wn, and Wz was successful at the end of 2020, using the new correlation hardware.

Table 1 Staff members of RTW.

Name	Affiliation	Function	Special tasks
Torben Schüler	BKG	head of the GOW	
Alexander Neidhardt	FESG	head of the microwave group, VLBI chief	
Ewald Bielmeier	FESG	technician	
Martin Brandl	FESG	mechatronic engineer	
Elena Dembianny	FESG	physicist (starting March 2020)	
Gerhard Kronschnabl	BKG	electronic engineer (chief engineer TTW)	
Christian Plötz	BKG	electronic engineer (chief engineer RTW)	O'Higgins
Willi Probst	FESG/ BKG	physicist (starting January 2020)	Correlation, Quality control
Raimund Schatz	FESG	software engineer (till March 2020)	
Walter Schwarz	BKG	electronic engineer	WVR
Michael Seegerer	BKG	IT	Admin, Correlation
Robert Wildenauer	BKG	physicist	SW, Correlation
Armin Böer	BKG	electronic engineer	Infrastruct., RTW
Martin Hohlneicher	BKG	physicist	PRS, expansion project

To solve all new tasks, a new scientific staff was permanently employed in 2020, while further positions might follow, so that at least up to 24 new positions might be possible. This is the largest increase since the beginning of the observatory.

3 Staff

The staff of the GOW consists of over 40 members in total (plus student operators) mainly on permanent but also on fixed-term contracts to do research, operations, maintenance, and repairs, or to improve and develop all systems of the GOW. The staff operating VLBI is summarized in Table 1. Christian Plötz will become the BKG head of VLBI resort at Wettzell in 2021.

4 20-m Radio Telescope Wettzell

The 20-m RTW (Wz) has been supporting geodetic VLBI activities of the IVS and partly other partners, such as the EVN, for over 37 years now. The telescope is still in a very good and stable state supporting legacy S/X observations. The main priority was laid on the participation in all daily one-hour Intensive sessions (INT/K/Q) in order to determine UT1–UTC. Using the Field System extension for remote control and unattended observations, mostly all sessions were operated unattendedly starting mid-2020. The antenna supported all main IVS 24-hour sessions and is still one of the main components of the IVS.

Operation hours in the reporting period compared to the other telescopes are plotted in Figure 3. The operational hours of RTW are listed in Table 2.

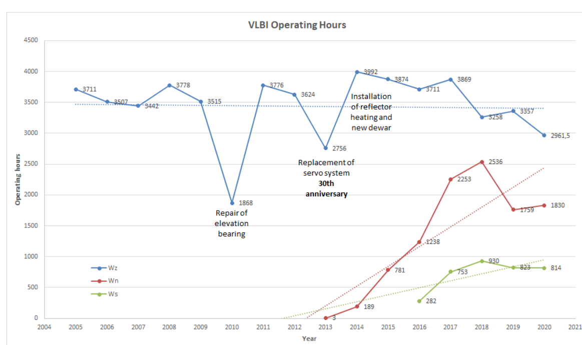

Fig. 3 Annual hours of operation of the Wettzell antennas since 2005.

Table 2 Annual participation of RTW in services.

Network	Number of observations	Hours of operation	Percent of operation
2019			
IVS	558	3157	94 %
Local (X9)	31	200	6 %
Others	0	0	0 %
2020			
IVS	470	2916	98.5 %
Local (X9)	171	42	1.4 %
Others (EVN)	2	3.5	0.1 %

All VLBI data from the 20-m RTW is transferred with e-VLBI techniques to Bonn, Tsukuba, Haystack, Washington, and Socorro, using TSUNAMI or Jive5ab on the 1 Gbit/sec connection of the Wettzell observatory. Bonn and Washington correlators fetch sessions from Flexbuff systems at the Wettzell observatory. Most of the sessions are recorded on Mark 5B+ systems and later on transferred to the local Flexbuff servers in the reporting period. In mid-2020, the complete recording was changed to a direct recording on Flexbuff after an upgrade of volume (currently 281 TB plus 72 TB).

Monthly maintenance days were scheduled to give enough time to maintain the systems. Additionally, service periods were necessary to finalize the cleaning and coating of the antenna tower, the back structure, and the cabins by an external contractor. The NASA Field System is now on version 9.13.2. All DBBC2s use now firmware DDC v105_1 and are connected to a FILA10G to stream data over 10 Gbit/s networks.

Open issues of an oil leakage in two elevation gears were solved. Test with RF-over-fiber were performed and will become the future technique. A safe and automated wind stow mechanism was established and all automated processes were checked with risk analysis and risk matrixes.

5 13.2-m Twin Telescope Wettzell North (TTW1, Wn)

The Twin Telescope Wettzell project is Wettzell's implementation of a complete VGOS conformity. Currently, the northern antenna Wn is still equipped with an S/X/Ka receiving system to support the standard S/X sessions of the IVS. It was used for tests with the new QRFH feed to get performance values of the whole system. The feed was dismounted again after the tests. The northern antenna was the first available antenna supporting fast slewing modes in the IVS and uses a DBBC2 (firmware DDC v105_1) in combination with a Mark 5B+. It is used in sessions like the 20-m antenna. Its performance in operating hours can be found in Figure 3 (also see Table 3). All recorded data is transferred with e-VLBI techniques.

Table 3 Annual participation of TTW1 in services.

Network	Number of observations	Hours of operation	Percent of operation
2019			
IVS	177	1557	88.5 %
Local (X9)	26	196	11.1 %
Others (EVN)	3	6	0.4 %
2020			
IVS	130	1702	93 %
Local (X9)	37	116	6.3 %
Others (EVN)	1	12	0.7 %

The Wn antenna runs stable and reliable. It is controlled with the NASA Field System version 9.13.2.

6 13.2m Twin Telescope Wettzell South (TTW2, Ws)

The southern antenna Ws of the twin telescope is Wettzell's first VGOS compliant antenna using a broadband feed (Elevenfeed). It uses a tunable up-downconverter, two DBBC2s, and a Mark 6 to record four bands in both polarizations. Meanwhile, Ws is a regular part of the IVS VGOS network doing bi-weekly observations. Its performance in operating hours can be found in Figure 3 (also see Table 4). Data of the VGOS sessions is shipped on modules to Haystack for correlation because of the huge data amount of about 16 or 32 Terabyte per day. VGOS Intensives started with tests and became a regular task.

The staff at Wettzell does continuous upgrades, implementations, and tests of the backend system. A DBBC3 was installed and is under testing. Ws uses the VGOS branch of the NASA Field System version 9.12.7.

Table 4 Annual participation of TTW2 in services.

Network	Number of observations	Hours of operation	Percent of operation
2019			
IVS	54	708	86 %
Local	11	115	14 %
2020			
IVS	61	757	93 %
Local	6	57	7 %

7 Other VLBI Relevant Activities

To improve the e-VLBI capacities, Flexbuff systems with a total volume of 353 TB are used. The main systems behind are extendable DELL PowerVault MD3460 Storage Arrays connected to a DELL PowerEdge R730 server. All systems are accessible with Jive5ab.

For a better overview of antenna parameters and for emergency detections, a monitoring system was installed as central data archive using the ZABBIX software, sending alert levels to the guard of the observatory. Trained operators monitor and control laser ranging systems and VLBI systems from one control room. An on-call service was established to interact with the system in cases of alerts.

The TUM at Wettzell still works in the project "Joining up Users for Maximizing the Profile, the Innovation and Necessary Globalization of JIVE" (Jumping JIVE) to implement a monitoring infrastructure for the whole EVN network coordinated by Joint Institute for VLBI ERIC, Dwingeloo, The Netherlands. Jumping JIVE is funded by the Horizon 2020 program of the European Union. Part of the local Wettzell development and installation is a web-based monitoring system for the NASA Field System, which can be used to retrieve about 110 parameters. Additionally, data collectors and web screens were implemented for other hardware.

The permanent survey of the reference point of the twin antennas was continued using total stations on different pillars and 20 to 30 reflectors in the back structure of the antenna. With about four sessions per year, a continuous monitoring of the reference point over the year is possible.

Wettzell also became a scheduling center, so that INT3 and T2 sessions are produced at Wettzell. The scheduling process is meanwhile completely automated, which was realized as cooperation with TU Vienna, Austria, and ETH Zürich, Switzerland.

The year 2020 was marked by the pandemic situation with Covid-19, so that most of the work and operations were made remote using teleworking capabilities. Nevertheless, all sessions could be observed, so that no data losses or reductions were seen.

8 Future Plans

Dedicated plans for the next reporting period are:

- Improving and extending automated observations,
- Establishing of routine workflows of correlation and post-processing,
- Routine correlation of ongoing INT9 programs,
- Upgrade of the Internet connection to 2×3 Gbit per second,
- Continuous improvements with the VGOS broadband system at TTW2,
- Use of DBBC3s for both Twin telescopes,
- Use of QRFH feed to establish two VGOS antennas with hybrid to directly convert to circular polarization,
- Test of time and frequency distribution over compensated fiber.

Yebes Observatory Report

J. González-García, F. Beltrán, E. Martínez, P. de Vicente

Abstract We describe the observations performed by the 40-m radio telescope and the VGOS 13-m radio telescope during the period 2019–2020 as part of the IVS network and the current status of the instrumentation for both instruments. We also present recent technical developments relevant for the IVS community and future plans within Yebes Observatory to keep the station as one of the most dynamic elements of the network.

1 General Information

The National Geographic Institute of Spain (Instituto Geográfico Nacional, Ministerio de Transportes, Movilidad y Agenda Urbana), has run geodetic VLBI programs at Yebes Observatory since 1995 and nowadays operates two radio telescopes on-site that contribute to the IVS. A 40-m radio telescope, station code "Ys", has been operating regularly since 2008. The 13.2-m VGOS-compatible antenna inaugurated in 2014 with code "Yj" (RAEGYEB) has been observing bi-weekly in the VGOS 24-hour sessions. Detailed information on RAEGE is available on the Web at http://www.raege.net/. IGN Yebes Observatory is also the reference station for the Spanish GNSS network and holds permanent facilities for gravimetry. Since 2014, IGN Yebes Observatory has been a Technology Development Center for the IVS. Activities are described in the corresponding contribution in this Biennial Report.

Yebes Observatory

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2 Activities during the Past Two Years

In 2019, the 40-m radio telescope observed 23 IVS experiments, of which fifteen were of R4 type, two R1, four EURD, one CRF, and one EINT. The radio telescope also participated in one of the VITA experiments to explore remote clock distribution in VLBI experiments. The numbers were increased to a total of 37 in 2020, with 18 R4 sessions, 14 R1, three R&D sessions (mixed-mode observations), and two T2. Additionally, YEBES40M participated in five experiments of the RUA project. All the observations were successful except one, which was aborted due to mechanical failures in the antenna structure, and another three that were observed with minor errors.

Generally speaking, the antenna's sensitivity has remained in its nominal values, but internal investigation detected an internal source of RFI that has been present since the beginning of operations. The engineering group found a solution, and the new status has allowed the correlator to save one of the S-band channels that was being routinely eliminated from the post-processing.

The old meteorological station was replaced in the summer of 2019 with a MET4 station from Paroscientific. The wind sensor was also replaced with a Vaisala WXT532, without moving parts. The telescope has seen its storage capacity increased to 216 TB (there is an extra pool devoted exclusively to the EVN). Back in 2018, a thunderstorm hit the station and damaged the primary GPS antenna used for time synchronization, thus forcing to use the secondary GPS time system. After some time, replacement parts were acquired and verified, although we avoided to change again the master time reference, so we are still using a CNS Clock as primary GPS receiver. With regard to the GPS time synchronization, both the primary and the secondary receivers safely managed the GPS Week Rollover back in 2019.

Table 1 IVS observations participated by Yebes 40 m.

YEBES40M (Ys)	2019	2020
IVS-R1	2	14
IVS-R4	15	18
IVS-T2	0	2
EURD	4	0
R&D	0	3
CRF	1	0
EINT	1	0
Total	23	37

The 13.2-m VGOS-compatible telescope continued its participation in the VGOS-VO sessions. In 2019 this amounted to 23 sessions, and 25 in 2020. In addition, it observed 13 and 15 EU-VGOS experiments in 2019 and 2020, respectively. It has also participated in two out of the three R&D sessions in 2020, missing RD2006 because of an overcurrent in the cryogenics compressor. Luckily it caused minor damages as only a fuse needed to be replaced.

Several maintenance and upgrade operations affected the VGOS telescope during the past two years. The air conditioning system in the receiver cabin was modified in several phases during the summer of 2020 with the aim of reaching better stability and reducing the short-term fluctuations that can potentially damage the quality of the geodetic products. These tasks were included in the framework of the Cable Delay Measurement System (CDMS) upgrade, which allows the analysts to introduce ad-hoc corrections for each station to compensate for the systematic variations in the electrical length of the cable carrying the reference signal to the Phase-Cal Antenna Unit. The complete Ground Unit was replaced with a new version that incorporates a high resolution multi-meter and a Raspberry-Pi that reads the value. This is an intermediate step towards a new design based on a 24-bit ADC to increase the measurement resolution. The reference cable itself was also replaced with a different one with smaller temperature coefficient. Furthermore, this cable has been thermally isolated with an external foam layer.

The receiver is currently being under a second upgrade in the workshop, while the VGOS receiver built to be installed in Santa María (Azores, Portugal) is being used as a replacement in the meanwhile. A new QRFH that was optimized by the RF engineering group is to be installed, together with new cryo couplers characterized by 30 dB Insertion Loss to replace the current ones (20 dB IL). The receiver already underwent a first upgrade in November 2019, to replace the single amplifier channel with a balanced LNA, which was already in use for the other polarization. This configuration reduces significantly the Input Loss to the amplifier at the expense of a small increment in the receiver noise temperature. This new upgrade, which is intended to be installed on the telescope during the first half of 2021 will also allow to separate a Low Band (2.20–2.37 GHz) to allow legacy S/X observations. The current setup only allows observations in the frequency range of 3 to 12 GHz, limited in the lower side of the spectrum by the RFI environment.

Table 2 VGOS and EU-VGOS participations of RAEGYEB.

RAEGYEB (Yj)	2019	2020
VO obs	23	25
EV obs	13	15
Total	36	40

In 2020, a local tie survey was performed to update the data from the previous campaign in 2018, but the results are not publicly available yet. Within this project, a new script has been developed in Octave and Python to obtain the invariant reference point of both radio telescopes (13 m and 40 m) using targets on different parts of the antenna structures. Preliminary results allow to determine relative coordinates for both telescopes with a standard deviation of 0.1 mm. Additionally, an initial exploration of the relative coordinates of the 40-m and 13-m antennas by means of VLBI observations was also performed and compared with the local tie method. This project is to be continued in 2021.

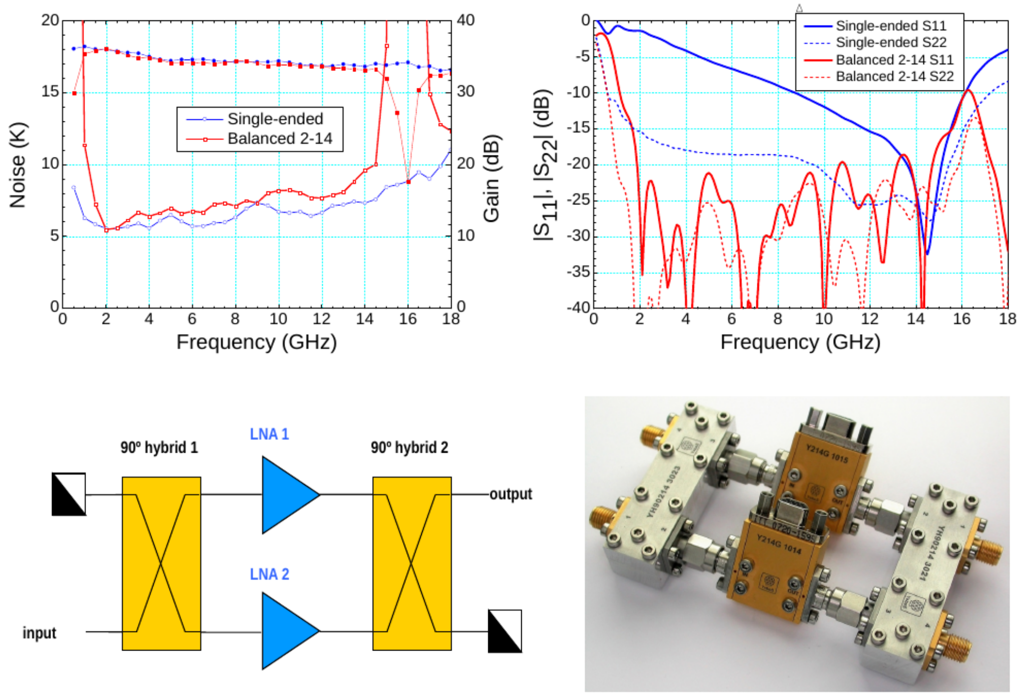

Fig. 1 The balanced LNA configuration developed at Yebes Observatory. Above: Noise and IL performance compared to single amplifier configuration. Below: schematic (left) and final built component (right).

3 Current Status

The observatory runs two active Hydrogen masers from T4-Science that provide the frequency references (5, 10, and 100 MHz and also 1PPS TTL signal) for all the electronics involved in VLBI operations, in a master-backup scheme. This same setup is also used to secure the GPS time synchronization by means of two GPS receivers (CNS Clock II and Symmetricom XLi, now Microsemi).

The 40-m is equipped with a simultaneous S/X receiver, C-band, W-band, and simultaneous K/Q. The W- and Q-band were built in Yebes labs during 2018 and commissioned on January 2019. All the receivers can record dual-circular polarization except W and Q which are linear, but lambda quarter plates are available for its use in circular polarization mode. Continuous calibration is available in the S/X, C, and K receiver using a noise diode driven by a 80 Hz signal generated in the backend. Q- and W-band observations can be calibrated with a hot-cold load system.

Since its first light, the 13.2-m VGOS-type telescope is equipped with four RDBE-G backends connected to a single Mark 6 unit. The frontend signal chain consists on a cryo-temperature QRFH feed connected to Yebes' own broadband receiver that sends the full 3 to 12 GHz band through an optical fiber link to four UDCs, each of them adapting a 512-MHz band in Nyquist zone 2 to be digitized by a RDBE-G. All the experiments since then were performed using this configuration, and the whole signal chain has shown good reliability, being able to run for months without human intervention other than routine monitoring operations.

YEBES40M is still involved in geodetic VLBI operations under the legacy network. RAEGYEB is doing bi-weekly observations within the emerging VGOS network.

4 Future Plans

The modifications to the VGOS receiver, that are currently being done at Yebes laboratories, are expected to be completed in the first trimester of the year and will give better sensitivity to the antenna. It is expected to have lower than 50 K receiver's equivalent noise temperature at any frequency from 2 to 14 GHz and well below 20 K above 6 GHz. The upgrades to the CDMS in 2020 had already demonstrated better stability in the cable length measurements, but we still expect further improvements when the final system is installed later in 2021. We also plan to deploy four R2DBEs which allow 1-GHz bandwidth and two IFs (polarizations) each, once the firmware is installed and tested.

During 2020, a DiFX correlator was installed in a small cluster for testing purposes. A couple of Very Short Baseline Interferometry sessions between YEBES40M and RAEGYEB were done and correlated to explore the pipeline, with promising results. That was the first step towards the design of a regular series of Local-Tie VLBI experiments to be started in 2021.

Finally, the observatory, as part of the national high-speed network for Investigation and Education (RedIRIS) in Spain, is upgrading the networking equipment to support a new 100-Gbps connection to the RedIRIS backbone, in view of higher bit rates for data transfer of wide bandwidth observations (over 1 GHz).

Acknowledgements

We want to acknowledge Leonid Petrov and Alexey Melnikov for their support in the first VSBI experiments between the 40-meter and 13.2-meter radio telescopes in the path to local tie determinations.

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OPERATION CENTERS

CORE Operation Center 2019–2020 Report

Cynthia C. Thomas, Daniel S. MacMillan

Abstract This report gives a synopsis of the activities of the Continuous Observation of the Rotation of the Earth (CORE) Operation Center from January 2019 to December 2020. The report forecasts activities planned for the year 2021.

1 Changes to the CORE Operation Center's Program

The Earth Orientation Parameter goal of the IVS program is to attain precision at least as good as 3.5 μs for UT1 and 100 μas for pole position.

The IVS program, which started in 2002, used the Mark IV recording mode for each session. The IVS program began using the Mark 5 recording mode in mid-2003. By the end of 2007, all stations were upgraded to Mark 5. Due to the efficient Mark 5 correlator, the program continues to be dependent on station availability and media storage. The following are the network configurations for the sessions for which the CORE Operation Center was responsible in 2019 and 2020:

- IVS-R1 (2019): 53 sessions, scheduled weekly and mainly on Mondays, five to 12 station networks
- RV (2019): Six sessions, scheduled evenly throughout the year, 14 station networks
- IVS-R&D (2019): Ten sessions, scheduled monthly, six to nine station networks

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CORE Operation Center

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- IVS-R1 (2020): 52 sessions, scheduled weekly and mainly on Mondays, four to 14 station networks
- RV (2020): Six sessions, scheduled evenly throughout the year, 13 to 14 station networks
- IVS-R&D (2020): Ten sessions, scheduled monthly, five to 16 station networks

2 IVS Sessions from January 2019 to December 2020

This section describes the purpose of the IVS sessions for which the CORE Operation Center is responsible.

- IVS-R1: During the period of January 2019 through December 2019, the IVS-R1s were scheduled weekly with five to 12 station networks. The last two sessions of 2019 only had five stations because the sessions were scheduled during the holiday season and most of the stations were not available. Seventeen different stations participated in the IVS-R1 network, and 12 stations participated in at least 26 of the 52 sessions. This was a decrease from 2017–2018 when 14 stations participated in at least half of the scheduled sessions.
  During 2020 the IVS-R1 sessions were scheduled differently. John Gipson proposed that we strive for the same level of accuracy as CONT17, for half of the IVS-R1 sessions, over an extended period of time. The Observing Program Committee (OPC) approved the scheduling of a series of 14 station sessions with a bi-weekly cadence using the same observing setup as CONT17. These 14 station IVS-R1 networks were scheduled with the CONT17 data rate of 512 Mbps. The other 26 sessions were

scheduled with networks with fewer than 14 stations and with a 256 Mbps data rate. Unfortunately, due to station problems, mainly due to the COVID-19 pandemic, many of the 14 station networks lost several stations.

Starting with R1704 in 2015 and continuing through the end of 2019, the IVS-R1 sessions were observed with two different frequency sequences: 256 Mbps for the odd sessions and 512 Mbps for the even sessions. This scheduling scheme was changed during 2020 because of the 14 station network sessions. Many of the European VLBI Network (EVN) stations participated in the 14 station IVS-R1 sessions. Therefore, these sessions had to be scheduled during non-EVN periods. There are three EVN periods every year: late February to mid-March, late May to mid-June, and mid-October to early November. The monthly e-VLBI sessions as well as the Global mm-VLBI Array (GMVA) sessions had to be avoided as well. As a result, there is no pattern to which sessions observed with a 256 Mbps or 512 Mbps data rate.

The purpose of the IVS-R1 sessions is to provide weekly EOP results on a timely basis. These sessions provide continuity with the previous CORE series. The "R" stands for rapid turnaround because the stations, correlators, and analysts have a commitment to make the time delay from the end of data recording to the analysis results as short as possible. Participating stations are requested to ship disks to the correlator as rapidly as possible or to transfer the data electronically to the correlator using e-VLBI. The "1" indicates that the sessions are mainly on Mondays. The time delay goal is a maximum of 15 days from the end of data recording to the end of correlation. Sixty-four percent of the IVS-R1 sessions were completed in 15 or fewer days during 2019. The remaining 36% were completed in 16 to 24 days [16 days (nine), 17 days (three), 19 days (one), and 20–24 days (six)]. During 2020, the percentage of R1 sessions being processed within 15 days increased from 64% to 86.5%. The remaining 13.5% ranged from 16 to 17 days [16 days (six) and 17 days (one)]. The largest delay in 2019 was 24 days, but in 2020 the largest delay was 17 days.

- RV: There are six bi-monthly coordinated astrometric/geodetic experiments each year that use the full ten station VLBA plus up to seven geodetic stations. These sessions are coordinated by the geodetic VLBI programs of three agencies: 1) USNO performs imaging and correction for source structure; 2) NASA analyzes RDV data to determine a high accuracy terrestrial reference frame, and 3) NRAO uses these sessions to provide a service to users who require high quality positions for a small number of sources. NASA (the CORE Operation Center) prepares the schedules for the RDV sessions.
- R&D: The purpose of the ten R&D sessions in 2019, as decided by the IVS OPC, was to vet Gaia transfer sources. The purpose of the R&D sessions in 2020, as decided by the OPC, was to vet Gaia transfer sources for seven sessions and to observe mixed-mode sessions (mixed S/X and VGOS network) for three of the sessions (RD2005, RD2006, and RD2007) with the primary purpose to tie the S/X and VGOS frames together.

3 Current Analysis of the CORE Operation Center's IVS Sessions

Table 1 provides the median Earth Orientation Parameter (EOP) formal errors for the R1, R4, and RDV sessions observed in 2019 and 2020. The standard deviation of the formal errors for each case is also shown to give an indication of the variability of the formal errors.

Median R1 formal uncertainties in 2020 did not differ significantly from those in 2019 (5–15% depending on the component). The variability of the uncertainties was significant, but this was largely due to large outliers corresponding to sessions with small networks. Similarly, the R4 formal uncertainties from 2019 were not significantly different from those in 2020 (7–17%). RDV median formal uncertainties were better in 2020 versus 2019 by about 20%. One of the RDV sessions in 2019 had a network only consisting of the ten VLBA stations with no additional IVS geodetic stations, which had the effect of roughly doubling the formal EOP uncertainties. Table 1 also shows the median uncertainties and RMS variabilities for each session series after removing large outliers.

Table 2 shows EOP biases and WRMS differences with respect to the IGS Finals series for the R1, R4, and RDV series. To do this calculation, we used the latest operational GSFC EOP series based on the GSFC 2020a quarterly solution. This solution used

Table 1 Median and variability of EOP formal uncertainties for 2019 and 2020.

	Num	X-pole (µas)	Y-pole (µas)	UT1 (µs)	X nutation (µas)	Y nutation (µas)
R1	53(49), 52(51)	40 (40), 42(42)	38(37), 32(32)	2.8(2.6), 2.5(2.4)	31(30), 28(27)	31(30), 28(28)
		24(10), 21(13)	25(12), 20(16)	1.4 (0.9), 1.4(1.4)	20 (12), 19(13)	23(12), 19(13)
R4	52(46), 53(51)	43(41), 46(45)	42(37), 38 (36)	2.8(2.6), 2.9 (2.9)	36(32), 33 (30)	35(33), 35 (34)
		42(18), 28 (12)	25(18), 22 (9)	2.6(1.34), 1.1(0.5)	33(20), 26 (13)	27(18), 26 (12)
RDV	6(5), 6	62(55), 44	44(41), 34	2.9(2.5), 2.8	41(35), 26	38(33), 25
		15, 4	10, 3	4.3(0.4),0.3	40(13), 4	36(11), 4

Values are given for 2019 and 2020 in that order. The RMS variabilities are given on the second lines. The values in parentheses were computed by removing sessions with large outliers.

Table 2 Offset and WRMS differences (2019 and 2020) relative to the IGS Finals Combined Series.

	Num	X-pole Offset (µas)	X-pole WRMS (µas)	Y-pole Offset (µas)	Y-pole WRMS (µas)	LOD Offset (µs/d)	LOD WRMS (µs/d)
R1	53, 52 (978)	−181, −114 (−110)	62, 76 (98)	17, −43 (23)	69, 61 (85)	−0.4, −0.2 (0.1)	14, 14 (18.4)
R4	52, 53 (978)	−176, −146(−118)	79, 76 (133)	5.3, −35 (24)	76, 73 (98)	−2.1, −1.0 (−0.1)	13, 14 (18.6)
RDV	6, 6 (126)	−214, −139 (−86)	82, 104 (123)	26, 12 (47)	52, 45 (73)	7.6, −0.9 (0.9)	9, 16 (14.5)

Values are for 2019 and then 2020 and in parentheses for the entire series (since 2000) for each session type.

the ITRF2014 earthquake site models for co-seismic offsets and post-seismic deformation. In doing this, we no longer needed to estimate post-seismic station positions for TSUKUB32 and TIGOCONC. This reduces the formal uncertainties as well as allowing these stations to contribute fully to EOP estimation. We found that this leads to better agreement between VLBI and IGS polar motion. The WRMS differences were computed after removing a bias; but estimating rates does not affect the residual WRMS significantly. The R1 series has somewhat better WRMS agreement with IGS polar motion than the R4 series. The X-pole biases for all of the VLBI series (176 to 214 µas in 2019 and 114 to 146 µas in 2020) are significantly larger than expected from the formal EOP uncertainties and appear to be likely due to overall reference frame bias between the VLBI and IGS, because the biases are all at the same level. On the other hand, the Y-pole biases are much smaller.

4 The CORE Operations Staff

Table 3 lists the key technical personnel and their responsibilities so that everyone reading this report will know whom to contact about their particular question.

Table 3 Key technical staff of the CORE Operation Center.

Name	Responsibility	Agency
Dirk Behrend	Organizer of CORE program	NVI, Inc./GSFC
Brian Corey	Analysis	Haystack
Jay Redmond	Receiver maintenance	Peraton
John Gipson	SKED program support and development	NVI, Inc./GSFC
David Horsley	Software engineer for the Web site during 2019	NVI, Inc./GSFC
Mario Bérubé	Software engineer for the Web site during 2020	NVI, Inc./GSFC
David Gordon	Analysis	NVI, Inc./GSFC
Ed Himwich	Network Coordinator	NVI, Inc./GSFC
Dan MacMillan	Analysis	NVI, Inc./GSFC
Katie Pazamickas	Maser maintenance	Peraton
Lawrence Hilliard	Procurement of materials necessary for CORE operations	NASA/GSFC
Cynthia Thomas	Coordination of master observing schedule and preparation of observing schedules	NVI, Inc./GSFC

5 Planned Activities during 2021

The CORE Operation Center will continue to be responsible for the following IVS sessions during 2021:

- The IVS-R1 sessions will be observed weekly and recorded in Mark 5 mode. The 14 station sessions will be scheduled again for 26 sessions with the 512 Mbps data rate.
- The IVS-R&D sessions will be observed ten times during the year.
- The RV sessions will be observed six times during the year. The analysis of the sessions will switch to USNO due to personnel changes.

DACH Operation Center Biennial Report 2019/2020

Matthias Schartner[1], Christian Plötz[2], Thomas Klügel[2], Walter Schwarz[2], Torben Schüler[2], Lisa Kern[3], Johannes Böhm[3], Benedikt Soja[1]

Abstract The newly founded DACH Operation Center is a joint cooperation between the Federal Agency for Cartography and Geodesy in Germany (BKG), ETH Zurich (ETHZ), and Technische Universität Wien (TU Wien). The main motivation to establish a new Operation Center (OC) was to bring together the scheduling expertise at TU Wien and ETHZ and the technical and operational expertise at BKG. Together, it was possible to develop a fully automated scheduling procedure that is currently used for various IVS observation programs such as AUA, OHG, T2, INT2, INT3, EU-VGOS, VGOS-B, and more. Within the cooperation, BKG is responsible for the technical aspects and is ensuring the long-term stability of the OC, while ETHZ and TU Wien are focusing on scientific studies and potential improvements to VLBI scheduling such as the newly developed scheduling parameter optimization based on Artificial Intelligence.

1 General Information

With the retirement of Arno Müskens, who had maintained the scheduling activities at the University of Bonn (IGG) for the last 30 years, the official IVS sessions supervised at Bonn had to be transferred to another Operation Center (OC). Around the same time, a new VLBI scheduling software was developed at TU Wien: VieSched++[1] [1]. To test the new scheduling software and to ensure a smooth transition of the scheduling activities from Bonn to a suitable successor, first tests were started in late 2018 by using the new scheduling software supervised at TU Wien. Initially, the work focused on improving the scheduling of the T2 sessions; but soon other observation programs followed.

Meanwhile, it was decided that Wettzell should be designated as a new Operation Center and continue the work of Arno Müskens to ensure the long-term stability of the scheduling activities. Because there was evidence of significant improvement gained by using VieSched++ and by following the scheduling approaches developed at TU Wien, VieSched++ was selected as the scheduling software to be run by the Wettzell OC operationally. To ensure a generation of high-quality schedules and to benefit from the scheduling experience gained with the first tests of VieSched++, a cooperation between TU Wien and BKG was founded in 2019. With the move of Matthias Schartner, the main developer of the VieSched++ software package, from TU Wien to ETH Zürich, a third institution joined the cooperation, so that the BKG, the ETH Zürich, and the TU Wien jointly performed the assigned scheduling tasks in the context of the Operation Center Wettzell. In late 2020, it was decided to bundle the current activities as a joint Operation Center called "DACH"[2] to streamline the activities and reduce the confusion about official responsibilities.

1. ETH Zürich
2. Federal Agency for Cartography and Geodesy
3. Technische Universität Wien

DACH Operation Center

IVS 2019+2020 Biennial Report

1 https://github.com/TUW-VieVS/VieSchedpp

2 https://www.bkg.bund.de/DE/Observatorium-Wettzell/IVS-VLBI-Operations_Center/IVS-VLBI-Operations_Center.html

2 Activities during the Past Year

In the last year, the main focus was on the establishment of the new OC. Right from the beginning, it was planned to aim for a fully automated approach. For this purpose, VieSched++ was extended by VieSched++ AUTO[3], an automated scheduling framework written in Python. In this regard, VieSched++ AUTO can be seen as a frontend to VieSched++. The automated scheduling routines are controlled by the session master files. Based on a daily cronjob, the schedule master files are checked, and upcoming sessions are identified. These sessions are then scheduled, and notification e-mails are distributed to responsible persons for human quality control as described in Section 3. Additionally, the schedule files are automatically uploaded to the IVS servers in case no human intervention is necessary. Since VieSched++ AUTO is written in the very popular and easily accessible programming language Python and is completely decoupled from the complex VieSched++ algorithms, maintaining and customizing VieSched++ AUTO is a fairly simple process. Thus, a special handling of individual observation programs is possible; this may include the addition of custom steps in the scheduling process, such as making custom changes to the VEX files required by the VLBA stations or custom changes to the SKD files required for VGOS sessions.

At the same time, new hardware facilities at Wettzell provided for the automatic scheduling ensure a long-term environment oriented for all of the necessary IT infrastructure with hardware redundancy and data backup procedures. These aspects are especially emphasized at the Geodetic Observatory Wettzell to provide a robust infrastructure concerning a potential failure analysis to reach quality-oriented requirements as an OC.

From a scientific point of view, the main focus was on improving the automation through an Artificial Intelligence powered parameter optimization [2]. This approach mimics evolutionary processes such as selection, crossover, and mutation to iteratively explore the scheduling parameter space to find an optimal solution for any given session. In particular, it optimizes the individual station weights and the weight-factors of the different optimization criteria [1]. A drawback of this approach is the excessive computational load. But this drawback is diminished by the fact that the software runs automatically as a daily cronjob and can produce all schedules overnight.

3 Current Status

In Table 1, the main staff members contributing to the DACH OC are listed together with their related tasks.

As of the beginning of 2021, several IVS Intensive observing series (INT2, INT3, and VGOS-B) and the 24-hour session series AUA, CRDS, CRF, EU-VGOS (only partly and scheduled by hand), T2, and OHG are officially scheduled by the DACH OC. Furthermore, the INT1, R1, R4, and VGOS sessions are also automatically scheduled for testing purposes but without uploading them to the IVS Data Centers. But their results can also be found on our web page. Additionally, other non-official IVS sessions are scheduled as well, for example the Southern Intensives (SI), local baseline sessions at Wettzell (GOW08), and BKG internal Intensives between Wettzell and AGGO (INT9 and GOW16) and between Wettzell, AGGO, and O'Higgins (GOW17). Table 2 lists the different observation programs as well as the number of automatically generated schedules (as of 2021-02-11) and the name of the first automatically generated session. In total, over 400 sessions have already been automatically scheduled.

Figure 1 provides a high-level flowchart of the automated DACH scheduling procedure. For every VLBI observing program, some schedule template files are provided, and a dedicated scientific goal was defined. In the most simple case, the scientific goal can be defined as a mixture of achieving the best mean formal errors and/or repeatability values for the Earth orientation parameters and/or station coordinates. But in principle more complex and more sophisticated

Table 1 Contributors to DACH OC and their tasks.

Matthias Schartner	main software developer, quality control
Christian Plötz	technical support, coordination
Walter Schwarz	lead technical support
Torben Schüler	head of observatory Wettzell
Lisa Kern	quality control
Johannes Böhm	head of VLBI group at TU Wien
Benedikt Soja	head of Space Geodesy group at ETHZ

Table 2 List of automatically generated schedules per observation program. The first block lists IVS Intensive sessions assigned to the DACH OC. The second block lists IVS 24-hour sessions assigned to the DACH OC. The third block lists other IVS sessions not assigned to the DACH OC but automatically scheduled for testing purposes. The final block lists non-IVS sessions scheduled at the DACH OC. Column "#sessions" lists the number of automatically scheduled sessions (as of 2021-02-11), while column "first session" lists the first session of the observation program that was automatically scheduled.

Name	#sessions	first session	(date)
INT2	62	Q20200	(2020-07-18)
INT3	24	Q20188	(2020-07-06)
VGOS-B	10	B20329	(2020-11-24)
AUA	7	AUA066	(2020-07-15)
CRDS	4	CRD108	(2020-08-04)
CRF	3	CRF120	(2020-09-07)
T2	3	T2141	(2020-09-15)
OHG	3	OHG126	(2020-07-28)
INT1	148	I20188	(2020-07-06)
R1	29	R1957	(2020-07-27)
R4	30	R4956	(2020-07-23)
VGOS	14	VO0219	(2020-08-06)
GOW08	5	WD344I	(2020-12-09)
GOW16	24	WD212Q	(2020-07-30)
GOW17	1	WD287R	(2020-10-13)
INT9	5	WD233Q	(2020-08-20)
SI	31	SI0181	(2020-06-29)

goals are possible as well. To simplify the generation of a scientific goal and its implementation within VieSched++ AUTO, hundreds of pre-defined statistics are available.

The schedule template files serve as a starting point and contain information about the proper observing mode to use and the scheduling boundary conditions that are necessary. For every session, these template files are adjusted and further serve as input for the scheduling software VieSched++. For example, within the template files the station network and start and stop times are adjusted, and necessary down and tag-along times are assigned. If general changes to the scheduling approach are necessary, for example, if the target observation signal-to-noise ratios need to be adjusted or the minimum observation time needs to be changed, it is mostly sufficient to do these adjustments in the template files directly. Because they are human-readable and the file format is the very popular and standardized Extensible Markup Language (XML), no programming skills are required to perform these adjustments. Additionally, it is possible to use the VieSched++ graphical user interface to change the template files or to produce new ones.

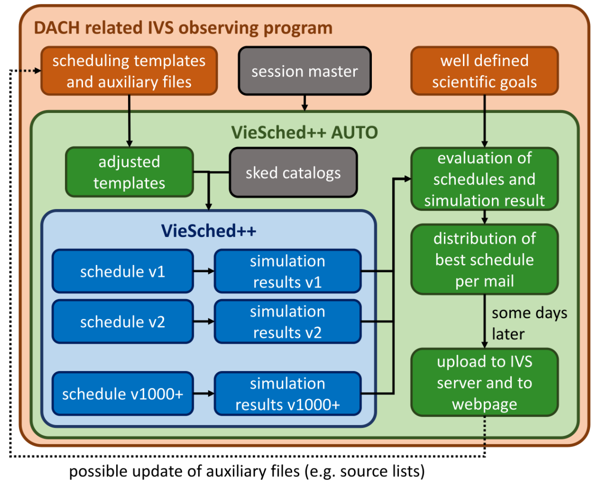

Fig. 1 High-level flowchart for the automated DACH scheduling procedure. Orange boxes represent files/metrics defined for every observation program. Green boxes are tasks executed by VieSched++ AUTO. Blue boxes depict scheduling results of VieSched++. Gray boxes represent external data sources.

Defining a dedicated scientific goal is necessary for several reasons. First, the concept of VieSched++ is that it will not only generate one schedule per session but a multitude of different schedules using different observation strategies and approaches. Often more than one thousand different schedules are generated per session. Every session is further simulated at least one thousand times to receive reliable repeatability estimates, leading to over one million simulation runs per session. Based on the dedicated scientific goals the best schedule is selected. This approach further ensures a transparent decision making without any human bias solely based on Monte-Carlo simulations.

The best schedule, together with meaningful statistics and comparison graphs, is distributed via e-mail to some responsible persons for human quality control. Here, great care was taken to make it possible to quickly judge solely based on the notification e-mail and attached figures if the schedule is good or not. This approach is reducing the human workload significantly, because no additional software packages need to be used to inspect the scheduling results, and the quality control can be done on every computer. In the case that there is no human intervention necessary, the schedule is automatically uploaded to the IVS Data

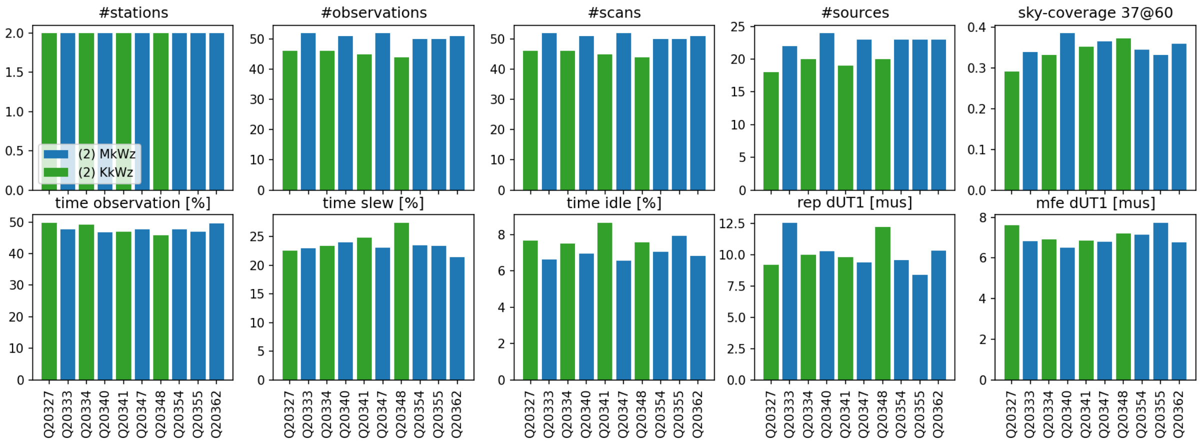

Fig. 2 Statistics of the INT2 observing program as attached to the scheduling e-mails for human quality control. Besides general statistics, the simulated dUT1 mean formal errors (mfe) and repeatability values (rep) are listed as well as information about the sky coverage.

Centers some days after the scheduling was done. It should be noted that the automated scheduling process is very robust. Within a 30-day period in early 2021, no human interaction was necessary. Furthermore, VieSched++ AUTO automatically distributes error notifications via e-mail in case problems arise, and log files are stored for inspection.

Figure 2 depicts a summary plot of the INT2 statistics. Every time a new INT2 session is scheduled the statistics figure gets updated. It is also attached to the notification e-mails for human quality control. In the figures, various interesting and meaningful statistics of the last ten sessions of this observation program are visualized. Therefore, it is possible to quickly compare the scheduling performance with the ones of previous sessions to identify potential problems. Depending on the observation program and the session goal, the displayed statistics vary.

As an example, Figure 3 displays the sky coverage of session Q20348 (IN220-348) in a stereographic projection (only the northern half) observed on 2020-12-13 and scheduled by the DACH OC. This kind of graphics is automatically distributed by e-mail for human inspection and for quality control. Here, the integration time is color-coded, but similar plots with a color-coded observation start time with respect to the session start time exist and are distributed as well.

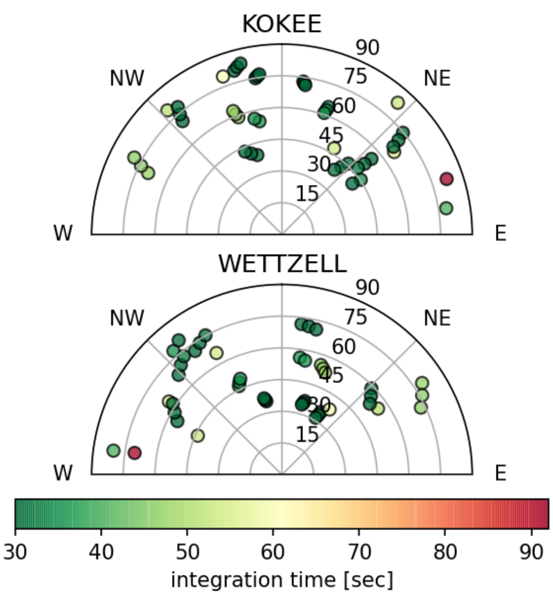

Fig. 3 Sky coverage of session Q20348 with color-coded integration times. These plots are attached to the automatically generated notification e-mails distributed by VieSched++ AUTO and are uploaded to our web page.

4 Future Plans

As a next step, the plan is to incorporate actual analysis results into the statistics and decision making process. One could think of automatically analyzing the correlation and analysis reports looking for anomalies. Based on this information it would be possible to temporarily discard poorly performing sources from the source list or to put unreliable stations temporarily into tag-along mode. Additionally, we believe that the responsibility of an OC does not end with the distribution of schedule files, but it should also include quality control of the actual results.

Within the development of VieSched++ and its scheduling logic, a main focus will be laid on the inclusion of VLBI observations to satellites and spacecraft, because this will enable some interesting science cases. First steps in this regard are already taken, and a new VieSched++ version will be released soon.

Another major point in the future will be the changes due to the new upcoming data formats. With the resumption of the work on the VEX2 format, which will hopefully result in a final version soon, adjustments in the scheduling software are necessary to support the new format. The same holds for the newly proposed scheduling catalogs and the resulting changes in scheduling models (such as slew time, telescope sensitivity, and source flux density models). Although we do not plan to contribute to the development of these models, we will ensure that necessary adjustments in the scheduling software VieSched++ are performed in case the IVS agrees to use the new formats and models.

Besides these operational and scientific points, we would like to discuss our approaches with other OCs as well and motivate them to test and establish our routines themselves. Therefore, we offer full support in the installation and utilization of our software products, which are all publicly available on GitHub.

Acknowledgements

JB would like to thank the Austrian Science Fund for supporting the development of the scheduling software as part of project VGOS Squared (P 31625) and the BKG for financial support of the DACH Operation Center.

References

1. M. Schartner, J. Böhm, VieSched++: A new VLBI scheduling software for geodesy and astrometry, *Publications of the Astronomical Society of the Pacific*, 131(1002), ab1820, 2019.
2. M. Schartner, C. Plötz, B. Soja, Automated VLBI scheduling using AI based parameter optimization, *Journal of Geodesy*, submitted, 2020.

NEOS Operation Center

David M. Hall

Abstract This report covers the activities of the NEOS Operation Center at USNO for 2019 to 2020. The Operation Center schedules IVS-R4 and the INT1 Intensive sessions.

1 VLBI Operations

NEOS operations in the period covered consisted, each week, of one 24-hour duration IVS-R4 observing session, on Thursday-Friday, for Earth Orientation, together with five daily one-hour duration “Intensives” for UT1 determination, Monday through Friday. In 2019–2020, the operational IVS-R4 network included VLBI stations at Kokee Park (Hawaii), Wettzell (Germany), Ny-Ålesund (Norway), Fortaleza (Brazil), Tsukuba (Japan), Svetloe, Badary and Zelenchukskaya (Russia), Hobart, Katherine and Yarragadee (Australia), Yebes (Spain), and Matera and Medicina (Italy). A typical R4 consisted of 8 to 12 stations. The regular stations for the weekday IVS Intensives were Kokee Park and Wettzell. Intensives including Kokee Park, Wettzell, and Svetloe were occasionally scheduled in order to characterize the Kokee Park to Svetloe baseline so that Svetloe can be used as an alternate for Wettzell should it be needed. The Operation Center updated the version of *sked* as updates became available. All sessions are correlated at the Washington Correlator, which is located at USNO and is run by NEOS.

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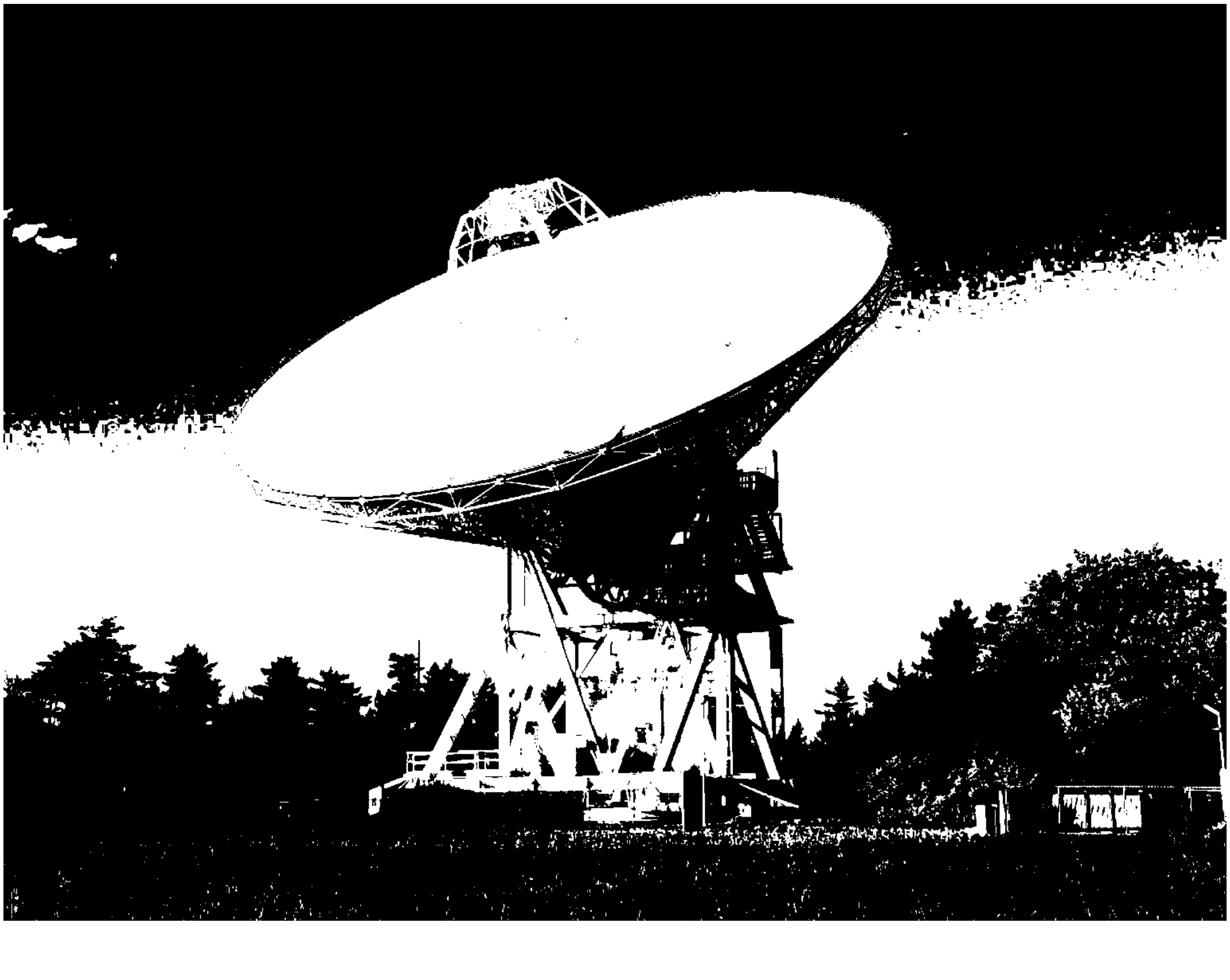
2 Staff

D. M. Hall and M. S. Carter are the only staff members of the NEOS Operation Center. Mr. Hall is responsible for the overall management, and Carter makes the schedules. M. S. Carter is located at the USNO Flagstaff Station (NOFS).

CORRELATORS



The Bonn Correlation Center

Simone Bernhart[1,2], Walter Alef[3], Yoon Kyung Choi[1,2], Sven Dornbusch[3], Mikhail Lisakov[3], Arno Müskens[4], Yurii Pidopryhora[3], Helge Rottmann[3], Alan Roy[3], Jan Wagner[3]

Abstract We present a status report of the Bonn Distributed FX (DiFX) correlator for the years 2019 and 2020. This software correlator is operated jointly by the Max-Planck-Institut für Radioastronomie (MPIfR), the Institut für Geodäsie und Geoinformation der Universität Bonn (IGG), and the Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt, Germany. One of the most notable recent achievements was its contribution to the first picture of a black hole published in 2019.

1 General Information

The Bonn correlator is hosted at the MPIfR[1] VLBI correlator center in Bonn, Germany. It is operated jointly by the MPIfR in Bonn and the Federal Agency for Cartography and Geodesy (BKG)[2], with the support of the IGG [3]. The MPIfR hosts the correlator facility and shares with the BKG the costs of the cluster, of most of the staff, and of the Internet connectivity. The IGG contributes to the connectivity of the cluster and pays one member of the geodetic staff. Since January 2017, the geodetic personnel responsible for the correlation are employed by the BKG via a private contractor, the Reichert GmbH.

1. Reichert GmbH
2. Bundesamt für Kartographie und Geodäsie
3. Max-Planck-Institut für Radioastronomie
4. Institut für Geodäsie und Geoinformation der Rheinischen Friedrich-Wilhelms Universität Bonn

Bonn Correlator

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[1] https://www.mpifr-bonn.mpg.de/
[2] https://www.bkg.bund.de/
[3] https://www.gib.uni-bonn.de/

2 Correlator Capabilities

Several versions of the Distributed FX software correlator (Deller et al. 2011) are available at the Bonn correlator, and in particular, a branch version developed by J. Anderson and others specifically for RadioAstron[4] experiments (Bruni et al. 2014) with important upgrades and bug fixes made recently by J. Wagner. For geodetic production we use the latest stable DiFX release, and before switching to a newer DiFX version we perform a comparison of the resulting observables. In 2020, we switched from DiFX-2.5.2 to DiFX-2.6.1.

The correlator is running on a High Performance Computing (HPC) cluster, which was renewed in 2015 to match both VGOS and mm-VLBI requirements. Its specifications can be gathered from the previous biennial report (La Porta et al. 2020).

The raw data are recorded at the stations on Mark 5 or Mark 6 modules, or on storage servers usually referred to as Flexbuffs. For geodetic experiments the data are mostly e-transferred to the HPC cluster that is connected to the Internet through two 1-Gbit lines, one of which is a duplex line. Both are part of the German Research Network (Deutsches Forschungsnetz - DFN) where the non-duplex line is connected to the DFN via the Bonn University high speed network.

Various data formats have already been correlated in Bonn: Mk4, Mk5, DVP, and various flavors of VDIF. The correlated data (SWIN files) can be exported to FITS and HOPS (MK4) formats. For post-processing the following software packages are available: AIPS, CASA, PIMA, and HOPS (Haystack Observatory Post-processing System), the latter of which is the standard tool for geodesy. In the course of geodetic VGOS (test) correlations, the HOPS package was upgraded to HOPS 3.21 in 2020 (currently rev 2937). The correlator outputs and other important files (e.g., VEX and v2d files) are backed up daily on the HPC cluster. The final products are archived on the MPIfR archive server, where they will be kept for at least ten years.

The EXPAD and COMEDIA tools are used for bookkeeping of experiments correlated in Bonn. They are the frontends to a local data-base which records all relevant information such as the observation date, participating stations, modules, and status of the experiment.

3 Staff at the Bonn correlator

The **geodesy group at the Bonn correlator** has 2.1 FTEs.

A. Müskens – scheduler of various IVS sessions, namely of INT3, EURO, T2, and OHIG, generated with the VieVS software (VieSched++). He went on a sabbatical in April 2020 and will retire in spring 2021.

S. Bernhart and **Yoon Kyung Choi** – coordinate the data logistics including e-transfer and module shipment, prepare and supervise the correlation, carry out the post-processing, and deliver the resulting observables to the IVS repository in form of databases. Besides these standard duties, they provide the stations with feedback on their performance and support tests of the VLBI systems, in particular for the Wettzell Observatory.

Laura La Porta – performed the same duties but left the group in August 2019.

The **MPIfR staff at the Bonn correlator** is a subgroup of the VLBI Technical Department, headed by W. Alef before his retirement in November 2019 and handing over his duties to H. Rottmann. Its members are A. Roy, J. Wagner, Y. Pidopryhora, M. Lisakov, S. Dornbusch, and G. Tuccari (guest). In addition to the scientific staff, there is one technician (R. Märtens), one engineer (M. Wunderlich), and one operator (H. Sturm) until he retired in May 2020.

The group is responsible for keeping the cluster software up to date, for hardware maintenance and repair, as well as for IT support and software correlator improvements. The group members are involved in several astronomical projects, which are focused on very high resolution imaging especially with the Event Horizon Telescope (EHT).

W. Alef – (retired) head of the VLBI technical department, computer systems and cluster administration, manager of the BRoad bAND (BRAND) receiver project, VLBI expert, and consultant to the EU-VGOS project.

H. Rottmann – (new) head of the VLBI technical department, computer systems and cluster administration, responsible for the beamforming software of ALMA, DiFX developer.

A. Roy – project manager for VLBI at the Atacama Pathfinder EXperiment (APEX), for DBBC3 commissioning, and head of the polarization conversion effort for Atacama Large Millimeter/submillimeter Array (ALMA) VLBI and the BRAND system.

G. Tuccari – guest scientist from INAF, leader of the Digital Base Band Converter project (DBBC) and the Fila10G development, as well as project engineer of the BRAND receiver.

J. Wagner – developer of DiFX, Mark 5 and Mark 6 software, responsible for correlation of EHT VLBI experiments, support scientist with instrumentation and observing-related work in mm-VLBI (EHT and GMVA).

Y. Pidopryhora – organizes, conducts, correlates, and performs the post-processing of the Global mm-VLBI Array (GMVA) sessions and of various soft/hardware related tests.

M. Lisakov – takes care of the correlation and post-processing of the RadioAstron imaging observations. He also participates in the DiFX software correlator improvement for the needs of space VLBI.

S. Dornbusch – developer of firmware and software for the DBBC3 backend, responsible for maintenance of software for the DBBC2 backend, test and verification of the DBBC2 and DBBC3, support for stations that use a DBBC2 or a DBBC3. He is also active developer of soft- and firmware of the BRAND receiver system.

The Bonn correlator also serves as an inherent test-bench for the DiFX and e-transfer software, so that all its personnel contribute to the debugging of these tools.

4 Activities During the Past Two Years

IVS regular sessions: During 2019 and 2020 we correlated 104 R1, ten EURO, eleven T2, 72 INT3, and thirteen OHIG. Since May 2018 the databases are produced solely via the nuSolve software (vgosDbMake) in vgosDB format.

Scheduling: A. Müskens had tested the VieVS scheduling program (VieSched++) in collaboration with the Vienna group. In 2019, scheduling of the INT3 sessions with VieSched++ was initiated yielding good results. In spring 2021, A. Müskens will retire. Since he began a sabbatical in April 2020, the scheduling tasks were handed over to Christian Plötz from the Geodetic Observatory Wettzell and Matthias Schartner, who in the meantime moved from the Vienna correlator to ETH Zurich.

EU-VGOS Project: The collaboration among the three European stations of Wettzell, Onsala, and Yebes and the Bonn correlator, which started in March 2018, is still ongoing; it was intermittently joined by the Ishioka and Svetloe stations. The aim of the project is to verify the processing chain for VGOS experiments end-to-end, from the scheduling to the geodetic analysis of the derived observables.

Since the beginning of the project, 41 sessions have been observed until the end of 2020. 23 observations have been correlated and partly been post-processed in single band and pseudo Stokes I mode, the latter based on the Haystack VGOS post-processing chain which was released with HOPS 3.20 in 2019. Four of the sessions have also been used to test the polarization conversion for VGOS data based on the PolConvert software for VGOS developed by I. Marti-Vidal (Marti-Vidal et al. 2015).

VGOS test correlations: In 2020, a VGOS Intensive session and a 24-hour VGOS experiment were processed at the Bonn correlator in order to compare the results with those of Haystack and other Correlation Centers (Barrett et al. 2020).

RadioAstron: Six experiments have been correlated in Bonn in 2019–2020. Three experiments were recorrelated and an extensive fringe search was performed upon requests from P.I.s. Those sessions involved up to 36 antennas and baseline lengths up to ten Earth diameters. The H-maser onboard the satellite stopped working in September 2017. Since then, there were two modes employed: a closed-loop mode (a.k.a. coherent mode) as default and a rubidium clock mode. To implement the closed-loop correlation mode, the RadioAstron-related version of the DiFX software correlator was patched by J. Wagner. The results were compared to those of the ASC correlator (Moscow) by M. Lisakov and J. Wagner. As a result, the DiFX correlator in Bonn is now capable of correlating all imaging experiments performed within the RadioAstron project.

Global Millimeter VLBI Array (GMVA): Four sessions with 20+ antennas were correlated in Bonn during the past two years. Starting from spring 2018, the GMVA network includes the brand new Greenland telescope, GLT. Although normally a part of the GMVA spring sessions, ALMA did not observe either in 2019 or in 2020 due to harsh weather conditions in 2019 and the COVID-19 crisis in 2020. The standard recorded data rate of 2 Gbps (except for ALMA which always recorded at 16 Gbps), became 4 Gbps in autumn 2019, thus doubling the data storage requirements. The three antennas of the Korean VLBI network also switched to the 4-Gbps recording mode (previously they observed in a 1-Gbps mode).

The VLBA stations now observe in a 4×128 MHz frequency configuration. To match it to the 8×64 MHz configuration of the other stations, the correlation requires to use the so-called “zoom bands”, which allow to split the wider bands.

Event Horizon Telescope (EHT): The Bonn cluster is used also to correlate one half of EHT mm-VLBI experiments. The other half of the data is correlated at the MIT Haystack Observatory. The observing campaign of April 2017 lead to the first image of a black hole (The EHT Collaboration 2019).

The EHT campaigns in April 2017 and in April 2018 were carried out on five days using the phased ALMA and SMA, and up to seven single mm-VLBI antennas. The frequency setup consisted of four or eight 2048-MHz-wide IFs sampled by R2DBE backends. Each IF was recorded in dual polarization on separate Mark 6 units.

The April 2017 session had two IFs (2×2048 MHz dual polarization) and was recorded on two Mark 6 recorders using eight modules at a total data rate of 32 Gbps. The April 2018 session had four IFs (4×2048 MHz dual polarization) and was recorded on four Mark 6 units recording on 16 modules at 64 Gbps total. Aggregate rates are reaching 0.5 Tbps, with total storage requirements of around 5–10 PB for raw recordings, and 5 TB for the correlated and final polarization converted visibility data.

Correlation is limited by the available playback units; 32 Mark 6 with 32 expansion chassis would be required for a full 4-IF correlation assuming that eight stations participated in the observations. Hence the correlation load is shared between the MIT Haystack Observatory and the Bonn MPIfR/BKG correlators. The full 230 GHz (1.3 mm) session is split by IF such that the Mark 6 modules of one IF subset are processed in Bonn and the other at MIT Haystack. Playback rate alone via fuseMk6 from a 2×2-module group is slightly above real-time and averages 2.4 GB/s total (18 Gbps).

Digital Backends (DBBC3): Noteworthy results from 2019 and 2020 include: development and testing of the DDC U firmware (universal) for the DBBC3, providing 16 BBCs for each IF with a selectable bandwidth from 2 MHz up to 128 MHz for each BBC. This mode provides up to 16 Gbps output data rate for each IF. Further technical modifications of the DBBC3 hardware, improving system stability, synchronization, and power consumption.

BRAND: The project is a collaborative effort of five European institutes. According to plan the BRAND prototype receiver should have produced fringes on the Effelsberg telescope together with VGOS antennas towards the end of 2020. The COVID-19 pandemic with its restrictions caused delays in the delivery of parts and the collaborative work due to severe travel restrictions. It is expected that the work can be finished in 2021. While all analogue parts could be finished, the so-called digital frontend which samples the BRAND band from 1.5 GHz to 15.5 GHz in one chunk could only be partly tested in the lab.[5].

5 Current Status and Future Plans

- After the first successful correlation of an official VGOS 24-hour experiment in October 2020, the Bonn correlator has started regular correlation of VGOS 24-hour experiments in January 2021. The current schedule comprises one experiment per month.

[5] https://events.mpifr-bonn.mpg.de/indico/event/154/session/4/contribution/15

The real challenge for VGOS turns out to be the data logistics, particularly since some correlators can only handle e-transferred data. Moreover, data storage is getting tight for both recording to Mark 6 modules and storing data on hard disk systems not only at the stations but also at the correlators. Moreover, the Internet connection partly still requires upgrades to adequate bandwidths at stations and correlators.
- The current bandwidth of two times 1 Gbps will be upgraded in the first half of 2021 to 10 Gbps. Due to the high prices of the German Research Network (DFN), the contract will most likely be awarded to a commercial contractor for the duration of two years.
- A. Müskens tested the VieVS scheduling program (VieSched++) in collaboration with the Vienna group for INT3 sessions in 2019, which yielded good results. Since he began a sabbatical in April 2020 and will retire in April 2021, the scheduling tasks were handed over to Christian Plötz from the Geodetic Observatory Wettzell and Matthias Schartner, who in the meantime moved from the Vienna correlator to ETH Zurich.
- In order to reduce the workload for Bonn, seven of the previous EU-VGOS experiments will be or have already been correlated by the colleagues from the Vienna correlator. Further observations will be carried out in 2021 for testing purposes. This is desired by all partners in light of the IVS-VGOS sessions. In particular, most of the European stations have different back-end systems compared to the American sites; therefore, the European stations must rely mostly on their own resources to debug their systems together with the correlator and the DBBC team in Bonn.
- Correlation of all remaining RadioAstron observations will be finished within 2021–2022.
- Recently the upgraded NOrthern Extended Millimeter Array (NOEMA), the next generation of IRAM'S Plateau de Bure instrument, joined the GMVA network. A first fringe test was successful.
- During the GMVA session carried out in spring 2019, the VLBA recorded for the first time on Mark 6 units so that the recording data-rate for the GMVA can be increased now to 4 Gbps.
- During the autumn 2019 GMVA session, DBBC3 was used in parallel with the standard DBBC2 for Pico Veleta. Not only was the test successful, but

the DBBC3 data were actually used for the production correlation of that session.

- A number of post-correlation analysis tools were developed by Y. Pidopryhora to help in assessment of the GMVA correlation results. AMON (alist monitor) uses a GUI to present a "bird-eye view" overview of a correlation for the whole project and at the same time to easily access detailed fringe plots for any particular scan-baseline combination of interest. ant_rep (antenna report) aggregates all the correlation and fringe-fitting logs and compiles essential statistics in easily readable text form, that can also be converted to histograms or plots as needed. Starting from 2019 outputs generated by these tools are included into the GMVA session reports.
- J. Wagner is working on DiFX output bands feature for DiFX 2.7. The feature is based on earlier stand-alone de-zooming 'difx2difx' he developed to recover and correlate GMVA+ALMA 2017 (Issaoun et al. 2019). It will enable correlation of VLBI experiments that have inconvenient sky-frequency IF placements and bandwidth mixtures of (non-)overlapping 32/58/62.5/64/128/2048 MHz wide bands.
- He is also working on a Mark 6 reading layer in DiFX together with FUSE layer fuseMk6, as well as improvements towards multi-datastream handling in DiFX native Mark 6 support. He implemented some improvements for playback of lossy or "clumpy" multi-threaded VDIF recordings affecting some VGOS stations and for the PolConverter conversion flow.

Even though the COVID-19 pandemic cut down activities in many places, the production correlation at the Bonn correlator and related (debugging) tasks were fortunately unaffected in this regard.

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MIT Haystack Observatory Correlator Report 2019–2020

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Abstract This biennial report summarizes the major activities in space geodesy and radio astronomy that have been carried out by the VLBI correlator at the Haystack Observatory facilities of the Massachusetts Institute of Technology (MIT) during the 2019–2020 period.

1 Introduction

The MIT Haystack Observatory correlator, located in Westford, Massachusetts (herein the "Haystack correlator," also simply the "correlator"), includes a computer cluster where correlation of raw VLBI data is performed using a distributed FX-type (DiFX) software correlator [*Deller et al.,* 2011] and fine-tune post-correlation processing using the Haystack Observatory Post-processing System (HOPS) software package [*Capallo,* 2017].

The Haystack correlator is supported by the NASA Space Geodesy Program (SGP) and the National Science Foundation (NSF), and it is dedicated approximately equally to the geodetic pursuits for the International VLBI Service (IVS) and to radio astronomy imaging for the Event Horizon Telescope (EHT) project.

The Haystack correlator serves as a research and development system for testing new correlation modes, such as those needed for observations with the next-generation VLBI system—the VLBI Global Observing System (VGOS [*Niell et al.,* 2018])—and for technology developments, such as for the Mark 6 recorder system. Software support for the processing of VLBI experiments is also provided to the general IVS community including similar DiFX and/or HOPS installations at the U.S. Naval Observatory (USNO) in Washington D. C., the Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn, Germany, and other software correlators worldwide.

MIT Haystack Observatory

MIT Haystack Correlator

IVS 2019+2020 Biennial Report

2 Summary of Activities

2.1 General VGOS Activities

The primary contributions of the Haystack correlator to the now operational VGOS network continue to be the processing of geodetic session data, feedback to stations for repairing problems, equipment tests and commissioning or testing of new stations, and providing advice and assistance to other correlators. In addition to what is described later in this report, dozens of 24-hour VGOS sessions as well as mixed-mode (i.e., S/X legacy and VGOS) sessions, VGOS Intensives, and various smaller tests have been processed and analyzed under the auspices of the VLBI geodesy project. Extensive help has been rendered to station staff, VGOS engineers, analysts, and staff at other correlators. The level of activity in the last three quarters of 2020 was severely impacted by the COVID-19 pandemic.

2.2 General EHT Activities

EHT provides the lion's share of the equipment in the Haystack DiFX cluster, so a few words on work related to that project are deemed relevant to this report. By far the biggest news to come out of the EHT project was the release in April 2019 of the M87 black hole image resulting from the processing of the April 2017 observing campaign [*The EHT Collaboration,* 2019]. This is a result of fundamental astronomical importance.

Work on completing the processing of the April 2018 observing campaign concluded in February 2021, and work on a January 2020 dress rehearsal in preparation for a subsequently canceled 2020 observing run was also completed. The efficacy of observing at 345 GHz was validated by observations recorded in October of 2018. Significant help in all of this work was also provided to the MPIfR correlator for co-processing many of these efforts.

2.3 Deployment and Commissioning of MGO

Another NASA station was added to the VGOS network since the last biennial report: the McDonald Geodetic Observatory (MGO). As described in that report, the MGO data acquisition equipment underwent extensive testing during 2017–2018, including recording data in parallel with the standard backend at the Westford antenna—also known as zero-baseline tests—and processing both sets of data at the Haystack correlator. The entire build-out and commissioning process subsequently occurred very quickly due in a large part to successful engineering vetting during this pre-installation testing. MGO is now a regularly participating station in the VGOS network.

2.4 Mixed-mode Observations and Development Work

Extensive and intensive work was carried out since last reported in furthering the ability to observe in mixed mode between VGOS and legacy S/X stations. Processing of RD1804 and RD1810, which began in 2018, was completed, and databases were submitted to the IVS. In RD1804, VGOS stations Westford and GGAO were tagged along to an S/X network, while in RD1810 a third VGOS station, KPGO, was added to form a VGOS triangle. Three much larger, 16-station (eight VGOS and eight S/X) sessions were recorded in summer 2020: RD2005, RD2006, and RD2007. The first two have already been processed, and a preliminary database of session RD2005 was submitted to the IVS for inclusion in ITRF2020.

Major investments in personnel time and software development were made in modifying software in the mixed-mode processing chain so as to ensure valid results and to simplify and streamline the process of producing them. One major improvement was modifying parts of the software processing chain to make possible the production of all full-bandwidth VGOS, mixed legacy-VGOS, and legacy-only products in one single pass through the correlator. For RD1804 and all prior mixed-mode sessions, processing required a three-pass strategy, but from RD1810 on, all mixed-mode processing used a one-pass method, greatly simplifying the effort needed to produce the final products. Another improvement was the ability to manually assign *fourfit* [*Capallo,* 2017] channel labels to keep them consistent between the three different product flavors, greatly simplifying the *fourfit* control file structure and reducing the chance for errors.

2.5 TOW and Follow-Up Correlator Workshop

The 10th Technical Operations Workshop (TOW) was held at Haystack Observatory in May 2019. Immediately after the TOW, whose main objective is the training of station staff in IVS operations, a VGOS correlation workshop was conducted to transfer knowledge of the newly developed procedures for processing the VGOS sessions to staff at other correlators.

Following the VGOS correlation workshop, and to further broaden VGOS correlation knowledge and capabilities across the IVS community, the VGOS Intensive session VI9290 was processed at several correlators, and the 24-hour VGOS session VO0009 was correlated at the MPIfR correlator and post-processed at various others. The results of these correlations were compared among themselves and with those from the Haystack correlator to validate the practices at the other correlators. These hand-on exercises culminated in the production of several comparison memos [*Barrett et al.,* 2020a, *Barrett et al.,* 2020b, *Barrett et al.,* 2020c].

2.6 Effects of the Pandemic

The pandemic that descended upon us in March 2020 had a major impact on operations. The Haystack site was closed to all personnel except for those deemed essential to maintain the building infrastructure. It is important to note that scientific research operations were deemed non-essential, and this included operation of the correlator. Correlation activities had to move mostly off-site. As this had not been done extensively heretofore, the infrastructure to support it had to be built. After some development work, the correlator is now in a much better position to conduct remote operations fairly efficiently. There is definitely great disadvantage to operating remotely relative to operating on-site, as there are correlation-related activities such as mounting of Mark 6 modules and overall trouble shooting and testing that require physical presence and benefit from in-person exchange, but the best is being made of the situation.

2.7 DiFX Version Control

The level of complexity in VGOS and mixed-mode operations has resulted in a complex amalgam of different versions of the DiFX software correlator package that need to be used to produce quality results. Efforts are being made to correct various software flaws in various versions in order to consolidate all of the needed fixes into a single version of the DiFX build that all correlators can use.

2.8 Correlator Infrastructure Upgrades

Although no new major additions of hardware or capability were made to the Haystack cluster in the last two years, the physical infrastructure supporting and surrounding it changed in a major way. A new special-purpose room with customized cooling was designed and constructed to support, isolate, and protect the correlator equipment. This project was a necessity as the 60-year-old air conditioning system for the correlator equipment was failing and was not in conformance with environmental regulations regarding ozone-layer-depleting gas emissions. The execution of this project necessitated two major moves of the entire cluster. In the spring of 2020 the correlator was moved to a new temporary location in the large room where it is housed. The new room, including new electrical infrastructure, was then constructed in the area from which the cluster had been moved. Upon completion in the fall of 2020, the cluster was moved into its newly constructed space (Figure 1).

2.9 Clock Summit Meetings

The clock teleconference series referred to in the last report culminated in a memo and GitHub repository intended to standardize and facilitate consistent clock setting practices among correlators [*Himwich and Corey,* 2020]. Although this is a work still in progress, the fundamentals are now documented, and it is only a matter of establishing best practices at all facilities. Determining whose job it is to maintain and update station “peculiar offsets” and sampler delays over time remains to be done.

3 e-VLBI

Non-real-time electronic transfers (e-transfer) of VLBI data have continued during this period. Data from 15 stations for 124 VLBI sessions (including R4, RDV, and R&D) were transferred to MIT Haystack Observatory during the past two years for in-house correlation and data hosting or conversion to Mark5/Mark6 media prior to shipping for off-site correlation. Moreover, Haystack also handled e-transfers of VGOS data for Onsala and Yebes. Furthermore, all VGOS Intensive sessions processed by the Haystack correlator over this period were e-transferred (e.g., data from stations KPGO, Wettzell, Westford, and GGAO).

Fig. 1 Cluster correlator (background) and Mark 6 playback units (foreground) at the MIT Haystack Observatory.

4 Experiments Correlated

A total of approximately 58 geodetic VLBI sessions were processed, at least in part, during the 2019–2020 period. These include 36 VGOS Trials (VT), six VGOS Operations (VO, which are the evolution of VT starting in 2020), eight VGOS Intensives (VI), four mixed-mode sessions, four S/X-only R&D sessions, and various other VGOS-related test sessions that are not included in the count because they were too small to warrant individual experiment numbers. If not for the pandemic effect, significantly more VO and VI sessions would have been processed. These will be done in 2021.

5 Existing Correlator Capabilities

The cluster as described in the last report remains as is, i.e., the "first generation" of 16 EHT cluster PCs (each with a single deca core 2.8 GHz Intel Xeon processor controlled by two equivalent master nodes) and the 38 subsequently purchased PCs (each with dual deca core Intel Xeon CPUs) still comprise the full cluster. This merged monolithic (but easily subdivided) "super cluster" has over 1,152 cores. Connecting, providing data to, and supporting this computing infrastructure are a Gb Ethernet fabric with three 100 Gb Ethernet switches, 197 TB of data storage space, and three file storage servers that can also act as DiFX compute nodes providing >200 TB of file storage. A total of 11 Mark 6 playback units with DiFX fully installed are connected to the Gb Ethernet fabric. In addition, racks and uninterruptible power supplies condition and stabilize power provided from a 208-volt power distribution fabric. As mentioned earlier, all of this equipment is now housed in a dedicated climate-controlled room with new electrical infrastructure. The integrated cluster (Figure 1) is used to correlate data from EHT, VGOS, and legacy S/X observing sessions.

6 Staff

The following staff have participated in various aspects of correlation, post-processing, Mark 6, and e-VLBI development and operations.

6.1 Correlator Software Development

- John Barrett - software development and support
- Roger Cappallo - HOPS software development
- Geoff Crew - DiFX, HOPS, and Mark 6
- Tim Morin - cluster IT, hardware/software support
- Jon Rose - cluster IT, hardware/software support
- Jason SooHoo - cluster IT, Mark 6, and e-VLBI
- Chester Ruszczyk - Mark 6 and e-VLBI

6.2 Correlator Operations

- Peter Bolis - correlator maintenance
- Alex Burns - Mark 6 and general technical support
- Brian Corey - correlation oversight, station evaluation, technique development
- Glenn Millson - correlator operations
- Dhiman Mondal - post-processing analysis
- Arthur Niell - technique development
- Don Sousa - media management and shipping
- Mike Titus - correlator operations setup, oversight, and hardware/software testing
- Ken Wilson - correlator and Mark 6 maintenance

7 Conclusions and Outlook

The correlator at the MIT Haystack Observatory has significantly contributed to the advancement of VGOS from a budding concept to an operational network capable of generating high-quality geodetic products. Specific topics during the reporting period include the development of new VGOS correlation and post-processing software, knowledge transfer of this capability to other correlators, and the development of correlation software to process mixed-mode (S/X legacy and VGOS) observing sessions.

Recovery from reduced operational levels caused by the COVID-19 pandemic will be a major effort in the coming year. As always, a major focus will be on producing correlator products of high quality, especially for the challenging mixed-mode sessions, and on improving the quality where possible. Close collaboration with other correlators as they take on more of the VGOS processing load will continue, as will commissioning and testing activities as the VLBI station network expands [*Merkowitz et al.,* 2019].

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IAA Correlator Center Biennial Report 2019+2020

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Abstract The IAA Correlator Center activities in 2019 and 2020 are described. All regular observations of the Russian national geodetic VLBI programs were transferred to the IAA in e-VLBI mode and correlated using the ARC, RASFX, and DiFX correlators.

1 General Information

The IAA Correlator Center is located in St. Petersburg, Russia and maintained by the Institute of Applied Astronomy. The main goal of the IAA Correlator Center is the processing of the geodetic, astrometric, and astrophysical observations made with the Russian national Quasar VLBI network. The observatories "Svetloe", "Badary", and "Zelenchukskaya" are connected to the Correlator Center by a 2 Gbps link. At present, three correlators are operated by the Correlator Center: ARC, RASFX, and DiFX.

The Astrometric Radio Interferometric Correlator (ARC) is a six-station, 15-baseline hardware correlator. The ARC was designed and built by the IAA RAS in 2007–2009. The correlator is an XF-type and is based on FPGA technology. The ARC maximum data rate is 1 Gbps for each station, 6 Gbps total [1].

In 2014, the Russian Academy of Sciences FX (RASFX) six-station, near-real time GPU-based VGOS correlator was developed. The correlator software is installed on an HPC cluster, which contains 40 servers, each equipped with two Intel CPUs and two Nvidia GPUs, and is able to process up to a 96 Gbps input data rate [2].

Since 2015, multiple versions of the DiFX software correlator [3] have been installed and run on the HPC cluster.

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2 Activities during the Past Years

ARC typically operates with data obtained from the 32-m telescopes (RT-32) "Svetloe", "Badary", and "Zelenchukskaya". ARC processes daily Intensive one-hour sessions for UT determination and weekly 24-hour sessions for EOP determination in the standard legacy IVS geodetic setup (1-bit sampling, 16 frequency channels of 8 MHz bandwidth). Since 2020, RASFX is also involved in that processing. More than 800 legacy geodetic sessions were processed in 2019–2020.

Three VGOS-compatible 13.2-m radio telescopes (RT-13) located in Badary, Svetloe, and Zelenchukskaya were used to carry out observations on a regular basis. During 2019, up to five one-hour S/X and 0.5-hour S/X/Ka sessions have been done daily with the following setup: four frequency channels of 512 MHz bandwidth each and 2-bit sampling (8 Gbps data rate per station), resulting in a total data rate of nearly 4 TB per hour. In 2020 the duration of the daily sessions was increased to four two-hour S/X sessions and one-hour S/X/Ka. The RASFX and DiFX correlators were used for these sessions' data processing.

A few five-station (three RT-32: Bd, Sv, and Zc; two RT-13: Bv and Zv) and one six-station (three RT-32 and three RT-13) 23-hour sessions were performed to tie the positions of the 13.2-m antennas. These were

S/X observations recorded with 512 MHz bandwidth frequency channels at the RT-13 stations (4 Gbps) and with 32 MHz bandwidth frequency channels at the RT-32 stations (2 Gbps). These sessions were processed using the DiFX correlator in zoom band mode. For the same purpose, to tie the RT-13 "Svetloe" position, RT-13 "Svetloe" was added as a tag-along station to the R1972 session in 2020. This session was processed at MPIfR Bonn.

RT-13 "Svetloe" and "Badary" have participated in the EU-VGOS Intensive session ev0034 in tag-along mode to check the equipment compatibility. The data were transferred to St. Petersburg, and the correlation was done using the DiFX correlator. Post-processing of ev0034 is in progress and not finished yet.

Also we processed a few experiments with spacecraft. The signals were obtained using the RT-32 and RT-13 stations, and data processing was performed using the RASFX and DiFX correlators. High precision VLBI delays and delay rates were calculated.

The Correlator Center also processed calibration and equipment test observations for the Quasar VLBI network. In particular, we continued tri-band and ultra-wideband receiver testing, as well as a new pulse generator in 1 MHz and 5 MHz modes. Also a few three-station (RT-13) S/X/Ka sessions with 30-min scans were carried out in order to estimate the receiver's stability in terms of signal delay [4]. These sessions were processed using the RASFX correlator.

In summary, in 2019–2020 the following types of sessions were correlated:

- one-hour geodetic sessions in S/X band for UT determination ("R-I", two or three 32-m stations), daily, ARC, RASFX, and DiFX processing;
- 24-hour geodetic sessions in S/X band for EOP determination ("Ru-E", three 32-m stations), weekly, ARC, RASFX and DiFX processing;
- one- or two-hour geodetic sessions in S/X band for UT determination ("R", three VGOS 13-m stations), four to five per day, RASFX and DiFX processing;
- 0.5- or one-hour R&D sessions in S/X/Ka bands ("R-X", three VGOS 13.2-m stations), daily, RASFX and DiFX processing;

and a set of test observations ("Ru-TEST"):

- 23-hour test geodetic program in S/X band to improve the positions of the 13.2-m antennas (three 13.2-m and three 32-m radio telescopes), DiFX processing;
- Spacecraft VLBI observations test program, (32-m and 13.2-m stations), RASFX and DiFX processing;
- Determination of the instrumental errors of the RT-13 receiving and recording equipment, RASFX processing;
- Miscellaneous test sessions, including international cooperation.

3 Staff

The list of the staff members of the IAA Correlator Center in 2019–2020 is given below.

- Igor Surkis — leading investigator, software developer;
- Voytsekh Ken — HPC cluster maintenance, GPU software developer, data processing;
- Alexey Melnikov — DiFX maintenance and processing, scheduler;
- Vladimir Mishin — HPC cluster maintenance, software developer, data processing;
- Nadezhda Mishina — software developer, data processing;
- Alexander Kumeyko — software developer, post-processing;
- Yana Kurdubova — software developer, data processing;
- Violetta Shantyr — software developer, post-processing;
- Mikhail Zorin — software developer;
- Pavel Volkov — post-processing and analysis;
- Vladimir Zimovsky — data processing lead;
- Ekaterina Medvedeva — data processing;
- Alexander Salnikov — e-VLBI data transfer lead;
- Ilya Bezrukov — e-VLBI data transfer;
- Vladislav Yakovlev — e-VLBI data transfer.

4 Future Plans

In 2021 and 2022, the IAA Correlator Center activities will be focused on the following aspects:

- routine processing of geodetic observations;

- international session processing;
- test sessions for equipment compatibility and stability testing;
- developing new features for the RASFX correlator.

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Shanghai VLBI Correlator 2019–2020 Report

Fengchun Shu, Xuan He, Yidan Huang, Zhong Chen, Weimin Zheng

Abstract This report summarizes the activities of the Shanghai VLBI Correlator during 2019 and 2020. Highlights include preparation for VGOS data correlation, monitoring peculiar clock offsets, fringe tests of Shanghai VGOS stations, and K-band geodesy.

1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory (SHAO), at the Chinese Academy of Sciences (CAS). It is located at the Sheshan campus, about 40 kilometers from the Xujiahui headquarters of SHAO. The Shanghai correlator has been used in the data processing of the Chinese VLBI Network (CVN), which consists of the Seshan25, Tianma65, Kunming, Urumqi, and Miyun50 stations. The Shanghai correlator was accepted as an IVS component in March 2012. It became operational for IVS data correlation in 2015.

2 Component Description

We are operating two types of correlators. The CVN correlator developed by SHAO is mainly used for spacecraft VLBI tracking by producing differential VLBI observables. The data latency is less than one minute in real time mode, and the typical accuracy is better than 1 ns. The other one is the DiFX software correlator, which is dedicated to astronomical and geodetic data correlation.

The DiFX software was installed on a powerful hardware platform, with a 420-CPU core cluster system and a 400-TB storage space. A new disk array installed in 2020 provides 1 PB of additional data storage for VGOS data correlation. Three Mark 6 units have been tested and can be used to playback VDIF data. The suite version is Mark6_1.3c with dplane as 1.22 and cplane as 1.0.26. Features of the DiFX cluster system are as follows:

- DiFX 2.6.2, HOPS 3.21, nuSolve 0.6.4
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2*6 cores), 64 GB Memory, DELL R730 (E5-2623 CPU, 3.0 GHz, 2*4 cores), 64 GB Memory.
- Computing nodes: 20 DELL R630 nodes, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory, 400 cores in total
- I/O nodes: RAID6, 1400 TB raw data storage capacity
- Data playback units: three Mark 5B and three Mark 6.
- 56 G Infiniband for internal computing network connection
- 1/10 G Ethernet for internal and external network connection

3 Staff

The people involved in the operation and development of the correlator and the VLBI digital backend are listed below.

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3.1 Operations Team

- Fengchun Shu: group head, scheduler, experiment oversight
- Zhong Chen: e-transfer support, cluster administration
- Zhanghu Chu: media library
- Shaoguang Guo: Mark 6 maintenance
- Xuan He: DiFX operation
- Yidan Huang: DiFX operation, post-correlation technique development
- Tianyu Jiang: data playback, DiFX operation
- Wu Jiang: DiFX operation for astronomical data
- Xiuzhong Zhang: VLBI terminal and correlation technique development

Xuan He is the only person to work full-time on geodetic VLBI data correlation.

3.2 Technique Development Team

- Weimin Zheng: group head, software correlator and VLBI terminal development
- Jiangying Gan: FPGA programming
- Tetsuro Kondo: wideband bandwidth synthesis
- Lei Liu: software correlator development
- Xiaochuan Qu: CDAS development
- Ping Rui: visualization programming and operation for CVN correlator
- Fengxian Tong: VLBI scheduling and modeling
- Li Tong: VLBI raw data simulation
- Juan Zhang: software correlator development and maintenance
- Renjie Zhu: CDAS development

Tetsuro Kondo from NICT joined the group in mid 2017 as a distinguished scientist, offered by the CAS President's International Fellowship. He returned to Japan at the end of 2020.

4 Summary of Activities

4.1 DiFX Correlation

We use the latest stable version of DiFX and HOPS software for regular IVS data correlation. The vgosDB files are available at our ftp site[1]. We also produce FITS-IDI files, which can be downloaded on request by the users.

We investigated the data playback rate of Mark 6 units. The connection of Mark 6 units to the cluster data storage was replaced with 56-Gb Infiniband. Thus the data rate for gathering could be up to 11 Gbps. However, the data rate for VDIF multiplex is still very slow.

We introduced peculiar clock offsets to compensate instrumental delays of reference stations in early 2018. As shown in Figure 1, we analyzed all 36 correlated sessions, and derived a mean clock bias for each session, i.e., clock compensation errors with respect to the peculiar clock offset table. In most of cases, the mean clock bias is less than 0.5 µs. Only one session, CRF111, has a clock bias of 1 µs due to human error. Judging from nine sessions in 2020, we found Urumqi had a jump in the peculiar clock offset of about 1.1 µs. The mean clock bias should be much smaller, if only the most stable stations are used in the calculation.

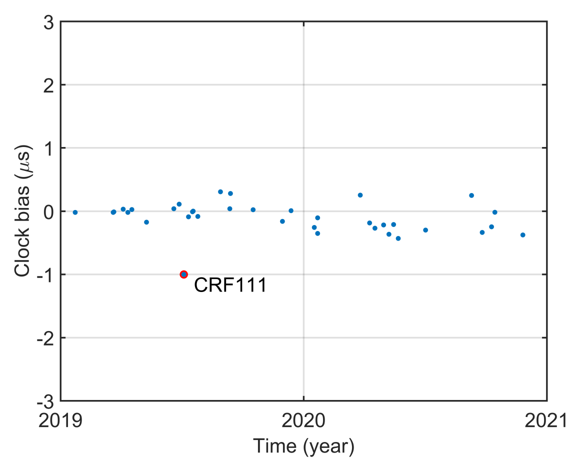

Fig. 1 Mean clock bias for each of the 36 sessions correlated at Shanghai.

[1] http://202.127.29.4/vgosDB/

4.2 Spacecraft Tracking

We performed regular VLBI tracking of the Tianwen-1 Mars spacecraft in its Earth-Mars transfer orbit. The typical RMS delay residual is about 0.1 ns.

The Chang'e-5 is the most complicated mission for our group. It is a big challenge for differential VLBI scheduling and data correlation. In one tracking session, sometimes we need to track two objects alternatively or in the same beam. The correlation model polynomials for two objects need to be calculated before timeshare data correlation.

In addition, there are regular tracking sessions for the Chang'e-4 data relay satellite. The sessions for tracking spacecraft are so frequent that they made an impact on geodetic or astronomical observations.

4.3 e-VLBI

The network links to Seshan25 and Tianma65 are 10 Gbps. The network links to the Urumqi, Kunming, and Beijing stations are 200 Mbps for tracking spacecraft. In the Chang'e-5 lunar mission and Tianwen-1 Mars mission, we made real-time data transfer at a 128-Mbps data rate for each station. However, for regular geodetic observations, the Chinese stations always ship modules to the Shanghai correlator.

In order to process IVS global sessions, we have established network links to most of the IVS stations and correlators. The regular data rate is 2 Gbps. Only two international stations, Matera and Kokee, need to ship modules.

4.4 Experiments Correlated

We correlated 20 IVS sessions in 2019 and 16 sessions in 2020. Most of them are focused on VLBI absolute astrometry. There were no stringent requirements on data latency. We aimed to deliver the correlation products in three months. More details can be found in Table 1.

We have correlated 134 IVS sessions since 2015, with 33 participating stations distributed over the globe. The cumulative data volume is approximately 4.2 PB, collected from more than 850 station days.

Table 1 Statistics of experiments correlated.

Session Name	2019	2020
AOV	6	5
APSG	2	2
IVS-CRF	6	6
IVS-R&D	6	3
Total	20	16

The top five stations with the most observing days are Yarragadee, Hobart26, Katherine, Kunming, and Warkworth. More details were shown in Figure 2.

It is worth noting that all APSG sessions and some AOV sessions were scheduled by SHAO. The APSG observing sessions are dedicated to measure positions and velocities of stations in the Pacific Rim. The AOV sessions organized by SHAO are focused on astrometry of weak sources in the ecliptic plane and southern hemisphere. Two stations belonging to the National Time Service Center (NTSC), Jilin and Sanya, participated in the APSG44 and APSG46 sessions as tag-along stations.

4.5 VGOS Correlation Campaign

We took part in the VGOS Intensive blind test. The data set is V19290 observed with Kokee12m and Wettz13s. We managed to finish data correlation, fringe fitting, and generation of database file independently.

A second campaign was the post-processing comparison of the multiple-station 24-hour VGOS session VO0009. The control files were provided by the Haystack correlator group. We gained experience in how to perform calibration at different stages.

The database files were submitted to the Haystack group who made correlation comparisons of the participating IVS correlators. More details can be found in the Haystack memos.

4.6 Fringe Tests of Shanghai VGOS Stations

We have performed a few fringe tests with the Shanghai VGOS stations.

We obtained first broadband fringes on the baseline Seshan13–Tianma13 on July 9, 2019. The IVS-VT ob-

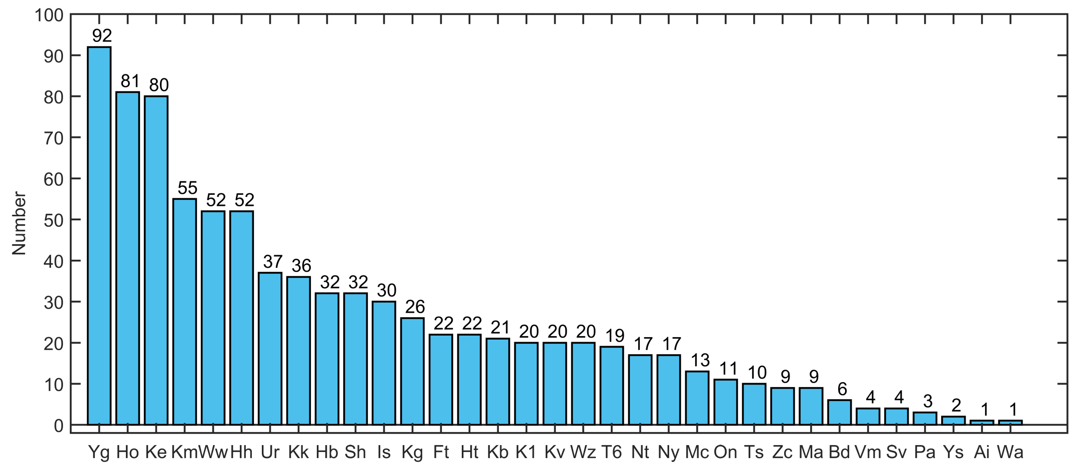

Fig. 2 Statistics of total session number for each station correlated at Shanghai over the last six years.

serving mode was used. Serious RFI caused by a 5G base station was detected at channels G and H.

Seshan13 was tagged along to VT9329. Tianma13 was tagged along to VT9343 and VT9360. Unfortunately, there was no opportunity to perform fringe tests with the other participating stations.

The first international fringe test was performed on July 7, 2020. Seshan13, Tianma13, and Ishioka observed for one hour using IVS-VT mode. Fringes were detected successfully. A misalignment of the polarizer of Seshan13 was detected, and then corrected a few months later.

The second international fringe test was performed on September 3, 2020. Seshan13, Tianma13, Hobart12, and Kath12m observed three hours. As the Australian VGOS stations have only three bands available due to a limitation of their DBBC3, the frequency sequence was re-designed to span over three bands with frequency coverage of 3.6–10.7 GHz.

On December 18, 2020, we obtained first broadband fringes between Shanghai and Urumqi antennas.

4.7 K-band Geodesy

We performed K-band geodesy using the East Asian VLBI Network (EAVN) plus some IVS stations. Following the standard geodetic VLBI data processing path, we added K-band observing mode in the schedule catalogs. Thus we could schedule K-band geodetic experiments similar to S/X band.

We performed a fringe test using EAVN stations, Russian stations, and Hobart26 on 19 November 2019, followed by a 24-hour session on 25 May 2020. The experiments were observed at a 1024-Mbps data rate, with eight IF channels (four USB and four LSB) and 2-bit sampling. Only LCP was used. Each IF channel was 32 MHz wide. We processed the data with DiFX and HOPS. The results of further data analysis are very promising; thus, more experiments will be conducted later on.

5 Future Plans

We plan to correlate some IVS VGOS sessions. For testing purposes, the Shanghai VGOS stations could be scheduled in those sessions as tag-along stations. With more VGOS stations coming online, the observing network can be optimized to alleviate the bottleneck pressure of data transfer.

Acknowledgements

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Tsukuba VLBI Correlator

Yu Takagi[1], Kyonosuke Hayashi[1], Tetsuya Hara[1,2]

Abstract This report summarizes the activities of the Tsukuba VLBI Correlator during 2019 and 2020. The correlator has been regularly involved in the weekend IVS intensive (INT2) sessions as well as the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions using the K5/VSSP correlation software.

1 Introduction

The Tsukuba VLBI Correlator, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is fully devoted to processing geodetic VLBI observations of the International VLBI Service for Geodesy and Astrometry (IVS). Almost all of the weekend IVS intensive (INT2) sessions for UT1−UTC (=dUT1) estimation and about half of the Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) sessions, which began in 2015 as regular IVS sessions, were processed at the correlator. The K5/VSSP correlation software developed by the National Institute of Information and Communications Technology (NICT) was used for processing of all the regular sessions.

1. Geospatial Information Authority of Japan
2. Advanced Engineering Service Co. Ltd.

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2 Component Description

2.1 e-VLBI

The Tsukuba VLBI Correlator has been connected to a broadband network, and all of the observed VLBI data are basically delivered via the network. The correlator has a 10-Gbps dedicated link to the *SINET5* operated by the National Institute of Informatics (NII), which is connected to several research networks in the world such as *Internet2* in the U.S., *GÉANT* in Europe, and *TEIN4* in Asia. It enables us to transfer a massive amount of data between the correlator and overseas IVS components. The Ishioka VLBI station has also been connected to the correlator and *SINET5* with a 10-Gbps dedicated cable since 2014.

2.2 K5/VSSP Correlation Software

The K5/VSSP correlation software, which was developed and has been maintained by NICT, is adopted at the correlator. The software consists of several programs for the calculation of a priori values of delay and delay rate (*apri_calc*), for the correlation processing for all observations (*fx_cor_new* or *cor_new*), and for monitoring the results of the correlation processing by performing a so-called "coarse search" (*sdelay*), followed by several utilities such as *komb* for the bandwidth synthesis [1]. The software can handle not only K5 format data but also Mark 5B or VDIF format data without format conversion in the latest version.

Table 1 Hardware capabilities of the Tsukuba VLBI Correlator.

	Main System	**Backup System**
Number of servers	16 – 14 for correlation processing – 2 for controlling correlation processing	8 – 5 for correlation processing – 2 for controlling correlation processing – 1 for data storage
Operating System	Red Hat Enterprise Linux 6.3	CentOS version 6.10, 7.7, and 7.8
CPU	Intel Xeon X5678 @3.60 GHz 4 cores x 2 x 16	Intel Xeon X3360 @2.83 GHz 4 cores x 2 Intel Xeon Gold 6130 GHz @ 2.10 GHz 16 cores x 2 Intel Xeon Gold 6230 GHz @ 2.10 GHz 20 cores x 3 Intel E5-2609v4 @1.70 GHz
Total storage capacity	513 Tbytes	273 Tbytes
Network	10 Gbps dedicated line connected to SINET5 by NII	

2.3 Correlation Procedure

The typical correlation process at the correlator and programs used in each process are as follows:

1. Transferring data from network stations to the correlator (*tsunami* and *tsunamid*, or *m5copy*).
2. Preparation of a priori parameter files (*apri_calc*).
3. Fringe search to find a clock offset at each pair of stations (*fx_cor_new* or *cor_new*).
4. Running correlation processing for all observations (*fx_cor_new* or *cor_new*).
5. Coarse search for estimating residual delay and delay rate, and plotting them on a 3-D diagram (*sdelay*).
6. Bandwidth synthesis to derive a multi-band delay (*komb*).
7. Database creation to be submitted to IVS Data Centers (*vgosDbMake*).

The correlation and analysis management programs developed by GSI can run the above processes consecutively and automatically. The program for the management of data transfer *rapid_transfer* accesses a data server in an observing station, executes *tsunamid* there, and then executes *tsunami* at the correlator side to transfer data automatically. As a result of its update in July 2020, automatic data transfer using *m5copy* is now available. It can transfer the data concurrently with the start of the session as needed.

Rapid_cor is a program to search for a fringe for each baseline based on the clock information of each station written in the FS log, as well as the station positions and source coordinates described in the schedule file and external a priori Earth orientation parameters. Once the fringe is detected, the main correlation processing runs one after another with the clock offset and rate information derived from the fringe search process until the last observation.

Rapid_komb executes *komb* on the stream of correlation outputs for bandwidth synthesis process. For the weekend Intensive sessions, *rapid_c5pp*, which gives an interface to VLBI analysis software *c5++* [2], executes analysis automatically as the bandwidth synthesis process finishes and delivers the result to the community (refer to the report "Tsukuba VLBI Analysis Center" in this volume for more details).

The database is created manually with *vgosDbMake* for the vgosDB format [3] and is submitted to IVS Data Centers. Although the Mark III format databases had also been created based on requests from a few Analysis Centers, only vgosDB format databases have been created since September 5, 2020; there have been no more requests since then.

2.4 Correlator Hardware Capabilities

The hardware supporting the activities of the correlator is summarized in Table 1. All these pieces of equipment are general-purpose and commercially available products. It means that no dedicated hardware is required in the K5 correlation processing. The main system consists of sixteen IBM X3650 servers and a Data Direct Networks storage system with a capacity of 513 TB (Figure 1).

The backup system was expanded during 2019–2020 and currently consists of seven servers and 273 TB data storage. At present, some test correlation processing using DiFX and HOPS software is carried out on this system (see Section 5).

3 Staff

The technical staff at the Tsukuba VLBI Correlator are:

- **Yu Takagi** — correlator/analysis chief, management.
- **Kyonosuke Hayashi** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

4 Correlator Operations

4.1 IVS Intensive for UT1−UTC

Almost all of the weekend Intensive series (INT2) were processed at the Tsukuba VLBI Correlator automatically in near real time using the *rapid_* programs (see Section 2.3). The number of sessions processed in 2019 and 2020 is listed in Table 2. Ishioka in Japan and Wettzell 20-m in Germany have usually participated in INT2 sessions.

Kokee Park or the VLBA antenna at Mauna Kea in Hawaii, U.S., was involved when Ishioka was not available because of its VGOS period for a few months per year or antenna mechanical trouble. Ny-Ålesund in Norway also filled in the absence of Wettzell 20-m. In addition, a few INT3 sessions on Monday were processed on behalf of the Bonn Correlator. Please refer to the report "Tsukuba VLBI Analysis Center" in this volume for results and more details.

Table 2 Intensive sessions processed at the Tsukuba VLBI Correlator.

2019	Stations	Period	# of sessions
Intensive 2	IsWz	Jan 5 – Dec 1	91
	IsNy	Jan 6	1
	MkWz	Dec 7 – Dec 28	4
	KkWz	Dec 15 – Dec 29	3
Total			99

2020	Baseline	Period	# of sessions
Intensive 2	IsWz	Mar 7 – Jun 14	29
	MkWz	Jan 4 – Dec 27	43
	KkWz	Jan 5 – Dec 13	25
Intensive 3	NyShWnWz	Jul 27	1
	ShWnWz	Dec 21	1
Total			99

4.2 IVS AOV Sessions

The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) is a regional subgroup of the IVS established in 2014 to foster and encourage closer collaboration in VLBI in the Asia-Oceania region. It has been coordinating regular VLBI observing sessions since 2015, and the number of sessions was twelve per year in 2019 and 2020. Correlation tasks are shared by the Tsukuba VLBI Correlator, the Shanghai Correlator operated by Shanghai Astronomical Observatory (SHAO), and the University of Tasmania. The sessions processed at the correlator in 2019 and 2020 are listed in Table 3. Most of the data, not only from Japan, but also from China, Korea, Australia, and New Zealand were transferred via the broadband network, while only the data of Syowa in Antarctica were shipped to Japan.

Table 3 AOV sessions processed at the Tsukuba VLBI Correlator.

Year	Name	Date	Stations
2019	AOV032	Feb 12	HoIsK1KeKgKvVmWwYg
	AOV035	May 14	HoIsK1KeKgSyWwYg
	AOV038	Aug 7	HoIsKeKgKvShUrWwYg
	AOV039	Sep 17	HoIsSyVmWwYg
	AOV041	Nov 12	HoIsKgYg
	AOV042	Dec 3	HoKgKvVmWwYg
2020	AOV044	Feb 11	HoKgKmVmWwYg
	AOV048	Jun 16	HoKgKmShSyVmWwYg
	AOV049	Jul 22	HoKgKvShWwYg
	AOV050	Aug 10	HoKgShSyWwYg
	AOV054	Dec 8	HoKgKmSyWwYg

5 Correlation and Data Processing Using DiFX and HOPS Software

For the VGOS correlation, the DiFX and HOPS software were installed on the backup system. Some correlation processing tests were carried out using DiFX and HOPS software. In 2020, the Tsukuba VLBI Correla-

Fig. 1 View of the main system (data processing servers and storage) at the Tsukuba VLBI Correlator.

tor participated in the blind-test exercise of the VGOS Intensive session VI9290 and obtained similar results to the other correlators [4].

6 Outlook

We will continue to process the IVS Intensive and AOV sessions. For more stable operation of especially near real time processing, we will make further improvements to the *rapid_* programs and maintain hardware and network. In addition to the regular S/X sessions, we are planning to learn the correlation processing techniques and enhance the hardware for the processing of the VGOS data.

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Vienna Correlation Center Report 2019–2020

Jakob Gruber[1], Frédéric Jaron[1], Axel Nothnagel[1], Johannes Böhm[1]

Abstract The Vienna Correlation Center is run by the Technische Universität Wien (TU Wien) and uses the hardware infrastructure of the Vienna Scientific Cluster (VSC-4). At the VSC-4, we have access to 480 processing cores and exclusive storage of 1 PByte. The VSC-4 is linked with a bandwidth of 10 Gbps into the global GEANT network. We use jive5ab and tsunami for data e-transfer and DiFX, HOPS, and PIMA for correlation and fringe-fitting. We use nuSolve for the creation of VGOS databases. In 2019 and 2020, we contributed to the IVS by correlating twenty AUSTRAL sessions, fifteen short-baseline sessions at HartRAO and Wettzell, twenty Intensive sessions with the network Hb-Ht-Yg, and five EU-VGOS sessions, and we took part in three VGOS correlator comparisons. In 2021, we plan to correlate ten VGOS-O sessions and further EU-VGOS sessions. From a scientific point of view, our focus will be on source structure in the fringe-fitting process.

1 General Information

At the research unit Higher Geodesy of the Technische Universität Wien (TU Wien), we correlate IVS VLBI sessions on an operational basis and for specific scientific projects. The VLBI correlation software components are installed on the currently most powerful supercomputer ever installed in Austria. The supercomputer is called Vienna Scientific Cluster-4[1] (VSC-4) and is located 2.5 km from our TU Wien offices (see Figure 1). The VSC is a collaboration of several Austrian universities that provides supercomputer resources and corresponding services to their users. Hence, the VSC is used for a variety of scientific projects in a wide range of disciplines. In total, the VSC-4 consists of 790 nodes. At the research unit Higher Geodesy, we have exclusive access to ten of these nodes, which are reserved for projects related to VLBI correlation and are accessible anytime for the members of our VLBI group. In addition, storage of 1 PByte was purchased to complete the VLBI correlation's hardware system, also in view of the enormous data volumes in the VGOS era.

1. Technische Universität Wien

VIEN Correlation Center

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[1] `https://vsc.ac.at/systems/vsc-4/`

2 Component Description

The capabilities of a VLBI correlator are frequently measured by three quantities: e-transfer rate, correlation data throughput, and storage size. These quantities and the software components are described in the following.

The VSC-4 consists of ten so-called login nodes, which are servers that are linked to the GEANT network, allowing a maximum data rate of 10 Gbps. This particular setup makes it possible to split up the data transfer over the ten login nodes, and data can be transferred simultaneously on the login nodes. Currently, the e-transfer to the Vienna correlator is organized in such a way that each VLBI station is assigned to a specific login node. Up to ten stations can thus transfer their data simultaneously to the VSC-4. However, it is essential to note that the 10 Gbps bandwidth is shared between the login nodes and other users of the VSC.

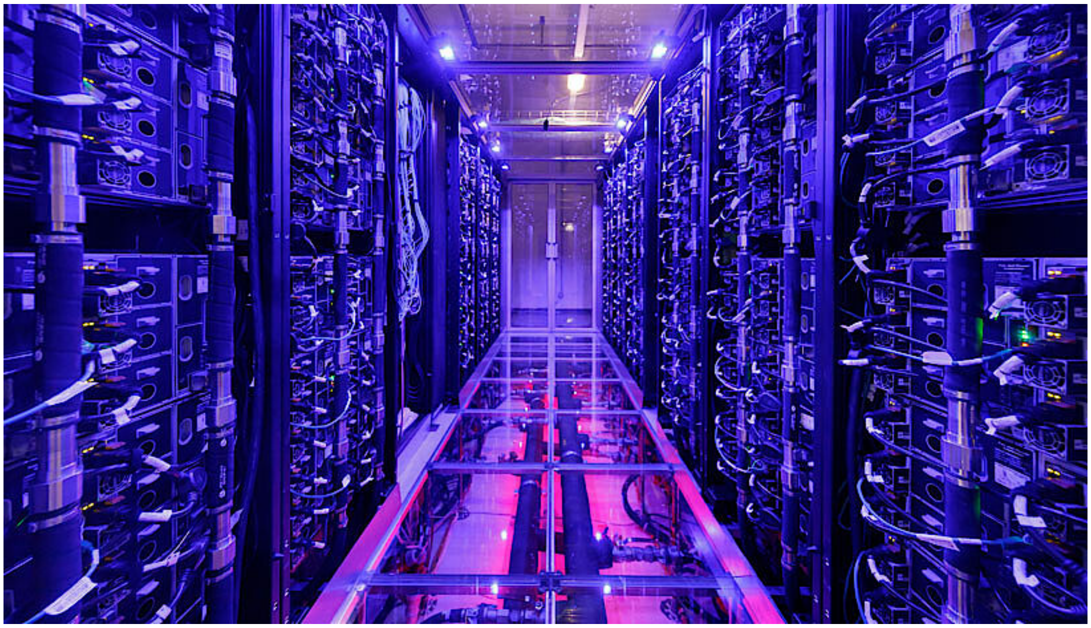

Fig. 1 VSC-4—the most powerful supercomputer in Austria. Ten nodes and 1 PByte are reserved for VLBI correlation. It is linked with 10 Gbps to the global research network GEANT. (©http://derknopfdruecker.com/)

Two independent test methods were applied to test the net data rate. On the one hand, the maximum possible net data rate was tested with the iperf3 tool, which actively measures the maximum achievable bandwidth on IP networks. On the other hand, the VLBI specific data e-transfer software jive5ab developed by H. Verkouter was used to test the maximum possible transfer rates between the Joint Institute for VLBI (JIVE) and the VSC-4. With iperf3 1.41 Gbps were achieved per stream, and 8.60 Gbps for ten streams in parallel. Using jive5ab, 2.9 Gbps were possible on a single login node. Parallel data streams were not tested with jive5ab. For operational purposes, we use jive5ab and tsunami for data transfer.

The VSC-4 consists of 790 water-cooled nodes (Lenovo SD650), each with two Intel Skylake Platinum 8,173 processors with 24 cores, interconnected with 100 Gbits/s OmniPath. For VLBI correlation, ten of these high-performance nodes reaching 2.7 PFlops/s are reserved. This means that up to 240 cores (24 cores per node) can be utilized for VLBI correlation simultaneously. The Distributed FX style correlation software (DiFX, [4]) is installed to realize level-0 processing of the raw VLBI telescope data. While we continuously keep our DiFX installation up to date with the latest official releases, we also keep several older versions of DiFX to allow the processing of VGOS and legacy S/X observations. The Slurm[2] workload management and job scheduling software is used to efficiently process the VLBI raw data by DiFX and reach a high parallelization level. A single session can be parallelized, but also several sessions can be processed in parallel. The assignment of the processing cores for single and multi-session correlation with DiFX is handled by Slurm. A brief investigation of the data throughput by DiFX on the VSC-4 showed an excellent scaling with an increasing number of processing cores. The maximum data throughput which could be achieved by using 480 cores was 320 Gbps.

For data storage, a General Parallel File-System (GPFS) with 1 PByte size is mounted to the VSC-4. This data volume is dedicated to VLBI correlation only within the VSC-4.

Besides DiFX, the Haystack Postprocessing System (HOPS), PIMA, and nuSolve are installed at the VSC-4 to complete the entire raw data VLBI processing chain. Consequently, it is possible to process raw VLBI data and provide vgosDB files to the IVS community.

[2] https://slurm.schedmd.com/documentation.html

3 Staff

Two persons are involved in the work at the TU Wien IVS VLBI Correlator Center. Their names and most important responsibilities are listed below. Additionally, Johannes Böhm is involved as the responsible contact point to the VSC-4 team, and Axel Nothnagel acts as a consultant, concerning correlation/fringe-fitting and raw data simulation.

- Jakob Gruber
  - Ph.D. student in the field of VLBI raw data processing
  - maintenance of data transfer
  - AUSTRAL, short baseline, VGOS correlation
  - raw data simulation
  - development of third party software to support correlation and fringe-fitting and correlation of various other special VLBI sessions
- Frédéric Jaron
  - Postdoc Researcher
  - maintenance of data transfer
  - VGOS correlation
  - EU-VGOS correlation and organization
  - special interest in source structure for VGOS
  - development of third party software to support correlation and fringe-fitting and correlation of various other special VLBI sessions

4 Current Status and Activities

4.1 AUA Sessions 2019 and 2020

In 2019 and 2020, twenty Austral (AUA) sessions were correlated, about one session per month. The network consisted of the telescopes: Ht, Hh, Hb, Ho, Yg, Ke, Ww, and Wa. In 2019, the sessions were dedicated to the SOuthern Astrometry Program (SOAP)[3]. The scientific goal of SOAP is to improve positions of compact extragalactic sources with declinations below −45 degrees. In 2020, the sessions were dedicated to mixed-mode observations, where Hb was the only station observing with a VGOS receiver.

[3] `http://astrogeo.org/soap/`

4.2 Southern Intensive Sessions 2020

Besides the operational AUA sessions in 2020, Intensive experiments were carried out to estimate precise dUT1 values with the network Ht-Yg-Hb. As for the AUA 2020 sessions, Hb observed with the dual-linear polarized VGOS feed, whereas Ht and Yg observed in legacy S/X mode. In total, 34 one-hour sessions were observed in 2020 and are being correlated in Vienna. The AUA 2020 and Southern Intensive data of 2020 can be used to determine the currently unknown peculiar offset for the Hb antenna, which can be of great interest to the VLBI correlation community.

4.3 Local Wettzell Sessions 2020

In 2020, three experiments with the local Wettzell network were processed to estimate precise local tie vectors. These are X-band only observations with Wn, Ws, and Wz, whereas Ws observed with a dual-linear polarized VGOS feed.

4.4 Short Baseline HartRAO Sessions 2019 + 2020

Like the local Wettzell sessions, short baseline (SBL) sessions on the Hh-Ht baseline with a six-hour duration were carried out and correlated in Vienna. They will be used to investigate the local ties in HartRAO [3]. For correlation, a frequency offset is applied, which is also present in the observation, to decorrelate the phase cal tones on the local baseline. In total there are 12 SBL sessions.

4.5 VGOS Comparison Campaign

In 2019 and 2020, the Vienna correlator took part in three dedicated IVS VGOS correlator comparisons, led by MIT Haystack Observatory. Detailed comparisons between Haystack, Washington, Bonn, Shanghai, and Vienna were carried out. The first comparison was a so-called blind test for a VGOS Intensive session, which showed the great importance of a consistent clock model setup between correlators. The second comparison was a level-1 processing comparison of a 24-hour VGOS session, which showed an excellent agreement between the Haystack and the Vienna correlator. The third comparison was between the Washington and the Vienna correlators, and there was an excellent agreement in the group delays. However, the proxy-cable calibration delay results showed significant differences, which requires further investigations.

4.6 Simulation at the Raw Level (VieRDS)

Within the last couple of years, a novel simulation tool called VieRDS [2] has been developed to generate single dish VLBI raw data in VDIF format. The simulated data can be processed by DiFX and can be used, e.g., to test new VLBI observation scenarios in a real correlation environment. The software is distributed within the umbrella of the Vienna VLBI and Satellite Software (VieVS, [1]) and can be downloaded from `https://github.com/TUW-VieVS/VieRDS`.

4.7 EU-VGOS

The EU-VGOS collaboration regularly carries out research and development sessions with a European network of VGOS antennas. The participating stations currently are: Oe, Ow, Ws, and Yb. In addition, the Japanese station Is joins the network when possible. We are currently processing six EU-VGOS sessions, five of them have particularly short scan lengths. The PI for these sessions is Matthias Schartner, who scheduled these experiments while he was still a member of our group in Vienna before moving to ETH Zürich. We are testing the performance of the calibration algorithms released by MIT Haystack Observatory for VGOS sessions. And we are investigating the quality of geodetic observables obtained from these sessions.

5 Future Plans

In 2021, we plan to correlate ten VGOS-O sessions, on which we will put a sharp focus. The session network will consist of eight stations: Gs, K2, Mg, Oe, Ow, Wf, Ws, and Yj. We expect each station to record around 30 TBytes, which sums up to 240 TBytes per session. Hence, we should be fine with our current storage capacity of 1 PByte. Since K2 has been upgraded to e-transfer, we plan to set up the e-transfer link to K2 soon, which will be a significant simplification of the challenging VGOS transfer logistics. Besides the operational VGOS-O correlation, we plan to utilize VieRDS to carry out raw data simulations for VGOS observations. We will continue to process EU-VGOS sessions at the Vienna correlator center.

Acknowledgements

The authors are grateful to the Austrian Science Fund (FWF) for supporting this work with the project P31625 (VGOS Squared). The computational results presented were achieved in part using the Vienna Scientific Cluster (VSC).

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DATA CENTERS

BKG Data Center

Anastasiia Girdiuk, Markus Goltz, Gerald Engelhardt, Dieter Ullrich

Abstract This report summarizes the activities and background information of the IVS BKG Data Center for the years 2019 and 2020. In particular, VLBI sessions in vgosDb data format collected from all correlators and the CDDIS are made available at our server. We present the corresponding extension of the BKG Data Center, the current operational status, and future plans.

1 General Information

The BKG Data Center is hosted by the Federal Agency for Cartography and Geodesy (BKG) and constitutes one of three IVS Primary Data Centers. We collect and maintain all VLBI related data from all of the following IVS components: Operation Centers, Network Stations, Correlators, and Analysis Centers. Since the establishment of the BKG Data Center, the same script, developed by Frank Gomez, was used to fulfill the IVS Data Center duties. In 2019, new procedures were set up in addition to that script to gather the VLBI data in the vgosDb format. Also, the vgosDb data are received from the CDDIS Data Center as a part of the data mirroring process occurring several times per day. According to the IVS Data Center agreement, newly submitted data are synchronized by checking a designated directory. Besides, we screen the entire data set at the OPAR Data Center and compare it with our current data set. The sketch in Figure 1 shows the principle of data mirroring. The assembled data are provided in open access for the IVS community and all interested parties.

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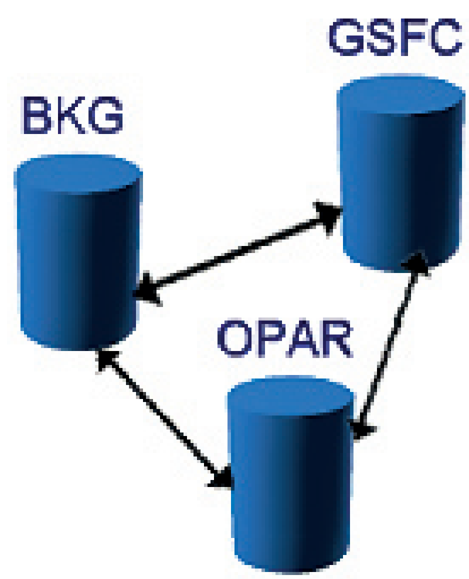

Fig. 1 Principle of data mirroring.

2 Component Description

IVS community members are free to submit their data to the BKG Data Center as well as to any other Primary Data Center. The data management is granted by Primary Data Centers in several steps. First, all uploaded data are received at the incoming area. The BKG incoming area is protected, and users need to obtain a username and password by contacting the IVS Coordinating Center or the BKG Data Center representative. Second, the data management script verifies new arrivals and categorizes them either to the appropriate Data Center directory or to the unknown data area in case of a recognition procedure failure. At the end of the operations, the incoming script writes a log report in the status directory. All activities of the Data Center are monitored to achieve data consistency and to control the data handling starting from the data arrival to the data display in open access.

The BKG Data Center is running under a Linux environment with 1 TB storage capacity. For the next few years the projected annual storage extension is 1 TB plus an additional extension of 10 TB for raw VLBI data. Public access to the BKG Data Center is available through FTP and HTTP:

`ftp://ivs.bkg.bund.de/pub/vlbi/`

`http://ivs.bkg.bund.de/vlbi/`

The BKG Data Center supports additional directories for vgosDb data handling:

```
ivsdata/
  vgosdb_bkg/ : vgosDb processed
                by the BKG
Analysis Center
from version 1
  vgosdb_bonn/: Bonn Correlator
  vgosdb_gsi/ : GSI Correlator
  vgosdb_shao/: SHAO Correlator
  vgosdb_usno/: vgosDb submitted
                by the USNO group
  vgosdb_utas/: UTAS Correlator
  vgosdb_wien/: Vienna Correlator
```

The structure tree of the BKG IVS Data Center is:

```
ivscontrol/     : control files for the Data Center
ivsdata/        : VLBI observation files
    aux/        : session supplementary data
    db/         : mk3db data storage
    ngs/        : NGS cards data storage
    vgosdb/     : CDDIS data holding
ivsdocuments/   : IVS documents
ivsformat/      : master-format
ivsproducts/    : analysis products
   crf/         : source coordinate products
   trf/         : station position products
   eops/        : Earth Orientation (24h sessions) time series
   eopi/        : Earth Orientation (Intensive sessions) time series
   daily_sinex/ : daily SINEX files (24h sessions)
   int_sinex/   : daily SINEX files (Intensive sessions)
   trop/        : tropospheric products
gsfc/           : software supplementary data
   ancillary/   : a priori station, EOP and source data
RECENT/         : most recent data from the incoming area
```

Note that initial data provided by correlators—wrapper file version 1—are not processed vgosDb data. All processed vgosDb data are located in `ivsdata/vgosdb`. Besides, the BKG Analysis Center (AC) submits its own processed vgosDb files, which are available only at the BKG Data Center. The BKG AC starts the analysis from vgosDb version 1. These data are expected to be merged with `ivsdata/vgosdb`.

3 Staff

The staff members during the report period were:

- Reiner Wojdziak, until June 30, 2020 (Data Center coordination, Web design)
- Anastasiia Girdiuk (data analysis, Data Center coordination, anastasiia.girdiuk@bkg.bund.de)
- Markus Goltz, since September 1, 2020 (Data Center, Web design, markus.goltz@bkg.bund.de)
- Gerald Engelhardt (data analysis, Data Center, gerald.engelhardt@ bkg.bund.de)
- Dieter Ullrich (data analysis, Data Center, dieter.ullrich@bkg.bund.de)

We unexpectedly lost our long-term staff member Reiner Wojdziak, who passed away on June 30, 2020.

4 Current Status

To ensure the synchronization between the three Primary Data Centers, the designated directory `RECENT` is mirrored with the same script four times a day. This script does not recognize vgosDb. vgosDb data are managed by our internal scripts: we collect and display all available data at the correlators and at the CDDIS. The BKG Data Center structure has been extended to include vgosDb data with the ultimate goal being to hold all of the IVS data including vgosDb. But this data structure is an intermediate solution. New software is being developed by the GSFC and CDDIS groups on the basis of the CDDIS internal procedures. In collaboration between the Primary IVS Data Centers (the CDDIS, OPAR, and BKG), we are adopting this software for use at BKG. This software is designed to manage all VLBI data types consistently. BKG and OPAR are expected to use this script for the incoming data management, and the CDDIS will perform a similar data handling as a part of their own internal service.

5 Future Plans

The most urgent matter is to implement the new software to ingest all VLBI data types, in particular to include the vgosDb data. The provision of the additional folder structure at the BKG Data Center will be discontinued once the vgosDb data can be merged into a single vgosDb database. At BKG we also intend to include raw data which requires additional storage capacity. For many reasons—such as new internal security protocols, the new ingest software, and the encrypted data access to the CDDIS—switching to encrypted protocols is on our agenda as well.

CDDIS Data Center Report for 2019–2020

Patrick Michael, Sandra Blevins

Abstract This report summarizes activities during the years 2019 through 2020 and the future plans of the Crustal Dynamics Data Information System (CDDIS) with respect to the International VLBI Service for Geodesy and Astrometry (IVS). Included in this report are background information about the CDDIS, the computer architecture, archive contents, and future plans for the CDDIS within the IVS.

1 General Information

The Crustal Dynamics Data Information System (CDDIS) has supported the archiving and distribution of Very Long Baseline Interferometry (VLBI) data since its inception in 1982. The CDDIS is a central facility that provides users access to data and derived products to facilitate scientific investigation. The full CDDIS archive of GNSS (GPS, GLONASS, Galileo, etc.), laser ranging, VLBI, and DORIS data is available online for remote access. Information about the system is available via the web at the URL `https://cddis.nasa.gov`. In addition to the IVS, the CDDIS actively supports other IAG services including the International GNSS Service (IGS), the International Laser Ranging Service (ILRS), and the International DORIS Service (IDS), as well as the International Earth Rotation and Reference Systems Service (IERS), and the IAG's observing system, the Global Geodetic Observing System (GGOS). The current and future plans for the CDDIS support of the IVS are discussed below.

NASA Goddard Space Flight Center

CDDIS Data Center

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The CDDIS is one of NASA's Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs) (see `https://earthdata.nasa.gov`); EOSDIS Data Centers serve a diverse user community and are tasked to provide facilities to search and access science data and products. The CDDIS is also a regular member of the International Science Council (ISC) World Data System (WDS, `https://www.worlddatasystem.org`) and the Earth Science Information Partners (ESIP, `https://www.esipfed.org`).

2 System Description

The CDDIS archive of VLBI data and products is accessible to the public through encrypted ftp at `gdc.cddis.eosdis.nasa.gov` and https at `https://cddis.nasa.gov/archive`. Anonymous unencrypted ftp access was deprecated in November 2020.

2.1 File Submissions

The CDDIS utilizes an https-based protocol method for delivery of files from suppliers of data and products. The validation is performed through the EOSDIS Earthdata Login system, the same system used for access to the CDDIS real-time caster. The file uploads can be performed through a webpage interface or a

Table 1 IVS data and product directory structure.

Directory	Description
Data Directories	
vlbi/ivsdata/db/yyyy	VLBI database files for year yyyy
vlbi/ivsdata/ngs/yyyy	VLBI data files in NGS card image format for year yyyy
vlbi/ivsdata/vgosdb/yyyy	VLBI data files in vgosDB format for year yyyy
vlbi/ivsdata/aux/yyyy/ssssss	Auxiliary files for year yyyy and session ssssss
	These files include: log files, wx files, cable files, schedule files, correlator notes.
vlbi/ivsdata/swin/yyyy	VLBI SWIN files for year yyyy
Product Directories	
vlbi/ivsproducts/crf	CRF solutions
vlbi/ivsproducts/eopi	EOP-I solutions
vlbi/ivsproducts/eops	EOP-S solutions
vlbi/ivsproducts/daily sinex	Daily SINEX solutions
vlbi/ivsproducts/int sinex	Intensive SINEX solutions
vlbi/ivsproducts/trf	TRF solutions
vlbi/ivsproducts/trop	Troposphere solutions
Project Directories	
vlbi/ITRF2013	IVS contributions to the ITRF 2013 efforts
vlbi/ITRF2014	IVS contributions to the ITRF 2014 solution
vlbi/ivs-pilotbl	IVS Analysis Center pilot project (baseline)
Other Directories	
vlbi/ivscontrol	IVS control files (Master Schedule, etc.)
vlbi/ivsdocuments	IVS document files (solution descriptions, etc.)
vlbi/raw	Raw VLBI data

command line application that can perform an http "post" operation, which is more commonly used for scripting. This process allows data suppliers to authenticate through the Earthdata Login system and provide their files through https to CDDIS for ingest into the archive. More information on the CDDIS file upload system, including an FAQ, is available at URL: `https://cddis.nasa.gov/About/CDDIS_File_Upload_Documentation.html`.

2.2 File Ingest Processing

Starting in 2018, the CDDIS worked with the GSFC VLBI staff to transition code for processing incoming VLBI-related files into a new, common file ingest software. This new common ingest software would be shared with the other IVS global Data Centers to ensure a common quality control (QC) and metadata process was shared across the global Data Centers. In late 2020, CDDIS moved its entire VLBI ingest process to this new collaborative process. Several changes were made to enable more rapid acceptance of new data/product files by the incorporation of data definition files (DDFs). These DDFs are unique to each file type and specify a range of QC and metadata requirements for each file type. This, in turn, is parsed by the ingest software to determine the QC and metadata actions to accomplish for each incoming file before acceptance into the archive.

3 Archive Contents

The CDDIS has supported GSFC VLBI and IVS archiving requirements since 1979 and 1999, respectively. The IVS Data Center content and structure is shown in Table 1 (a figure illustrating the flow of information, data, and products between the various IVS components was presented in the CDDIS submission to the IVS 2000 Annual Report). As described above, the CDDIS has established a file upload system for providing IVS data, product, and information files to the archive. Using specified filenames, Operation and Analysis Centers upload files to this system. Automated archiving routines peruse the directories and move any new data to the appropriate public disk area. These routines migrate the data based on the filename DDFs to the appropriate directory as described in Table 1. Software on the CDDIS host computer, as well as all other IVS Data Centers, facilitates equalization of data and product holdings among these Data Centers by placing all new received data/products into a RECENTS directory for action by the other Data Centers. At this time, performance of mirroring is scheduled to begin again between the IVS Data Centers located at the CDDIS, the Bundesamt für Kartographie und Geodäsie in Leipzig, and the Observatoire de Paris in late June 2021.

The public file system in Table 1 on the CDDIS computer consists of a data area, which includes auxiliary files (e.g., experiment schedule information and session logs) and VLBI data (in the database, NGS card image, and new vgosDB formats). A products disk area was also established to house analysis products from the individual IVS Analysis Centers as well as the official combined IVS products. A documents disk area contains format, software, and other descriptive files.

4 Significant New Data Sets

CDDIS in late 2019 began to work with GSFC VLBI staff to archive the VLBI Level 1 correlator output files (SWIN). Because these files were previously only housed at each individual correlator, there was a significant risk that data files could be lost. Therefore, CDDIS working with the IVS created a request for NASA HQ to fund the expansion of CDDIS operations to perform quality control on this data set and archive it. In the summer of 2020, hardware was procured and installed, and by late 2020, most of the QC and ingest software had been developed. CDDIS is projecting that acceptance of this data set will begin in late March 2021.

5 Accessing the CDDIS Archive

The CDDIS has a large international user community; over 600,000 unique hosts accessed the system in 2020. As per U.S. Government and NASA directives, the CDDIS moved users away from reliance on anonymous ftp and terminated all unencrypted ftp on 1 November 2020. The CDDIS has configured servers to utilize protocols that allow two new methods for system access: https (browser and command line) and ftp-ssl (command line). The https protocol is as efficient as ftp transfer and is without the firewall/router issues of ftp. The access to the CDDIS archive through both methods continues to present the same directory structure as the old unencrypted ftp. Archive access through the https protocol utilizes the same NASA single sign-on system, the EOSDIS Earthdata Login utility, as is used for the file upload. Before using the https protocol to access the CDDIS archive, new users must initially access the webpage `https://cddis.nasa.gov/archive` to establish an account and authorize access; this page will then redirect the user to the Earthdata Login page. Earthdata Login allows users to easily search and access the full breadth of all twelve EOSDIS DAAC archives. Earthdata Login also allows CDDIS staff to know our users better, which will then allow us to improve CDDIS capabilities. Once an account is established, the user has all permissions required to access the CDDIS archive using the https protocol, via a web browser or via a command line interface (e.g., through cURL or Wget) to script and automate file retrieval. In addition, ftp-ssl access, an extension of ftp using TLS (transport layer security), can be used for scripting downloads from the CDDIS archive. The ftp-ssl is the option most similar to standard unencrypted anonymous ftp. As with https, ftp-ssl will satisfy U.S. Government/NASA requirements for encryption. Examples on using these protocols, including help with the cURL and Wget commands, are available on the CDDIS website; users are encouraged to consult the available documentation at `https://cddis.nasa.gov/About/CDDIS_File_Download_Documentation.html` as well as various presentations on these updates to the CDDIS archive access (see Section 7 below and `https://cddis.nasa.gov/Publications/Presentations.html`).

6 System Usage

During the 2019—2020 time period, over 36,000 distinct hosts accessed the CDDIS to retrieve VLBI-related files. These users, which include other IVS Data Centers, downloaded over 4.88 Tbytes (6.6 M files) of VLBI-related files from the CDDIS in this two year period.

7 Future Plans

The CDDIS staff will continue to work closely with the IVS Coordinating Center staff to ensure that our system is an active and successful participant in the IVS archiving effort. A major area of focus will be the continued modifications to the CDDIS ingest processing software to accommodate all incoming VLBI-related files.

The staff is also testing providing a WebDAV (Web Distributed Authoring and Versioning) interface to provide another method for accessing the CDDIS archive. If feasible for CDDIS, this interface method would allow users to securely connect to the CDDIS archive as if it were a local drive on their computer.

The CDDIS has established Digital Object Identifiers (DOIs) for several of its collections of GNSS, SLR, and DORIS data and products; website landing pages have been established, linking to these published DOIs. DOIs for additional items, including VLBI data and products, are under development and review prior to registering and implementation.

Italy INAF Data Center Report

Monia Negusini

Abstract This report summarizes the activities of the Italian INAF VLBI Data Center. Our Data Center is located in Bologna, Italy and belongs to the Institute of Radioastronomy, which is part of the National Institute of Astrophysics.

1 Introduction

The main INAF analysis activity and storage is concentrated in Bologna, where we store and analyze single databases using CALC/SOLVE and the newer νSolve software.

IRA started to store geodetic VLBI databases in 1989; at the very beginning, the databases archived in Bologna mostly contained data that included European antennas'data from 1987 onward. In particular most of the databases available here had VLBI data with at least three European stations. Additionally we stored all of the databases with the Ny-Ålesund antenna's observations. In 2002 we decided to store the complete set of databases available on the IVS Data Centers, although we limited the time span to the sessions observed from 1999 onwards. All the databases were processed and saved with the best selection of parameters for the final arc solutions. In order to perform global solutions, we have computed and stored the superfiles for all the databases.

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INAF Data Center

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Moreover, some Italian VLBI (VITA) sessions have been observed in the last years, and the relevant databases are available.

2 Computer Availability and Routing Access

To date, we have two Linux workstations where all of the VLBI dataset was migrated. One computer, on which the latest release of the Mark 5 Calc/Solve software is installed, has the internet address geovlbi.ira.inaf.it. The νSolve software is installed on a more recent Linux workstation, and its internet address is antartide.ira.inaf.it. Since 2016, a new server with a storage capacity of 11 TB has been available, and, therefore, all sessions observed in the previous years were downloaded and archived, thus completing the catalog. After the transition from the MK3 database format to the vgosDB format, a new directory has been set up. All databases already analyzed were converted to the new format. At present, the MK3 databases are stored in the following directories:

1 = /iranet/geo/dbase1
2 = /iranet/geo/dbase2
3 = /iranet/geo/dbase
4 = /iranet/geo/dbase3
5 = /iranet/geo/dbase4

VgosDB files are stored in: /iranet/geo/vgosDb.
The superfiles are stored in: /iranet/geo/super_c11.
The list of superfiles is stored in the file /iranet/geo/solve/mk5/save_files/SUPCAT.

The username for accessing the databases is geo. The password may be requested by sending an e-mail to negusini@ira.inaf.it.

Paris Observatory (OPAR) Data Center

Christophe Barache, Teddy Carlucci, Olivier Becker, Sebastien Lambert

Abstract This report summarizes the OPAR Data Center activities in 2019–2020. Included is information about functions, architecture, status, future plans, and staff members of the OPAR Data Center.

1 General Information

The Paris Observatory (OPAR) has provided a Data Center for the International VLBI Service for Geodesy and Astrometry (IVS) since 1999. The OPAR (together with CDDIS and BKG) is one of the three IVS Primary Data Centers. Their activities are done in close collaboration for collecting files (data and analysis files) and making them available to the community as soon as they are submitted. The three Data Centers have a common protocol, and each of them:

- has the same directory structure (with the same control file),
- has the same script,
- is able to receive all IVS files (auxiliary, database, products, documents),
- mirrors the other ones every three hours, and
- gives free FTP access to the files.

This protocol gives the IVS community a transparent access to a Data Center through the same directories and continued access to files in case of a Data Center breakdown. The mirroring between OPAR and CDDIS is made with the new secured LFTP SSL since October 2020. The OPAR mirroring script will be replaced by the python scripts provided by IVS and CDDIS after being fully tested and configured by BKG.

The OPAR Data Center is located at Paris Observatory and is operated, since October 2020, on a PC Server with a Debian 10 Linux operating system. To make all IVS products available on-line, the disk storage capacity was significantly increased with a 500 GB disk. The OPAR server is accessible 24 hours per day, seven days per week through an Internet connection with a 2 Mbps rate. Users can get the IVS products by using the new secured FTP protocol (login: anonymous, password: your email). Access to this server is free for users.

To obtain information about the OPAR Data Center please contact: ivs.opa@obspm.fr.

2 Submission of Data and Product Files

To be able to put a file onto the Data Center, Operation and Analysis Centers have to be registered by the IVS Coordinating Center. The file names have to conform to the name conventions. A script checks the file and puts it into the right directory. The upload protocol to submit files to the ivsincoming directory of ivsopar assumes that cURL is set up on the client side. For Windows users, there exist dedicated cURL versions for Windows. You can, e.g., search for a version compatible with your version of Windows at `https://curl.haxx.se/download.html`.

The submission protocol in use since 2017 is as follows. The user is provided by us with a script; say it is named submitopar. To make the script active, the user

SYRTE, Observatoire de Paris - Université PSL, CNRS, Sorbonne Université, LNE

OPAR Data Center

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has to replace the relevant two lines by the login and password that will be sent by us in a separate email.

For UNIX-type system users, the following command submits the files `opa2017a.eops` and `opa2017a.eops.txt` to the Data Center (actually it pushes them to ivsincoming):

```
submitopar -upload opa2017a.eops
               opa2017a.eops.txt
```

To list the files that are currently present in the ivsincoming directory, type:

```
submitopar -display
```

For Windows users, the cURL command line is

```
curl.exe -k -u LOGIN:PASSWD
  -F "fichier=@"FILENAME
  -F "mode=upload"
  https://ivsopar.obspm.fr/upload/
```

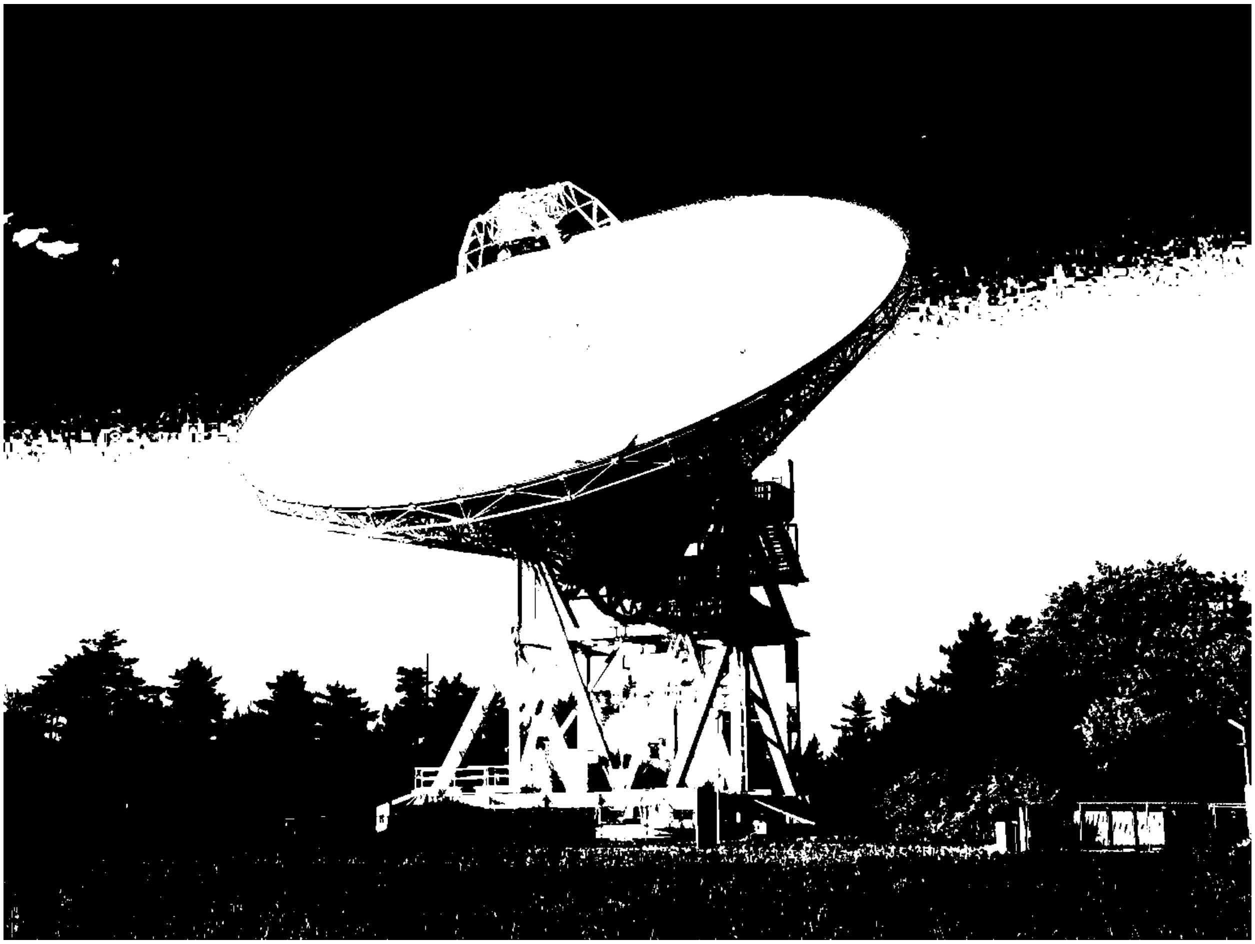
where LOGIN and PASSWD are the login and password that will be sent in a separate email, and FILENAME is the name of the file you want to upload. Note that there is *no space* between @ and the double quotes sign (") before FILENAME.

One can also submit files directly via a web browser at the address `https://ivsopar.obspm.fr/upload/`. The script undergoes permanent improvement and takes into account the IVS components' requests.

The structure of the IVS Data Center is:

- `RECENT\` used for the new mirroring method,
- `ivscontrol\` provides the control files needed by the Data Center (e.g., session code, station code, solution code),
- `ivsdocuments\` provides documents about IVS products,
- `ivsdata\` provides files related to the observations,
- `ivsdata\aux\` provides auxiliary files (e.g., schedule, master, log),
- `ivsdata\db\` contains observation files in database CALC format,
- `ivsdata\ngs\` contains observation files in NGS format,
- `ivsdata\sinex\` contains observation files in SINEX format,
- `ivsproducts\` provides results from Analysis Centers,
- `ivsproducts\eopi\` provides Earth Orientation Parameter results from Intensive sessions,
- `ivsproducts\eops\` provides Earth Orientation Parameter results from 24-hour sessions,
- `ivsproducts\crf\` provides Celestial Reference Frame results,
- `ivsproducts\trf\` provides Terrestrial Reference Frame results,
- `ivsproducts\daily_sinex\` gives solutions in SINEX format of Earth orientation parameters and site positions, mainly designed for combination,
- `ivsproducts\int_sinex\` gives daily Intensive solutions in SINEX format, mainly designed for combination, and
- `ivsproducts\trop\` contains tropospheric time series (starting July 2003).

ANALYSIS CENTERS



Analysis Center of Saint Petersburg University

Dmitriy Trofimov, Sergey Petrov

Abstract This report briefly summarizes the activities of the Analysis Center of Saint Petersburg University during 2019 and 2020. The current status, as well as our future plans, is described.

1 General Information

The Analysis Center of Saint Petersburg University (SPU AC) was established at the Sobolev Astronomical Institute of the SPb University in 1998. The main activity of the SPU AC for the International VLBI Service before 2007 consisted of routine processing of 24-hour and one-hour observational sessions for obtaining Earth Orientation Parameters (EOP) and rapid UT1–UTC values, respectively. In 2008 we began submitting the results of 24-hour session processing.

2 Component Description

Currently we support two series of the Earth Orientation Parameters: spu00004.eops and spu2015a.eops.

- All parameters were adjusted using the Kalman filter technique. For all stations (except the reference station), the wet delays, clock offsets, clock rates, and troposphere gradients were estimated. Troposphere wet delays and clock offsets were modeled as a stochastic process such as a random walk. The clock rates and the troposphere gradients were considered to be the constant parameters.
- The main details of the preparation of the EOP time series spu00004.eops and spu2015a.eops are summarized below:
  - Data span: 1989.01–2020.12
  - CRF: fixed to ICRF-Ext.2
  - TRF: VTRF2005 was used as an a priori TRF
  - Estimated parameters:
    1. EOP: x, y, UT1–UTC, dψ, dε;
    2. Troposphere: troposphere gradients were estimated as constant parameters, and wet troposphere delays were modeled as a random walk process;
    3. Station clocks were treated as follows: offset as a random walk process, rate as a constant.
  - Nutation model: IAU 1980 (spu00004.eops), IAU 2000 (spu2015a.eops)
  - Mapping function: VMF1
  - Technique: Kalman filter
  - Software: OCCAM v.6_2

3 Staff

The assistant professor of Saint Petersburg University, Dmitriy Trofimov, was in charge of the routine processing of the VLBI observations. General coordination and support for the activities of the SPU AC at the Astronomical Institute were performed by the head of the chair of astronomy, Sergey Petrov.

Sobolev Astronomical Institute of Saint Petersburg University

AI SPbU Analysis Center

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4 Current Status and Activities

Until 2019, we processed observations only in NGS format. In 2019 we started working with the vgosDB format. In 2019, we continued the estimation of the five Earth Orientation Parameters. The OCCAM software package (version 6_2) was used for the current processing of VLBI data [1]. The time series is named spu00004.eops. It includes data obtained by the IRIS-A, NEOS-A, R1, R4, RDV, and R&D observing programs, and it covers 32 years of observations (from January 2, 1989 until December 2020). The total number of sessions processed at the SPU AC is about 2,550, of which about 200 VLBI sessions were processed in 2019–2020 and cover the interval from August 2018 to December 2020.

The new series of the Earth Orientation Parameters launched in 2015 was also continued. The total number of points in spu2015a.eops is about 2,550, of which about 200 VLBI sessions were processed in 2019–2020 and cover the interval from August 2018 to December 2020.

Our experience and the equipment of the Analysis Center was used for giving lectures and practical work on the basics of radio interferometry to university students. We use our original manual on the training in modern astrometry and in particular VLBI [2].

5 Future Plans

We had planned to start processing a new series based on the new catalogs of radio sources and stations, but unfortunately we have not yet begun. But these plans have remained. We also plan to improve the equipment in order to solve some technical problems. Lectures and practical exercises for students in a special course on radio astrometry will continue. This course is part of the curriculum of astronomical education at the St. Petersburg State University.

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Geoscience Australia Analysis Center Report 2019–2020

Oleg Titov

Abstract This report gives an overview of the activities of the Geoscience Australia IVS Analysis Center for the period 2019–2020.

1 General Information

The Geoscience Australia (GA) IVS Analysis Center is located in Canberra within the National Geodesy Section; National Positioning Infrastructure Branch; Place, Space and Community Division (PSCD).

2 Activities during the Years 2019–2020

Several celestial reference frame (CRF) solutions have been prepared using the OCCAM 6.3 software. The latest solution (aus2020b.crf) was released in November 2020. VLBI data consisting of approximately 4,000 daily sessions from May 1993 to September 2020 have been used to compute this solution. This includes 10,796,358 observational delays from 4,817 radio sources having three or more observations. Earlier VLBI data between 1980 and 1993 were not used for this solution due to poor quality of astrometric parameters.

Station coordinates were also estimated using No-Net-Rotation (NNR) and No-Net-Translation (NNT) constraints. The long-term time series of the station coordinates have been used to estimate the corresponding velocities for each station. The tectonic motion for the Gilcreek VLBI site after the Denali earthquake was modelled using an exponential function typical of post-seismic deformation.

The adjustment was made by least squares collocation, which considers the clock offsets, wet troposphere delays, and tropospheric gradients as stochastic parameters with a priori covariance functions. The gradient covariance functions were estimated from GPS hourly values.

Observations of several radio stars were undertaken within the Asia-Oceania VLBI (AOV) observational program. Four radio stars were observed (HR1099, UX Ari, HD132742, and LSI+61 303), and the new results were used with the previous astrometric data to improve positions and proper motions of these objects. The preliminary results were reported during the "Journées 2019" meeting in Paris [Titov et al. (2020a)].

A special investigation was made to solve a problem of the transformation of the relativistic group delay model due to the transition from the XF-type correlators to the FX-type correlators. While the legacy baseline-based XF-type correlators calculate the observable values referring to the epoch of reference station, the modern station-based FX-correlators refer the observable to the epoch of the geocenter. This transition from XF- to FX-correlator was not followed by any changes in the IERS Conventions model that still refers to the epoch of the wavefront passage at the reference station. Therefore, the alternative equation of the relativistic group delay model was suggested for application [Titov et al. (2020b)].

Geoscience Australia

GA Analysis Center

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Acknowledgements

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Report for 2019–2020 from the Bordeaux IVS Analysis Center

Patrick Charlot[1], Arnaud Collioud[1], César Gattano[1], Maria Eugenia Gomez[1], Stéphane Paulin-Henriksson[2]

Abstract This report provides an overview of the activities of the Bordeaux IVS Analysis Center in 2019 and 2020. In this period, the imaging of the RDV sessions proceeded in continuation of our previous work, disseminating the resulting images and related information (e.g., structure indices, source compactness, flux densities) through the Bordeaux VLBI Image Database. We carried on with our observing program to monitor optically-bright ICRF3 sources, taking advantage of the ongoing R&D sessions. On the other hand, analysis activities using the GINS software were on hold for most of the time due to personnel leaving. Related to our imaging activity was the development of an algorithm that determines the VLBI jet direction in an automatic way from any given VLBI image. Comparing such directions to preferred directions of astrometric variability shows close consistency for about half of the sources, indicating that this variability is likely due to source structure evolution. Finally, another achievement was the validation of the new geodetic capabilities of the JIVE correlator as part of our contribution to the EU-funded JUMPING JIVE project.

1 General Information

The *Laboratoire d'Astrophysique de Bordeaux (LAB)* is a research unit funded by the University of Bordeaux and the *Centre National de la Recherche Scientifique (CNRS)*. It is part of a bigger organization: the *Observatoire Aquitain des Sciences de l'Univers (OASU)*, formerly Bordeaux Observatory. The OASU has a wider scope, covering environmental sciences besides historic activities in astronomy and astrophysics. A specific role of the observatory is to provide support for acquiring, analyzing, and archiving observations of various types in these fields, including the participation in national and international services such as the IVS. Delivering such support, specifically, falls within the mandate of the *Pluridisciplinarité au service de l'Observation et de la Recherche en Environnement et Astronomie* (POREA) service unit of the OASU.

VLBI activities at the LAB are carried out within the M2A (*Métrologie de l'espace, Astrodynamique, Astrophysique*) team. Contributions to the IVS have been mostly concerned with maintaining and improving the International Celestial Reference Frame (ICRF). This includes regular imaging of the ICRF sources and evaluation of their astrometric suitability, as well as developing specific VLBI observing programs for enhancing the celestial frame. In addition, the group conducts VLBI analyses with the GINS software package, a multi-technique software developed by the CNES (*Centre National d'Etudes Spatiales*) which has the ability to process data from most space geodetic techniques, including GNSS, DORIS, SLR, LLR, VLBI, satellite altimetry, and other space missions [1].

2 Description of the Analysis Center

The Bordeaux IVS group is engaged in analyzing the IVS-R1 and IVS-R4 sessions with the GINS software package. From these sessions, Earth Orientation Pa-

1. OASU–Laboratoire d'Astrophysique de Bordeaux
2. OASU–Pluridisciplinarité au service de l'Observation et de la Recherche en Environnement et Astronomie

Bordeaux Analysis Center

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rameter (EOP) estimates with six-hour resolution were produced. The focus of this analysis work is placed upon developing a state-of-the-art operational VLBI solution with the goal of contributing to the IVS primary EOP combination in the future.

The Analysis Center is further engaged in imaging ICRF sources on a regular basis. This is achieved by a systematic analysis of the data from the RDV sessions, which is carried out with the AIPS and DIFMAP software packages. The aim of the regular imaging work is to assess the astrometric suitability of the sources based on the so-called "structure index." Characterization of the source positional instabilities and comparison of these instabilities with their structural evolution is an additional direction of work. Such studies are essential for identifying sources of high astrometric quality, a requirement to best define the celestial frame.

Occasionally, the group is also involved in specific observing programs or other VLBI developments. For the present period, these include the monitoring of optically-bright ICRF sources (i.e. detected by the Gaia mission) and the validation of the newly-implemented geodetic capabilities of the Joint Institute for VLBI-ERIC (JIVE) correlator (within the JUMPING JIVE project), both of which are described below.

3 Scientific Staff

The period 2019–2020 was marked by some changes in personnel. As noted in our previous report, a new post-doctoral fellow, Maria Eugenia Gomez, hailing from the University of La Plata (Argentina), had joined us just before that, in November 2018, for a two-year contract. On the other hand, César Gattano completed his post-doctoral stay at the end of 2019, after more than two years with us. Additionally, two long-standing staff members, Antoine Bellanger and Géraldine Bourda, left the group in mid-2019, moving to other activities. Since both of them were involved in analyses and developments relating to the GINS software package, the consequence was that such activities remained on hold until a new person, Stéphane Paulin-Henriksson, from the POREA unit in OASU, took over during 2020. In all, five individuals contributed to one or more of our VLBI analysis and research activities in the period. A description of what each person worked on, along with an estimate of the time spent on it, is given below.

- Patrick Charlot (50%): researcher with overall responsibility for Analysis Center work. His primary interests include all aspects of ICRF, comparisons with the Gaia frame, studies of radio source structure and its impact on astrometric VLBI, and astrophysical interpretation. He also leads a work package about geodesy in the JUMPING JIVE project.
- Arnaud Collioud (90%): engineer with a background in astronomy and interferometry. His duties include imaging the sources observed in the RDV sessions using AIPS and DIFMAP and developing the Bordeaux VLBI Image Database and *IVS Live* tool. He also contributes to research in astrometry and astrophysics making use of these data.
- César Gattano (50%, until December 2019): post-doctoral fellow funded by the CNES. His interest is in the celestial frame, in particular in the characterization of the time series of source positions and the connection of the observed instabilities with the source astrophysics. He is now with the Astronomical Institute at the University of Bern (Switzerland).
- Maria Eugenia Gomez (until November 2020): post-doctoral fellow funded by the JUMPING JIVE project to validate the geodetic capabilities of the JIVE correlator and to determine the positions of the European VLBI Network (EVN) telescopes. She is now back at the University of La Plata.
- Stéphane Paulin-Henriksson (70%): engineer with a background in astronomy. His tasks are to maintain the GINS software package installation locally, to contribute to comparisons with other VLBI software packages, and to develop procedures to automate the processing for future operational analyses.

4 Current Status

As reported previously, one of our goals is to implement an operational analysis of the IVS-R1 and IVS-R4 sessions using the GINS software package. Since the VLBI capability of GINS has not been widely used, a prerequisite is to assess the quality of the results derived with GINS by validating them against equivalent results obtained with other VLBI software packages. In particular, we wish to compare the individual components of the VLBI delay model in GINS with the same such components calculated independently. Based on expertise within the group, we have selected the Vienna

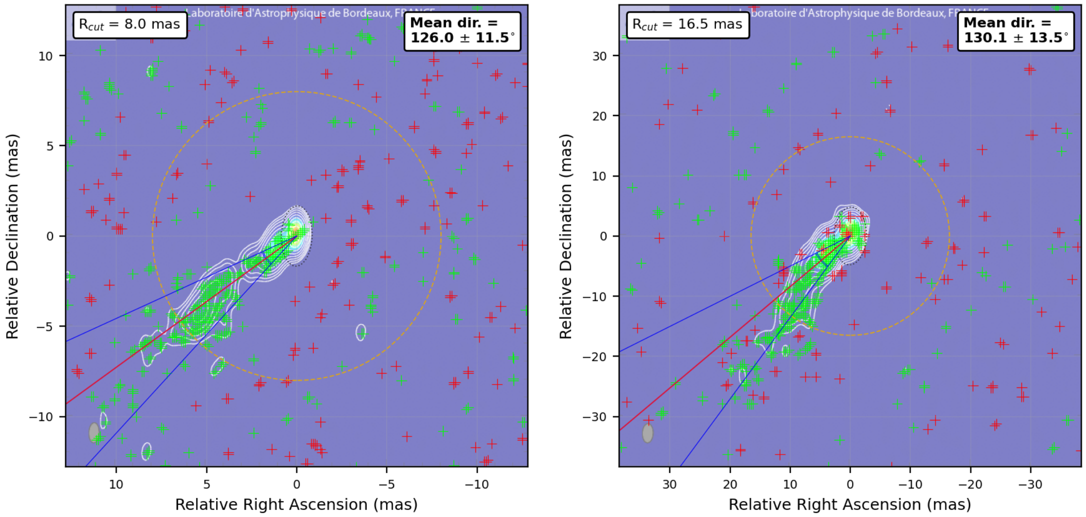

Fig. 1 VLBI contour maps of the ICRF3 source 0333+321 at X band (left panel) and S band (right panel) for epoch 2009 July 29. The superimposed green and red crosses show the underlying clean components which define the source model. Also superimposed onto each map are the jet direction and its uncertainty (shown as red and blue straight lines), as determined automatically with the method that we devised. The yellow circle indicates the cutoff radius that served to extract the clean components used in the calculation.

VLBI Software (VieVS) as the reference software for these comparisons. Unfortunately, due to the change of personnel outlined above, this work was on hold for most of the period and was reactivated only recently.

Another major part of our activity consists in systematically imaging the sources observed in the RDV sessions. During 2019 and 2020, four such sessions were processed (RV126, RV128, RV140, RV142), resulting in 591 VLBI images at either X- or S-band for 228 different sources. The imaging work load has been shared with USNO since 2007 (starting with RDV61); the USNO group processes the odd-numbered RDV sessions while the Bordeaux group processes the even-numbered ones. The VLBI images are used in a second stage to derive structure correction maps and visibility maps along with values for structure indices and source compactness (see [2, 3] for a definition of these quantities) in order to assess astrometric source quality. All such information is made available through the Bordeaux VLBI Image Database (BVID)[1] [4]. At present, the BVID comprises a total of 6,992 VLBI images for 1,420 different sources (with links to an additional 6,775 VLBI images from the Radio Reference Frame Image Database of USNO) along with 13,767 structure correction maps and as many visibility maps. These originate from 83 sessions spanning a total of 26 years.

[1] See http://bvid.astrophy.u-bordeaux.fr.

5 Achievements

Apart from the recurring activities described in the previous section, we have also developed specific work to take the BVID images further. One line of investigation was aimed to estimate VLBI jet directions in an automatic way, directly from the BVID images and without going through the usual (and time-consuming) model-fitting approach. The algorithm that we devised for this purpose first determines the distribution of flux density in a VLBI image as a function of azimuth, considering all clean components within a given radius (as measured from the central VLBI component position), which is steadily increased up to a certain cutoff value depending on the image noise level. The overall jet direction is then derived as the mean of the directions calculated for all radius values considered. Figure 1 plots the jet directions obtained in this way for the source 0333+321 at X-band and S-band based on the BVID images from the RDV76 session. As shown in this figure, the estimated jet directions agree well with those observed by inspecting visually the contour maps which are superimposed in each panel. A practical application of such a calculation is the optimization of scheduling in a way that avoids observing scans in a configuration where the sky-projected VLBI baseline is parallel to the jet, since these scans are subject to large structural delay effects for extended sources like 0333+321.

The determination of the VLBI jet directions with the method described above has also allowed us to further explore the connection between VLBI astrometric variability and source astrophysics. As reported in our previous biennial report and more recently in [5], we found that more than half of the 215 sources most-observed in geodetic VLBI may be characterized by at least one preferred direction of astrometric variability, with three-quarters of these showing a unique preferred direction and the rest showing two or more such directions. We presupposed that these preferred directions reflect astrophysical phenomena occurring within the VLBI jets, which modify the apparent source structure and hence the observed VLBI astrometric position. To assess this hypothesis, we compared the set of preferred directions derived from the source position time series and the jet directions extracted from the BVID source maps for a sample of 115 common sources. For each of these sources, an averaged jet direction was calculated by combining the jet direction extracted from all available images (i.e., at multiple epochs). The average jet direction was then compared to the preferred direction(s) extracted from the position time series. From this comparison, we found that the first or second preferred direction of astrometric variability lies within 15° of the VLBI jet direction for 55 of the sources, that is about half of the sample, hence indicating that the observed astrometric variability is most likely due to the changing VLBI jet morphology for those sources.

On the observing side, we have taken advantage of the R&D sessions to pursue further the monitoring of some under-observed optically-bright ICRF3 sources (i.e., detected by Gaia). Starting from summer 2020, our initial strategy [6] was refined in a way that the list of targets is now adjusted prior to each R&D session. Only sources that have not been observed for the past 30 days, taking into account all IVS sessions, are scheduled, with preference given to those that are brighter than magnitude 18, and then 19 and 20 (in decreasing order), all of which are subject to having a structure index smaller than 3 (as previously). This new scheme was made possible thanks to the *IVS Live* Web tool (see below) which allows us to obtain the observing status of any given source at any given moment.

Another achievement during the period was the validation of the newly-implemented geodetic capability of the EVN software correlator at JIVE (SFXC) as part of our contribution to the JUMPING JIVE project [7]. Although not directly related to IVS activities, this capability is nonetheless of interest to the IVS community, since it now makes the SFXC correlator fully able to process IVS-style data and export them through the standard Mark4-HOPS-vgosDB geodetic route. For exercising this route, the data from the IVS-R1872 session, originally correlated with the Bonn DIFX correlator, were reprocessed with the SFXC correlator, fringe-fitted with HOPS, and exported to vgosDB format, after which the content of the resulting vgosDB file was compared to that of the original file produced in Bonn. Looking at the multi-band delays (Figure 2), the comparison indicates that the differences between the two sets of quantities have a weighted rms of 5.5 ps and fall within the calculated uncertainty for 95% of the data, which is in line with the expectations [8]. Taking advantage of this new capability, we have also gone further and conducted two dedicated EVN experiments, in June 2018 and October 2020, for the purpose of determining the geodetic positions of the EVN non-geodetic antennas, also one of the goals of the JUMPING JIVE project. Here again the new route was successfully exercised and the corresponding data are being analyzed.

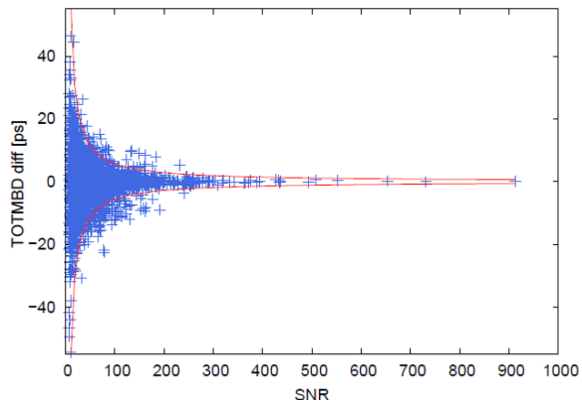

Fig. 2 Comparison of the total X band delay derived with the Bonn and JIVE correlators for the data of the session IVS-R1872 conducted on 10 December 2018. Differences are plotted with respect to SNR. The red curve materializes the $\pm 1\sigma$ uncertainty.

Finally, it is worth pointing out that the ICRF3 work has also been fully published during the period [9]. Besides the frame presentation and various comparisons, including between radio and optical positions, the paper also addresses the future evolution of the ICRF and prospective observations by the IVS for this purpose.

6 Dissemination and Outreach

The *IVS Live*[2] website, a specific tool developed by the Bordeaux group, provides "Live" information about ongoing IVS sessions, including VLBI images of the observed sources [10]. The website is updated automatically based on the IVS master schedule. It now incorporates 10,396 IVS sessions, involving 87 stations and featuring 2,992 sources. Tracing the connections indicates that there were 896 visits from 611 different users in 37 countries during 2019 and 2020. The statistics of access to the BVID, 1,149 visits from 594 different users in 57 countries over that period, are of the same magnitude. As for dissemination, Patrick Charlot taught various aspects of VLBI at two training schools, the 3rd IVS Training School on VLBI for geodesy and astrometry held in Las Palmas (Gran Canaria, Spain) on 14–16 March 2019 and the African VLBI Network training school that took place in Hartebeesthoek (South Africa) in May 2019. Also to be mentioned is the preparation of a poster about IVS that is now hanging in the main conference room of the OASU building.

7 Future Plans

Our plans for the next two years will follow the same analysis and research lines. We expect at first to validate the quality of the geodetic VLBI results derived with GINS by extensive comparisons against those drawn from other VLBI software packages, in particular the Vienna VLBI software. After this validation, the aim will be to move towards an operational analysis of the IVS-R1 and IVS-R4 sessions. Imaging the RDV sessions and evaluating the astrometric suitability of the sources, a specificity of the Bordeaux group, will be pursued further. Based on the images available in BVID, we also plan to explore the relationship between source structure and the positional offsets that are observed between the three ICRF3 frequencies and between VLBI and Gaia for some sources [9], taking also advantage of the algorithm that we developed to determine the VLBI jet directions. On the geodesy side, our goal will be to complete the analysis of the two dedicated experiments that have been conducted to estimate the positions of several non-geodetic EVN antennas.

[2] Available at http://ivslive.astrophy.u-bordeaux.fr.

Acknowledgements

We would like to thank the OASU for continued support of the Bordeaux IVS Analysis Center. The JUMPING JIVE project received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 730884.

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BKG VLBI Analysis Center

Gerald Engelhardt, Anastasiia Girdiuk, Markus Goltz, Dieter Ullrich

Abstract In 2019 and 2020, the activities of the BKG VLBI Analysis Center, as in previous years, consisted mainly of routine computations of Earth orientation parameter (EOP) time series. The VLBI group at BKG continued its regular submissions of time series of tropospheric parameters and the generation of daily SINEX (Solution INdependent EXchange format) files. The analysis of *Intensive* sessions for UT1–UTC estimation was also continued. All solutions from 2019 are based on the Calc/Solve software, release 2014.02.21 [2], using the old Mark III database format. At the same time, the new geodetic VLBI software νSolve [4] was also used for the analysis of sessions in the new vgosDB data format. At the end of 2019, the new Calc/Solve software, release 2019.11.21 [3], was successfully installed and tested to generate input for the ITRF2020 VLBI combination solution.

1 General Information

The Federal Agency for Cartography and Geodesy (BKG) maintains a VLBI Analysis Center for the generation of products defined by the International VLBI Service for Geodesy and Astrometry (IVS). This includes data analysis for generating IVS products and special investigations with the goal of increasing accuracy and reliability.

The BKG VLBI Analysis Center is responsible for the computation of time series of EOP and tropospheric parameters, for the generation of SINEX files for 24-hour VLBI sessions and one-hour *Intensive* sessions, and for the generation of quarterly updated global solutions for TRF and CRF realizations. Besides data analysis, the BKG VLBI group was also responsible for writing schedules for the *Int2* UT1–UTC observing sessions in 2019.

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2 Data Analysis at BKG

At BKG, the Mark 5 VLBI data analysis software system Calc/Solve, release 2014.02.21 [2], has been used for VLBI data processing in the old chain of Mark3 databases. It is running on a Linux operating system. At the same time, data analysis of sessions in the new vgosDB format was carried out with the new interactive geodetic VLBI software νSolve [4].

Furthermore, the new Calc/Solve software, release 2019.11.21 [3], has been used since the end of 2019 after its successful installation and testing. All old Mark3 databases could thus be transformed into the new vgosDB data format. This new software also allows the use of new models in the VLBI evaluation, e.g., galactic aberration and gravitational deformation of VLBI antennas or the generation of so-called tropospheric path delay (TRP) files derived from the Vienna Mapping Function (VMF3) data. The TRP files contain external information about the troposphere on a scan-by-scan basis, specifically the a priori delay, dry and wet mapping functions, and gradient mapping functions. The BKG VLBI group uses TRP files to input data related to VMF3. The VMF3 data were downloaded daily from the server of the Vienna University of Technology.

On the basis of the new software, it was possible to further develop the new processing chain of vgos databases for the generation of IVS products in the reporting period. The technological connection between the VLBI data in the Data Center, preliminary evaluation with νSolve, product-based evaluation with Calc/Solve, and product generation for the IVS Data Centers is realized by Python scripts.

- **Processing of Correlator Output**
  The BKG group continued the generation of calibrated databases in the new vgosDB format for the sessions correlated at the Max Planck Institute for Radio Astronomy (MPIfR)/BKG Astro/Geo Correlator at Bonn (e.g., EURO, OHIG, and T2) and submitted them to the IVS Data Centers.
- **Scheduling**
  In cooperation with the Institute of Geodesy and Geoinformation of the University of Bonn (IGGB), BKG continued scheduling the Int2 *Intensive* sessions, which are mostly observed on the ISHIOKA–WETTZELL baseline. In 2019, a total of 102 schedule files were created. In 2020, this work was discontinued due to the establishment of the IVS VLBI Operation Center Wettzell, which took over this function.
- **BKG EOP Time Series**
  The BKG EOP time series bkg00014 was continued [1] but only for the R4 session series, available in the old MK3 data format. This old EOP time series based on MK3 databases was stopped at the end of 2020. It was replaced by the new bkg2020a series, based on sessions in the new vgosDB data format. The main difference to the previous solution is the use of new models for, for instance, galactic aberration, mean pole tides, gravitational deformation, and high-frequency EOP, which are also used for the realization of ITRF2020. Further, the new VLBI stations NYALE13S in Norway and SVERT13V in Russia were included successfully in the data processing.
  Each time after the preprocessing of any new VLBI session (correlator output vgosDB database version 1), a new global solution with 24-hour sessions since 1984 was computed, and the EOP time series bkg2020a was extracted. Altogether, 5,785 sessions were processed. The main parameter types in this solution are globally estimated station coordinates and velocities together with radio source positions. The datum definition was realized by applying no-net-rotation and no-net-translation conditions for 25 selected station positions and velocities with respect to ITRF2014 and a no-net-rotation condition for 303 defining sources with respect to ICRF3. The station coordinates of the telescopes AGGO (Argentina), AIRA (Japan), CHICHI10 (Japan), CTVASTJ (Canada), DSS13 (USA), DSS34 (Australia), DSS36 (Australia), ISHIOKA (Japan), KASHIM11 (Japan), KASHIM34 (Japan), KOGANEI (Japan), NYALE13S (Norway), PT_REYES (USA), RAEGSMAR (Azores), RAEGYEB (Spain), SEST (Chile), SINTOTU3 (Japan), SVERT13V (Russia), TIANMA65 (China), TIDBIN64 (Australia), TIGOCONC (Chile), TSUKUB32 (Japan), UCHINOUR (Japan), VERAISGK (Japan), VERAMZSW (Japan), WARK30M (New Zealand), WETTZ13N (Germany), WIDE85_3 (USA), and YEBES40M (Spain) were estimated as local parameters in each session.
- **BKG UT1 *Intensive* Time Series**
  The analysis of the UT1–UTC *Intensive* time series bkgint14 was continued. But this old time series based on MK3 databases was stopped at the end of August 2020 and replaced by the new bkg2020a series, which is based on *Intensive* sessions in the new vgosDB data format. The main difference to the old series is again the use of the new models and the new a priori TRF and CRF.
  The series bkg2020a was generated with fixed TRF (ITRF2014) and fixed ICRF3. The a priori EOP were taken from final USNO series [5]. The estimated parameter types were only UT1–TAI, station clock, and zenith troposphere. A total of 1,198 UT1 *Intensive* sessions were analyzed for the period from 2018.01.02 to 2020.12.30.
- **Tropospheric Parameters**
  The VLBI group of BKG continued regular submissions of long time series of tropospheric parameters to the IVS (wet and total zenith delays and horizontal gradients) for all VLBI sessions since 1984, which were still available in the old MK3 data format. This old series, bkg00014, based on MK3 databases was stopped at the end of 2020. It was replaced by the new bkg2020a series, which is based on sessions in the new vgosDB data format. The tropospheric parameters were extracted from the standard global solution bkg2020a and trans-

formed into tropospheric SINEX format for IVS submission.

- **Daily SINEX Files**
The VLBI group of BKG also continued regular submissions of daily SINEX files (bkg2014a) for all available 24-hour sessions in the old MK3 data format for the IVS combined products and for the IVS time series of baseline lengths. This solution was stopped in mid-2020 and replaced by a solution, bkg2020a, based on sessions in the new vgosDB data format and new parameterization aligned with ITRF2020 requirements.
The new 24-hour session solutions (bkg2020a) include estimates of station coordinates, radio source coordinates, and EOP including the X,Y-nutation parameters. The a priori datum for TRF is defined by the ITRF2014, and ICRF3 is used for the a priori CRF information.
- **SINEX Files for *Intensive* Sessions**
The generation of SINEX files for all *Intensive* sessions (bkg2014a) in the old MK3 data format continued until mid-2020. This solution was replaced by a new set of SINEX files (bkg2020a) based on *Intensive* sessions in the new vgosDB data format and new models and a priori TRF (ITRF2014) and CRF (ICRF3) in the parameter estimation.
The parameter types are station coordinates, pole coordinates and their rates, and UT1–TAI and its rate. But only the normal equations stored in the SINEX files are important for further intra-technique combination or combination with other space geodetic techniques.
- **Contribution to ITRF2020**
The BKG Analysis Center submitted 6,201 SINEX files for 24-hour sessions to IVS as input to a combined VLBI solution for ITRF2020. There is no difference in the parameterization to the IVS product daily SINEX files bkg2020a. The contribution from BKG to ITRF2020 also includes 38 SINEX files that were generated from the analysis of broadband vgosDB databases.

3 Personnel

Table 1 Personnel at the BKG Analysis Center.

Gerald Engelhardt	gerald.engelhardt@bkg.bund.de +49-341-5634438
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Dieter Ullrich	dieter.ullrich@bkg.bund.de +49-341-5634328
Reiner Wojdziak (until June 30, 2020)	reiner.wojdziak@bkg.bund.de +49-341-5634286

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BKG/DGFI-TUM Combination Center 2019+2020 Biennial Report

Sabine Bachmann[1], Hendrik Hellmers[1], Sandra Schneider-Leck[1], Sonja Geist[1], Daniela Thaller[1], Mathis Bloßfeld[2], Manuela Seitz[2]

Abstract This report summarizes the activities of the BKG/DGFI-TUM Combination Center in 2019 and 2020 and outlines the planned activities for 2021 and 2022. The main focus in 2019 and 2020 was the continuous generation of combined products for the rapid sessions R1 and R4, as well as generating quarterly solutions based on all 24-hour sessions since 1984. Additional IVS Analysis Centers were included in the combination as soon as their contributions were validated. We started a major update and re-design of the combination software as well as the combination procedures in order to become more flexible and more user-friendly. Furthermore, the planning and testing of the IVS combination for generating the official IVS input to the ITRF2020 started, and the session-wise IVS combined SINEX files will be submitted to the ITRS Combination Centers in early 2021.

1 General Information

The BKG/DGFI-TUM Combination Center was established in October 2008 as a joint effort of the Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG) and the German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut) at the TU Munich (DGFI-TUM). The participating institutions as well as the tasks and the structure of the IVS Combination Center are described in [9]. The tasks comprise quality control and a timely combination of the session-based intermediate results of the IVS Analysis Centers (ACs) into a final combination product (e.g., Earth Orientation Parameters, or EOP). There are two types of combined products: (1) a rapid product as a session-wise combination of the R1 and R4 sessions and (2) the so-called Quarterly combination accumulating all 24-hour sessions over approximately 40 years now. In close cooperation with the IVS Analysis Coordinator, the combination results are released as official IVS products. The Combination Center is also expected to contribute to the generation of the official IVS input to any ITRF realization.

The BKG/DGFI-TUM Combination Center performs a combination of session-based results of the IVS ACs on an operational basis. The strategy for the combination is based on the combination of normal equations and was adopted from the combination process as developed and performed by the IVS Analysis Coordinator (cf., [7, 8]).

At BKG, the following tasks are performed:

- Quality control of the AC results: checking the format of the results and their suitability for combination, identification and reduction of outliers, comparison of the Analysis Centers' results with each other, and comparison of the results with external time series provided by the IERS (International Earth Rotation and Reference Systems Service), IGS (International GNSS Service), and ILRS (International Laser Ranging Service).
- Feedback to the Analysis Centers: quality control results are available at the BKG IVS Combination Center website [6].
- Generation of high-quality combination products and timely archiving and distribution: combination

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products are created by using the combination part DOGS_CS of DGFI-TUM's software package DOGS (DGFI orbit and geodetic parameter estimation software) [4].
- Submission of official IVS combination products to the IERS: the products are submitted to the responsible IERS components to be used for IERS product generation (e.g., for EOP rapid products and the EOP series IERS C04).
- Generation of the official IVS input to the ITRF: the combined session products (from 1984 to present) are submitted for ITRF computation in the form of normal equations in SINEX format. This work is also supported by the staff of the IERS Central Bureau hosted at BKG.
- Archiving of final results: Final results are archived in the IVS Data Center at BKG and mirrored to the IVS Data Centers at Observatoire de Paris (OPAR) and the Goddard Space Flight Center (GSFC). This work is assisted by the staff of BKG's IVS Data Center in Leipzig and Frankfurt.

DGFI-TUM is in charge of the following Combination Center activities:

- DGFI is developing state-of-the-art combination procedures. This work, as well as the following item, is related to the ITRS Combination Center at DGFI and DGFI's efforts within the IERS WG on Combination at the Observation Level (COL).
- The software DOGS_CS is updated by implementing and documenting the developed state-of-the-art combination procedures.
- The DGFI DOGS software package is continuously updated to be in accordance with the IERS Conventions.

2 Activities during the Past Years

At BKG, the following activities were performed in 2019 and 2020:

- Integration of the new DOGS_CS software into the IVS combination process.
- Generation of a combined solution for IVS 24-hour rapid sessions twice a week.
- Generation of a combined long-term solution of IVS 24-hour sessions every three months.
- Ensuring that the combination process is in agreement with the IERS2010 Conventions.
- Preparing the IVS combined contribution to the ITRF2020 for the IERS ITRS Combination Centers.
- Inclusion of new ACs: National Geographic Institute of Spain (IGE) and Onsala Space Observatory, Sweden (OSO) into the routine rapid combination.
- Testing of potential new ACs: Instituto Geografico Nacional, Argentina (IGN) and European Space Agency (ESA).
- Refinements of the combination procedure and implementation of source position combination.

Concerning the operational rapid combination, contributions of two additional ACs were added. IGE using the software Where and OSO using ivg::ASCOT were introduced into the combination routine. This increases the number of regularly contributing ACs to twelve.

At DGFI-TUM, the following activities were performed in 2019 and 2020:

- Full re-design of software handling.
- Construction and integration of restitution equations.
- Update of the similarity transformation program.
- Handling of the new SINEX block with the loading corrections.

3 Staff

The list of the staff members of the BKG/DGFI-TUM Combination Center in 2019+2020 is given in Table 1.

4 Current Status

By the end of 2020, up to twelve IVS ACs (ASI, BKG, DGFI-TUM, GFZ, GSFC, IAA, IGE, NMA, OPA, OSO, USNO, and VIE) contributed regularly to the IVS combined rapid and quarterly product (see [6]). The rapid solutions contain R1 and R4 sessions only, and new data points are added twice a week as soon as the SINEX files of at least four IVS ACs are available. Long-term series are generated usually in a quarterly

Table 1 Staff members of the BKG/DGFI-TUM Combination Center.

Name	Affiliation	Function	E-Mail
Sabine Bachmann	BKG	Combination procedure development	sabine.bachmann@bkg.bund.de
Hendrik Hellmers	BKG	Operational combination	hendrik.hellmers@bkg.bund.de
Sandra Schneider-Leck	BKG	Operational combination	sandra.schneider-leck@bkg.bund.de
Sonja Geist	BKG	IVS CC website	sonja.geist@bkg.bund.de
Daniela Thaller	BKG	Scientific guidelines	daniela.thaller@bkg.bund.de
Mathis Bloßfeld	DGFI-TUM	Combination strategies, DOGS_CS development	mathis.blossfeld@tum.de
Manuela Seitz	DGFI-TUM	Combination strategies	manuela.seitz@tum.de

sequence and include all 24-hour sessions since 1984. The quarterly series include long-term EOP, station positions, and velocities. Furthermore, a VLBI TRF is generated and published.

The IVS combination software was extended to process source parameters for session-wise source combination as well as for a consistent generation of TRF and CRF.

The preparations for the combined IVS input to ITRF2020 started. The handling of the new SINEX block providing the loading corrections applied by the ACs has been implemented and tested within the combination procedures. The process for generating the official IVS combined contribution to ITRF2020 is set up in the following way: The session-wise combined SINEX files will include EOPs at 12:00 UTC epochs, the loading corrections by the ACs are removed so that the IVS combined solutions are free of loading corrections, and the session-wise SINEX files of the official IVS combination will contain only station coordinates and EOPs. The inclusion of radio source positions into the session-wise combined SINEX files needs further investigations, and the submission of experimental combined SINEX files is foreseen in the course of 2021.

In general, the entire combination process was updated along with the fully re-designed software in order to allow a more flexible and user-friendly operation of the IVS combination. Several tests of the new software and combination procedures are already done successfully. The complete transition from the old combination software and procedures to the new set-up was almost finished by the end of 2020 for the quarterly combination as well as for the combined contribution to ITRF2020. The transition for the rapid combination will be finished in the first half of 2021.

The results of the combination process are archived by BKG's IVS Data Center.

The combined rapid EOP series, as well as the results of the quality control of the AC results, are also available directly at the BKG/DGFI-TUM Combination Center website [6] or via the IVS Analysis Coordinator website.

5 Future Plans

In 2021 and 2022, the work of the BKG/DGFI-TUM Combination Center will focus on the following aspects:

- Generating the official IVS combined contribution for ITRF2020 (i.e., session-wise SINEX files containing station coordinates and EOPs).
- Transitioning to ITRF2020 for the IVS combined products as soon as ITRF2020 becomes official.
- Investigating the impact of different ITRS realizations (DTRF2020, ITRF2020, and JTRF2020) on the combined EOP (in analogy to [3]).
- Generating a combined IVS product with homogeneously estimated TRF, CRF, and EOPs.
- Investigating the impact of homogeneously estimating TRF, CRF, and EOPs on the resulting parameters.
- Generating an experimental IVS combined series based on the input by the ACs for ITRF2020 (i.e., session-wise SINEX files containing also radio source positions together with station coordinates and EOPs).
- Including new ACs into the routine rapid and quarterly combination.
- Improving the combination strategy for small station networks to increase their contribution to the EOP.
- Developing strategies and processes for an automatic generation of IVS combined products.

- Improving and extending the presentation of the IVS combined results at our website.
- Embedding the IVS combination processes into BKG's quality management following ISO 9001.

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Matera CGS VLBI Analysis Center

Roberto Lanotte[1], Simona Di Tomaso[1], Giuseppe Bianco[2]

Abstract This paper reports the VLBI data analysis activities at the Space Geodesy Center (CGS) of the Italian Space Agency (ASI) in Matera, from January 2019 through December 2020, and the contributions that the CGS intends to provide for the future as an IVS Analysis Center.

1 General Information

The CGS VLBI Analysis Center is located at the Matera VLBI station close to the town of Matera in the middle south of Italy. The Matera VLBI station became operational at the ASI/CGS in May 1990. Since then, it has been active in the framework of the most important international programs. The CGS, operated by E-GEOS S.p.A. (an ASI/Telespazio company) under an ASI contract, provides full scientific and operational support using the main space geodetic techniques: VLBI, SLR, and GPS. The work presented in this report is carried out by the E-GEOS staff consisting of Roberto Lanotte and Simona Di Tomaso.

2 Activities during the Past Years

During 2019-2020, the following activities were performed at CGS:

- Global VLBI Solutions asi2019a and asi2020a.
  In these years we continued the annual realization of global VLBI solutions. The solutions are named asi2019a and 2020a and were realized using the CALC/SOLVE software developed at NASA/GSFC. The main and final characteristics of them are:

  asi2019a:

  – Data span: 1984.01.04–2018.12.29 for a total of 5,080 sessions.
  – Estimated Parameters:
    · Celestial Frame: Right ascension and declination as global parameters for 3,850 sources,
    · Terrestrial Frame: Coordinates and velocities for 92 stations as global parameters, and
    · Earth Orientation: X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dX, and dY.

  asi2020a:

  – Data span: 1981.11.18–2019.12.20 for a total of 3,689 sessions.
  – Estimated Parameters:
    · Celestial Frame: Right ascension and declination as global parameters for 4,447 sources,
    · Terrestrial Frame: Coordinates and velocities for 59 stations as global parameters, and
    · Earth Orientation: X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dX, and dY.

- IVS Tropospheric Products.
  Regular submission of tropospheric parameters (wet and total zenith path delays, east and north horizontal gradients) for all VLBI stations observing in the IVS R1 and R4 sessions continued

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during 2019–2020. Currently, 2,030 sessions were analyzed and submitted, covering the period from 2002 to 2020. The results are available at the IVS products ftp site.

- Daily Solution Files (DSNX).
  Regular submission of daily sinex files for the IVS project "Daily EOP + station-coordinates solutions" continued during 2019-2020. All sessions lasting at least 18 hours were analyzed, and at the present approximately 5,900 sessions were submitted to IVS.
- CGS contribution to IVS combination for ITRF2020.
  Approximately 6,600 VLBI sessions from 1979 to the end of 2020 were analyzed following the instructions provided by the IVS Analysis Coordinator, John Gipson. The produced sinex files were submitted to be included in the IVS contribution to ITRF2020.
- Software development.
  We continued the development of the software "*resolve*". The main goal of this software is the visual editing of a VLBI database. One of the reasons that led us to the development of this software was to have the capability of working on the output obtained from a run of SOLVE in BATCH mode. At present we have used *resolve* to edit approximately all of the databases of the daily sinex production.

2.1 Staff at CGS Contributing to the IVS Analysis Center

- Dr. Giuseppe Bianco, responsible for CGS/ASI (primary scientific/technical contact).
- Dr. Rosa Pacione, responsible for scientific activities, E-GEOS.
- Dr. Roberto Lanotte, geodynamics data analyst, E-GEOS.
- Dr. Simona Di Tomaso, geodynamics data analyst, E-GEOS.

3 Future Plans

- Continue and improve the realization of our global VLBI solution, providing its regular update on time.
- Continue to participate in the IVS analysis projects.

DGFI-TUM Analysis Center Biennial Report 2019+2020

Matthias Glomsda, Manuela Seitz, Detlef Angermann, Michael Gerstl

Abstract This report describes the activities of the DGFI-TUM Analysis Center (AC) in 2019 and 2020. Besides regular IVS submissions, DGFI-TUM reprocessed nearly all past VLBI sessions that were selected for the ITRF2020. In connection with the latter, our analysis software DOGS-RI was extensively enhanced to consider the new geophysical models and technical details to cope with all legacy S/X and new VGOS sessions. An additional research focus was set on the application of non-tidal loading at different levels of the parameter estimation process.

1 General Information

DGFI-TUM has been serving as an IVS AC since the establishment of the IVS in 1999. Since November 2008, we are an operational AC regularly submitting datum-free normal equations for the rapid turnaround sessions in the SINEX format. Since 2008, we are also involved in the BKG/DGFI-TUM Combination Center by maintaining the combination software DOGS-CS (DGFI Orbit and Geodetic parameter estimation Software – Combination and Solution).

DGFI-TUM is an institute of the Technische Universität München (TUM) since January 2015 and located in the city center of Munich, Germany. The research performed at DGFI-TUM covers many different fields of geodesy (e.g., reference systems, satellite altimetry, or Earth system modeling) and includes contributions to national and international scientific services and research projects, as well as various functions in scientific organizations (see http://www.dgfi.tum.de).

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2 Staff

At the beginning of 2019, Matthias Glomsda took over the operational IVS analysis from Younghee Kwak, who left DGFI-TUM at that time. Michael Gerstl retired in 2018 but is still supporting the software development of our VLBI analysis software DOGS-RI (Radio Interferometry). Table 1 lists all VLBI-related staff members.

Table 1 Staff members and their main areas of activity.

Name	Tasks
Detlef Angermann	Group leader of *Reference Systems*
Michael Gerstl	Software development
Matthias Glomsda	Operational data analysis; software development
Manuela Seitz	CRF/TRF combination; combination of different space geodetic techniques

3 Current Status and Activities

In 2019, we worked on two major topics. First, we investigated the impact of non-tidal loading, a geophysical effect that is currently only partly considered in VLBI analysis. Next to the non-tidal atmospheric loading, which is already included for the IVS solutions, we also applied non-tidal oceanic and hydrological loading, both individually and as a whole. Furthermore, we

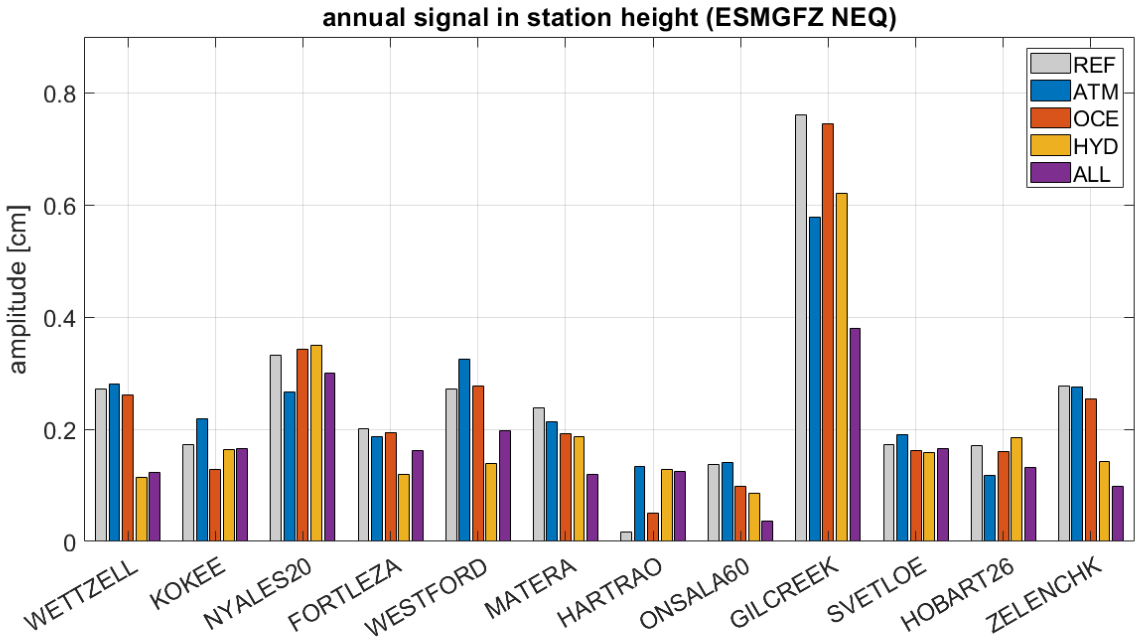

Fig. 1 We analyzed more than 4,000 sessions between 1984 and 2017. For each of them, five different setups were used: no non-tidal loading (REF), non-tidal atmospheric loading only (ATM), non-tidal oceanic loading only (OCE), hydrological loading only (HYD), and all non-tidal loading types at once (ALL). Here, we compare the amplitudes of the annual signal in the time series of station heights for all distinct setups and observe that the signals are often reduced when hydrological loading is applied (HYD, ALL). The non-tidal loading data was taken from the Earth System Modelling group of the Deutsches GeoForschungsZentrum and applied at the normal equation level.

examined two application levels: the observation and the normal equation level. We showed that considering non-tidal loading at either level is beneficial for various geodetic parameters, e.g., by reducing the scatter and/or periodic signals in their time series (compare, for instance, Figure 1, which is taken from [1]). Thereby, all three loading types are relevant and should be applied jointly.

Secondly, we had to prepare DOGS-RI for the upcoming realization of the International Terrestrial Reference System (ITRS), the ITRF2020 (International Terrestrial Reference Frame 2020). The most important modifications were the implementation of:

- the secular pole function as agreed upon at the Unified Analysis Workshop (UAW) 2017,
- the Desai and Sibois [2016] model for sub-daily EOP variation,
- the usage of Galactic Aberration in connection with the latest realization of the International Celestial Reference System (ICRF3), and
- the empirical model for the gravitational deformation of selected VLBI antennas.

All these new models also had to be considered for the official IVS solutions starting from January 2020.

In 2020, we hence released our new IVS contribution of datum-free normal equations for the rapid turnaround sessions (*dgf2020a*). Furthermore, we started to reprocess VLBI observations for the ITRF2020. The list of relevant sessions comprises basically all VLBI experiments with at least three antennas, many of which had never been analyzed at DGFI-TUM before. As a consequence, we had to handle almost 2,000 “new” VLBI sessions in 2020. These sessions also comprise the new session series of the next-generation VLBI system, the so-called VLBI Global Observing System (VGOS) sessions. The latter make use of smaller, fast-moving antennas with broadband receivers, and hence the analysis approach had to be augmented in comparison to the legacy S/X sessions.

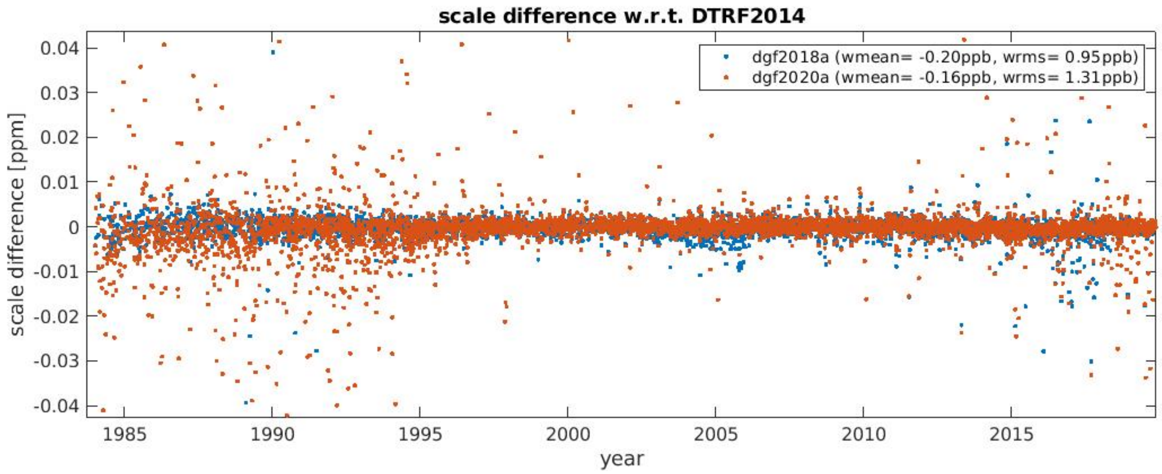

Fig. 2 Time series of the scale parameter in a Helmert transformation with respect to the DTRF2014, DGFI-TUM's realization of the ITRS with data as available through 2014. The session-wise transformations are based on VLBI station positions obtained from the solutions *dgf2018a* (blue) and *dgf2020a* (red).

To process all "new" VLBI experiments, DOGS-RI needed a few more modifications. By the end of 2020, we managed to complete almost all relevant ITRF2020 sessions, and we created a first global VLBI solution by combination of the single-session normal equations.

In the context of the ITRF2014 computation, the discussion on the consistency of the scales realized by VLBI and Satellite Laser Ranging (SLR) played an important role. For the ITRF2020, the analysis and comparison of the realized scales will still be of high interest, especially since—not only for VLBI, but also for SLR—changes in modeling and parameterization have been implemented (compare above). At DGFI-TUM, we have thus performed some initial analyses of the scale parameter in a Helmert transformation with respect to the DTRF2014 (see [3]). Figure 2 shows the corresponding time series derived for solution *dgf2020a* and its predecessor *dgf2018a*, which did not contain the four new models for the ITRF2020. It can be clearly seen that no significant change in the mean scale, scale rate, or RMS is caused by the changes in VLBI modeling.

Finally, we continued our research on non-tidal loading effects, and a second paper was submitted (see [2]). It contains a rather theoretical assessment and confirms, amongst others, that the differences between the application at the observation and normal equation levels are mainly driven by the temporal resolution of the loading data.

4 Future Plans

The year 2021 will be dominated by the generation of the ITRF2020. DGFI-TUM's reprocessed normal equations will be part of the combined IVS contribution, and probably some further tasks will arise from that. In particular, we want to establish and analyze a combined CRF/TRF solution from our VLBI data.

With respect to software development, we want to make DOGS-RI fully capable of performing simulations, and we plan to routinely process Intensive sessions next to the rapid turnarounds.

Acknowledgements

We thank Younghee Kwak for her valuable support and expertise during her time at DGFI-TUM. We wish her all the best for her future.

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ETHZ VLBI Analysis Center Biennial Report 2019/2020

Benedikt Soja, Matthias Schartner, Grzegorz Kłopotek

Abstract This report presents the activities of the ETHZ VLBI Analysis Center since its inception at the end of 2020. The ETHZ VLBI Analysis Center analyzes several types of IVS sessions for research purposes and aims to make regular IVS submissions, supported by improvements in automation.

1 General Information

At the end of 2020, a new IVS Associate Analysis Center was established at ETH Zurich (ETHZ). In the past, ETHZ has already been involved in research related to the combination of geodetic data sets, including VLBI observations. However, the newly established Chair of Space Geodesy at ETHZ has an even stronger focus on VLBI, with several of its members having experience in VLBI. For the first time, this allows ETHZ to contribute actively to IVS goals and products. In addition to analyzing specific VLBI data sets as called for by the Analysis Coordinator, ETHZ performs research-driven analyses of specific data sets, such as those related to the CONT campaigns, R1/R4 sessions, and the Intensives, with the aim of processing both legacy and VGOS observations.

ETHZ focuses on increasing the degree of automation of VLBI data analysis tasks. We believe that in this context, there is a lot of potential for strategies and methodologies based on artificial intelligence, including supervised and unsupervised machine learning. Increased automation will allow us to participate in demanding reprocessing efforts that smaller VLBI groups typically cannot undertake.

In this contribution, we provide an overview of the activities and future plans of the IVS Associate Analysis Center at ETHZ, including first analysis results, automation strategies and utilized tools. Additionally, we showcase other analysis-related VLBI research that is pursued at ETHZ.

ETH Zürich

ETHZ VLBI Analysis Center

IVS 2019+2020 Biennial Report

2 Staff

The Chair of Space Geodesy was established at ETHZ in 2020 and is held by Prof. Benedikt Soja. His research group currently consists of two PhD students and two postdoctoral researchers (see Figure 1). Three members of the Space Geodesy Group are associated with the newly established ETHZ Analysis Center (see Table 1). Other group members focus on large-scale analysis of various time series related to space geodesy with the aim of attaining better knowledge of geodynamics, earth orientation, space weather, or the troposphere.

Table 1 Members of the research group of the Chair of Space Geodesy affiliated with the ETHZ Analysis Center.

Benedikt Soja	Head of Space Geodesy Group, coordinator of VLBI AC activities
Matthias Schartner	VLBI scheduling and analysis
Grzegorz Kłopotek	VLBI analysis

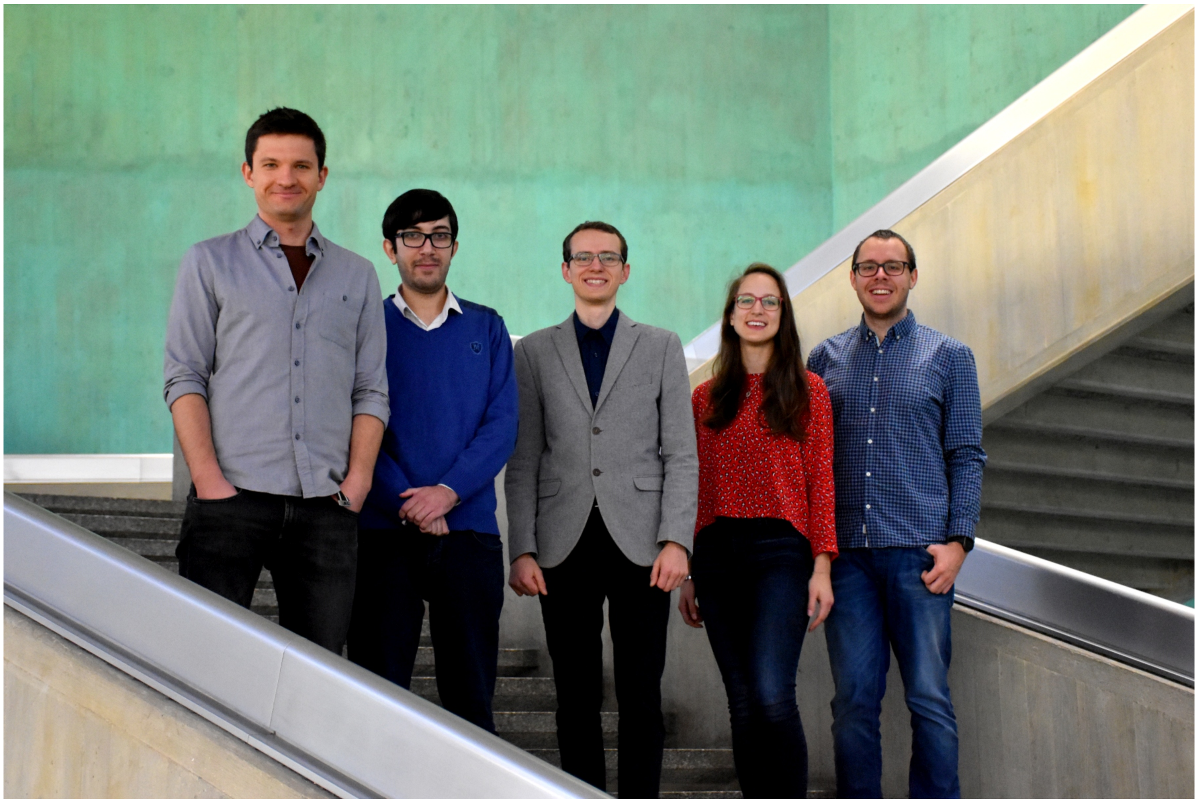

Fig. 1 Members of the research group of the Chair of Space Geodesy at the end of 2020. From left to right: Grzegorz Kłopotek, Mostafa Kiani Shahvandi, Benedikt Soja, Laura Crocetti, and Matthias Schartner.

3 Current Status and Activities

Relying on experience gained from automating VLBI scheduling for the IVS DACH Operation Center, we plan to apply similar processing schemes regarding VLBI analysis at the ETHZ AC. For our processing efforts, we have created a VLBI repository, including VLBI observational data and auxiliary information, that is updated on a routine basis. This allows us to attain frequent information on available VLBI databases as an input for subsequent processing with our analysis routines. The processing pipeline at ETHZ also includes automatically generated comprehensive analysis reports, in the form of email notifications, that are disseminated to all members of our Analysis Center whenever a new session is processed. This allows our members to focus on analysis results that look suspicious and need human intervention.

3.1 Software Development

The software packages we plan to utilize throughout the course of our VLBI analysis activities include *VieVS*, *PORT* (*VieVS@GFZ*), *nuSolve*, and *c5++*. However, in order to meet the goal of automatically analyzing various VLBI databases, it is necessary to develop external tools for this purpose. Rather than modifying existing software packages at the source code level, we focus our actions on developing a front-end for VLBI analysis software packages addressing automatic processing of observations interactively and via dedicated scripts. Our external interface, so far tested with *VieVS*, enables automatic and recurrent session analyses supporting additional features including clock break detection, outlier flagging, tests of various calibration data, and testing/utilization of various machine learning algorithms. Following this approach, we will be able to comprehensively and seamlessly investigate the impact of various models and algorithms on the derived global and station-based parameters of interest.

3.2 Analysis Activities

With the software packages at our disposal and sophisticated tools facilitating automatic processing to be developed in the near future, we plan to perform reprocessing of routine VLBI sessions and study the impact of our approach on the solution quality and derived parameters. As an example, first results from our automated analysis of IVS-R1 and IVS-R4 sessions from 2019 and 2020 are summarized in Figure 2 in the form of histograms of both session-based reduced χ^2 and post-fit residuals.

One part of our automated processing pipeline consists of a newly developed clock break detection algorithm. The method first identifies potential clock breaks in the residuals and then evaluates candidates by statistical means, discarding non-significant anomalies in the residuals. An example of the clock breaks identified by the algorithm in one of the IVS-R1 sessions is shown in Figure 3. Further tests are necessary to validate and fine tune the algorithm.

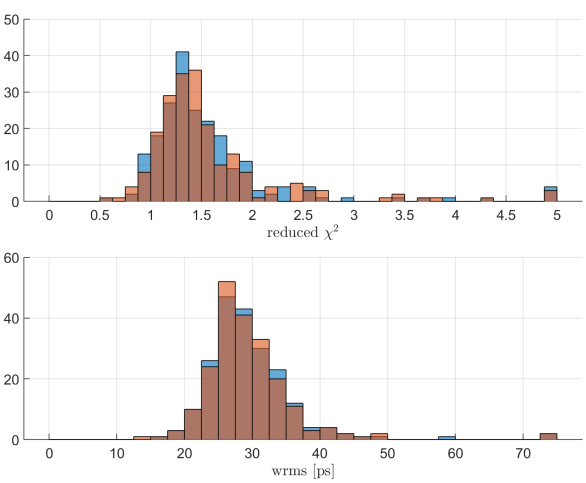

Fig. 2 Histogram of session-based reduced χ^2 (chi-square per degree of freedom, upper plot) and wrms (weighted root-mean-square, lower plot) from 2019 and 2020 IVS-R1 and IVS-R4 sessions analyzed with VieVS. Blue: standard analysis with human input (provided by the VIE AC). Orange: fully automated analysis at the ETHZ AC.

3.3 Research Activities

3.3.1 ML Methods for VLBI Analysis

Machine learning (ML) is a widely used tool for prediction and optimization problems [4], as well as for discovering hidden anomalous patterns within complex data sets. This family of computer algorithms is applied when it is difficult to develop conventional algorithms capable of performing the required tasks or when one copes with large amounts of heterogeneous data that are often highly dimensional and exhibit large spatio-temporal variability.

The focus of our group within this topic is to explore various machine learning algorithms and investigate their feasibility for VLBI data analysis and the determination of geodetic products. In this context, ML-based approaches and models will facilitate data screening, automatic anomaly detection, data fusion, and other related tasks otherwise requiring labor-intensive human actions.

Primarily, we plan to use supervised machine learning methods, training our algorithms on existing labeled data (e.g., clock break and outlier flags). Additionally, we will investigate reinforcement learning to potentially improve pre-trained ML frameworks by iteratively testing new analysis configurations and decisions. Considering the diverse nature of VLBI sessions, it is important that the algorithms generalize well to different data sets.

3.3.2 VLBI Observations of Satellites

The research activities include combinations of different space-geodetic techniques and new observing concepts for VLBI. In this domain, we explore the concept of VLBI observations of artificial radio sources such as satellites with the use of both simulation studies, including investigations related to optimal scheduling, and orbit determination, with the idea of potentially realizing such observations in the future. This subject requires therefore a holistic approach, in which specialized system configurations, scheduling, dedicated instruments, and revised data processing routines are thoroughly studied.

Our investigations in this topic cover potential co-location missions at medium Earth orbit (MEO) or cube satellite technology at low Earth orbit (LEO).

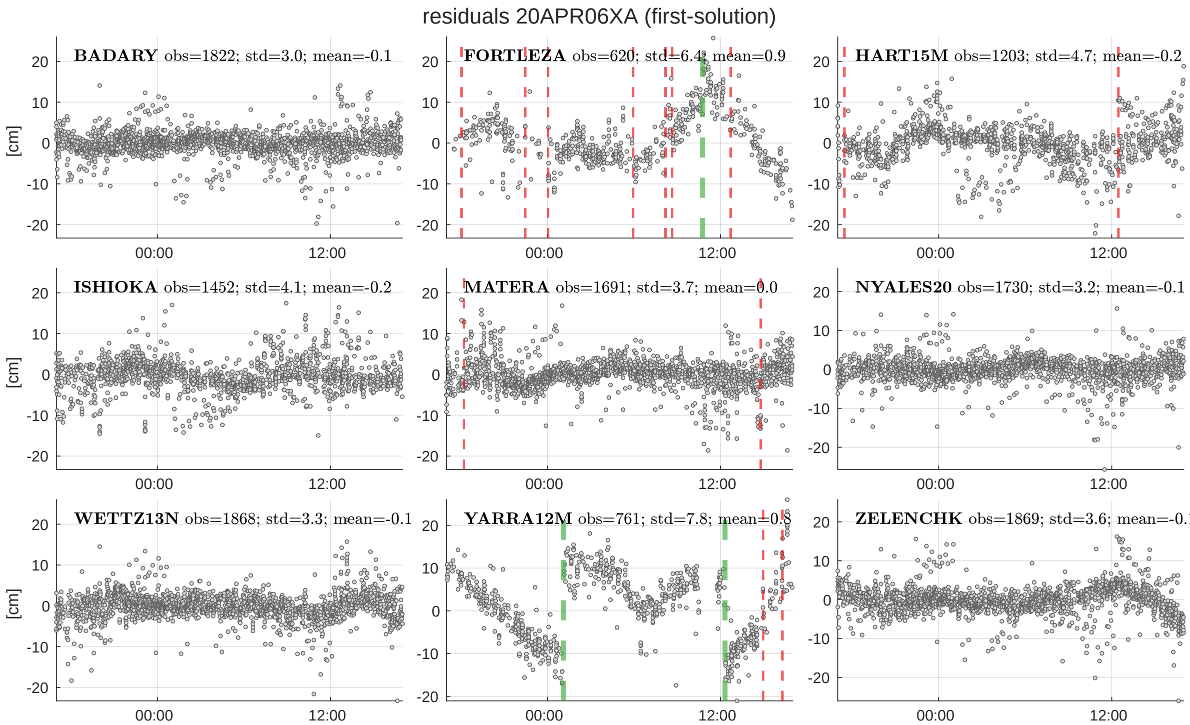

Fig. 3 Automated clock break detection for session 20APR06XA (IVS-R1). The observation residuals of the first solution are displayed as gray dots. Red dashed lines mark the potential clock breaks that are discarded by the statistical tests. Green dashed lines mark clock break candidates that are further investigated and tested.

When ground-based geodetic instruments observe co-location satellites, new geometrical connections, with enhanced spatio-temporal resolution, can be in turn realized for increased consistency among space-geodetic techniques and the products these techniques provide [1].

3.3.3 Scheduling and Simulations

Besides our activities related to VLBI analysis and research, our group is a part of the DACH Operation Center (see the corresponding report by the DACH OC). We contribute state-of-the-art schedules and simulations of various IVS observing programs based on the scheduling software *VieSched++* [2], as well as on an extension for automatic scheduling *VieSched++ AUTO* [4]. The experience in scheduling and simulating VLBI sessions has allowed us to investigate optimal locations of VGOS telescopes [3] and the ideal geometry for Intensive VLBI sessions [5]. We will continue our efforts to improve and optimize the performance of our schedules and simulations. Related to this, we will have a student project during spring semester 2021 on the topic “Optimizing geodetic VLBI simulation parameters based on evolutionary strategies and swarm intelligence.”

4 Future Plans

Our goal for the near future is the ongoing improvement and refinement of our automated processing approach. Once a sufficient quality of geodetic results can be guaranteed, we plan to submit our solutions regularly to the IVS. We hope to extend our automated processing approach to all types of VLBI sessions, including VGOS sessions, allowing us to participate in demanding re-processing campaigns. Our activities will remain research-driven with the aim of developing new methods and approaches that will benefit the international VLBI community and lead to new scientific discoveries.

Acknowledgements

We thank the members of the DACH OC from TU Wien and Geodetic Observatory Wettzell for their co-operation and collaboration that has enabled some of the results presented here.

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GFZ Analysis Center 2019–2020 Report

Robert Heinkelmann[1], Susanne Glaser[1], Georg Beyerle[1], Harald Schuh[1,2], James Michael Anderson[2,1], Kyriakos Balidakis[1], Sujata Dhar[1], Okky Syahputra Jenie[1,2], Chaiyaporn Kitpracha[1,2], Susanne Lunz[1,2], Nicat Mammadaliyev[2,1], Sadegh Modiri[1,2], Shrishail Subash Raut[1,2], Jungang Wang[2,1]

Abstract This report provides general information and a component description of the IVS Analysis Center at GFZ. Current activities and recent results are mentioned, and the planned future work is outlined.

1 General Information

The Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences is the national research center for Earth sciences in Germany. At this research facility, within Department 1 "Geodesy" and Section 1.1 "Space Geodetic Techniques," a VLBI group has been established at the end of 2012. This group is an Associate Analysis Center (AC) of IVS.

2 Component Description

GFZ is an Associate AC of the IVS. We have installed and partly automatized our VLBI analysis process in preparation for becoming an Operational AC. We are also supporting a combination center for tropospheric products.

1. Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences
2. Technische Universität Berlin KAI 2-2, Department of Geodesy and Geoinformation Science, Chair of Satellite Geodesy

GFZ Analysis Center

IVS 2019+2020 Biennial Report

3 Staff

Since the 2017–2018 Biennial Report, Suxia Gong has left the VLBI group to join the Local Environment Management and Analysis Department of University of Liège, Belgium. We wish her the best of luck in her future career. Minghui Xu is now a Research Fellow with the Department of Electronics and Nanoengineering of Aalto University, Finland, and works in a project of Tuomas Savolainen entitled 'NT-VGOS: From quasars to geodesy: how astronomy can enable a new era in ultra-precise geodetic measurements.' He is still closely related to us and to our work through his role as Mercator Fellow (DFG) in our project 'ECORAS: extension of the coordinate parameterization of radio sources observed by VLBI.' Kyriakos Balidakis and Sadegh Modiri have successfully defended their PhD theses [1, 23]. In 2019 Csilla Fodor [6], Eötvös Loránd University, Faculty of Science, Geophysics, Budapest, Hungary and in 2020 Pakize Küreç Nehbit [13], Department of Geomatics Engineering, Kocaeli University, Turkey, kindly visited our group as guests. Additionally, we have had the pleasure of welcoming the following new colleagues to our group, all of which will be pursuing a PhD (in alphabetical order):

- Sujata Dhar, B.Tech (Hons) degree from NIT Raipur and PMRF from IIT Kanpur, India, is investigating the Earth Orientation Parameters from VLBI and GNSS and does simulations and combinations of space geodetic techniques.
- Shrishail Subhash Raut from India, M.Eng Space Engineering of TU Berlin, works on the improvement of Earth Orientation Parameters by combining VLBI and GNSS.

- Jungang Wang, ME Geodesy and Surveying Engineering from Tongji University, Shanghai, China, works on Integrated Processing of GNSS and VLBI on the observation level.

The current members of the VLBI group and their main topics are listed in Table 1, and a picture of us is presented in Figure 1.

4 Current Status and Activities

VLBI Data Analysis Software Development

The VLBI group at GFZ Potsdam employs the Potsdam Open Source Radio Interferometry Tool (PORT) for data processing and analysis. The MATLAB source code of PORT was originally based on the Vienna VLBI Software (VieVS). Since 2012 PORT development at GFZ is directed towards operational data processing in support of GFZ's IVS activities as well as implementation of alternative analysis algorithms, such as parameter estimation using Kalman filtering. Within the last years, efforts were directed at re-factoring tasks to improve code efficiency and to implement modularity. The code is going to be open source and will be made available via GFZ's source code repository, once the first stable public release version is ready.

ITRF2020 Contribution

The GFZ VLBI group delivered input to the current International Terrestrial Reference Frame (ITRF2020) call, employing PORT. Our contribution consists of 6,552 SINEX featuring estimates for station and AGN coordinates, and EOP and the rates thereof, as well as the related datum-free normal equation systems. The vast majority of the sessions analyzed have S-/X-Band observations, and a few VGOS sessions were analyzed as well. While the effect of non-tidal atmospheric loading was taken into account adopting GFZ's models, its impact on the solution may be removed by means provided within the SINEX (calibration blocks). To accommodate the latter as well as other special considerations for ITRF2020, PORT has been enhanced accordingly (e.g., gravitational telescope deformation modeling [25] and handling of poorly observed AGN). The baseline length repeatability of our solution decays as a function of baseline length x following $\sqrt{(5.4 \pm 1.3)^2 + ((0.0027 \pm 0.0002)x)^2}$.

Reference Frame Simulations towards GGOS

GGOS-SIM[1]: Simulation of the Global Geodetic Observing System is a joint project of TU Berlin and GFZ Section 1.2 situated in Oberpfaffenhofen near Munich, Germany. It is funded by the German Research Foundation (DFG, SCHU 1103/8-2). Therein, we simulate the four space geodetic techniques (GNSS, SLR, DORIS, and VLBI) currently contributing to the ITRF and investigate the impact of different local tie scenarios on the combined frame of GPS, SLR, and VLBI [8]. Furthermore, we simulated the future network development of SLR in combination with GPS and VLBI [7]. In the second phase of GGOS-SIM that started on January 1, 2019, we focus on simulations of co-location in space involving the four space geodetic techniques [18]. In the project ADVANTAGE funded by the Helmholtz Gemeinschaft the impact of a future GNSS constellation "Kepler" on geodetic parameters also within the combination with VLBI [9] is investigated with simulations.

Gaia–VLBI

The optical astrometric satellite mission Gaia (ESA) is providing positions and proper motions of hundreds of thousands of quasars at a level of precision comparable to or even better than the current ICRF3 position accuracies. In the research project ECORAS funded by the DFG (HE 5937/2-2, SCHU 1103/7-2) the comparison of the Gaia and VLBI celestial coordinates is being exploited to determine systematic, possibly technique-dependent, reference frame effects [14]. We paid particular attention to the analysis of the misalignment of the Gaia bright reference frame, which we enhanced by homogenizing and extending the VLBI data [15, 16]. As part of the efforts to improve the alignment of the radio and optical frames and the agreement of the positions of individual sources, we have studied the detection, modeling, and correction of radio source structure effects on celestial coordinates and observables [27, 28]. In addition, we are investigating effects such as core shift that potentially induce frequency-dependent position variations, as well as apparent proper motions induced by the evolution of intrinsic source structure.

[1] https://www.earth.tu-berlin.de/menue/forschung/laufende_projekte/ggos_sim/parameter/en/

Table 1 Current members of the VLBI group at GFZ including one MSc student.

Name	Main activity / function
Harald Schuh	Director of Department 1 and Head of Section 1.1 of GFZ
Robert Heinkelmann	Head of VLBI group
Sadegh Modiri	Prediction and geophysical effects of EOP
Susanne Glaser	Combination and simulation of space geodetic techniques, projects: GGOS-SIM, ADVANTAGE
Jungang Wang	Combination on the observation level
Shrishail Raut	Combination of GNSS and VLBI for EOP determination
Georg Beyerle	PORT development, project: ADVANTAGE
Fikri Bamahry	MSc student, climate signals obtained from VLBI data analysis
Chaiyaporn Kitpracha	Combination of GNSS and VLBI tropospheric parameters and atmospheric ties
Kyriakos Balidakis	Atmospheric and geophysical effects, PORT development
Nicat Mammadaliyev	Co-location in space, project: GGOS-SIM
Susanne Lunz	Gaia–VLBI, project: ECORAS
Sujata Dhar	Real-time prediction of EOP, simulations
James Anderson	Source structure, project: ECORAS, PORT development, EU-VGOS

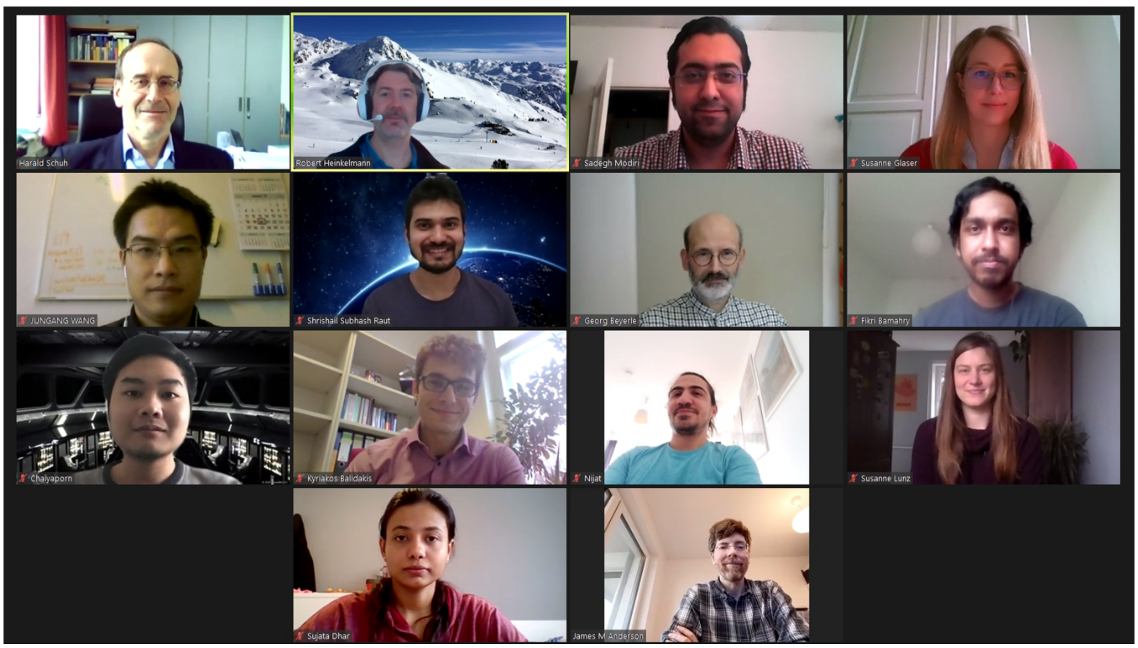

Fig. 1 A screenshot of the GFZ VLBI group during a meeting on January 22, 2021. The names given in Table 1 are ordered from top left to bottom right.

Geophysical Loading Effects

Transient mass redistribution within Earth's fluid envelope (atmosphere, oceans, and continental water storage) displaces VLBI stations at the cm-level at a large frequency spectrum. We develop consistent models for these effects and provide them operationally.[2] A study assessing these models in the analysis of VLBI and GNSS observations has been carried out [17].

[2] http://rz-vm115.gfz-potsdam.de:8080/repository

Atmospheric Refraction Effects, Ties and Modeling, Climatological Studies

In addition to an appropriate parameter set-up in the geodetic adjustment, advanced atmospheric delay modeling is necessary to improve the accuracy of geodetic products. Employing the in-house ray-tracing software and state-of-the-art NWMs such as ERA5 (31 km) and ECMWF's operational model (9 km), we have worked on the development of accurate ray-traced delays, mapping functions, and non-linear asymmetric delay models and assessment thereof in VLBI data analysis. We have also investigated the improvement from employing water vapor radiometer data in VLBI data analysis. Starting from 2019, we make publicly available[3] atmospheric delays from an ECMWF operational analysis (9 km) and ERA5 since 1979.

To explore the potential of atmospheric ties being used in addition to local/global/space ties in the multi-technique combination, an IAG Joint Working Group (JWG 1.3) was established by R. Heinkelmann in 2015. In the current IAG term (2019–2023), K. Balidakis has taken over the organization of the JWG together with D. Thaller (BKG). To summarize activities related to "Intra- and Inter-Technique Atmospheric Ties", a Web page has been set up.[4] At GFZ, we have studied the intra- and inter-technique differences mainly induced by varying frequency, position, and observing system [e.g., 2]. Employing simulated observations we can perform the multi-technique combination utilizing NWM-derived atmospheric ties, to the advantage of the combined solution. The combination of real VLBI and GNSS data at the observation equation level employing atmospheric ties has been explored in the PhD thesis of J. Wang that will be defended in 2021. To predict zenith wet delays, we have utilized machine learning techniques, in particular long-short term memory and a combination of singular spectrum analysis (SSA) and copula. We have obtained promising results for tropospheric delay prediction at Wettzell, but this approach needs to be refined further to achieve geodetic accuracies.

We have continued studying long-term integrated water vapor variations estimated from VLBI, GNSS, and state-of-the-art weather models, such as ERA5. The spatio-temporal evolution has been continued in the framework of the MSc thesis of Fikri Bamahry.

IVS Tropospheric Combination

The algorithm for the IVS tropospheric combination was revised making it more robust. Several changes are in progress, including the epochs at which the tropospheric products are reported (from HH:00 to HH:30) and the combination of gradients. As too few IVS Analysis Centers currently contribute to this product, the combination is on hold and will be reactivated once the submissions become available. Following the expression of interest on behalf of IGS and EUREF, we look forward to more Analysis Centers contributing to the product.

[3] ftp://ftp.gfz-potsdam.de/pub/home/kg/kyriakos/internal/PMF/

[4] https://www.gfz-potsdam.de/en/section/space-geodetic-techniques/projects/iag-jwg-atmospheric-ties/

Earth Orientation Parameters

The GFZ VLBI group continued its activities to improve Earth Orientation Parameter theories and models in cooperation with other institutes and universities. We studied several minor effects on Earth rotation, derived from geophysical properties not considered so far [21, 6]. We have investigated how to improve the estimation of daily and sub-daily ERP from CONT17 data [24]. Together with the University of Alicante, Spain, we developed some studies on the revision and improvement of Earth rotation theories and models' accuracy and consistency [4, 5].

Moreover, we proposed a novel hybrid approach to predict EOP. A stochastic method called copula combined with singular spectrum analysis (SSA) was introduced for EOP prediction [19]. We analyzed the potential of copula-based methods for predicting Earth rotation parameters derived from the combination of different satellite geodetic sensors and other geophysical parameters, such as effective angular momentum functions [22]. Our new hybrid method is competitive with the existing ones and even better than many of them depending on the EOP and the prediction length, taking into account the final design of the procedures. Our method was also applied to predict other geophysical parameters.

Another challenging task was investigating the interconnection between the celestial pole motion (CPM) and geomagnetic core field (GMF) in order to improve the current CPM prediction methods. We use the CPM time series obtained from VLBI observations and the latest GMF model to explore the correlation between CPM and the GMF [20]. Our preliminary results reveal significant common features in the CPM and GMF variations, which show the potential to improve our understanding of the GMF's contribution to Earth rotation [23].

European VGOS

In an effort to learn how to utilize and improve geodetic VLBI using VGOS, many groups within Europe formed the European VGOS (EU-VGOS) project to investigate how VGOS results could be improved through changes in scheduling, correlating, calibrating, fringe-finding, correcting for source structure, and various other areas. Initially starting with observations at three European VGOS sites, EU-VGOS test sessions have since incorporated the Ishioka VGOS station as well. The GFZ has been involved in the EU-VGOS project since its inception.

5 Future Plans

In addition to continuing to improve VLBI data analysis by better understanding systematic and random effects, the following activities are planned for 2021–2022: (i) development of PORT source code towards the first public release of the open access source code and beyond, (ii) automation of VLBI data analysis based on the vgosDb format, and (iii) working on GNSS–VLBI combination.

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GSFC VLBI Analysis Center Report

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Abstract This report presents a description of the GSFC VLBI Analysis Center and its activities during 2019 and 2020. The GSFC VLBI Analysis Center analyzes all IVS sessions, makes regular IVS submissions of data and analysis products, and performs research and software development aimed at improving the VLBI technique.

1 Introduction

The GSFC VLBI Analysis Center is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland. It is part of a larger VLBI group which also includes the IVS Coordinating Center, the CORE Operation Center, a Technology Development Center, and a VGOS station. The Analysis Center participates in all phases of geodetic and astrometric VLBI analysis, software development, and research. We provide several services and maintain several important data and information files for IVS and the larger geodetic community. We continued to support the International Mass Loading Service (atmosphere pressure loading, hydrology loading, and nontidal ocean loading), the Network Earth Rotation Service, and the International Path Delay Service (troposphere raytraced delays for VLBI sessions). Data and information files include VMF1/VMF3 TRP files for every IVS session, the IVS Source Name Translation Table, various station information files, a file of source and station a prioris, a mean gradients file, a JPL planetary ephemeris file for *Calc/Solve/νSolve*, and several other files.

1. NVI, Inc.
2. NASA Goddard Space Flight Center
3. Science Systems and Applications Inc.

GSFC Analysis Center

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2 Analysis Center Staff

In 2019, the staff consisted of one GSFC civil servant and six NVI, Inc. employees who worked under contract to GSFC. Dr. Leonid Petrov, the civil servant, was the GSFC VLBI Lead Scientist. Dr. John Gipson was the GSFC VLBI Project Manager for NVI, as well as the IVS Analysis Coordinator and an IVS Directing Board member. The other NVI employees were Dr. Daniel MacMillan, Dr. Sergei Bolotin, Dr. David Gordon, Dr. Karine Le Bail, and Ms. Karen Baver. In 2020, Dr. Nlingi Habana of Science Systems and Applications Inc. joined the Analysis Center, and Le Bail and Gordon departed. They now work at the Chalmers University of Technology and the U.S. Naval Observatory, respectively. We are grateful for their many contributions and the time we spent with them. The Analysis Center hosted interns Hanna Ek and Rickard Karlsson in 2019 and Cody Hesse and Ugne Miniotaite in 2020.

3 Software Development

The GSFC VLBI Analysis Center develops and maintains the *Calc/Solve* analysis system, a package of $\sim$120 programs and 1.2 million lines of code. Several new versions were released in 2019–2020. Important new features of *Solve* are the abilities to apply antenna gravitational deformation models, new high frequency EOP models, and galactic aberration. *Solve* was modified to allow users to analyze VGOS broadband sessions.

S. Bolotin continued development of ν*Solve* and the *vgosDB* software and utilities. ν*Solve* is now fully operational and replaces the legacy interactive *Solve* program. These utilities, as well as ν*Solve*, are distributed in one package called "nusolve" and are available at https://sourceforge.net/projects/nusolve.

S. Bolotin developed a utility for extraction of various station calibrations (e.g., system temperature, phase calibration) from the field system log file of a station. This information will allow the monitoring of station performance.

L. Petrov incorporated support of linear polarization and mixed polarization observations in the NASA VLBI visibility analysis software tool PIMA. Work continued on improving the robustness of the computation of the polarization complex bandpass.

L. Petrov and N. Habana added new simulation capabilities to a pSolve data analysis tool that accounts for 2D source modeling, elevation dependence of SEFDs, and atmosphere turbulence.

H. Ek and R. Karlsson developed Python scripts to display vgosDB information. C. Hesse worked on a script to help to ingest data at the IVS Data Centers. U. Miniotaite worked on scripts to extract and display Tsys information.

4 Analysis Activities

The GSFC VLBI Analysis Center analyzes all IVS sessions using the *Calc/Solve/*ν*Solve* system and performs the *fourfit* fringing and *Calc/Solve/*ν*Solve* analysis of the VLBA-correlated RDV and other VLBA sessions. The group submitted analyzed databases to IVS for all R1, RV, R&D, AUST, AUG, AOV, AUA, APSG, CRF, CRDS, INT01, INT03, and INTVI sessions.

During 2019–2020, GSFC analyzed approximately 379 24-hour IVS sessions and approximately 847 one-hour UT1 sessions (INT01, INT02, and INT03). With the advent of broadband observing, GSFC analyzed 38 24-hour broadband VGOS sessions and 11 VGOS UT1 (INTVI) sessions. Updated EOP and daily Sinex files were submitted to IVS immediately following analysis.

D. Gordon and D. MacMillan, with assistance from K. Baver, generated quarterly solutions 2019a, 2019d, 2020a, 2020b, and 2020c, which provided 24-hour global, 24-hour baseline, and Intensive plots and data.

D. Behrend et al. wrote a paper describing the efforts required to organize the CONT17 campaign [5].

5 Research Activities

5.1 Reference Frames

As the IVS Analysis Coordinator, J. Gipson directed the efforts of Analysis Centers to generate ITRF2020 solutions for the IVS Combination solution. Eleven Analysis Centers submitted solutions, which included S/X sessions from 1979–2020 as well as VGOS sessions (CONT17 and sessions from 2019–2020). Among the ACs, seven different software packages were used. D. MacMillan generated the GSFC solution using Calc/Solve.

Three NVI personnel (D. Gordon, S. Bolotin, and D. MacMillan) actively participated in the generation of ICRF3 as members of the IAU ICRF3 Working Group. The ICRF3 group wrote a paper on ICRF3 and its generation [8].

D. MacMillan, as chair of the IVS Galactic Aberration Working Group, wrote a paper along with group members summarizing their investigation [12]. The paper recommended the galactocentric acceleration constant that was then used to generate the ICRF3 solution.

K. Le Bail continued to monitor the proposed 195 Gaia transfer sources. She wrote a report on the seven years of the R&D sessions for review by the OPC to show the progress of the program.

K. Le Bail worked with PI Alet de Witt to select the optimal station network for the CRF sessions to strengthen the southern hemisphere of ICRFs.

5.2 Source Structure

L. Petrov along with co-authors showed that VLBI-Gaia (optical) source position offset angles are nearly uniform over the sky. The VLBI-Gaia offset directions were shown to be correlated with jet direction [14]. Work continued on the study of the systematic differences between VLBI and Gaia source position differences. New strong evidence was obtained that confirms the initial hypothesis that observed position offsets are manifestations of optical jets [16].

L. Petrov and F. Schinzel continued VLA and VLBA multi-frequency monitoring of 3C48. They found brightening and dimming of the stationary component within 1.5 mas of the core. A paper is in preparation.

S. Bolotin analyzed the VGOS CONT17 broadband sessions, which revealed the effects of source structure in the group delay residuals. To take this effect into account, Bolotin developed a multi-point source structure model and implemented it in *νSolve* [6].

S. Bolotin wrote a paper on source structure effects in CONT17 VGOS observations (submitted 2019). He found that broadband delays are radio source brightness distributions and developed source structure models of sources that had large systematic residuals. Application of the models removed these systematic variations.

K. Le Bail compared the noise floor of the sources in the S/X catalog with the noise floor of the sources in the K-band catalog [11].

K. Le Bail worked with Leonid Petrov on the selection of sources from Petrov's RFC catalog that are strong and compact, and that show no apparent structure, as candidates for the good geodetic source catalog. Thirty seven of these sources were added to the good geodetic catalog in May 2020.

5.3 Observing Surveys

A decade-long observing campaign (LCS2) using a network of radio telescopes in Australia, New Zealand, and South Africa resulted in elimination of the hemisphere bias where the number of compact radio sources in the Southern hemisphere was much less than the Northern hemisphere. Elimination of the bias improves the capability of maintaining the terrestrial reference frame. L. Petrov et al. discussed the results of this program in [13].

L. Petrov and colleagues continued observation programs of pathfinder VLBI astrometry surveys, VCS10 and VCS11, that along with other observing programs added 3,666 new VLBI-detected sources. Positions and images have been derived from the data of the VCS10 program. A paper is in preparation.

Popkov et al. studied VLBI data from the Northern Polar Cup Survey and the population of the unbiased sample of sources drawn from the parent NVSS catalog without selection based on spectral index [17].

L. Petrov and colleagues have completed the SOuthern Astrometric Program for improving the positions of 217 southern sources. A paper is in preparation.

L. Petrov and colleagues ran the KVN observing program "A search for high-frequency calibrators within 10 degrees of the Galactic center" at 22 and 43 GHz. They have detected 91 previously known compact sources and 24 new sources. They are also running the VLBA program "K- and Q-band VLBI Calibrators near the Galactic Center" with the goal of improving the positions of 115 sources within 10 degrees of the Galactic center detected with the KVN.

In addition, L. Petrov carried out "The wide-field VLBA calibrator survey – WFCS" [15] and was involved in research on microarcsecond VLBI pulsar astrometry with PSRpi [9].

5.4 Gamma Ray Sources

S. Bruzewski et al. continued a VLA and ATCA program of observations of Fermi unassociated sources [7]. They conducted the LBA observing program "Unveiling the nature of gamma ray sources in the 4FGL catalogue - LBA Observations" that is the follow-up of prior ATCA observations.

L. Petrov participated in a further survey of unassociated gamma ray objects in the seven-year Fermi/LAT catalog, which found 310 associated gamma ray sources. In total, VLBI association was found for 54% of extragalactic objects. Redshifts were determined for 28% of Fermi gamma ray sources via VLBI association [1]. Among gamma ray loud AGNs, a VLBI association was found for 90% of the sources [2].

5.5 Galactic Gravitational Field

L. Petrov was involved in a study of the impact of the non-stationarity of the gravitational field in the Galaxy on precise astrometry. They found that this effect causes a jitter in source positions that is potentially observable. This jitter sets a fundamental limit of astrometric accuracy that space flight at distances of several kiloparsecs is required to overcome [10]. They ran a pilot program with the KVN for detection of the background position noise due to the non-stationarity of the Galactic gravitational field at 22 GHz.

5.6 Intensive Sessions

K. Baver finished studying the effect of source flux catalog latency on S/X Intensive schedules [3]. Baver and J. Gipson finished evaluating the "BA 50" strategy of using 50 sources chosen to balance source strength and sky coverage in S/X Intensive schedules [4].

K. Baver ran simulations with the goal of improving S/X or VGOS Intensive scheduling. She scheduled 22 VGOS INTVI sessions, some of which also tested schedule configuration changes suggested by GSFC and MIT personnel.

5.7 Analysis Comparisons

S. Bolotin developed a script to process S/X INT sessions automatically for the purpose of comparing automated and manual analysis of these sessions. Tests applying this script to all INT sessions from the latest three years show that just a few percent of sessions need to be processed manually: for the remaining sessions, the results from automatic processing are the same as from manual processing. Eskil Varenius from Onsala Space Observatory used a similar script to process ultrashort VGOS sessions (with three Onsala antennas) as well as VGOS INT sessions that were correlated at the Onsala Space Observatory.

S. Bolotin and J. Gipson made comparisons of a VGOS session (24-hr VGOS session VO0009) correlated at Bonn and Haystack. In the end, the results using the two correlations yielded two very close (but not identical) solutions. A second test was done for INT VGOS session 20DEC15VI and compared the correlations from USNO (Washington, DC) and the TUV (Vienna, Austria). Both databases were practically identical except for the calculation of the PCMT cable corrections.

5.8 Miscellaneous Topics

Krásná and Petrov processed data from the astronomical VLBA program MOJAVE at 15 GHz in geodetic mode. They estimated baseline repeatability and compared it with repeatability from geodetic VLBA sessions at 2.3/8.4 GHz. They also evaluated quantitatively the impact of the residual ionosphere on baseline repeatability from single band 15-GHz observations (H. Krásná et al, 2021, in preparation).

Kierulf et al. performed quantitative analysis of the effect of glacial loading on the positions of the VLBI and GNSS stations at Svalbard, Norway. They found that the disagreement between the predicted and observed vertical seasonal signals is at the level of 5% (H. Kierulf et al, 2021, in preparation).

Ray et al. computed mass loading from the ψ_1 tide and evaluated its impact on nutation [18].

L. Petrov and N. Habana investigated the feasibility of using ngVLA for space geodesy. They modified the pSolve software to support an experiment with up to 256 sources and started processing a simulated dataset from ngVLA. The focus of the study is to evaluate the impact of routine ngVLA observations that include observations of strong calibrators on geodesy.

J. Gipson chaired an IERS Working Group on HF-EOP. The goal of this Working Group was to recommend a replacement for the current IERS model, which was 20 years old. The new model will be used for ITRF2020. Gipson gathered ten different HF-EOP models and put them in a common format. He also wrote software to calculate the predicted HF-EOP. As of the end of 2018, tests done using VLBI and GPS data indicated that the two best models are one based on TPX 8 altimetry data by Desai and Sibois, and an empirical model based on VLBI data by Gipson. The final recommendation was to use the Desai and Sibois model.

D. MacMillan investigated the differences between EOP and TRF scale parameters estimated from the simultaneous observing sessions of the two legacy and the VGOS networks. A paper was submitted to the Journal of Geodesy (VLBI special issue).

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IAA VLBI Analysis Center 2019–2020 Report

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Abstract This report presents an overview of the IAA VLBI Analysis Center activities in 2019 and 2020, and future plans.

1 General Information

The IAA IVS Analysis Center (IAA AC) operates at the Institute of Applied Astronomy of the Russian Academy of Sciences, St. Petersburg, Russia. The IAA AC contributes to IVS products, such as daily SINEX files, TRF and CRF solutions, and rapid and long-term series of EOP obtained from the IVS observational sessions. The IAA AC stopped submitting IVS NGS files due to the transition of IVS to the new vgosDB data format. The IAA AC generates NGS files from VGOS files for the QUASAR and OCCAM/GROSS softwares. Besides IVS VLBI data, the IAA AC deals with the data treatment of the domestic observations produced by both the RT-32 radio telescopes (SVETLOE, ZELENCHK, and BADARY) and the RT-13 VGOS radio telescopes (ZELRT13V, BADRT13V, and SVERT13V).

2 Staff

- Dr. Sergey Kurdubov: development of the QUASAR and analysis software.
- Prof. Vadim Gubanov: development of the QUASAR software and the methods of stochastic parameter estimation.
- Dr. Elena Skurikhina: team coordination; VLBI data processing, and OCCAM/GROSS software development.
- Svetlana Mironova: development of the QUASAR software, VLBI data processing, global solution and DSNX files calculation, data combination with SINCOM software
- PhD Student Alexey Kudelkin: studies in the field of the stochastic data modeling, development of new technique of schedule for VLBI observations.
- Marina Gribanova: VLBI data processing, development of new technique of EOP prediction.

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3 Activities during the Past Years

During 2019 and 2020, the IAA AC analyzed data of the IVS (legacy S/X and VGOS) and domestic observations, submitted to the ITRF2020, and made some investigations.

3.1 Routine Analysis

In 2019 and 2020, the IAA AC continued to generate daily SINEX (DSNX) files from analysis of IVS-R1 and IVS-R4 sessions using the QUASAR software. DSNX files were submitted to the IVS for combination with results of other Analysis Centers.

The IAA AC operationally processed the 24-hour and Intensive VLBI sessions using OCCAM/GROSS and submitted the results to the IERS and the IVS on a regular basis. Processing of the Intensive sessions is fully automated.

Calculation of new EOP time series with ITRF2014 and ICRF3 were performed as well.

3.2 Analysis of Domestic Sessions

The IAA Analysis Center processes all observational data of the domestic VLBI programs RuE, RI, R, and test sessions. A detailed description of the main kinds of the domestic sessions is given in the previous IVS Biennial Report [1].

Observational data from all these sessions are transmitted to the correlators using e-vlbi data transfer. The processing of RI sessions is fully automated. Calculated UT1–UTC time series is available at ftp://quasar.ipa.nw.ru/pub/EOS/IAA/eopi-ru.dat. The EOP time series calculated from RuE data is available at ftp://quasar.ipa.nw.ru/pub/EOS/IAA/eops-ru.dat.

In 2019 and 2020, 67 RuE and 718 RI sessions were observed using the QUASAR legacy network. RI sessions are the most rapid with latency at about 2.5 hours. During 2019 these sessions were duplicated on the PT13 network (RI RT13 sessions), but in 2020 this program was stopped.

Coordinates for the new radio telescope RT-13 at Svetloe observatory (SVERT13V) were the preliminary estimates from a 24-hour session on a six-station network (SVERT13V, SVETLOE, ZELENCHK, BADARY, ZELRT13V, and BADRT13V). The results are presented in Table 1. Values of velocities were fixed for the solution by the values from ITRF2014: for SVERT13V we used the velocities of SVETLOE.

Table 1 SVERT13V station positions at 2010.0 epoch.

Station	Svetloe
X, m	2730074.965 ± 0.001
Y, m	1562230.721 ± 0.001
Z, m	5530072.747 ± 0.001

Since March 2019 the new radiotelescope RT13 at Svetloe observatory started observations on experimental mode twice a day for the R program. Since the end of 2019 until February of 2020 we have the experimental observations using new receivers with linear polarization on the SVERT13V–BADRT13V baseline; these sessions are designated as LP in Table 2. From March 2020, SVERT13V station participates in all sessions for the R and X programs. SVERT13V was commissioned on 24/11/2020.

Program X is the experimental series at S/X/Ka range. It was a 0.5-hour duration from 2016 until 2019, while from March 2020 onward the X sessions are one hour. From the end of March until June 2020, once a day we observed R with experimental scheduling with long scans. Since August 07, 2020 we observe R sessions four times a day at a two-hour duration. Some statistics for the domestic Intensive sessions for the years 2019 and 2020 are given in Table 2.

Table 2 Statistics for the RT-13 sessions of the years 2019 and 2020.

Program	Number of sessions used	rms [μs]	bias [μs]
2019			
RI	354	61.6	46.1
RI RT13	339	42.9	4.5
R	1358	39.5	5.2
2020			
RI	351	60.3	66.0
LP	170	36.7	−37.0
R	992	28.3	−15.0
X	311	39.5	−11.2

The IAA RT13 Intensive time series composed from one-hour and two-hour S/X range sessions R, RI, and X as compared to the IERS finals.dat series is presented in Figure 1. The number of points is 3,173, rms is 37.6 μs, and bias is −7.3 μs.

The two-hour R sessions as compared to the IERS finals.dat series is presented in Figure 2. The rms is 18.7 μs, and the bias is 13.1 μs.

3.3 New Software Package for Scheduling VLBI Intensive Sessions

A new software package for scheduling VLBI Intensive sessions, called “aa_skd”, was developed. This package uses a modification of the covariance matrix optimization method. From March to July 2020, a series of experimental VLBI sessions scheduled by

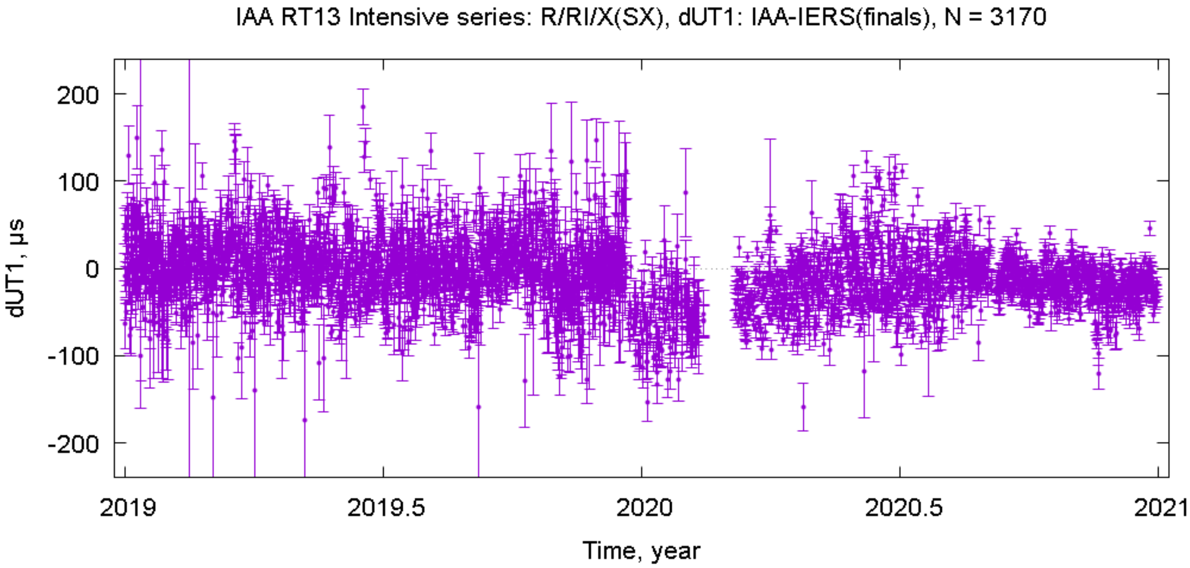

Fig. 1 IAA Intensive series vs. IERS finals.dat.

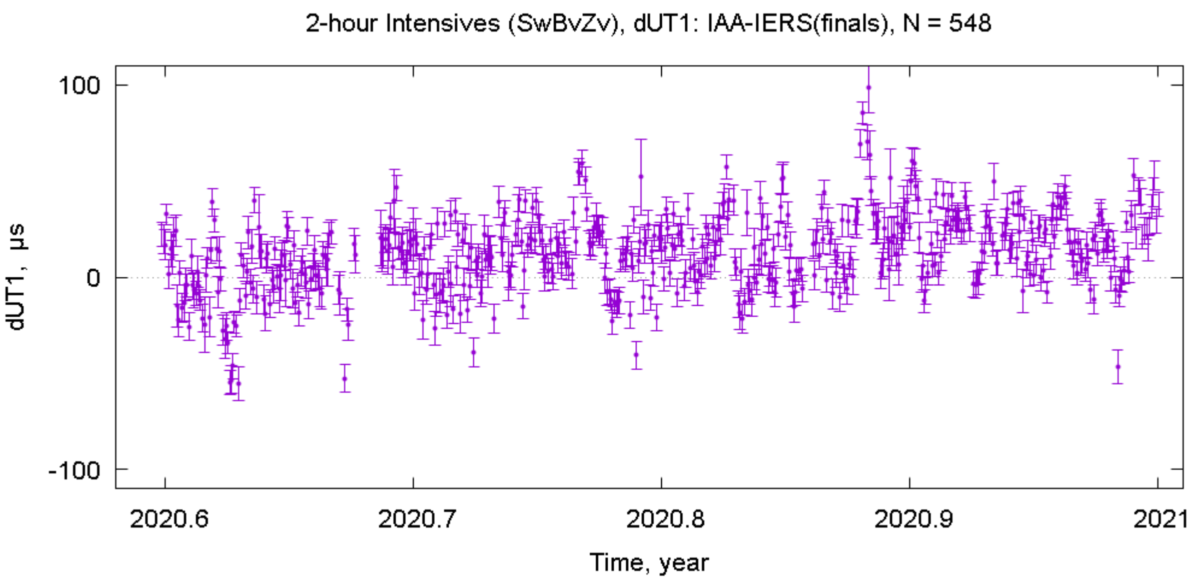

Fig. 2 IAA Intensive series vs. IERS finals.dat, 2-hour R (SwBvZv).

"aa_skd" was carried out. Figure 3 shows the results that were obtained. Regularly sessions scheduled by "Sched" software using sky covering algorithm [2] are indicated by a dot, while the experimental sessions scheduled by "aa_skd" are shown as a star.

As shown in the figure, this method provides potentially better WRMS than sky covering one; however, it gives greater dispersion of UT1–UTC correction. It is probably due to low reliance on tropospheric turbulence. Another issue is inaccurate computation of the a priori observation variance for some sources. For this reason, at the beginning of the experimental sessions, there is a weak quality of parameters determination and WRMS.

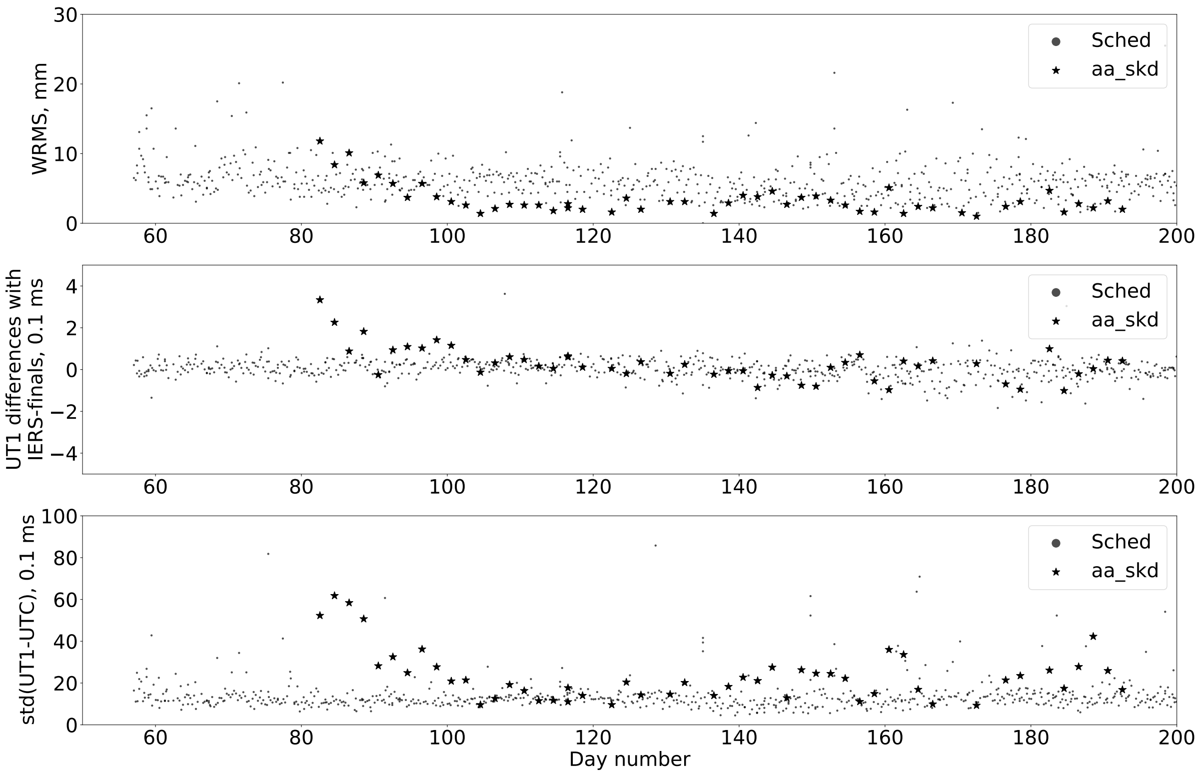

Fig. 3 "Sched" and "aa_skd" comparison.

4 Current Status

The IAA AC processes the data of all kinds of VLBI geodetic observation sessions. We use the QUASAR and the OCCAM/GROSS software packages for VLBI data analysis. All observation models in these packages are compliant with the IERS Conventions (2010). Both packages use NGS files as input data. The QUASAR and the OCCAM/GROSS software packages are supported and developed further. The QUASAR software was modified to adhere to ITRF2020 requirements.

5 Future Plans

- To continue submitting all types of IVS product contributions.
- To continue investigations of EOP, station coordinates, and tropospheric parameter time series.
- To improve algorithms and software for processing VLBI observations.
- Further work is planned to take stochastic tropospheric effects into account and increase the accuracy of a priori observation variance.

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IGN Argentino Associate Analysis Center Report

Ayelén Acosta Manschula, Facundo Nahuel Barrera, Micaela Carbonetti, Hernán Guagni

Abstract This report briefly presents a description of the IGN VLBI Analysis Center and its activities from the establishment of the center to the present. Recent results and plans for the future are mentioned. Since April 2020, IGN has been managed as an IVS Associate Analysis Center by the National Geographic Institute of Argentina (IGN-Ar) with the aim of increasing participation in the operational generation of geodetic products.

1 General Information

The IGN Analysis Center is the entity in charge of VLBI processing within the Research Center for Applied Geodesy (CIGA). It is supported and operated by the National Geographic Institute (Figure 1) in Buenos Aires, Argentina.

IGN-Ar is the institution responsible in Argentina for the determination of geodetic reference frames. In 2005, the IGN developed and began to operate the GPS Data Scientific Processing Center (CPC-Ar) with the purpose of updating the National Geodetic Reference Frame POSGAR (Argentine Geodetic Positions). The IGN is in charge of the development and maintenance of the Argentine CORS Network (RAMSAC), the National Leveling Network (RN-Ar), and the National Gravimetric Network (RG-Ar). Furthermore, CPC-Ar has been associated with the Geocentric Reference System for the Americas (SIRGAS) as an Official Processing Center, beginning its contributions to Working Group 1 in 2011.

Instituto Geográfico Nacional de Argentina

IGN Analysis Center

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Fig. 1 National Geographic Institute of Argentina.

The installation of the Argentine-German Geodesy Observatory (AGGO), a joint project between the National Council for Scientific and Technical Research of Argentina (CONICET) and the Federal Agency for Cartography and Geodesy of Germany (Bundesamt für Kartographie und Geodäsie, BKG), gave new impetus to the national geodetic community by being the first Argentinian co-location point of multiple geodetic techniques such as GNSS, SLR, and VLBI. In 2017, IGN developed CIGA aiming to process geodetic data obtained at AGGO and provide solutions for different international services such as IVS, ILRS, and SIRGAS.

In 2018, the VLBI AGGO antenna became part of the IVS observing program. The temporal evolution of

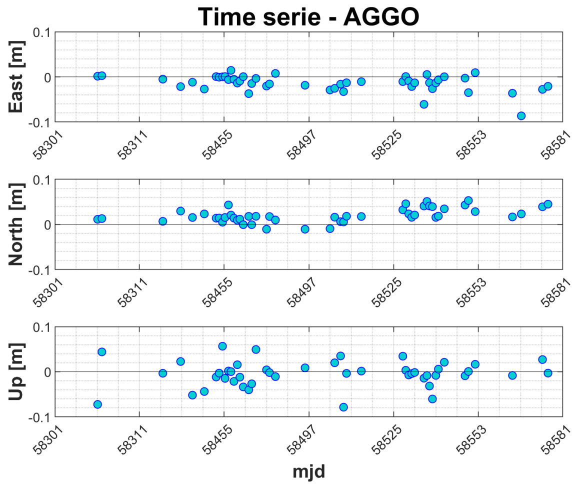

Fig. 2 Temporal evolution of the position of AGGO.

the antenna coordinates with respect to reference, a priori coordinates is shown in Figure 2 for the first two years of measurements.

The main activities of the IGN VLBI group consist of routine processing of 24-hour and one-hour observational sessions to obtain an estimation of all Earth Orientation Parameters (EOP), rapid UT1–UTC values, and station coordinates and velocities together with radio source positions. In 2020, we began submitting the results of 24-hour session processing to IVS.

2 Training Activities on VLBI Processing

In recent years, IGN promoted the development of human resources to use scientific software, through training courses and seminars with the intention of working with VLBI data.

Training began with an intensive course taught by Hayo Hase, at the facilities of the Argentine-German Geodesy Observatory. Subsequently, staff members were instructed through meetings with Dieter Ullrich, Gerald Engelhardt, and Reiner Wojdziak at the German Federal Agency for Cartography and Geodesy in Leipzig. In 2019, Robert Heinkelmann taught a course at our institution on the state-of-the-art VLBI processing techniques. Personnel of CIGA also participate in VLBI-related webinars and virtual events.

3 Staff

The National Geographic Institute has approximately 300 employees. Its responsibilities include contributing to the maintenance of international, regional, and national geodetic networks; production and dissemination of knowledge and geographic information on the Argentine Republic; and management, production, and publication of geospatial information under international standards and norms.

Members who are contributing to the VLBI Analysis Center are listed in Table 1 (in alphabetical order).

Table 1 Staff members.

Name and Email	Function
Ayelén Acosta Manschula [aacosta@ign.gob.ar]	Head of VLBI group and Operational data analyst
Daniel Fernandez [dfernandez@ign.gob.ar]	Web site and database maintenance
Facundo Nahuel Barrera [fbarrera@ign.gob.ar]	Operational data analyst
Hernán Guagni [hguagni@ign.gob.ar]	Head of Reference Frames Department
Micaela Carbonetti [mcarbonetti@ign.gob.ar]	CIGA Analyst

4 Current Status

The VLBI group at IGN generates daily solution files (DSNX) containing an estimation of 24-hour Earth orientation parameters and site positions, as well as their covariances and decomposed normal equations.

Moreover, results with a 48-hour epoch per session are generated in order to get two EOP offsets. These offsets are estimated at midnight before and after the session. Thereby, our solutions are ready to be integrated into the IVS combination effort.

Currently, IGN-Ar uses the VieVS scientific software (Vienna VLBI and Satellite Software), developed by Vienna University, Department of Geodesy and Geoinformation. We apply the following models and international standards:

- Earth Reference Frame: ITRF2014
- Celestial Reference Frame: ICRF3
- Troposphere mapping function: VMF3
- Oceanic loading model: TPX07.2
- Polar drift model: LINEAR IERS2019
- Antenna thermal deformation model: Nothnagel
- Atmospheric loading model: GSFC
- Precession/Nutation model: IAU_2006/2000
- A priori EOPs: IERS C04 14
- High Frequency EOP model (HF-EOP): Desai & Sibois (2016)

The implementation of these models and standards will allow our contribution to the realization of ITRF2020.

In April 2020, the IGN Analysis Center started to process regularly and submit daily sinex files for the IVS project "Daily EOP & station-coordinates solutions." All IVS 24-hour sessions were processed up to 2014. A comparison between IERS and IGN results for polar motion, UT1, and LOD are shown in Figures 3, 4, and 5, respectively.

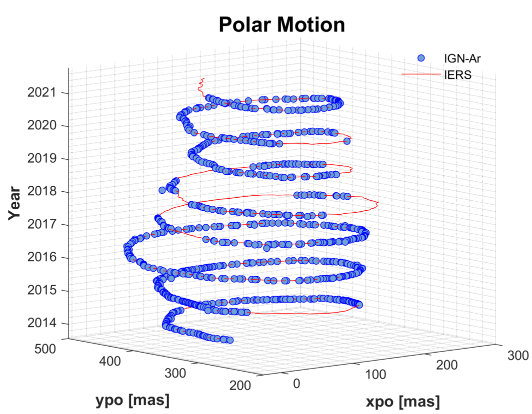

Fig. 3 Difference between polar motion XPO-YPO calculated by IGN and IERS.

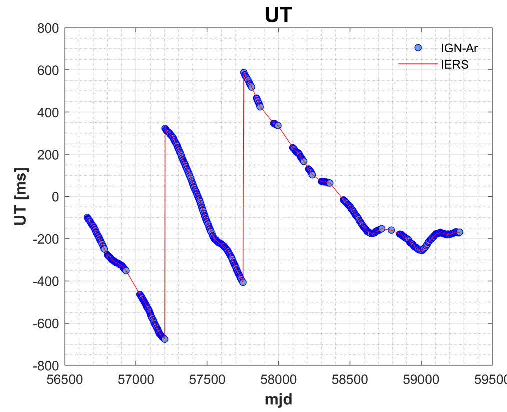

Fig. 4 Difference between UT1 calculated by IGN and IERS.

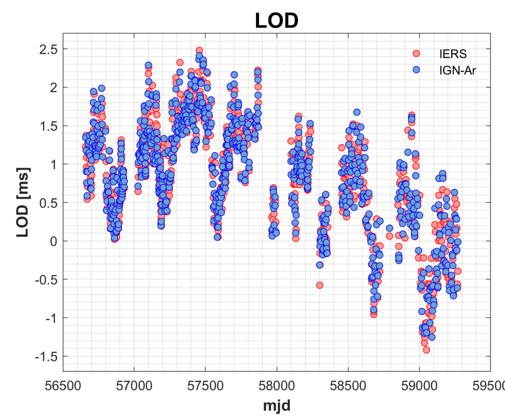

Fig. 5 Difference between LOD calculated by IGN and IERS.

5 Future Plans

As future activities, IGN-Ar plans to continue with the analysis and submission of 24-hour sessions to IVS and to extend our contribution to Intensive sessions as well. Our institution will continue its efforts to become an Operational Analysis Center, and we would like to participate in the data generation for ITRF2020.

In addition to continuing to improve our VLBI Analysis Center, we want to promote geodetic techniques and contribute to the advancement of the scientific development in our region.

Italy INAF Analysis Center

Monia Negusini, Roberto Ricci, Matteo Stagni

Abstract This report summarizes the activity of the Italian INAF VLBI Analysis Center. Our Analysis Center is located in Bologna, Italy and belongs to the Institute of Radio Astronomy (IRA), which is part of the National Institute of Astrophysics (INAF). IRA runs the observatories of Medicina and Noto, where two 32-m identical VLBI AZ-EL telescopes are located. This report contains the AC's VLBI data analysis activities and illustrates the latest experiments, involving the Italian antennas and correlator, carried out in the last two years.

1 Current Status and Activity

Following the installation of the software correlator DiFX in 2012 at Bologna, there have been a number of experiments to test the correlation pipeline for geodesy. These VLBI experiments were performed mainly on a single baseline, Medicina–Noto, and subsequently extended to Matera after seeking a collaboration with ASI, which manages the antenna facility. The VITA (ITAlian Vlbi network) project has been launched as a national pilot project, obtaining observing time at the stations. We have obtained first successful fringes on the three baselines in April 2015 and carried out eight 24-hour experiments until the end of 2020.

In these last years the group has been involved in the LIFT (Italian Link for Frequency and Time) project in collaboration with INRIM (National Institute of Metrology), which set up a distributed time and frequency optical link at Medicina. VLBI tests in a geodetic setup were performed, to verify the accuracy and reliability of their solution compared to standard maser clock timing in use at the antenna. After the first VLBI experiment, during EUR137 in 2015, VITA experiments have been set up to try to solve the issues raised after the first tests. There have been updates to the INRIM system at Medicina, so the infrastructure has become much more reliable. A detailed description of the optical fiber link is provided in [1, 2]. Results from this test have been published in [3].

On November 2018, the Matera antenna was connected to the distributed time and frequency link, thanks to the newly founded MeTGeSp (Metrology for Geodesy and Space) project. The link serves the Milan financial district, the Medicina observatory, the Italian Laboratory for Non-linear Spectroscopy (LENS) in Florence, the Telespazio Facility in the Fucino Plain, where one of the main stations of the European Galileo satellite network for global navigation is located, and the National Institute of Optics in Pozzuli, to reach finally the Matera fundamental geodetic station. In May 2019 the first common-clock geodetic VLBI experiment was carried out involving, besides Medicina and Matera, the Onsala and Yebes antennas. Data were successfully correlated, and a consistent solution was found. The best fit estimation of the clocks' parameters showed that, within the uncertainty, no difference is appreciable between the two clock signals delivered at Medicina and Matera [4].

Moreover, a new type of experiment (Timing VLBI) has been carried out with the aim of comparing the synchronicity of atomic clocks located at Italian and European stations by means of the interferometric phase rms noise statistics. VLBI clock timing should

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be a valid alternative to satellite-based techniques such as Global Navigation Satellite System or Two-Way Satellite Time and Frequency Transfer. First results have been presented at the 2019 EVGA Meeting [5].

At the end of 2020 a new series of observations (geodetic and VT experiments with the optical link on/off) have been carried out, and the data is being analyzed.

The presence of the LIFT infrastructure linking Medicina to Turin, where an optical clock has been developed, allowed the installation of a Japanese small antenna (NICT's Marble 2.4-m antenna) with the aim of comparing optical clocks at the intercontinental scale via VLBI. Broadband VLBI observations between Medicina and the other Marble antenna located in Koganei, in conjunction with the Kashima 34-m antenna, were carried out between October 2018 and February 2019 [6]. INAF contributed to the VLBI solution that was used for successfully comparing the IT-Yb1 optical lattice clock (Turin) to the NICT-Sr1 optical lattice clock (Koganei) [7].

2 Data Analysis and Results

The IRA started to analyze VLBI geodetic databases in 1989, using the CALC/SOLVE package on an HP workstation first located at the Medicina observatory and later at the Bologna headquarters. Since 2007, Linux workstations have been set up for the migration of all of the VLBI data analysis, and Mark 5 Calc/Solve has been installed. During the last years, our Analysis Center had some internal problems, and we did not participate regularly in IVS activities. However, we continued to update the catalog, and we installed and tested the latest releases of CALC/SOLVE and νSolve.

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KTU-GEOD IVS Analysis Center Report

Emine Tanır Kayıkçı[1], Kamil Teke[2], Özge Karaaslan[3]

Abstract This report summarizes the activities of the KTU-GEOD IVS Analysis Center (AC) in 2019 and 2020 and outlines the planned activities for the years 2021 and 2022. Our specific interests and focused subjects for 2019 and 2020 were as follows; (1) implementing new outlier detection methods to the least squares (LS) module of the GFZ (GeoForschungsZentrum, Potsdam, Germany) version of VieVS software, (2) estimating the velocity field of the Alpine Himalayan Earthquake Zone from GNSS and VLBI observations, and (3) estimating the M_2 tidal constituent of the ocean loading displacements from the observations of the IVS CONT14 campaign.

1 General Information

The IVS [1, 2] KTU-GEOD Analysis Center (AC) [3] is located at the Department of Geomatics Engineering, Karadeniz Technical University, Trabzon, Turkey. The Department of Geomatics Engineering, at Hacettepe University in Ankara supports the activities of the KTU-GEOD IVS Analysis Center (AC), for instance, through analyzing the VLBI observations.

1. Karadeniz Technical University, Department of Geomatics Engineering
2. Hacettepe University, Department of Geomatics Engineering
3. Gümüşhane University, Department of Geomatics Engineering

KTU-GEOD Analysis Center

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2 Staff at KTU-GEOD Contributing to the IVS Analysis Center

Members who have contributed to the research and activities of the KTU-GEOD IVS Analysis Center (AC) in 2019 and 2020 are listed in Table 1 (in alphabetical order) by their main focus of research and working location [3, 4, 5].

Table 1 Staff.

Name	Working Location	Main Focus of Research
Emine Tanır Kayıkçı	Karadeniz Technical Univ., Dept. of Geomatics Eng., Trabzon, Turkey	responsible person from AC, parameter combination
Kamil Teke	Hacettepe University, Dept. of Geomatics Eng., Ankara, Turkey	data analysis
Özge Karaaslan	Gümüşhane University, Dept. of Geomatics Eng., Gümüşhane, Turkey	data analysis, velocity estimation

Fig. 1 A photo during Emine Tanır Kayıkçı's presentation at GFZ Potsdam in July 2019.

3 Current Status and Activities

During 2019, we implemented new approaches to the LS module of the GFZ (GeoForschungsZentrum, Potsdam, Germany) version of VieVS (Vienna VLBI and Satellite Software, [6]) to detect outliers within the research stay of Emine Tanır Kayıkçı at GFZ Postdam. The research project addressed the performance of standard outlier detection methods used in the GFZ version of VieVS by looking at the accuracy obtained for the Earth Orientation Parameters. In our work, we intend to investigate problems connected with outlier detection and elimination in VLBI data analysis [7, 8]. For this purpose, the impact of using different outlier detection criteria was assessed.

The detection and elimination of outliers in VLBI observations is an important pre-processing step for VLBI parameter estimation. A common technique to handle this problem is based on a so-called k-sigma Criteria Method. The so-called k-sigma Criteria is a commonly used technique for the detection and elimination of outliers in the observations. It is standard in the VLBI data processing using the GFZ version of VieVS software.

The main idea is to compare each residual with standard deviation of unit observation with factor k (typically $k = 3$ or $k = 5$) or with a standard deviation of residual with factor k. In case the i-th observational residual is greater than the compared standard deviation, the corresponding observation is detected as an outlier and eliminated. Otherwise, it is kept. This procedure removed the impact of outlier observation on the estimated parameter.

In outlier detection and elimination of VLBI data analysis, the analyst has to decide between removing, down-weighting, or retaining incorrect data which may negatively affect the results. Removing data seems to be the least desirable action as it leads to losing information or even to lack of the solution (due to the singularity of normal equations). Moreover, excluding any station causes disability to determine coordinates of this site and changes in the geometry of the network. On the other hand, if we want to improve the solution, retaining bad data is not an option. The most appropriate solution seems to be down-weighting observations, as it allows saving the required data [9].

The down-weighting practically eliminates the impact of the observation on the estimated parameters. With the standard outlier detection method [10] used in VieVS, the theoretical factor corresponds with a normal distribution, whereas the proposed method in this research points to a t-distribution.

The standard-used outlier detection algorithm in the VieVS software starts with an initial least-squares adjustment. Afterwards, all observations are eliminated from the data whose residuals exceed their respective standard deviations (sigma) by a factor of 3 or 5. The final parameters are estimated after the elimination of outliers in the second step. The standard outlier observation detection method is rather fast but too simple, since it might tend to wrongly eliminate correct observations.

In our work, we applied the so-called k-sigma Criteria Method as the standard outlier detection method with the standardized standard deviation and student t-test which depends on an alternative way for the calculation of standard deviation points to a t-distribution. We focus here on Earth Orientation Parameters (EOP). We compare student t-test [11, 12] with the standard approach. With the student t-test method of the outlier detection, the formal (standard) error, s_{v_i} of the i^{th} observational residual (v_i) is calculated as follows

$$s_{0i} = \sqrt{\frac{1}{f-1}([pvv] - \frac{v_i^2}{q_{v_i v_i}})} \qquad (1)$$
$$s_{v_i} = s_{0i}\sqrt{q_{v_i v_i}}$$

where

$$q_{vv} = diag(Q_{ll} - AQ_{xx}A^T) \qquad (2)$$

In Equations (1) and (2), f denotes the degrees of freedom of the adjustment, $[pvv]$ is the weighted square sum of the observational residuals, v_i the residual to the i^{th} observation, q_{vv} are the diagonal elements of the cofactor matrix of the observational residuals, Q_{ll} the inverse of the weight matrix of observations, and A the coefficient matrix of the linearized observation equations.

For the study, fifteen CONT17 VLBI sessions were used. The VLBI data were processed at the GFZ using the software GFZ Version of VieVS software [6]. In this research, we inserted the student t-test outlier detection method in vie-lsm module. For this purpose, special VLBI campaigns like CONT17, scheduled and observed from 28 November 0 UT to 12 December 2017 24 UT, were used to perform research work. k-sigma Outlier Elimination Criteria both by factor were evaluated for achieving the proposed student t-test outlier detection method in LSM for single-session analysis in VieVS.

Several investigations were performed to compare the accuracy of various parameters estimated by the standard outlier detection method with those estimated by student t-test outlier detection. MATLAB codes in vie-lsm have been modified properly. The impact of applying different outlier detection methods, for standard outlier detection and t-test and analysis procedures, were assessed by investigating formal errors of the dUT1 estimation results from the fifteen CONT17 XE sessions (see Figure 2).

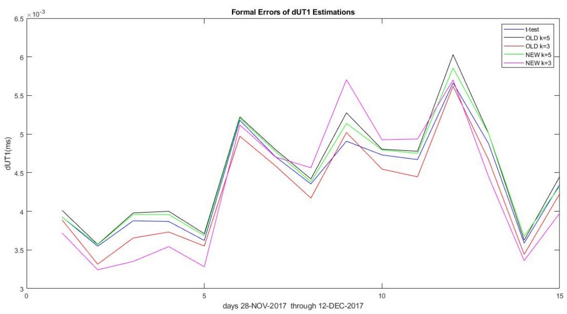

Fig. 2 UT1 formal errors with different outlier detection methods.

In a second study, we aim to determine and interpret crustal movements at velocities determined from data obtained from different space-geodetic techniques, i.e., VLBI and GNSS. The VLBI co-located IGS network which consists of the stations CRAO in Ukraine, MADR in Spain, MATE in Italy, MEDI in Italy, METS in Finland, NOT1 in Italy, ONS1 in Sweden, SVTL in Russia, TIT2 in Germany, WTZR in Germany, YEBE in Spain, and ZECK in Russia was considered for the study. For the period from January 2017 until January 2020, the coordinates are estimated through analyzing the daily data, with Bernese *v*5.2 [13]. The coordinates of the VLBI stations, i.e., CRIMEA in Ukraine; MATERA, NOTO, MEDICINA in Italy; WETTZELL in Germany; ONSALA60 in Sweden; SVETLOE, ZELENCHK in Russia; METSHAHOV in Finland; and YEBES in Spain (see Figure 3) are estimated from the analysis of the IVS daily sessions between January 2017 and January 2020 using VieVS. The linear global velocities of the GNSS and VLBI stations will be estimated in the next step of this study.

Fig. 3 VLBI stations considered for the study.

The Alp-Himalayan Earthquake Zone: starting from Indonesia, it reaches the Atlantic Ocean through the Himalayas and the Mediterranean. It is the second most seismically active region in the world, after the circum-Pacific belt (the Ring of Fire), with 17% of the world's largest earthquakes. Main ranges: Cantabrian Mountains (incl. the Basque Mountains), Sistema Central, Sistema Ibérico, Pyrenees, Alps, Carpathians, Balkan Mountains (Balkanides), Rila-Rhodope massifs, Thracian Sea islands, and the Crimean Mountains—entirely in Europe. Taking into consideration, two separate networks (more IGS stations relative to VLBI) will be created and analyzed as well as the position changes of the stations will be interpreted. It is aimed to determine the velocity field of the region, examine the results of different space-geodetic techniques, i.e., the horizontal and vertical deformations detected at the geodetic stations, and finally evaluate the crustal movements of the region from a geophysical point of view.

In a third study, the amplitudes and Greenwich phase-lags for each coordinate component, i.e., radial, west, and south of the principal lunar semidiurnal tide, M_2 of the ocean tide loading displacements were estimated at the VLBI sites of the 15-day long Continuous VLBI campaign 2014, IVS-CONT14. In the estimation of the amplitudes and Greenwich phase-lags of the M_2 tidal constituent, hourly VLBI station coordinate time series were used as observations derived through analyzing one-hour VLBI sessions of the

CONT14 campaign. In the analysis of hourly sessions of the CONT14 campaign, using VieVS [14] to derive accurate hourly station coordinates, troposphere delays estimated from daily sessions were reduced from the observations a priori to the analysis. For further details, readers are referred to [15].

4 Future Plans

In 2021 and 2022, our group will be working on estimating station velocities of the European IGS and VLBI sites in the scope of the Ph.D. thesis of Özge Karaaslan. Besides, the principal semi-diurnal and diurnal tidal constituents of the high-frequency Earth rotation variations due to the ocean tides from the recent models will be compared with those observed by VLBI and GNSS.

Acknowledgements

We are thankful to the governing board of the IVS [1, 2]. We are grateful to Karadeniz Technical University, Hacettepe University, Deutsche GeoForschungsZentrum-Potsdam, and Technische Universität Wien for their financial, technical and/or scientific support of the KTU-GEOD IVS AC research activities.

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NICT VLBI Analysis Center Report for 2019–2020

Mamoru Sekido

Abstract The VLBI analysis activities of NICT target the development and application of broadband VLBI for precise frequency comparison. A pair of small-diameter broadband VLBI stations is used for the nodes of the frequency comparison, and high sensitivity antennas support the VLBI observation by boosting the sensitivity ('Node-Hub' Style: NHS). This NHS VLBI observation scheme was used for the frequency comparison between Yb and Sr optical lattice clocks operated in Italy and Japan, respectively. The frequency ratio of the two optical clocks was measured at a 2.8×10^{-16} fractional frequency uncertainty, which is the lowest uncertainty of optical lattice clock frequency ratio over a 9,000-km distance. Effective atmospheric excess path delay calibrations with VMF3 atmospheric delay data was one of the keys of the VLBI delay analysis of the single long baseline. In the aspect of geodetic performance, baseline repeatability between the 2.4-m antenna pair achieved the same level with that of IVS R1 and R4 sessions.

1 General Information

The VLBI activity at NICT is operated by a group of the Space-Time Standards Laboratory (STSL) of the National Institute of Information and Communications Technology (NICT). The STSL is keeping Japan Standard Time (JST) at the Koganei headquarters in Tokyo, and development of state-of-the-art optical lattice clocks is a part of its activity. The VLBI group is working at the Kashima Space Technology Center, where two radio telescopes, Kashima 34-m and Kashima 11-m, are located.

Driven by the rapid progress of quantum technology, the frequency uncertainty of optical lattice clocks reaches 10^{-18}. This exceeds the microwave emission of Cs atom, which defines the 'second' as the SI unit of time. The metrological community is planning the redefinition of the 'second' with optical frequency standards [1]. Although the optical fiber link is the best way for accurate frequency comparison, it does not reach overseas distances. Thus, techniques for a long distance frequency link have been required.

The VLBI technique is also a tool for frequency transfer, similar to GNSS. We have been conducting the development of a broadband VLBI system for the application to intercontinental precise frequency comparisons as the main mission. Our broadband VLBI system [2, 3] has a similar broad observation frequency range (3.2–14 GHz) as the VGOS specification [4]. Unique features of our data acquisition system include the utilization of the originally developed broadband 'NINJA' feeds, RF direct sampling at a 16-GHz sampling rate, and digital filtering. Additionally, the Node-Hub Style (NHS) VLBI [3] scheme, which utilizes virtual group delay observable between small antenna pair derived by using closure delay relation, is a challenging approach for geodesy and frequency transfer VLBI.

2 Activities during the Past Two Years

The Kashima VLBI group of NICT is taking part in IVS in terms of technology development and observa-

NICT Kashima Space Technology Center

NICT Analysis Center

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tion stations by using the Kashima 34-m antenna and two 11-m diameter antennas at Kashima and Koganei. Historically, the Kashima group had played a pioneering role in the field of VLBI development in Japan. Our developed Japanese K3/K4/K5 VLBI terminal and correlator systems resources have been used by VLBI related Japanese research institutes.

Activities of the Analysis Center were performed mostly for the aim of our own VLBI project. Currently, VLBI experiments and data analysis has been conducted for the aim to realize long distance frequency transfer with VLBI observation. Our broadband GALA-V system acquires four channels of 1-GHz bandwidth data. Cross-correlation processing is made by our GICO3 software correlator [5], while bandwidth synthesis (fringe-fitting) of the broadband VLBI data is made by 'komb' [6], respectively. The derived delay and auxiliary data are stored in Mk3 database system via MK3TOOLS [7]. Finally, VLBI data analysis is made by CALC Ver.11.01 and SOLVE Ver. 2014.02.21, developed by NASA/GSFC.

3 Current Status

3.1 VLBI Experiments between Italy and Japan with Transportable Broadband VLBI Stations

One of the 2.4-m broadband VLBI antennas (MARBLE1) was installed at the Medicina Radio Astronomical Station of the Institute of Radio Astronomy/National Institute for Astrophysics (IRA/INAF) in 2018. A stable reference frequency was provided to the Medicina station from the Istituto Nazionale di Ricerca Metrologica (INRiM) in Turin, where an Ytterbium (Yb) optical lattice clock is operated. Another small antenna (MARBLE2), located at the Koganei campus of NICT where a Strontium (Sr) lattice clock is operated, was used for the other end of the experiment. The overview of the frequency link experiment over a distance of 9,000 km is depicted in Figure 1. Figure 2 shows the block diagram of the frequency link between the Yb optical clock in Italy and the Sr optical clock in Japan. Several hydrogen masers (H-masers) were used as flywheels to link the frequency chain.

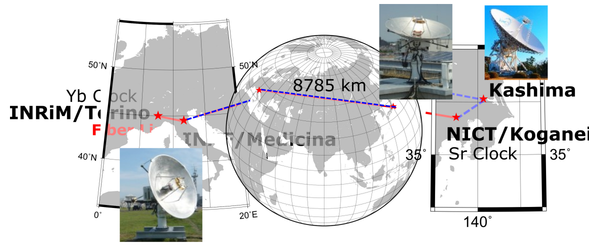

Fig. 1 Overview of the frequency link experiment between Italy and Japan. Reference frequency of Ytterbium lattice clocks operated at INRiM was provided to Medicina (INAF) by fiber link. Frequency link from Medicina to Koganei (NICT) was made by using VLBI observation. Kashima 34-m antenna participated the VLBI experiment to enable VLBI between 2.4 m antenna pair via NHS VLBI scheme.

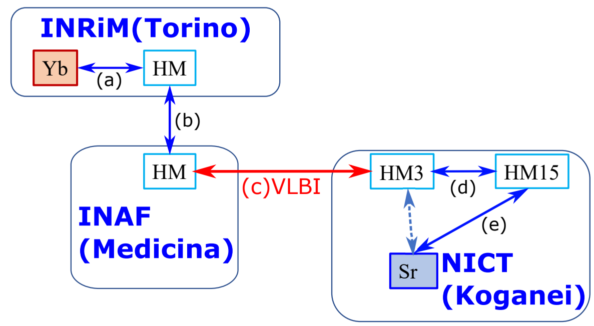

Fig. 2 Block diagram of the frequency chain between INRiM and NICT. Since optical lattice clocks (Yb, Sr) are operated intermittently with several hours of run, hydrogen masers (HM) are used as a flywheel to keep the frequency and link the frequency chain. Frequency ratios between each pair of nodes are measured, and the longest link was made by the VLBI observation.

Table 1 lists a series of frequency link VLBI experiments conducted between Medicina, Koganei, and the Kashima 34-m antennas. The lack of sensitivity of the small-diameter antenna pair was overcome via the NHS VLBI scheme by using the Kashima 34-m antenna as a Hub station. The virtual delay between the small antenna pair was analyzed by Calc/Solve with estimating station coordinates, atmospheric zenith delay, and clock parameters. A single clock rate was estimated for each session. The clock rate corresponds to the fractional frequency ratio between two H-masers at each end of the baseline. Atmospheric calibration was a concern in this experiment. Because sky coverages are limited at each station due to the single long baseline, accurate estimation of the atmospheric

Table 1 List of experiments conducted by the network of broadband antennas: the Kashima 34-m antenna, 2.4-m antenna at Medicina, and 2.4-m antenna at Koganei.

Session Date	Session [hours]	No.Scans (Used/Total)	WRMS residual [ps]
5 Oct. 2018	31.4	1366 / 1470	30
14 Oct. 2018	28.9	1155 / 1415	32
24 Oct. 2018	29.0	—— Failure at MBL2 ——	
4 Nov. 2018	30.6	1452 / 1645	39
14 Nov. 2018	29.0	1419 / 1539	24
24 Nov. 2018	28.8	1291 / 1435	29
4 Dec. 2018	29.0	1344 / 1511	33
15 Dec. 2018	29.5	1379 / 1470	26
25 Dec. 2018	28.9	1439 / 1501	22
15 Jan. 2019	29.0	1363 / 1437	24
25 Jan. 2019	30.6	1336 / 1591	26
4 Feb. 2019	31.0	1342 / 1500	30
14 Feb. 2019	35.8	1341 / 1585	29
30 May 2019	168.0	1718 / 2088	58
12 Jun. 2019	113.6	1182 / 2168	53
03 Jul. 2019	68.0	1372 / 1421	52
18 Jul. 2019	108.0	1485 / 1530	64
31 Jul. 2019	29.5	1591 / 1667	61

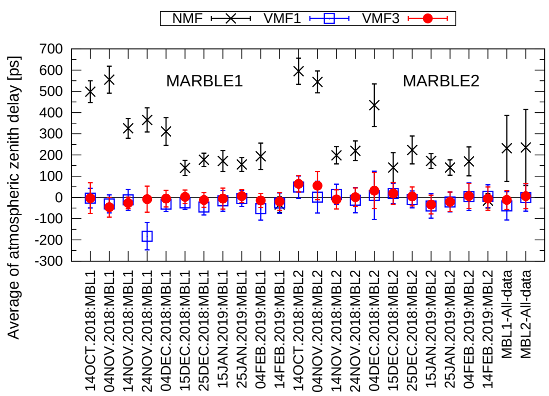

Fig. 3 Session-wise average of estimated zenith delay for MARBLE1 and MARBLE2 for three cases of atmospheric a priori calibration (with NMF, VMF1, and VMF3).

delay parameter from VLBI data itself was difficult. We took advantage of the Vienna Mapping Function 3 (VMF3) [8] for a priori atmospheric delay correction. The VMF3 data [9] provides dry, wet, and gradient components of zenith delay and their mapping function by six hours of interval. We have tested three atmospheric models (NMF [10], VMF1 [11], and VMF3) for the a priori delay correction. The session-wise average of the estimated zenith delay residuals are plotted in Figure 3. The small residuals for VMF1 and VMF3

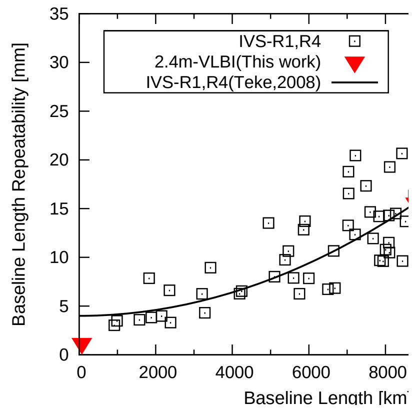

Fig. 4 Baseline repeatabilities of IVS R1/R4 session (squares) in 2011–2013 and the 2.4-m antenna pair of broadband VLBI with NHS scheme (red down triangle). The solid line is regression curve by Teke [13].

is owing to their accurate atmospheric delay prediction computed by the ray tracing technique with numerical weather models of the ECMWF (European Centre for Medium-Range Weather Forecasts). Better stability of the VMF3 than VMF1 in the plot is attributed to the advantage of anisotropic modeling of VMF3 by its atmospheric gradient.

3.2 *Results in Metrology and Geodesy*

Like the results of the VLBI frequency link experiment from October 2018 to February 2019, the frequency ratio between Yb and Sr lattice clocks was measured with 2.8×10^{-16} fractional frequency uncertainty [12].

The geodetic performance of these experiments was evaluated by comparing them to the IVS R1/R4 sessions in terms of baseline repeatability (BLR). We demonstrated that BLR of the 2.4-m antenna pair by the NHS scheme was at the same level as the IVS R1 and R4 sessions (Figure 4).

4 Future Plans

The Kashima 34-m antenna, which played the role of a hub station in the experiments, was seriously damaged by strong typhoon Faxai on 9 September 2019. It was constructed in 1988 as the first Japanese dedicated VLBI radio telescope for ‘Western pacific VLBI network’ project [14]. With consideration of its deterioration, it was decided to dismantle the antenna in 2020–2021. Although it became difficult to continue the experiments, the scheme developed in this project can be applied if one of the VGOS stations takes the role of hub station.

Acknowledgements

H. Ujihara of NICT developed broadband feed for the Kashima 34-m and 2.4-m antennas. T. Kondo and K. Takefuji of NICT developed the bandwidth synthesis software. We are grateful to our Italian colleagues at INRiM (M. Pizzocaro, D. Calonico, C. Clivati, et al.), the Medicina observatory at INAF/IRA (M. Negusini, F. Perini, G. Maccaferi, et al.), and NICT colleagues (K. Takefuji, M. Tsutsumi, N. Nemitz, H. Hachisu, T. Ido, et al.) for pursuing VLBI experiments for comparison of optical frequency standards. Y. Fukuzaki, S. Kurahara, and T. Wakasugi, et al. supported the development of the broadband VLBI system by the joint VLBI experiment with the Ishioka 13-m VGOS antenna. The intercontinental VLBI experiments were supported by the high speed research network of JGN, APAN, Internet2, GÉANT, and GARR enabling fast data transfer and sharing. The data transfer was made by JIVE5ab, developed by H. Verkouter of JIVE. Finally, we thank NASA/GSFC for allowing our experiment scheduling, antenna control, and data analysis by software Sked, FS9, and Calc/Solve.

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Norwegian Mapping Authority Analysis Center Biennial Report 2019–2020

Ann-Silje Kirkvik

Abstract During 2019 and 2020, the Norwegian Mapping Authority has continued the development of the analysis software **Where** that began in 2015. NMA started to contribute to the operational analysis of R1 and R4 sessions in 2019 and has contributed to the ITRF2020. Work has also been done to scan the antenna dish at NYALES20 to model the effect of gravitational deformation. The operational analysis is expected to continue, and special attention will be given to the analysis of data from Ny-Ålesund in the near future.

1 General Information

The Norwegian Mapping Authority (NMA) has been an Associate Analysis Center within the IVS since 2010. The Analysis Center is operated by the Geodetic Institute at NMA with main offices in Hønefoss, Norway. NMA is a governmental agency with approximately 800 employees, and the IVS activities at NMA are completely funded by the Norwegian government.

NMA is using the analysis software **Where**, which is developed at NMA. **Where** and its companion library **Midgard** is freely available as an open source at GitHub.[1,2] At the moment **Where** is capable of analyzing single sessions of VLBI data, but work is also underway to analyze weekly SLR data and some special applications of GNSS.

Norwegian Mapping Authority (NMA)

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[1] https://kartverket.github.io/where
[2] https://kartverket.github.io/midgard

1.1 Staff

The Geodetic Institute at NMA has approximately 50 employees. Some of the responsibilities include maintaining the national reference frame, geoid, and height system. The Geodetic Institute also provides a network-RTK positioning service and operates the VLBI stations in Ny-Ålesund [2].

The Analysis Center is organized under a small section named Global Geodesy, and in April 2020 Hans Christian Munthe-Kaas replaced Laila Løvhøiden as the section manager. The VLBI analysis group is small and listed in Table 1. Development of SLR analysis is led by Ingrid Fausk, and development of GNSS applications is led by Michael Dähnn.

Table 1 VLBI analysis group.

Name	Role
Ann-Silje Kirkvik	Developer and analyst
Åsmund Skjæveland	Analyst
Leo Olsen	Analyst

2 Activities during the Past Years

The years 2019–2020 have certainly been a special period. While 2019 was pretty normal, 2020 was not. In Norway the whole country went into lockdown on the

12th of March due to the global pandemic with the novel coronavirus. Everyone that was able was sent home and had to work from home. Despite these challenges, the operations of the Analysis Center and related activities have managed fairly well.

2.1 Analysis Center

Towards the end of 2018 analysis results obtained using **Where** were finally comparable with analysis results from other established analysis software packages [1]. And in March 2019 the first submissions for the operational daily SINEX solution started. Shortly afterwards, the version 4 VGOSDB which **Where** relies upon to do the analysis became unavailable for approximately two months, but the regular analysis and submissions resumed in May of the same year. Since then, the analyzed R1 and R4 sessions submitted by NMA have been included in the combined IVS solution. The submitted solutions can be found at the IVS Data Centers with the solution code `2019a`. But, on request from the IVS Combination Center (CCIVS), NMA switched to a new solution (`2020a`) from the 22nd of October 2020 and onwards. The `2020a` solution is updated with the same models used for the ITRF2020.

The operational R1 and R4 analysis is to some degree automated, but there is still significant room for improvement. The observation files are downloaded automatically, and the analysis is also started automatically when a new observation file has been added or an old one has been updated. Files which contain a priori information needed by the analysis are also downloaded and updated automatically. After the automated analysis is complete some key parameters are investigated. These are parameters such as variance factor, root mean square, and parameter estimates. If any of these parameters is outside normal values human interaction is needed. If everything is normal the solution is also delivered automatically. The operational analysis is managed by Åsmund Skjæveland.

2.2 ITRF2020

The main activity during these past two years has been preparation for an analysis of sessions for ITRF2020. **Where** had to be updated to support the new models that were required. These models are available from version 1.0.4 of **Where** and include:

- New mean pole-tide model;
- New high frequency EOP model;
- ICRF3 and galactic aberration, and
- Gravitational deformation of VLBI antennas.

The IVS contribution to the ITRF2020 includes approximately 6,500 S/X sessions and 38 VGOS sessions. This was the first time all of these sessions were analyzed with **Where**, and it was a substantial task to investigate these sessions to look for clock breaks, outliers, and other potential problems. See Figure 1 for a screenshot from **There** (the graphical companion program to **Where**) of a sample session from the ITRF2020. The final ITRF2020 submission from NMA was delivered at the beginning of 2021. Development of **Where** and analysis for ITRF2020 has been done by Ann-Silje Kirkvik.

2.3 Gravitational Deformation Model for NYALES20

Because gravitational deformation of VLBI antennas was to be included in the analysis for the ITRF2020 and the other operational products in the near future, NMA started to investigate the possibilities of doing a laser scanning of the antenna at the station NYALES20. This station has a long time series going back to 1994 and has participated in many sessions over the years and is therefore an important station in the network.

NMA did not have the equipment or resources to do this job without aid and therefore came to an agreement with the Swedish company RISE[3], which had experience doing a similar job for the station ONSALA60. This work was led by Torbjørn Nørbech (retired) from NMA with the assistance of the personnel at the station.

The original plan was to do the scanning in May 2020, but travel restrictions all over the world made it

[3] www.ri.se

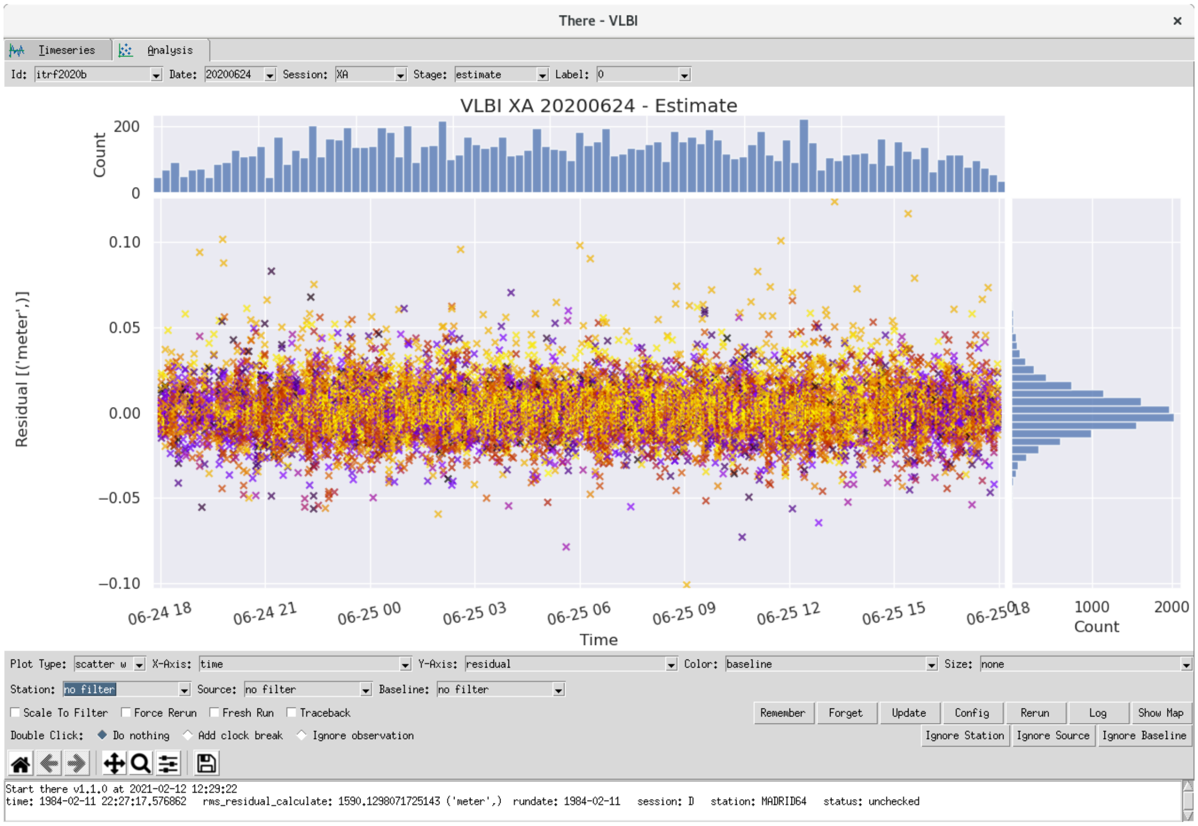

Fig. 1 Postfit residuals (before outlier rejection) for the mixed mode session RD2005 (20JUN24XA), one of thousands of sessions analyzed for the ITRF2020.

impossible to stick with the original plan. The scanning was postponed to the end of August 2020, and the deformation model became available at the beginning of November. The model is ready to be applied for the rapid operational products whenever the IVS chooses to do so. The modelled deformation can be seen in Figure 2, where the black line dL is the total change in path length. RISE is working on a publication to document the work that has been done.

2.4 Other News

The Analysis Center at IGN (Spain), which is using **Where**, has also started operational analysis of R1 and R4 sessions. IGN has also recently hired José Carlos Rodriguez, who has experience with SLR analysis from his previous work, and he has been a helpful resource for Ingrid Fausk with the development of the SLR analysis in **Where**. To facilitate this cooperation the complete SLR code for **Where** was also released at GitHub in version 1.1.0. The SLR analysis is not complete, and the results should not be used for anything yet, but input on how to improve the analysis is welcome.

3 Current Status

The global pandemic is still upon us, and as much work as possible is still done from home. The operational analysis is going smoothly, and the ITRF2020 submission is complete.

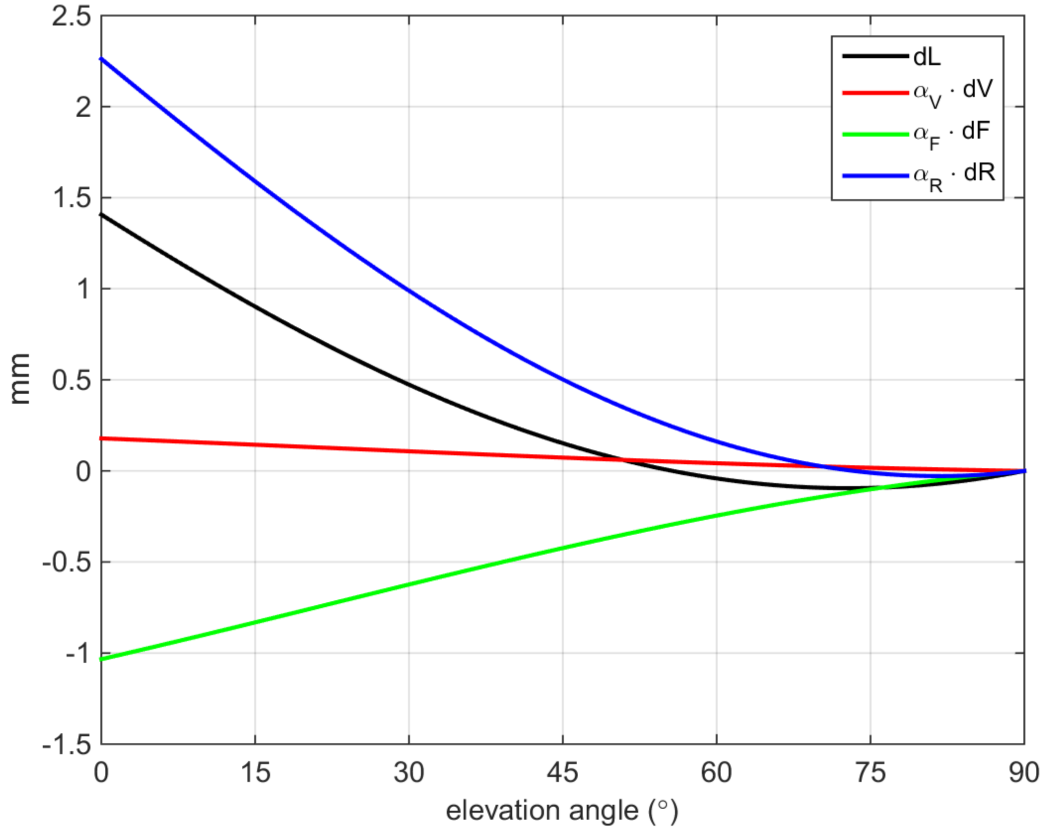

Fig. 2 Gravitational deformation of the NYALES20 antenna. Provided by RISE.

4 Future Plans

NMA will continue with the operational analysis of R1 and R4 sessions. With the completion of ITRF2020, the focus will shift towards investigating the upcoming sessions from Ny-Ålesund: both the future VGOS sessions from NYALE13N and the S/X sessions from NYALES20 and NYALE13S. The latter will be useful for comparing the computed baseline with the measured local tie vector.

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Service and Research at Paris Observatory Analysis Center (OPAR)

Sébastien Lambert, Christophe Barache, Teddy Carlucci

Abstract We report on the VLBI-related service and research activity at the Paris Observatory Analysis Center (OPAR) during the years 2019 and 2020. Featured items include the use of VLBI to assess the frequency dependence of the polar motion resonance (also known as the Chandler frequency), the check of systematic errors in the existing VLBI and Gaia realizations of the ICRS, and the modeling of 4C31.61 by a triple system of supermassive black holes.

1 Service

In 2019–2020, OPAR continued the processing of IVS data, both diurnal and Intensive sessions, in the opa2019a and opa2019i solutions with Calc/Solve. SINEX files were produced routinely for opa2019a so that OPAR could contribute to the IVS combination. Solution opa2019a uses the ICRF3 as an a priori radio source catalog and includes a model for the Galactic aberration, i.e., a dipolar displacement field of the quasars toward the Galactic center of amplitude 5.8 μas per year, as recommended by the IVS Working Group 8 (MacMillan et al. 2019) and as used for the production of the ICRF3 catalog (Charlot et al. 2020). The reference epoch of the Galactic aberration modeling is 2015.0, consistent with the ICRF3. As a consequence, the opa2019a quasar coordinate catalog should be read as follows: coordinates listed in the catalog correspond to the apparent position of the sources at 2015.0; at another epoch, the position of the sources should be corrected by the Galactic aberration effect using the above amplitude. As non-official products, OPAR continued to update radio source coordinate time series, station coordinate time series, and baseline length time series. All of these products are made available at the OPAR website.

OPAR also contributed to the preparation of ITRF2020 by processing the list of observing sessions asked by the Analysis Coordinator.

The Analysis Center made a complete transition to the new VGOS database format (thereby not using anymore the old format).

SYRTE, Observatoire de Paris - Université PSL, CNRS, Sorbonne Université, LNE

OPAR Analysis Center

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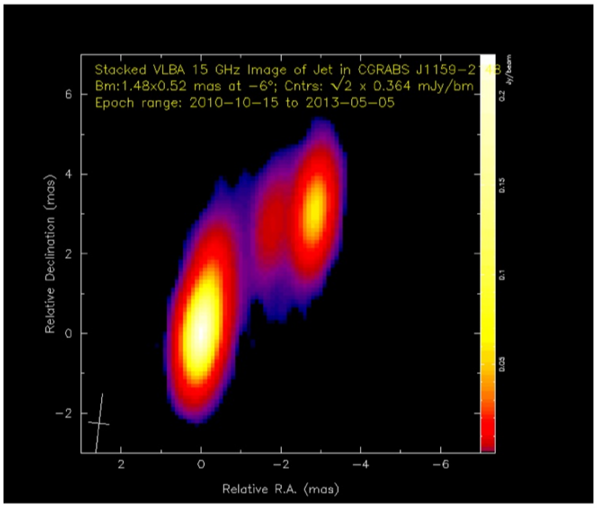
2 Research

Several research items in the space geodesy team of Paris Observatory/SYRTE involved VLBI measurements at the product or data level. Ibnu Nurul Huda defended his PhD Thesis at the end of 2019 on the topic of the analysis of Earth rotation series to determine the resonance frequencies and some rheological properties of the Earth. This problem is generally well-known when one thinks about the free core nutation (FCN) whose resonance affects the amplitude of nutation when the period is close to 430 days in the space-fixed frame of reference. Ibnu extended the research into two directions. First, he developed an approach of fitting the nutation amplitudes directly to the VLBI delay, as opposed to the traditional approach in which the nutation amplitudes are fitted to time series of celestial pole offsets. Second, he looked for the free inner core nutation resonance (FICN, see Nurul-Huda 2019; Nurul-Huda et al. 2020; Ziegler et



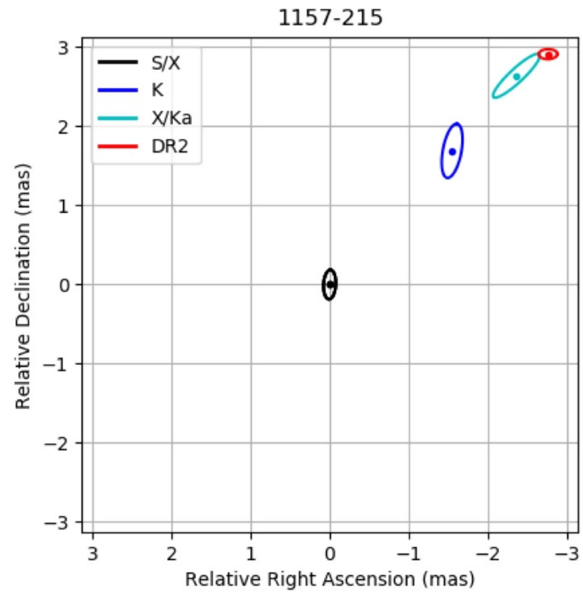


Fig. 1 An example of matching between the structure of an AGN (here from the 15 GHz VLBA MOJAVE database of Lister et al. (2019) and the absolute astrometry positions from Gaia and VLBI.

al. 2020) as well as for the polar motion resonance (PMR). The latter is actually known as the Chandler wobble when observed in the seasonal band in the Earth-fixed frame. Its period is close to 433 days. Nevertheless, because it acts as a resonant frequency in the geophysical transfer function expressing the modification of the amplitude of the oscillations of a rigid Earth under the lunisolar tidal potential by the rheological properties of the real Earth and the ocean, the Chandler frequency can be fitted to observed amplitudes of these oscillations. In the retrograde diurnal band in the terrestrial frame (equivalent to nutations in the space-fixed frame), one finds that the Chandler period is close to 380 days. In the prograde semi-diurnal band, where polar motion is mainly composed of periodic terms caused by the diurnal oceanic tide, the resonant period is about 401 days. In the former case, two complementary factors account for the observed values: the non-equilibrium response of the ocean to the pole-tide potential in the diurnal band, and the resonance of the solid Earth tide at the free core nutation period (Bizouard et al. 2020; Nurul-Huda et al. 2021).

An important activity of the team was devoted to analyzing the recent AGN observations by VLBI and Gaia in view of understanding the radio–optical link in terms of astrophysical processes. An independent assessment of systematic errors in VLBI and Gaia astrometry was achieved by Liu et al. (2020). In this work, we compared the ICRF3 catalogs of three generations (Charlot et al. 2020) with the Gaia DR2 (Prusti et al. 2016; Brown et al. 2018) counterparts. The ICRF3 at X-band closely agrees with Gaia DR2 in terms of global systematics and is nearly free of zonal errors, contrasting notably with previous ICRF realizations. With the improved accuracy of the X-band positions, we can see clearly the radio-to-optical offsets at sub-mas level. Including K-band and Ka-band astrometry will soon benefit studies of the core-shift effect as well as optical signatures of accretion disks and host galaxies (Fig. 1). Nevertheless, a possible zonal error in the Ka-band catalog should not be omitted when considering a physical interpretation of the radio–radio and radio–optical positions.

VLBI imaging followed by a careful follow-up of the various ejected components is one basis of investigating the physical characteristics of a radio source and whether it is made up of a single black hole or a multiple black hole system. A study of 2203+315 (4C31.61) was led by Roland et al. (2020), who modeled trajectories of radio components observed by the MOJAVE survey (Lister et al. 2019). The study suggested that

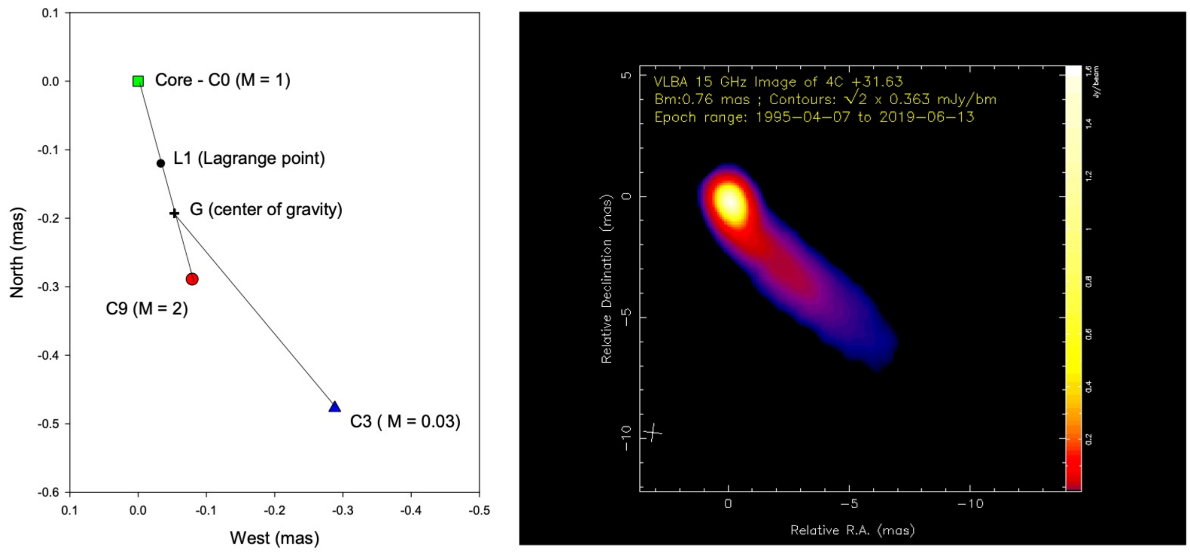


Fig. 2 Left: the system of black holes as modeled by Roland et al. (2020). Right: the MOJAVE stacked epoch 15 GHz VLBA image of Lister et al. (2019).

VLBI components are ejected from three different origins corresponding to three stationary components, one of which is the VLBI core. Most of the mass of the nucleus is associated with a supermassive binary black hole system whose separation is about 0.3 mas (i.e., 1.3 pc), and the mass ratio is 2. This model accounts for the variations detected in the astrometric coordinate time series obtained from geodetic VLBI and shows that it is possible to exploit large MOJAVE-like VLBI databases to propose more insights into the structure of the extragalactic radio sources that are targeted by VLBI in geodesy and astrometry programs. More generally, an ambitious exploitation (e.g., model-fitting of components) of the existing VLBI image database should be undertaken to address more systematically the physical characteristics and the inner structure of the radio sources.

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Onsala Space Observatory – IVS Analysis Center Activities during 2019–2020

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Abstract This report briefly summarizes the activities of the IVS Analysis Center at the Onsala Space Observatory during 2019–2020 and gives examples of results of ongoing work.

1 General information

We concentrate on research topics that are relevant for space geodesy and geosciences. These research topics are related to data observed with geodetic VLBI and complementing techniques.

2 Activities during the Past Two Years

We worked primarily on the following topics:

- VGOS Intensives
- Short-baseline interferometry
- Adaption of the ASCOT software
- VLBI to near-field radio sources
- Deformation of radio telescopes
- Atmospheric delays in space geodesy
- Radio telescopes as InSAR reflectors
- Coastal GNSS reflectometry
- Gravimetry
- Ocean tide loading

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3 VGOS Intensives

We investigated the scheduling of VLBI Intensive sessions with modern VGOS stations. This included both the use of twin telescope VGOS stations [3] as well as a new approach based on mixed-integer linear programming [4]. In both cases, the focus was on the impact of the new scheduling on the estimated UT1–UTC parameter, as well the local troposphere parameters at the participating stations and was based on extensive simulations. These studies show that the inclusion of twin telescopes in INT sessions promises to improve the

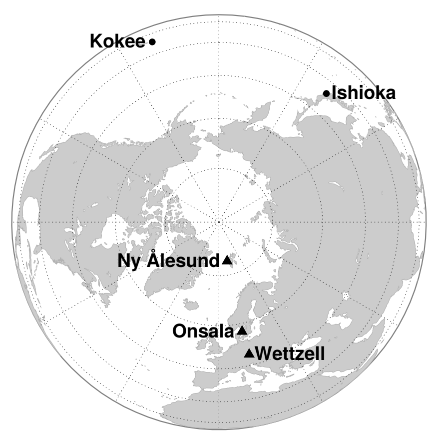

Fig. 1 Network geometry of simulations of Intensive sessions where the VGOS twin telescope sites Onsala and Wettzell were included. Figure taken from [3].

Succeeding these scheduling and simulation investigations, we observed twelve VGOS Intensives during December 2019 through February 2020, involving the VGOS twin telescopes at Onsala [8] and the VGOS station Ishioka. These so-called VGOS-B sessions were observed simultaneously to standard legacy S/X Intensives that were primarily using Wettzell and Kokee. The VGOS-B sessions were correlated and analyzed at Onsala to derive UT1–UTC [9]. The results show that the VGOS-B sessions achieve 3–4 times lower formal uncertainties for the UT1–UTC results than the simultaneously observed legacy S/X-band INT sessions. The comparison to UT1–UTC of the final IERS Bulletin B shows a slightly better RMS agreement for the VGOS-B results than for the simultaneously observed legacy S/X-band INT1 results. To study the topic further, a new series of VGOS-B sessions was started in late 2020.

4 Short-baseline Interferometry

We performed 25 short-baseline interferometry sessions with the three geodetic stations of the Onsala telescope cluster, i.e., On, Oe, and Ow. The aim was to connect the Onsala twin telescopes, Oe and Ow, with the legacy S/X station On. The observations were performed at X-band only, using dual-linear polarization for the OTT and one circular polarization for On. The sessions were planned, scheduled, observed, correlated, fringe-fitted, and post-processed at Onsala. Both group delay and phase delay solutions were performed, resulting in precise coordinates for Oe and Ow in VTRF2020b [23].

5 Adoption of the ASCOT Software

After the unfortunate closure of the VLBI group at the University of Bonn, we adopted the VLBI data analysis software ASCOT [1] that had been developed in Bonn during the last decade. ASCOT is now available at `https://github.com/varenius/ascot` and will be further developed by the Onsala VLBI Analysis Center. This software was used for the analysis of the VGOS-B sessions [9], the short-baseline interferometry sessions [23], as well as for the Onsala contribution to the IVS ITRF2020 solution.

6 VLBI with Near-field Radio Sources

We continued our work on VLBI with near-field radio sources. This included both analysis of real data of the OCEL (Observations of the Chang'E Lander) sessions [12], as well as a simulation study for precise orbit determination of Earth satellites [13]. For the latter, VLBI observations of medium earth orbiting satellites were simulated using both the actual CONT17 legacy S/X schedules, as well as simulated schedules for a hypothetical international VGOS network with 16 globally distributed stations. Various different scheduling options were studied, and different analysis strategies were tested with Monte Carlo simulations. The simulations of observations for Galileo satellites with a 16-station VGOS network show that satellite orbits can be determined with a precision of a few centimeters, see Figure 2. Furthermore, the results for the traditional VLBI parameters, in particular the polar motion and UT1–UTC, are not degraded by including observations to satellites. However, careful scheduling appears to be of major importance to balance the ratio of observing natural radio sources and satellites.

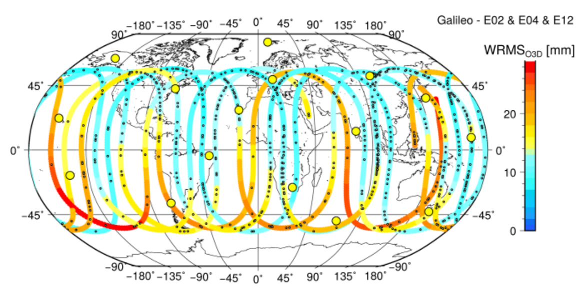

Fig. 2 Location-dependent 3-dimensional weighted root-mean square (WRMS) deviation (i.e., precision) of the orbit solutions for observations of three Galileo satellites (E02, E04, and E12) with a 16-station VGOS network (yellow dots). The figure is taken from [13].

7 Deformation of Radio Telescopes

During the last two years, we worked on studying deformations of the radio telescopes at Onsala. This includes both the gravitational deformation of the 20-m radio telescope [2, 16], as well as the Oe, one of the Onsala twin telescopes [14, 15].

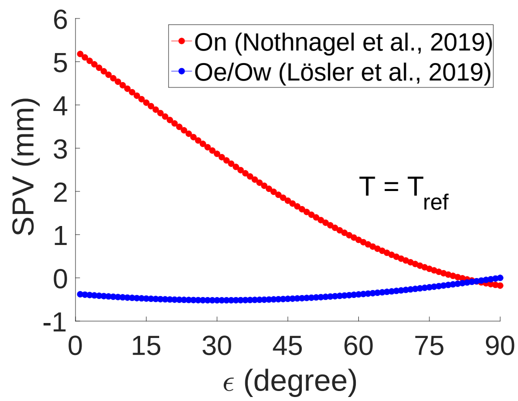

Fig. 3 Signal path variation (SPV) models for the Onsala 20-m telescope (On, red) and the Onsala twin telescopes (Oe, Ow, blue). The same temperature as the Onsala reference temperature was used in the modeling.

For the 20-m telescope, the gravitational stability of the telescope's reference point was studied using data acquired with a terrestrial laser scanner [11]. A gravitational deformation model was developed [16] that is recommended now by the IVS for regular data analysis. The signal path variation is more than 5 mm between 90^o and 0^o elevation, see the red curve in Figure 3.

The gravitational deformation model for the Onsala twin telescopes was derived from a photogrammetric survey [15]. The signal path variation is about -0.5 mm between 90^o and 0^o elevation (blue curve in Figure 3) and can easily be modeled.

8 Atmospheric Delays in Space Geodesy

We continued our research efforts concerning atmospheric delay effects in space geodesy. This included both the study of zenith wet delays [10] as well as horizontal gradients [5]. The horizontal gradients were estimated for the CONT14 campaign (6–20 May 2014) and compared to the corresponding results obtained from GNSS and microwave radiometry. Correlations from 0.56 to 0.71 were obtained when VLBI gradients were compared to the others using a temporal resolution of 6 hours. The temporal resolution can be increased with a better agreement for the use of the twin telescopes with faster slewing speeds and thereby an improved sampling of the atmosphere.

9 Radio Telescopes as InSAR Reflectors

In collaboration with Australian colleagues, we studied the possibility of using radio telescopes as reflectors for InSAR satellite signals [17]. While protecting the delicate receiving systems of the OTT, we tracked the European remote sensing satellites Sentinel-1a/b with the radio telescopes. Using radio telescopes with tracking capability provides the opportunity to achieve many more reflections, even at low elevations, than using dedicated fixed corner cube reflectors. Figure 4 shows an example of OTT reflections obtained for an ascending satellite track.

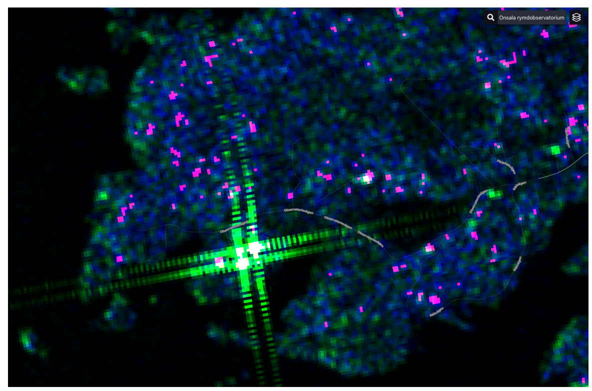

Fig. 4 InSAR picture of Onsala from an ascending track of Sentinel-1. The OTT had been tracking the satellite, resulting in strong reflection signals.

10 Coastal GNSS Reflectometry

We continued our research in the field of GNSS reflectometry. Besides investigating a real-time approach based on Kalman filter analysis [21], we also investigated the use of rather low-cost sensors for GNSS-R instead of high-end geodetic equipment [22].

Furthermore, we investigated the uncertainty level of GNSS-R for sea level observations [18], as well participated in an international comparison campaign on GNSS-R [7]. For the latter, one year of data from the Onsala GNSS-R installations was used.

11 Gravimetry

We assessed one decade of continuous measurements with the Onsala superconducting gravimeter (SG) and sixteen visiting absolute gravity (AG) campaigns [6, 19, 20]. The combined analysis of these data sets guarantees the long-term gravity reference better than 10 μGal [20].

12 Ocean Tide Loading

The Automatic Ocean Tide Loading service was operated throughout the year. It is heavily used by the international scientific community. Both new ocean models and new Green's functions were included during the last two years, see `http://holt.oso.chalmers.se/loading/`.

13 Future Plans

The IVS Analysis Center at the Onsala Space Observatory will continue its efforts to work on specific topics relevant to space geodesy and geosciences. We plan to intensify our work in particular concerning tropospheric parameters sensed by space geodetic techniques, as well as monitoring radio source flux density with local interferometry. We also plan in close collaboration with Lantmäteriet—the Swedish mapping, cadastral, and land registration authority—to analyze the global VLBI data set on a more regular basis and to contribute, for instance, to the IVS quarterly solutions.

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PMD IVS Analysis Center 2019–2020 Report

Vincenza Tornatore

Abstract The activities related to geodetic VLBI carried out at the IVS AC PMD during 2019 and 2020 were focused on different topics that are detailed below. As in previous years, routine computations of European baselines and tropospheric parameters were carried out. Comparisons of algorithms to detect jumps in time series were also performed in the framework of COST Action ES1206. The collaboration with the CRAF Committee has increased to defend the legacy S/X and VGOS frequency bands from external threats. And new collaborations and research under COST (DAMOCLES) and JRP GeoMetre projects have started. Visits and collaborations with other IVS ACs have also been organized and realized.

1 General Information

At the PMD IVS Analysis Center, hosted by the Politecnico di Milano DICA (see Figure 1), there were no significant changes compared to the previous two-year period (2017–2018) as regards to the location, the promoting agency, and the staff.

Politecnico di Milano, Department of Civil and Environmental Engineering (DICA), Geodesy and Geomatic Area

PMD Analysis Center

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Fig. 1 Politecnico di Milano Building 3, where the AC PMD is hosted.

2 Activities during the Past Two Years

2.1 Spectrum Protection for VGOS

During 2019 and 2020, we continued working on the issue related to spectrum managment at legacy S/X and VGOS antennas [1]. These studies were developed also under the framework of and in collaboration with the Committee on Radio Astronomy Frequencies of the of European Science Foundation (CRAF) [6] that coordinates activities to keep the frequency bands used by radio astronomy and space sciences free from interference. Geodetic and astrometric VLBI is a passive spatial technique; in the last years, its bands of interest were getting crowded by interferences caused by both terrestrial and space-borne private services [2]. Due to the increasing number of active terrestrial and space-borne private services that broadcast artificial signals it is becoming more and more difficult to protect observations from radio interference.

Fig. 2 Visit of the Meerkat telescope during the Fifth IUCAF Spectrum Management School for Radio Astronomy (Photo credit: Tasso Tzioumis).

One of the most dangerous threats to VGOS are the satellite systems Starlink and OneWeb downlink transmissions in the frequency range 10.7–12.75 GHz. In this range only the narrow band 10.6–10.7 GHz is allocated and protected by the radio astronomy service (RAS). On this matter technical studies at ECC project team SE40 have proposed several mitigation measures to protect the RAS band in Europe. Filtering requirements for the transmitters, constraints on power amplifier design, specified filtering, and deactivation of some channels when a satellite is in visibility of the telescopes were described in the ECC report 271 [8].

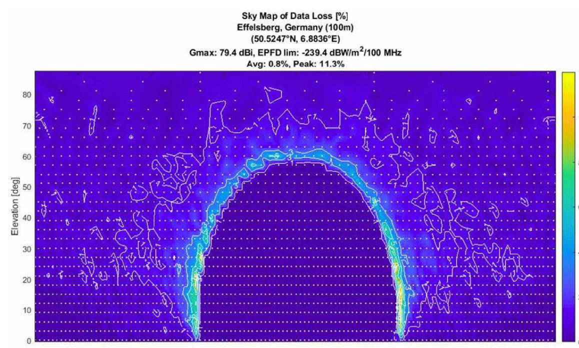

Fig. 3 Effelsberg sky map of data loss at 10.6–10.7 GHz (credit: ECC report 271).

Under the initiative of the “Dark and Quiet Skies for Science and Society” event, radio astronomy representatives from around the world recommended solutions for the negative impacts expected (see Figure 3). The event was organized by the United Nations Office for Outer Space Affairs (UNOOSA) and the government of Spain, jointly with the International Astronomical Union (IAU). After the meeting, a report [9] was prepared and will be presented to the Committee on the Peaceful Uses of Outer Space (COPUOS).

For the recognition of the VLBI Global Observing System (VGOS) services by the International Telecommunications Union (ITU) [10], *questions* to the Radiocommunications sector (ITU-R) Working Party 7D of RAS have been submitted. VGOS as a new global infrastructure makes passive use in four sub-bands of the spectrum in the range of 2–14 GHz to meet the targeted accuracy goals. A recognition of VGOS applications by the ITU should allow certain level of coordination with the satellite constellation agency for the overlapping frequency bands.

The Scientific Committee on Frequency Allocations for Radio Astronomy and Space Scienc (IUCAF) and the South African Radio Astronomy Observatory (SARAO), together with CRAF and RadioNet organized the Fifth IUCAF Spectrum Management School for Radio Astronomy in Stellenbosch, South Africa, on March 2–6, 2020 [7]. An optional visit to the MeerKAT Telescope was organized for school participants (see Figure 2) where people at Meerkat are shown.

2.2 Break Detection in Time Series of Tropospheric Parameters

An investigation on the performance of different break detection methods has been carried out on three sets of benchmark datasets, each consisting of 120 daily time series (1995–2011) of integrated water vapor (IWV) differences between Global Navigation Satellite System (GNSS) data and the numerical weather prediction reanalysis (ERA-Interim) data. The number methods used for breack detection is eight: two of them are based on Maximum Likelihood (ML) multiple break principle,three on Standard Normal Homogeneity Test, one on Singular Spectrum Analysis (SSA), and two on non-parametric methods.

The benchmark was developed with the use of known climatic characteristics and earlier estimates of inhomogeneities of IWV data in 120 observing sites of GNSS data. The benchmark includes homogeneous and inhomogeneous sections with added breaks in the latter.

To assess the performances of break detection methods w.r.t. dataset characteristics, three different variants of the benchmark time series were produced. They have increasing complexity, but the mean break frequency (2.5 per time series) and break magnitude distribution is the same for each variant. “Easy” dataset includes annual and sub-annual cycles of the means, breaks, and white noise only. “Moderate” dataset includes easy dataset plus first order autoregressive process of the first order (noise model = AR(1)+WN). “Complex” dataset is composed by Moderate dataset with gaps (up to 20% of missing data) and non-climatic trends added.

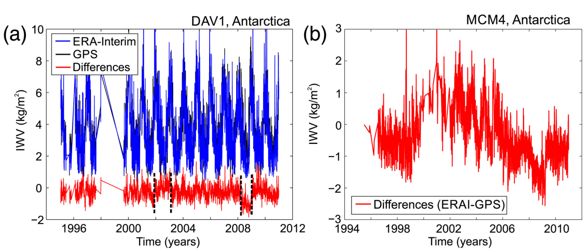

Fig. 4 Examples where break visual detection is (a) possible for DAV1 or (b) not possible for MCM4 (Credits to R. Van Malderen et al. 2020, Wiley’s Open Access).

The purpose of “Complex” experiments is to examine the performance of break detection methods in a more realistic case when the reference series are not homogeneous. In Figure 4, examples for two Antarctic stations are shown in the first case, DAV1 station; a break is visible and also reported in the IGS site log, while for MCM4 visual detection of breaks is not possible.

The performance of different break detection methods and software was evaluated using skill scores, centered root mean square errors (CRMSE), and trend differences relative to the trends of the homogeneous series. We found that most methods underestimate the number of breaks and have a significant number of false detections. Trend bias improvement decreases with increasing complexity of the datasets. In most experiments the maximum likelihood multiple break method and Standard Normal Homogeneity Test method achieved the best results. All characteristics of this work, detailed results, and discussions can be found in the publication [3]. These studies have been carried out under COST Action ES1206 Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC), sub-WG Data Homogenization.

3 Current Status

Under the COST ACTION CA17109 “Understanding and modeling compound climate and weather events (DAMOCLES)”, PMD AC collaborates in WG2 “Stakeholder involvement and science-user interface” and in WG4 “New statistical approaches for model development and evaluation” since 2019. The main objectives of the project are to bring together climate scientists, impact modellers, statisticians, and stakeholders to better understand, describe, and project compound events, and it foresees a major breakthrough in future risk assessments. Compound events arise from the combination of physical processes; they can produce high-impact hazards [4]. The extent of their impact can not be foreseen considering only single processes but also their interactions. For example, it is not clear whether climate models can capture major changes in risk associated with compound events.

Another project where AC PMD is involved as a stakeholder is the JRP s-09 GeoMetre "Large-scale dimensional measurements for geodesy," in particular for the WP3 "Local tie metrology at space-geodetic GGOS-CSs." One of the objectives of the project is to investigate the determination of the SLR and VLBI reference points. They are, in fact, a metrological challenge because it is inaccessible and non-materialized. Indirect methods are normally used to estimate the reference points in a rigorous way, but their determination with high accuracy is still an issue. A modified approach that meets the demands on an automated and continued reference point determination of the Global Geodetic Observing System (GGOS) is presented in [5]. Different studies are ongoing for all the different WPs of the GeoMetre project.

Data processing of European VLBI experiemnts is regularly carried out to study both station coordinates and tropospheric parameters. Time series of different estimated parameters are under investigation also for comparison with results from other spatial techniques in particular with GNSS. The VieVs software normally used for parameter estimation was updated to present version 3.2. Members of the PMD AC participated in the VieVS Days held online as a webinar from September 14–15, 2020. The first day was devoted to the VLBI module of the Vienna VLBI and Satellite Software (VieVS) with lectures on single session analysis, multi-session analysis, and global solution analyzing R&D sessions. The focus moved to scheduling package VieSched++ on the second day. More information is available at [11] on VieVS VLBI V3.2 as well as VieSched++ V1.1. Capabilities to generate schedules and simulations ware explored using VieSched++ V1.1 software during the second day.

Thanks to the ERASMUS+ project a visit has been carried out at the KTU-GEOD Analysis Center (Karadeniz Technical University) by PMD AC. During the visit, common projects between the two IVS ACs were discussed in detail and lectures were given to the KTU graduate and MSc/PhD students (see Figure 5).

Fig. 5 Lectures at KTU during ERASMUS+ program, February 2020 (Photo credit: Prof. E. Tanır Kayıkci).

4 Future Plans

In 2021 and 2022, IVS AC PMD will be working on the optimal estimations of the tropospheric VLBI parameter and comparison with results from GNSS data. Studies on ionospheric effects will also be tackled. Under COST ACTION CA17109 (DAMOCLES), work will be carried out with the aim to extend the network of collaborations with international colleagues from different fields, e.g., climate, wheather predictions, impact modellers, statisticians, and also to strengthen collaborations with Italian Meteorological Offices/Services, e.g., military aviation, which takes care of the weather forecast in Italy. Contributions to the GeoMetre project will also be given for the improvement of local tie determinations in Italy.

Acknowledgements

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We thank AC KTU and Karadeniz Technical University, Department of Geomatics Engineering for their kind hospitality and for research and teaching collaboration.

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Pulkovo Observatory (PUL) Analysis Center Report 2019–2020

Zinovy Malkin

Abstract This report briefly presents activities of the IVS Analysis Center at the Pulkovo Observatory (PUL) during 2019–2020 and plans for the coming years. The main topics of the scientific investigations at the PUL AC in that period were ICRF-related studies and research in the field of Earth rotation and geodynamics. Regular activities include OCARS catalog support and support of the PUL archives of data and products.

1 General Information

The PUL IVS Analysis Center was organized in September 2006. It is located at and sponsored by the Pulkovo Observatory of the Russian Academy of Sciences. It is a part of the Pulkovo EOP and Reference Systems Analysis Center (PERSAC) [1]. The main topics of our IVS-related activity are:

- Improvement of the International Celestial Reference Frame (ICRF).
- Analysis of Earth rotation parameters (EOP).
- Modeling of the celestial pole offset (CPO) and free core nutation (FCN).
- Computation and analysis of IVS observation statistics.

The PUL AC supports a website at [2]. Its contents was described in previous reports.

PUL staff members participated in activities of several IAU, IAG, IERS, and IVS committees, commissions, and working groups.

Pulkovo Observatory

Pulkovo Analysis Center (PUL)

IVS 2019+2020 Biennial Report

2 Staff

The following persons contributed to the PUL activity in 2019–2020:

1. Zinovy Malkin (70%).

3 Activities and Results

3.1 ICRF-related Research

The Analysis Center was involved in a number of ICRF-related activities:

- Team members participated in the activity of the IAU Division A WG "Third Realization of International Celestial Reference Frame" in preparation of the third release of the ICRF (ICRF3) [5].
- Team members contributed to the activity of the IVS Working Group 8 (WG8) on Galactic Aberration [6].
- Support of the OCARS catalog (Optical Characteristics of Astrometric Radio Sources) continued [7]. This compiled catalog provides source position, source type, redshift info, and photometric data in eleven visual and three NIR bands, as well as cross-identification with general radio, optical, NIR, Gamma-ray, X-ray, and UV catalogs for more than 13,000 radio sources (as of December 2020) with published VLBI-based positions. About 40 radio source position catalogs and separate radio source position determinations are used in OCARS. OCARS magnitudes and redshifts are taken from several data sources, such as Sloan

Digital Sky Survey[1] (SDSS), NASA/IPAC Extragalactic Database[2] (NED), SIMBAD[3] database managed by the Centre de Donnees astronomiques de Strasbourg (CDS), the Million Quasars (Milliquas) catalog[4], and Large Quasar Astrometric Catalogue[5] (LQAC), in the order of preference. The OCARS catalog is updated every several weeks and the latest version is available on the PUL website [3]. It consists of five files:

`ocars.txt`	main catalog file
`ocars_p.txt`	position data
`ocars_m.txt`	photometry data
`ocars_n.txt`	cross-identification table
`ocars.csv`	OCARS in CSV format

- A new method is proposed to divide the spherical surface into equal-area cells [8, 9]. The method is based on dividing a sphere into latitudinal rings of near-constant width with further splitting each ring into equal-area cells. It is simple in construction and use, and provides more uniform width of the latitudinal rings than other methods of equal-area pixelization of a spherical surface. The new method provides rectangular grid cells with latitude- and longitude-oriented boundaries, near-square cells in the equatorial rings, and the closest to uniform width of the latitudinal rings as compared with other equal-area isolatitudinal grids. The binned data is easy to visualize and interpret in terms of the longitude-latitude rectangular coordinate system, natural for astronomy and geodesy. Grids with arbitrary number of rings and, consequently, a wide and theoretically unlimited range of cell size can be built by the proposed method. The maximum number of rings that can be achieved with SREAG for coding with 32-bit integer is 41,068, which corresponds to the finest resolution of $\sim 16''$. Comparison with other methods used in astronomical research showed the advantages of the new approach in the sense of uniformity of the ring width, a wider range of grid resolution, and simplicity of use. Supporting routines for using SREAG are available on the PUL website [4].

[1] http://www.sdss.org
[2] http://ned.ipac.caltech.edu
[3] http://simbad.u-strasbg.fr/simbad/
[4] https://heasarc.gsfc.nasa.gov/W3Browse/all/milliquas.html
[5] https://cdsarc.unistra.fr/viz-bin/cat/J/A%2bA/624/A145

3.2 Earth Rotation Research

Two CPO and two FCN series were computed and analyzed. All the series use the IVS combined EOP solution as the primary data source for investigation of the celestial pole motion. These series are updated daily and are available on the PERSAC webpage [1]. Some series also include CPO/FCN prediction.

3.3 Other IVS-related Research

A statistical analysis of the results of 20 years of IVS activities was performed [10]. During the period of 1979–2018, the IVS Data Center has accumulated more than 18 million observations obtained in more than 17,000 observation sessions, including more than 10,000 short sessions for rapid determination of UT1. The dynamics of IVS development based on the statistical processing of the IVS observational data was followed. Statistics for observation years, stations, baselines, and radio sources are given. The evolution of observation statistics and the accuracy of the results obtained from the processing of VLBI observations is studied.

3.4 Regular Activities

Regular activities of the Analysis Center include:

- Archiving IVS data in NGS card format.
- Archiving IVS and IERS products.
- Development of algorithms and software for data processing and analysis continued.

4 Future Plans

Plans for the coming years include:

- Continuing ICRF-related studies.
- Continuing research on Earth rotation and geodynamics based on the IVS data and products.
- Continuing OCARS catalog support.
- Continuing support of PUL archives of data and products.

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SAI-VNF VLBI Analysis Center in 2019–2020

Vladimir Zharov[1], Sergey Pasynok[2]

Abstract This report presents an overview of the SAI-VNF VLBI Analysis Center activities. The AC analyzes all IVS sessions for computations of the Earth Orientation Parameters (EOP) and time series of the ICRF source positions and performs research and software development aimed at improving the VLBI technique.

1 General Information

The SAI - VNF VLBI Analysis Center is located at the Sternberg State Astronomical Institute (SAI) of Lomonosov Moscow State University in Moscow and at the National Research Institute of Physicotechnical and Radio Engineering Measurements (VNIIFTRI) in Mendeleevo, Russia. The Analysis Center participates in geodetic and astrometric VLBI analysis, software development, and research aimed at improving the VLBI technique, especially for support of the ASC correlator during the Radioastron mission [1].

2 Activities during the Past Two Years

AC SAI-VNF performs data processing of all kinds of VLBI observation sessions. For VLBI data analysis we use the ARIADNA software package developed by V. Zharov [2]. Version 4.11 of this software was used for operative VLBI data processing for Russian EOP operative services at VNIIFTRI [4] in 2019–2020. Now, the new version 5 of the software is under development.

1. Sternberg State Astronomical Institute (SAI) of Lomonosov Moscow State University
2. National Research Institute of Physicotechnical and Radio Engineering Measurements (VNIIFTRI)

SAI-VNF Analysis Center in 2019-2020

IVS 2019+2020 Biennial Report

3 Staff

The staff of the joint AC is:

- Vladimir Zharov, Prof.: development of the ARIADNA software, development of the methods of parameter estimation (SAI);
- Sergey Pasynok, scientific researcher: development of control scripts, global solution (VNIIFTRI);
- Natalya Shmeleva, engineer: VLBI data processing (SAI).

4 Current Status

- **Software development for VLBI processing**
  The ARIADNA software is being developed to provide contributions to IVS products. The software is used for calculating all types of IVS products. The EOP series was obtained from observations that were made in 2019–2020. The main features of version 4.11 are: handling input data in the VGOS [3] and NGS formats, performing all reductions in agreement with the IERS Conventions (2010), automatic generation of the SINEX files, and combination of some of the SINEX files to

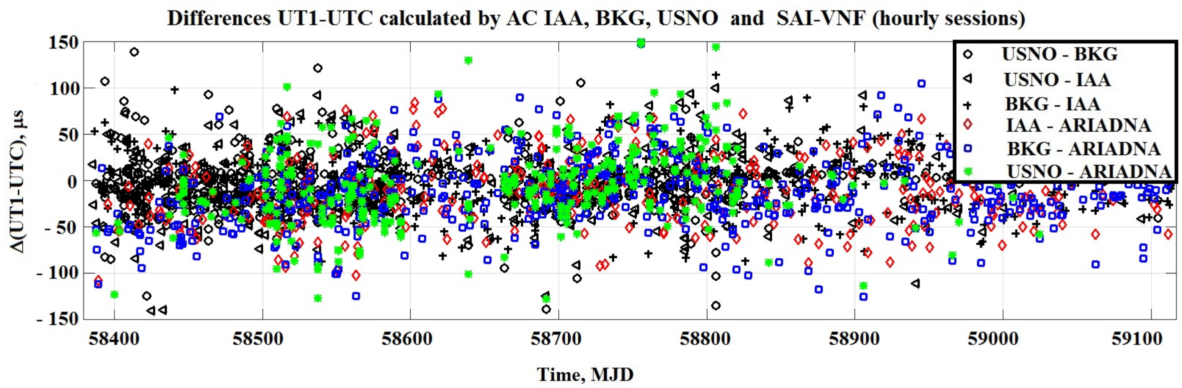

Fig. 1 UT1-UTC differences calculared by AC IAA, BKG, USNO, and SAI-VNF for Intensive sessions in 2019–2020. Differences with ARIADNA (AC SAI-VNF) are in color.

stabilize solutions in non-interactive mode, starting from version 4 software allowed to use the CIO based transformation matrix. The method that uses calculations of the equinox-based transformation matrix for precession-nutation was kept to compare new series with old ones. The equinox based matrix $Q(t)$ transforms from the true equinox and equator of date system to the GCRS composed of the classical nutation matrix, the precession matrix including four rotations, and a separate rotation matrix for the frame biases. Now, the new version 5 of the software is under development.

- **Routine analysis**
  During 2019–2020 the routine data processing was performed with the ARIADNA software using the least-squares method with rigid constraints.
  AC SAI-VNF operationally processed the 24-hour and Intensive VLBI sessions. Forming the data base of the VLBI sessions and processing of all sessions is fully automated. The EOP series $vnf\_vlbi.pvz$ was calculated. This series was computed with the catalog VTRF2015 of station positions and velocities.
  The SINEX files were generated for all sessions.
  UT1-UTC differences calculated by AC IAA, BKG, USNO, and SAI-VNF estimated from all Intensive sessions are shown in Figure 1. Differences with ARIADNA (AC SAI-VNF) are in color.

5 Future Plans

- Continue investigations of VLBI estimation of EOP, station coordinates, and source coordinates and their variability.
- Improvement of the ARIADNA software for processing of the GNSS troposphere zenith delays.

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Tsukuba VLBI Analysis Center

Yu Takagi[1], Kyonosuke Hayashi[1], Tetsuya Hara[1,2]

Abstract The Tsukuba VLBI Analysis Center has been regularly performing near real time analysis of the weekend IVS Intensive (INT2) sessions using the *c5++* analysis software. This report summarizes the results of the INT2 analysis and some activities of the Analysis Center during 2019 and 2020.

1 Introduction

The Tsukuba VLBI Analysis Center, located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). A major role of the Analysis Center is to regularly analyze the weekend IVS Intensive (INT2) sessions and deliver the results to the IVS community. The analysis is performed in near real time and the estimate of UT1–UTC (=dUT1) is provided to the IVS community rapidly after the end of observation. A dedicated link to the SINET5 operated by the National Institute of Informatics (NII) and several process management programs make it possible to derive the solutions rapidly. Our products are utilized for more accurate dUT1 prediction by the U.S. Naval Observatory (USNO) at the IERS Rapid Service/Prediction Center, which is responsible for providing Earth orientation parameters on a rapid-turnaround basis, primarily for real-time users and others needing the highest quality for the Earth Orientation Parameter (EOP) information sooner than that available in the final EOP series [1, 2].

1. Geospatial Information Authority of Japan
2. Advanced Engineering Service Co.,Ltd.

2 Component Description

2.1 Analysis Software

An analysis software named *c5++*, which was jointly developed by Hitotsubashi University, the National Institute of Information and Communications Technology (NICT), and the Japan Aerospace Exploration Agency (JAXA) for various space geodetic techniques including SLR, GNSS, and VLBI, is officially used to estimate dUT1 in the regular INT2 sessions at the Analysis Center [3]. Currently, the analysis software is being updated by the institutions mentioned above and Onsala Space Observatory [4]. At present, the analysis center uses version 0.0.1 (rev 926) of the analysis software. The correlation and analysis management programs, so-called *rapid_* programs developed by GSI, can execute all processes from data transfer through analysis and provide the results consecutively and automatically. *Rapid_c5pp* runs *c5++* on outputs of the bandwidth synthesis process and estimates dUT1 to be delivered to the community quickly. Please refer to the report "Tsukuba VLBI Correlator" in this volume for further details of *rapid_* programs.

The Analysis Center creates the version 4 databases to submit to IVS using *νSolve* developed by NASA GSFC [5]. The version of *νSolve* is 0.6.3 as of December 2020. Until the end of August 2020, the Tsukuba VLBI Analysis Center was providing Mark Ⅲ format databases in addition to vgosDB format databases based on requests from some Analysis Centers, but only vgosDB format databases have been provided since September 5, 2020, because there have been no more requests.

2.2 Analysis Center Hardware Capabilities

At the Analysis Center, *c5++* and *νSolve* are installed on several general purpose and commercially produced Linux computers to perform dUT1 analysis. The main analysis server has two 3-TB hard disk drives where the VLBI databases and necessary a priori files are stored. One is used as main storage and mirrored by the other regularly. We are planning to increase the storage capacities in the future.

3 Staff

The technical staff in the Tsukuba VLBI Analysis Center are:

- **Yu Takagi** — correlator/analysis chief, management.
- **Kyonosuke Hayashi** — correlator/analysis operator, coordination.
- **Tetsuya Hara** (AES) — correlator/analysis operator, software development.

4 Analysis Operations

4.1 Updates of the Analysis Environment

There were a few major updates of the analysis software and setting during this period.

- **Transition to ICRF3**

The Analysis Center had been conducting analysis with the ICRF2 source position catalog set for both *c5++* and *νSolve* since April 2010. Since ICRF3 was released in January 2019, the Analysis Center changed the source position catalog for *νSolve* from ICRF2 to ICRF3 in February 2019. For *c5++*, the catalog was changed in January 2020. In the INT2 analysis, we used ICRF3 starting with Q19054 for *νSolve* and with Q20025 for *c5++*.

- **Update of *c5++* Version**

The Analysis Center used version 0.0.1 (rev 907) of c5++ until January 2019, and updated the analysis software version twice between 2019 and 2020. First, we updated *c5++* to version 0.0.1 (rev 920) on January 22, 2020, because *c5++* began to support ICRF3 from version 0.0.1 (rev 918). For the INT2 analysis, this version was used from Q20025 to Q20138. The second update was to version 0.0.1 (rev 926) on May 23, 2020, because there were major updates regarding the available mapping functions from version 0.0.1 (rev 922) to version 0.0.1 (rev 924). We are using this version from Q20144 onward for the INT2 analysis.

- **Change mapping function**

In *c5++*, three mapping functions, VMF3, V3GR, and GPT3, provided by the Vienna University of Technology [6] have been available since version 0.0.1 (rev 922). The Analysis Center was using VMF1 as the mapping function, but with the update of *c5++* to version 0.0.1 (rev 926), we considered changing the mapping function to be used in the future to either VMF3 or V3GR. To investigate the effect of changing the mapping function, we compared the estimates of dUT1 for three different mapping functions of VMF1, VMF3, and V3GR, using the data of the INT2 sessions conducted from January 2019 to March 2020. Figure 1 shows the difference of dUT1 solutions using each mapping function from IERS EOP 14C04. The mean and standard deviation were 2.46±20.22, 2.44±20.20, and 1.14±19.70 microseconds for VMF1, VMF3, and V3GR, respectively. Although the difference from IERS EOP 14C04 was slightly the smallest when V3GR was used, there was no significant difference in each dUT1 values estimated with the three mapping functions. Therefore, we have been using VMF3 as the mapping function of *c5++* since May 23, 2020, because it is easy to migrate from VMF1. We will continue to consider the adoption of V3GR.

4.2 Summary of UT1–UTC Results

Almost all of the weekend INT2 sessions were processed at the Analysis Center automatically in near real time using the *rapid_* programs. Table 1 summarizes the INT2 sessions analyzed by the Analysis Center in 2019 and 2020. The number of analyzed INT2 sessions was 99 and 97 in 2019 and 2020, respectively. The estimated dUT1 were submitted to the IVS Data Center as gsiint2c.eopi.

Ishioka (ISHIOKA) in Japan and Wettzell 20-m (WETTZELL) in Germany usually participate in the

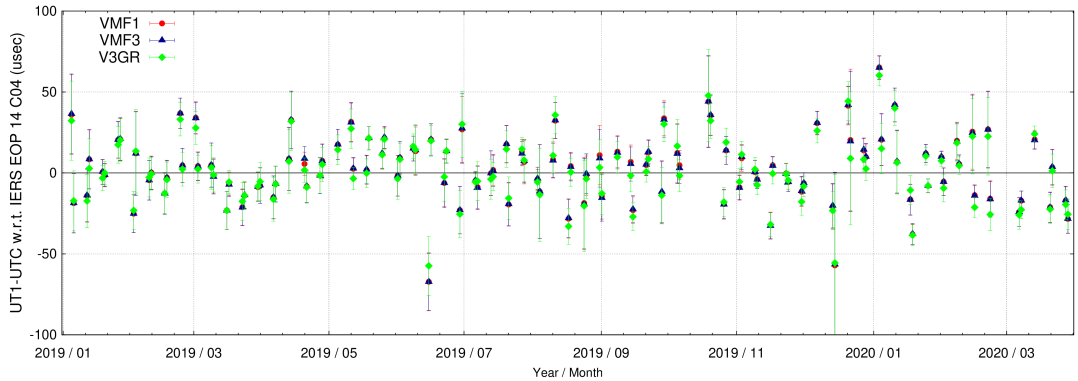

Fig. 1 The time series of the difference of dUT1 solution using each mapping function from IERS EOP 14C04. The data from the INT2 sessions conducted between January 2019 and March 2020 were used.

Table 1 Intensive sessions analyzed at the Tsukuba Analysis Center.

2019	Baseline	# of sessions	Ave. of dUT1 formal uncertainties
Intensive 2	IsWz	91	11.78 μsec
	IsNy	1	18.71 μsec
	MkWz	4	10.09 μsec
	KkWz	3	32.61 μsec
Total		99	12.44 μsec

2020	Baseline	# of sessions	Ave. of dUT1 formal uncertainties
Intensive 2	IsWz	29	9.21 μsec
	MkWz	43	8.19 μsec
	KkWz	25	10.05 μsec
Intensive 3	NyShWnWz	1	27.94 μsec
Total		98	9.28 μsec

Table 2 Summary of automated processing results.

	2019	2020
# of sessions	99	97
Success in real time processing	72	74
– Ave. of Latency	40 min	1 hour 20 min
Failed in real time processing	27	23
– Data quality (outlier)	5	14
– *rapid_* programs failure	4	1
– Station or data transfer failure	18	8

INT2 sessions. When ISHIOKA was not available because of its VGOS period for a few months in a year or its mechanical trouble, either the VLBA antenna at Mauna Kea (MK-VLBA) or Kokee Park (KOKEE) in Hawaii, U.S., participated in the INT2 sessions as substitute of ISHIOKA. Ny-Ålesund (NYALES20) in Norway also filled in the absence of WETTZELL.

The averaged formal error for the ISHIOKA–WETTZELL baseline, the typical baseline of the INT2 session, was about ten microseconds, and the averaged formal errors for most baselines fell within the range of 20 microseconds (Table 1). Figure 2 shows the differences between dUT1 solutions for each baseline and IERS EOP 14C04 from January 2019 through December 2020. The IVS Intensive 3 (INT3) session observed on July 27, 2020, correlated at the Tsukuba VLBI Correlator, was also analyzed.

Table 2 outlines the results of the near real time processing of the INT2 sessions processed at the analysis center in 2019 to 2020. 72 out of 99 and 74 out of 97 sessions were successfully processed in near real time in 2019 and 2020, respectively. A total of 50 near real time processing failures were due to problems with the observation data or the observing stations. The average time it took to obtain the dUT1 estimation was about 40 minutes in 2019 and about 1 hour and 12 minutes in 2020. In particular, when the near real time processing was successful, the estimated values for dUT1 were delivered within approximately one hour for the ISHIOKA–WETTZELL baseline.

5 Outlook

We will continue to analyze the data of the IVS Intensive sessions and deliver dUT1 products in near real time. In addition, we will keep updating our automatic

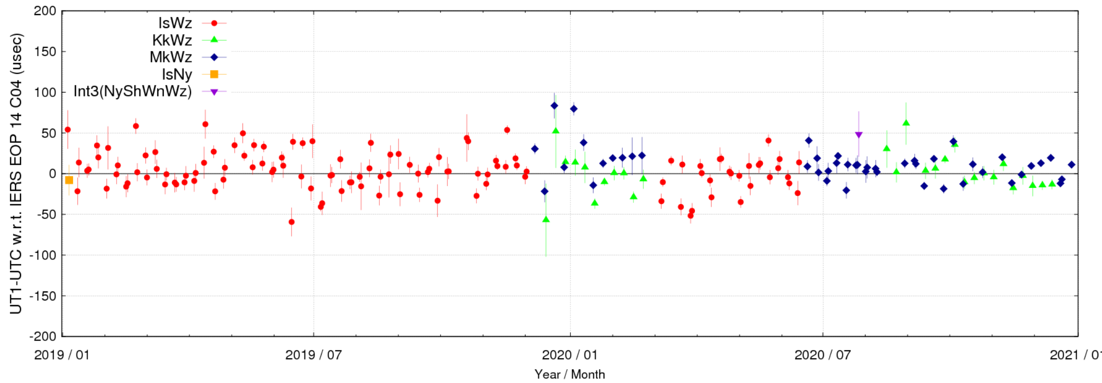

Fig. 2 The time series of UT1–UTC solutions obtained at the analysis center with respect to IERS EOP 14C04. Error bars are 1-σ formal uncertainties. Error bars are 1-σ formal uncertainties.

processing programs with the aim of improving the accuracy of dUT1 estimates and submitting more stable products.

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U.S. Naval Observatory VLBI Analysis Center

Megan Johnson, Christopher Dieck, Nicole Geiger, Lucas Hunt, Phillip Cigan

Abstract This report summarizes the activities of the VLBI Analysis Center at the United States Naval Observatory for calendar years 2019–2020. Over the course of the two years, Analysis Center personnel continued analysis and timely submission of IVS-R4 databases for distribution to the IVS. During the calendar years 2019–2020, the USNO VLBI Analysis Center used the VLBI global solutions designated usn2018b, usn2019c, usn2020a, and usn2020b. Earth Orientation Parameters (EOP) based on the solutions and updated by the latest diurnal (IVS-R1 and IVS-R4) sessions, were routinely submitted to the IVS. Sinex format files based upon the semi-weekly 24-hour sessions were also submitted to the IVS. During the 2019–2020 calendar years, Analysis Center personnel continued a program to use the Very Long Baseline Array (VLBA) operated by the NRAO for the purpose of measuring UT1–UTC. Routine daily 1–1.5-hour duration Intensive observations continued using the VLBA antennas at Pie Town, NM and Mauna Kea, HI.

1 Introduction

The USNO VLBI Analysis Center is supported and operated by the United States Naval Observatory (USNO) in Washington, DC. The primary services provided by the Analysis Center are the analysis of diurnal sessions, the production of periodic VLBI global solutions for estimation of the Terrestrial Reference Frame (TRF), the Celestial Reference Frame (CRF), and Earth Orientation Parameters (EOP). The Analysis Center continued the submission to the IVS of Intensive (EOP-I) and session-based (EOP-S) Earth Orientation Parameters based on USNO VLBI global solutions. Analysis Center personnel maintain the necessary software required to continue these services to the IVS including periodic updates of the GSFC CALC/SOLVE software package. In addition to operational VLBI analysis, Analysis Center personnel are actively engaged in research related to future reference frames.

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2 Current Analysis Center Activities

2.1 IVS Session Analysis and Database Submission

During the 2019–2020 calendar years, personnel at the USNO VLBI Analysis Center continued to be responsible for the timely analysis of the IVS-R4 sessions, with the resulting databases submitted within 24 hours of correlation for dissemination by the IVS. Analysis Center personnel also continued analyzing IVS Intensive sessions for use in the USN-EOPI time series and continued a series of Intensive sessions using the VLBA antennas at Pie Town, NM and Mauna Kea, HI. With the deployment of fiber to all ten VLBA antennas during the 2020 calendar year, USNO began including the St. Croix, VI antenna in the daily UT1–UTC Intensive series. The USNO Analysis Center continued the contributed analysis of the IVS-R1 sessions.

2.2 Global VLBI Solutions, EOP, and Sinex Submission

USNO VLBI Analysis Center personnel used the periodic global TRF/CRF/EOP solutions usn2018b, usn2019c, usn2020a, and usn2020b over the course of the 2019–2020 calendar years. Analysis Center personnel continued to submit the USN-EOPS series, which is based upon the current global solution and updated with new IVS-R1/R4 sessions. The updated EOPS series is submitted to the IVS twice weekly within 24 hours of session correlation and is included in the IERS Bulletin A. Analysis Center personnel also continued routine submission of Sinex format files based upon the 24-hour VLBI sessions. In addition to EOPS and Sinex series, USNO VLBI Analysis Center personnel continued to produce and submit an EOPI series based upon the IVS Intensive sessions.

2.3 ITRF2020 Submission

During calendar year 2020, the USNO VLBI Analysis Center generated and submitted Sinex files as part of a stand-alone global solution for contribution to the ITRF2020.

2.4 VLBA Intensive Sessions

During the 2019–2020 calendar years, Analysis Center personnel continued a program to use the Very Long Baseline Array (VLBA) operated by the NRAO for the purpose of measuring UT1–UTC. Routine daily 1–1.5-hour duration Intensive observations continued using the VLBA antennas at Pie Town, NM and Mauna Kea, HI. High-speed network connections to these two antennas are now routinely used for electronic transfer of VLBI data over the Internet to a USNO point of presence. During calendar year 2020, the VLBA was outfitted with high-speed network connections to all ten stations, which USNO utilized by including the St. Croix, VI antenna in the Intensive series. Once fully operational, it is anticipated that these VLBA Intensive sessions will be scheduled as IVS-INT4 sessions and that the data will be released to the IVS for community-wide distribution.

3 Staff

The staff of the VLBI Analysis Center is drawn from individuals in the Astrometry Department at the U.S. Naval Observatory. The staff and their responsibilities are as follows:

Name	**Responsibilities**
Alan Fey / Megan Johnson	Periodic global CRF/TRF/EOP solutions and comparisons; CRF densification research; VLBI data analysis.
Nicole Geiger	VLBI data analysis; EOP, database, and Sinex submission.
Christopher Dieck	VLBI data analysis; EOP, database, and Sinex submission.
Lucas Hunt	VLBI calibration and image analysis; CRF source structure research
Phillip Cigan	VLBI calibration and image analysis; CRF source structure research

4 Future Activities

The following activities for 2021 are planned:

- Continue analysis and submission of IVS-R4 sessions for dissemination by the IVS.
- Continue the production of periodic global TRF/CRF/EOP solutions and the submission of EOP-S estimates to the IVS updated by the IVS-R1/R4 sessions.
- Continue submission of Sinex format files based on the 24-hour sessions.
- Continue the analysis of IVS Intensive sessions and submission of EOP-I estimates to the IVS.
- Continue post-processing and analysis of VLBI Intensive data from the MK, PT, and SC VLBA stations.

USNO Analysis Center for Source Structure Report

Megan Johnson, Lucas Hunt, Phillip Cigan, Christopher Dieck, Nicole Geiger

Abstract This report summarizes the activities of the United States Naval Observatory Analysis Center for Source Structure for the 2019 and 2020 calendar years.

1 Analysis Center Operation

The Analysis Center for Source Structure is supported and operated by the United States Naval Observatory (USNO). The charter of the Analysis Center is to provide products directly related to the IVS determination of the "definition and maintenance of the celestial reference frame." These include, primarily, radio frequency images of International Celestial Reference Frame (ICRF) sources, intrinsic structure models derived from the radio images, and an assessment of the astrometric quality of the ICRF sources based on their intrinsic structure.

The primary service of the Analysis Center is maintaining a Web accessible data archive of radio frequency images of ICRF sources. We are currently in the midst of updating, improving, and expanding our archive. Historically, this Web accessible data archive was called the Radio Reference Frame Image Database (RRFID). We are changing the name of the archive to the Fundamental Reference Image Data Archive (FRIDA) and debuting an improved, more functional interface, which will be made publicly available in 2021.

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FRIDA will contain tens of thousands of images from the Very Long Baseline Array (VLBA) as well as other radio VLBI networks at frequencies of 2.3, 8.4, 24, and 43 GHz. FRIDA will also contain 74 images of 69 Southern Hemisphere ICRF sources using the Australian Long Baseline Array (LBA) at a radio frequency of 8.4 GHz.

Images of ICRF sources can also be obtained from the Bordeaux VLBI Image Database (BVID) at

`http://bvid.astrophy.u-bordeaux.fr`

2 Current Activities

2.1 VLBA Imaging

Very Long Baseline Array (VLBA) observations for maintenance of the celestial and terrestrial reference frames have been carried out since approximately 1994. Since 1997, these VLBA RDV (Research and Development VLBI) observations have been part of a joint program between the USNO, Goddard Space Flight Center (GSFC), and the National Radio Astronomy Observatory (NRAO). During each 24-hour VLBA RDV session, approximately 100 ICRF sources are observed at S/X-band (2.3/8.4 GHz) using the VLBA together with up to ten additional geodetic VLBI antennas. Images are produced from these observations and made available through the FRIDA.

Beginning in January 2017, USNO entered into a 50% timeshare agreement with the VLBA, under which we began observing ICRF sources for the purposes of astrometry, geodesy, and imaging. Since the start of the 50% timeshare agreement, in collaboration with GSFC, USNO has been running a series of observations called the UF/UG/UH-series. This series is observed at S/X-band (2.3/8.4 GHz) and is dual purpose in that the 24-hour experiments are designed for astrometry and geodesy but scheduled to optimize the *uv*-coverage of each source for imaging. The UF/UG/UH-series contains roughly 300 sources per session, most of which are primarily from the VLBA Calibrator Survey (VCS) catalog. Understanding the source structure characteristics of the objects in the VCS catalog is paramount to improving and maintaining the ICRF because of the high number and density of VCS sources in the current ICRF-3 iteration.

In addition to the UF/UG/UH-series, USNO has also been supporting a VLBA project at K-band under our timeshare agreement. The principal investigator of this project is Dr. Aletha de Witt from Hartebeesthoek Radio Astronomical Observatory (HartRAO). Nearly all of the K-band data that are included in the recently adopted ICRF-3 have come from this project. These observations are also maximized for imaging, and we plan to include these K-band images in our FRIDA Web accessible data archive once they become available.

3 Staff

The staff of the Analysis Center during 2019 consisted of Megan C. Johnson, Alan L. Fey, Lucas R. Hunt, John Spitzak, Christopher A. Dieck, and Nicole P. Geiger. The staff of the Analysis Center changed during 2020 with the retirement of Alan L. Fey and changes to the contractors; thus, it consisted of Megan C. Johnson, Lucas R. Hunt, Phillip Cigan, Christopher A. Dieck, and Nicole P. Geiger.

4 Future Activities

The Analysis Center currently has a program of active research investigating the effects of intrinsic source structure on astrometric position determination. Results of this program are published in the scientific literature.

The following activities for 2021 are planned:

- Continue with the imaging and analysis of VLBA 2.3/8.4 GHz experiments.
- Continue the development of the Fundamental Reference Image Data Archive (FRIDA) as a Web accessible database of radio frequency images of ICRF sources.
- Continue maintenance work of source structure for ICRF-3.

5 Relevant Publications

Publications of relevance to Analysis Center activities are:

- "The Precious Set of Radio-optical Reference Frame Objects in the Light of *Gaia* DR2 Data," Makarov, V. V., Berghea, C. T., Frouard, J., Fey, A., & Schmitt, H. R., 2019, ApJ, 873, 132
- "Toward the ICRF3: Astrometric Comparison of the USNO 2016A VLBI Solution with ICRF2 and *Gaia* DR1," Frouard, J., Johnson, M. C., Fey, A., Makarov, V. V., & Dorland, B., 2018, AJ, 155, 229
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Vienna Analysis Center Biennial Report 2019/2020

Johannes Böhm[1], Sigrid Böhm[1], Jakob Gruber[1], Andreas Hellerschmied[2], Frédéric Jaron[1], Lisa Kern[1], Hana Krásná[1,3], David Mayer[2], Markus Mikschi[1], Axel Nothnagel[1], Matthias Schartner[1,4], Helene Wolf[1]

Abstract The IVS Analysis Center VIE is jointly run by the Technische Universität Wien (TU Wien) and the Bundesamt für Eich- und Vermessungswesen (Federal Office of Metrology and Surveying, BEV). Besides the operational analysis of VLBI sessions, a focus in 2019 and 2020 was on the development of the new scheduling tool VieSched++, which is now widely used for the planning of VLBI sessions, and on the development of the raw data simulator VieRDS. Additionally, we continued the series of VieVS Days to educate interested groups in using the Vienna VLBI and Satellite Software (VieVS) and VLBI.

1 General Information

The Special Analysis Center in Vienna (VIE) is made up by members from the Technische Universität Wien (TU Wien) and the Bundesamt für Eich- und Vermessungswesen (Federal Office of Metrology and Surveying, BEV). The Department of Geodesy and Geoinformation (GEO) in the Faculty of Mathematics and Geoinformation of TU Wien is divided into seven research units. One of those entities, the research unit Higher Geodesy (HG) with about twenty members, is focusing on satellite navigation systems and VLBI for geodesy and astrometry. In September 2019, five out of the seven research units of GEO moved from Gußhausstraße 27 to the so-called “Freihaus” at TU Wien, located at the Wiedner Hauptstraße 8 (see Figure 1). HG has its offices in the yellow area on the second floor.

BEV is the institution responsible for official surveying, geo-information and weights and measures (metrology) in Austria. Currently, it belongs to the Federal Ministry on Digital and Economic Affairs. The Department of Control Survey at BEV is divided into several sections, such as the sections on reference systems as well as on geophysics and precise leveling. VLBI staff at BEV is attached to those two sections.

Personnel at TU Wien and BEV associated with the IVS Special Analysis Center in Vienna (see Figure 2) in the years 2019 and 2020 together with their main research fields and activities are summarized in Table 1. The staff members at TU Wien are partly paid by the regular budget from TU Wien, and partly they are funded by the Austrian Science Fund (FWF) within several projects listed in the acknowledgments.

1. Technische Universität Wien
2. Bundesamt für Eich- und Vermessungswesen
3. Czech Academy of Sciences
4. ETH Zürich

VIE Analysis Center

IVS 2019+2020 Biennial Report

2 Activities during the Past Years

2.1 Vienna VLBI and Satellite Software

The Vienna VLBI and Satellite Software (VieVS, [2]) is the umbrella for all software developments at HG. In the past two years, not only the VLBI module has been developed further (e.g., the possibility of baseline-dependent clock offset estimation), but also a new scheduling tool VieSched++ ([5]) and a VLBI raw data simulator VieRDS ([8]) have been developed. VieVS is distributed openly at https://github.com/TUW-VieVS, and a wiki is provided at https://vievswiki.geo.tuwien.ac.at. Addi-

Fig. 1 The "Freihaus" of TU Wien (second floor, yellow area) is the new home of the research unit Higher Geodesy of the Department of Geodesy and Geoinformation since September 2019.

Table 1 VIE members ordered alphabetically with their main tasks related to VLBI.

Johannes Böhm	Reference frames, Chair of HG
Sigrid Böhm	VieVS administrator, Earth orientation
Jakob Gruber	Correlation and fringe-fitting, raw data simulation
Andreas Hellerschmied	Operational VLBI processing, Web site
Frederic Jaron (since Sep. 2020)	EU-VGOS, correlation and fringe-fitting
Lisa Kern (since Oct. 2019)	Intensive sessions, Earth orientation
Hana Krásná	Reference frames, VLBI global solutions
David Mayer	Operational VLBI processing, ITRF2020 submission
Markus Mikschi	Analysis of VGOS sessions, local sessions
Axel Nothnagel (since Oct. 2019)	Consultant, Chair of IVS
Matthias Schartner (until Sep. 2020)	Development of VieSched++, scheduling VLBI sessions
Helene Wolf	Scheduling VLBI observations to satellites
Anna Zessner-Spitzenberg (from Oct. 2019 to Aug. 2020)	Terrestrial reference frames

tionally, we have set up a VieVS channel on Youtube where we provide useful tutorials on scheduling and the analysis of VLBI sessions with VieVS.

2.2 Scheduling

As part of his PhD thesis, Matthias Schartner developed a new scheduling software VieSched++ ([5]) in C++, which has been used in simulation studies ([6]) and is already operationally applied for many IVS ses-

Fig. 2 Picture of members of the Vienna Analysis Center taken in December 2019 (clockwise): Anna Zessner-Spitzenberg, Helene Wolf, Markus Mikschi, David Mayer, Lisa Kern, John Gipson (guest), Axel Nothnagel, Jakob Gruber, Matthias Schartner, Sigrid Böhm, Andreas Hellerschmied.

sions. Schedules generated with VieSched++ are optimized based on Artificial Intelligence, in particular by using evolutionary strategies ([7]). Large scale Monte-Carlo simulations with thousands of simulation runs of thousands of different scheduling approaches ensure a high-quality result.

Together with the Geodetic Observatory in Wettzell and ETH Zürich, the joint Operation Center DACH is run with fully automated tools for the generation of schedules. Based on these tools, almost all IVS sessions are automatically scheduled. After generating a schedule, the corresponding files, as well as meaningful statistics and charts, are distributed to responsible persons per mail for quality control. The schedule files are automatically uploaded to the IVS servers in the case that no human intervention is necessary and the observing program of the schedule is assigned to the DACH Operation Center. Based on this concept, the human workload was reduced to a minimum while ensuring a high-quality result.

A full list of all scheduled sessions, as well as graphics and statistics, can be found on the DACH Web page[1].

2.3 Web Site https://www.vlbi.at/

In order to reflect the cooperation between BEV and TU Wien, a joint Web site https://www.vlbi.at/ was set up to promote our activities and to distribute results and findings. The Web site not only covers our analysis results but contains information about our activities in scheduling, correlation, and fringe-fitting.

2.4 VieVS Days 2019 and 2020

In 2019 and 2020, VieVS Days were held at TU Wien. While the participation in 2019 was in person, the

[1] https://www.bkg.bund.de/DE/Observatorium-Wettzell/IVS-VLBI-Operations_Center/IVS-VLBI-Operations_Center.html

VieVS Days 2020 had to be organized as a virtual meeting. We daresay that this format worked reasonably well for the purpose of teaching the various modules of VieVS. However, the chats in between and the common dinner at a restaurant were missed.

2.5 Reference Frames and Earth Orientation

At TU Wien, we are routinely analyzing all VLBI sessions and submit the SINEX files of the 24h sessions to the IVS Combination Center via CDDIS. Additionally, all Intensive sessions are analyzed automatically, and the results are displayed at https://www.vlbi.at/. Together with colleagues at HartRAO, University of Tasmania, and ETH Zürich, we have started the observation and analysis of Southern Intensive sessions.

With VieVS, we analyze not only observations in the traditional S/X bands but also process K-band data (24 GHz, 1.2 cm), which we use for the estimation of reference frames and Earth orientation parameters ([3]). Furthermore, we analyze BL229 series from the astronomy VLBA campaign MOJAVE observed at Ku-band (15 GHz, 2 cm) where we focus on the estimation of geodetic parameters.

As a member of the IVS WG8, Hana Krásná studied the effect of Galactic aberration in VLBI analysis ([4]), and in 2020, much effort was put into the preparations for the submission of SINEX files for ITRF2020.

2.6 Analysis of VLBI Global Observing System Sessions

In 2019 and 2020, the number of available VGOS sessions was steadily increasing. One complication in the analysis of those sessions was the lack of accurate station coordinates of the new telescopes, making it impossible to use three or more sites to define the datum. Consequently, we determined coordinates of the new VGOS stations by fixing the coordinates of WESTFORD and the Earth orientation parameters in an unconstrained adjustment ([9]).

2.7 EU-VGOS

The EU-VGOS collaboration aims at verifying and further developing the VGOS processing chain from scheduling to final parameter estimation [1]. Of our group at TU Wien, several persons are members of the EU-VGOS collaboration. Matthias Schartner (now at ETH Zürich) develops new methods for scheduling, as part of VieSched++, and uses these methods to schedule test sessions with European VGOS stations, also in the role of PI for some experiments. Jakob Gruber and Frédéric Jaron are responsible for correlation and fringe-fitting. Jakob Gruber focuses on the processing of VGOS sessions. Frédéric Jaron takes care of the processing of EU-VGOS sessions. In order to advance the development of the VGOS processing chain, Frédéric Jaron organizes and chairs regular meetings within the EU-VGOS collaboration. Hana Krásná and Axel Nothnagel explore aspects of the analysis of EU-VGOS sessions with VieVS. Johannes Böhm supervises the EU-VGOS activities in the Working Group and is actively involved in the analysis aspects.

3 Current Status and Future Plans

In the next years, we will focus on the scheduling and analysis of VLBI observations to Galileo satellites. While optimization tools for satellite observations will be added to VieSched++, the VLBI module of VieVS will be equipped with sophisticated estimation procedures for the determination of Galileo and other orbits. Another focus will be on the best application of source structure corrections during the fringe-fitting process. We expect to improve the group delays significantly with advanced procedures. Jakob Gruber has developed the raw data simulator VieRDS as part of his PhD thesis. This module allows plenty of new investigations on the improvement of VLBI observables or the optimization of the observation setup.

Acknowledgements

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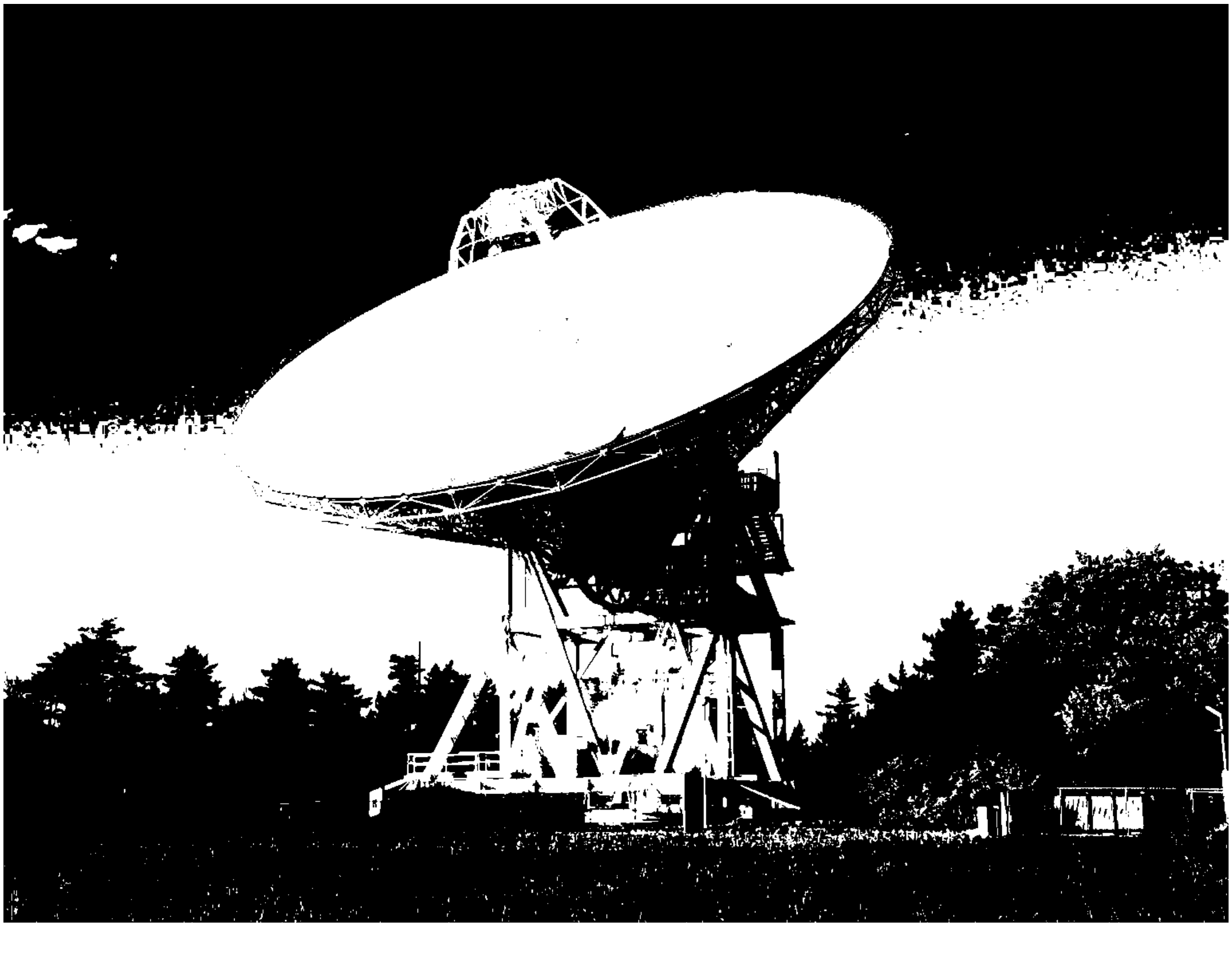
TECHNOLOGY DEVELOPMENT CENTERS



IVS GSFC Technology Development Center

Ed Himwich, John Gipson, Dave Horsley, Mario Bérubé

Abstract This report summarizes the activities of the GSFC Technology Development Center (TDC) and describes plans for the future. The GSFC TDC develops station software including the Field System (FS), Monitoring and Archiving System (MAS), IVS session Web page software, and scheduling software (*sked*); hardware including tools for station timing and meteorology; scheduling algorithms, and operational procedures. It provides a pool of individuals to assist with station implementation, check-out, upgrades, and training.

1 General Information

The IVS GSFC Technology Development Center (TDC) develops hardware, software, algorithms, and operational procedures. It provides manpower for station visits for training and upgrades. Other technology development areas at GSFC are covered by other IVS components such as the GSFC Analysis Center. The current staff of the GSFC TDC consists of John Gipson, Ed Himwich, Dave Horsley, and Mario Bérubé. The remainder of this report covers the status of the main areas supported by the TDC.

NVI, Inc.

GSFC Technology Development Center

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2 Field System

The GSFC TDC is responsible for the development, maintenance, and documentation of the Field System (FS) software package. The FS provides equipment control at VLBI stations. It interprets the *.snp* schedule and *.prc* procedure files (both as prepared by *drudg* from the *.skd* schedule file). The FS controls the antenna, data acquisition hardware, and related ancillary equipment needed for making VLBI measurements. All major VLBI data acquisition backends are supported. The FS is customizable to allow it to control station-specific equipment. It is used at almost all of the IVS Network Stations (more than 35) and also at many stations that perform VLBI only for astronomical observations. The only major VLBI facilities not using the FS are the DSN, LBA, VLBA, and VERA.

The main work on the FS for the period was:

- Conversion of the source to be 32- and 64-bit compatible. The key point for this conversion was to avoid the use of `long` variables, particularly in fixed length data structures. A utility *unlongify* was written to convert occurrences of `long` variables to `int` variables. Afterward it was necessary to change variables back if they were used in system calls that required `long` variables. Changes also had to made manually for the use of pointers and `time_t` variables, both of which are different lengths for 32- and 64-bit systems. The *unlongify* utility is available for stations needing to convert their station code for use on a 64-bit platform.
- Placing the source under *git* and distributing it using *github*. This effort included importing the existent history of FS source code. It includes over 130 FS9 versions (under Linux), 17 FS8 versions (under

VENIX), and two older versions (under HP RTE-1000/A) going back to version 5.5 in 1988. Having the source code in git greatly simplified the task of merging the main and VGOS branches. Having the historical code in *git* is a great resource for understanding its evolution.
- Merging the "main" and "VGOS" branches. The branches were merged using *git*, which made it more manageable and tracked the detailed changes that were made.
- Supporting Jonathan Quick (HartRAO) for development of FSL10, based on Debian *Stretch*. FSL10 is the current standard Linux distribution for the FS. It is expected to be under long-term support (LTS) until June 2022. The installation instructions can be found at: https://nvi-inc.github.io/fsl10/

The new FS was available for beta testing in 2020, The official release was in February 2021, and the update notes can be found at:

https://nvi-inc.github.io/fs/releases/10/0/10.0.0.html

2.1 Plans for the Future

Several other improvements are expected in future releases, including:

- Merging EVN-developed support for the DBBC3 rack;
- Adding support for R2DBE racks;
- Adding support for chopper-wheel and hot/cold load calibration methods;
- A complete update to the documentation and conversion to a more modern format that will be easier to use and maintain;
- *chekr* support for Mark 5A and Mark 5B systems;
- Support for periodic firing of the noise diode during observations;
- Completion of the VEX2 standard and implementation of it;
- Further unification of the Patriot 12-m (GGAO) and ISI 12-m (Kokee Park and McDonald) antenna interface code. This will allow a common code base to be used for the two very similar Antenna Control Units (ACUs), which are also used at other locations;
- FS Linux 11, based on Debian *Bullseye*.

3 Monitor and Archiving System (MAS)

The GSFC TDC is also responsible for development, maintenance, and documentation of the Monitoring and Archiving System (MAS) software package—formerly named TIG after its components: Telegraf, InfluxDB, and Grafana—and hardware specification. The MAS provides a system for collecting, storing, processing, and visualizing time-series data collected from various components of a VLBI station.

The software suite is comprised of several open-source packages along with some custom software specific for VLBI stations. The system is capable of collecting data from the Field System and PC diagnostic subsystems as well as certain meteorological devices, backends, and antennas. The suite can easily be expanded to include site-specific data. Currently the system is deployed at the NASA-managed stations, and the hardware specification and software are available to the community. There were no significant changes during this period.

4 Automation

The GSFC TDC is responsible for maintaining the IVS session Web pages, maintaining the master schedule, and providing analysis and scheduling of IVS sessions. These activities require finding, downloading, and validating many files stored on IVS or correlator data centers. To avoid duplication of efforts, an integrated approach has been developed to support automation of some activities at GSFC. The automation system is built around a database for rapid access to information and a message broker (https://en.wikipedia.org/wiki/Message_broker) for controlling data flow between processes. The approach is also using small processes controlled by the message broker. This is easier for maintenance than a large application. Also, adding new functionalities does not require changes to existing code but only re-routing the data flow using the message broker. Independent watchdog processes monitor the automated system, ensuring continuous operation.

For rapid access to available information, a database has been developed to store information about sessions, catalogs, available files, and some emails. This approach avoids reading numerous text files many times to find and validate any information. Master files and catalogs have been transferred to the database that is maintained by an automated process that validates any new master or catalog files. This database is also used for storing inventory of files on IVS Data Centers. This is mainly used for keeping the IVS session Web pages but also for synchronizing GSFC data files with IVS Data Centers.

Building the inventory of IVS Data Centers is done using ftp and http crawlers, or scanners, that are serving multiple purposes. When new files are detected, the scanners inform internal processes using the message broker. Using the same information, one process will update the IVS session Web pages while another one will download and pre-process the file.

One of the main objectives of this automated system was to support the analysis effort by ensuring that all files required for processing are available. A special scanner looks for any new vgosDB files on correlator data repositories. Using the message broker, the scanner initiates a special process that downloads, extracts, and pre-processes the vgosDB files. The analysts are then informed that a new database is ready for analysis. Post analysis processes have been improved by developing a new application for generating and submitting analysis reports and products.

After each observing session, GSFC also provides a network performance report that is used by correlators and analysts. This activity uses stations' emails and logs to generate a report on possible problems at stations. An automated process reads emails to extract session and station information and store it in a database. Logs are used to detect any antenna or recording problems. A small report of detected problems and emails are combined in a "sumops" file that is submitted to IVS Data Centers for each session.

IVS Operation Centers are required to submit observing sessions' schedule files seven days prior to the sessions' observing dates. Emails were sent in the past regarding missing schedules, but these emails disappeared after upgrades at CDDIS. A new automated process has been implemented to send emails directly to the IVS Operation Center that has not submitted a schedule in time.

The automated system has been operational for many months, and new functionalities are being developed to make it more robust and improve day-to-day operations.

5 *sked* and *drudg*

The GSFC TDC is responsible for the development, maintenance, and documentation of *sked* and *drudg*. These two programs are very closely related, and they operate as a pair for the preparation of the detailed observing schedule for a VLBI session and its proper execution in the field. In the normal data flow for a geodetic schedule that is written with *sked*, first *sked* is run at an Operation Center to generate the *.skd* file that contains the full network observing schedule. Then each station uses the *.skd* file as input to *drudg* to make the FS schedule and procedures for that station. Catalogs are used to define the equipment, stations, sources, and observing modes that are selected when writing a schedule with *sked*.

Changes to *sked* and *drudg* are driven by changes to equipment and by feedback from the users. The following sub-section summarizes some of the important changes to these programs during the report period. This summary includes only the most important bugs that were found and fixed over this period. A more complete summary of the changes can be found in the `change_log.txt` files associated with *sked* and *drudg*.

5.1 *sked* and *drudg* Changes

Overall the changes to *sked* and *drudg* were modest during this period, and no major features were added. The changes can be summarized as follows:

- The `implicit none` statement was added at the top of the files of almost all of the subroutines. The only exception was a set of externally written subroutines for which the change would have required a lot of work.
- The removal of obsolete features continued. Examples include support for S2 recorders, headstack, and passes. Inactive parts of code that refer to these features might still exist, but if schedules do not refer to headstacks or passes, they should run fine.
- The VGOS and S/X versions of *drudg* were merged. This involved changes to approximately 30 subroutines.

5.2 Catalog Changes

The *sked* catalogs were updated as new VGOS stations became operational, the equipment at stations changed, stations were added to existing observing modes, or new observing modes were requested.

5.3 Plans for the Future

Plans for the future include the following:

- Make VEX the native format for *sked*, so that there will be no more `.skd` files.
- With the finalization of VEX2, sked and drudg will be modified to read (and, in the case of *sked*, write) VEX2 schedules.

IAA Technology Development Center Report for 2019–2020

Dmitry Marshalov, Evgeny Nosov, Gennadii Ilin, Evgeny Khvostov, Vladimir Bykov, Alexander Isaenko,
Victor Stempkovskiy, Alexander Shishikin

Abstract The main activities of the IAA Center for Technological Development in 2019–2020 were focused on the work on upgrading equipment for the 32-m radio telescopes and creating equipment for the 13-m VGOS-compatible antennas. The presented report provides a brief overview of these activities.

1 The Electric Drive Pointing System of the 32-m Radio Telescopes

The automated pointing system is an integral part of the antenna system of the RT-32 radio telescope. The automated control system is a hardware and software complex for controlling the antenna drives. In the process of modernization, the control computers were updated, and the coordinate measuring system of the main mirror and subreflector was improved. A new subsystem for collecting data on the electric drive (DCS) was added.

1.1 Improving the Characteristics of the Coordinate Measurement Subsystem

Coordinate conversion units (CCUs) for four main mirror angle encoders (two main and two backup) and four counter reflector angle encoders were replaced. The CCUs of the subreflector were moved to the over-mirror cabin from the electric drive room, significantly reducing the length of the analog lines. The CCUs of the main mirror encoders remained in their places, next to the encoders. RS-485 and Ethernet interfaces are used to transfer data to the control system. The bit width of the new coordinate conversion units has been increased from 20 to 24 for the main mirror and from 14 to 16 for the subreflector (Figure 1). The data refresh rate is 125 Hz.

1.2 New Subsystem for Collecting Data on the Antenna System Electric Drive

The data collection system provides the RT-32 motion control system with additional data on the components of the electric drive. The DCS is designed as an independent device, consisting of a standard 19-inch rack with controllers located in it and separate data collection units—a block of current sensors and a block of tachogenerators. The system measures in real time the electrical parameters of the RT-32 antenna movement and provides processing and storage of the data of the electric drive, thermal stabilization of the angular coordinate pickup encoders, and the RT-32 antenna electric drive rooms (Figure 2). The DCS is built on the basis of two programmable logic controllers: Aries PLC110-60K.M and Aries SPK110.

Institute of Applied Astronomy (IAA RAS)

IAA Technology Development Center

IVS 2019+2020 Biennial Report

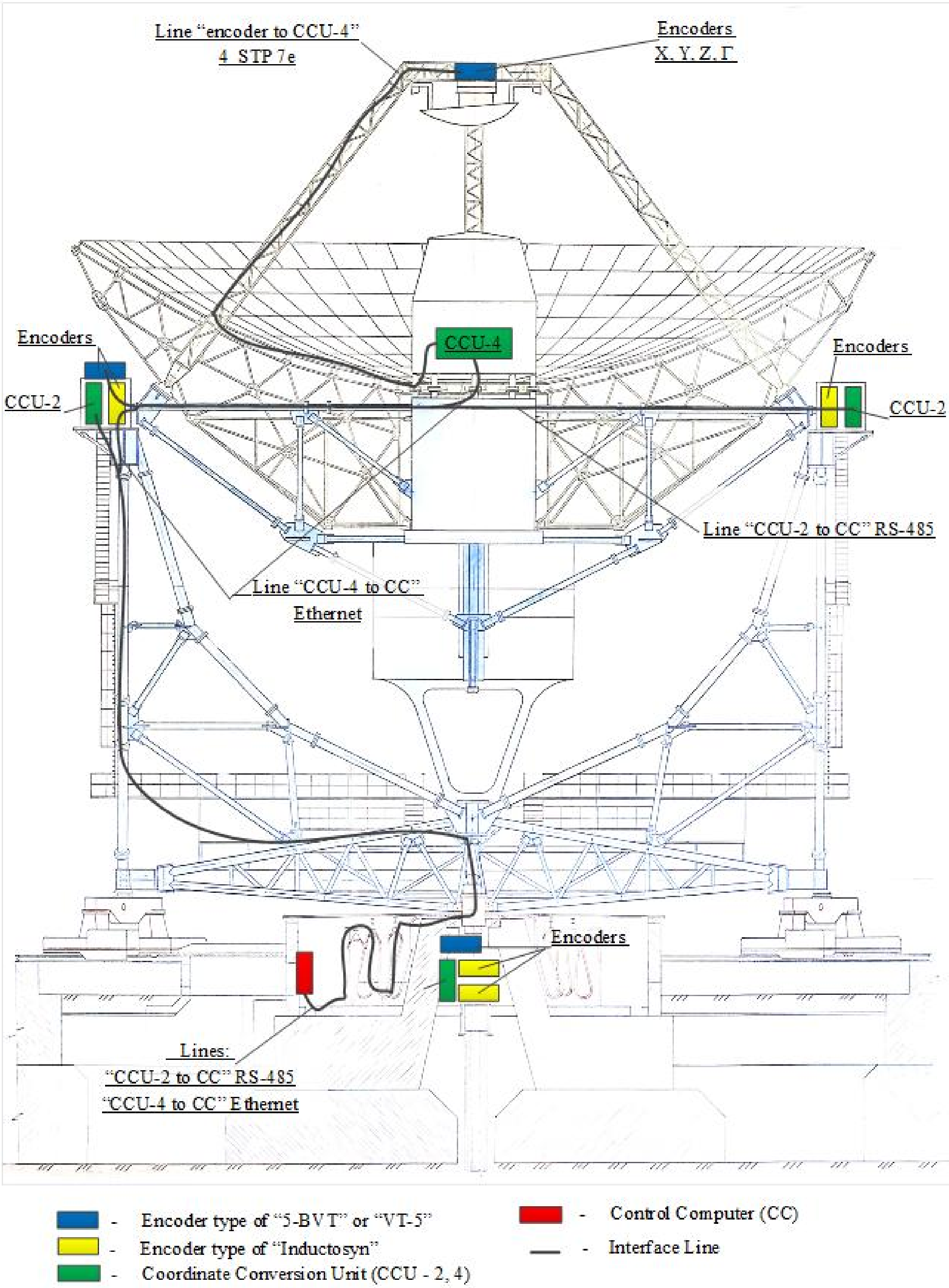

Fig. 1 New CCU blocks and their location on the antenna.

Fig. 2 General view of the DCS rack.

1.3 The Electric Drive Control Computer and Software

An industrial computer with up-to-date components that supports modern operating systems and has sufficient performance to implement the assigned tasks in the software part is used as a hardware basis. The new control software implements all previously developed control algorithms, provides for work with new measuring equipment, and also implements additional functions. The modernized software provides new opportunities, the demand for which arose during the long-term operation of RT-32 radio telescopes:

- optimization of the movement of the antenna in the high speed mode to reduce the loads on the mechanical structures,
- smooth passage of speed limit zones,
- automatic selection of the control voltage for the beginning of the movement of the antenna at a given coordinate, and
- correction of the parameters of the tracking algorithm for tracking sources, depending on the current values of the azimuth and elevation coordinates of the antenna.

The modernization of the automated control system of the RT-32 radio telescope made it possible to improve the operational and technical characteristics, which contributes to a more efficient use of the radio telescope for radio astronomy observations, as well as when servicing the radio telescope and ensuring its readiness for operation.

2 Ultra-Wide Band Receivers Upgrade

The Ultra-Wide Band (UWB) receiving system for the RT-13 radio telescopes of the "Quasar" VLBI network was designed at the IAA RAS [1]. The UWB receiver system operates on dual linear orthogonal polarizations in the 3–16 GHz band. In 2019–2020, the equipment was built and tested. The radio telescopes at the Badary and Svetloe stations were equipped with UWB receivers, and test observations were made. In order to widen the bandwidth of the initial UWB receiver design (from 1024–2048 MHz to 48–2048 MHz), the following parts of the receiver's Frequency Conversion Unit were replaced: the first Intermediate (IF) bandpass waveguide filter, the second IF filter, and the output amplifier. The Svetloe station's RT-13 radio telescope has undergone the upgrade mentioned. Badary and Zelenchukskaya are scheduled for 2021–2022.

3 Multifunctional Digital Backend (MDBE)

The MDBE is intended for equipping all radio telescopes of the "Quasar" VLBI network with unified, both legacy- and VGOS-compatible digital backends [1]. The system consists of up to 12 DSP units, connected by backplane with the Synchronization and Control Unit. Each DSP unit digitizes the input IF signal using the 4096 MHz sampling frequency, performs necessary digital processing in an FPGA, and outputs the data through a 40 Gbps or 10 Gbps fiber optical link. Table 1 presents basic parameters of the MDBE.

Table 1 Basic parameters of the MDBE.

Number of IF inputs (DSP units)	up to 12
Input frequency range	0.5–2048 MHz
Sampling frequency	4096 MHz
Synchronization	5/10/100 MHz 1 PPS (two inputs) 1 PPS monitor
Outputs per DSP unit	1x10 Gbps (SFP+) 1x40 Gbps (QSFP)
Output format	VDIF in raw Ethernet frames VDIF in UDP packets
Calibration features	PCAL extractor and analyzer Inner delay variation control Noise calibration
Control interface	10/100/1000 Ethernet (Fiber or copper)
Basic VLBI modes	Wideband channels: 2048, 1024, or 512 MHz DDCs mode: 0.5, 2, 4, 8, 16, or 32 MHz
Size	19” 3U case + 1U fan unit

Like the previous backend, the BRAS [2], the MDBE can be located in the focal cabin of the antenna, near to the receivers. As there is no direct access to the system for the staff while an observation is in progress, the MDBE provides full remote control of the system. The control features include measuring voltages, currents, fan speeds, and temperatures at key points of the system. Each DSP unit logs signal power, statistics of two-bit output data, the extracted PCAL signal (in the time domain), estimation of its group delay, and phases and amplitudes of the tones. The MDBE has an embedded calibration system that allows control of the phase/delay stability of the clock synthesizer, ADCs, and clock distributors.

Since September 2020, the MDBE has operated at the Svetloe observatory for the domestic observation program. Figure 3 presents the view of the MDBE installed in the focal cabin of the RT-13 radio telescope.

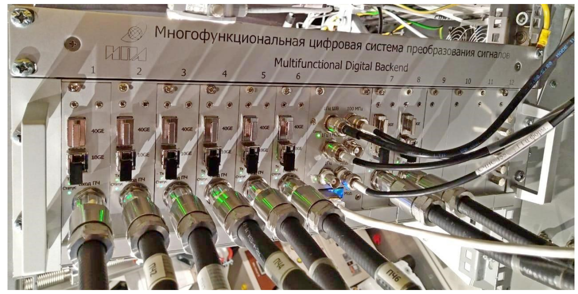

Fig. 3 The MDBE installed in the focal cabin of the RT-13 radio telescope at the Svetloe observatory.

Most of the time the MDBE is used in the 512 MHz bandwidth mode, although it was also tested in the 32 MHz mode (VGOS mode) in joint observations with the Onsala twins. In 2021, the next two MDBEs will be produced. The team is also working on improving the firmware and adding new features. The detailed description of the MDBE can be found in the paper “Multifunctional Digital Backend for Quasar VLBI Network”, which is expected to be published in the Journal of Instrumentation in 2021 (it has been accepted for publication, but the DOI has not been issued yet).

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2. E. Nosov, D. Marshalov, A. Melnikov. “Operating Experience with the Broadband Acquisition System on the RT-13 Radio Telescopes”. *IVS 2016 General Meeting Proceedings*. Edited by D. Behrend, K. D. Baver, and K. L. Armstrong. NASA/CP-2016-219016. pp. 53–57, 2016.

NICT Technology Development Center 2019+2020 Biennial Report

Kazuhiro Takefuji[1,2], Hideki Ujihara[1], Tetsuro Kondo[1]

Abstract The National Institute of Information and Communications Technology (NICT) is developing and testing VLBI technologies and conducts observations with this new equipment. This report gives an overview of the Technology Development Center (TDC) at NICT and summarizes recent activities.

1 NICT as IVS-TDC and Staff Members

The Communications Research Laboratory (CRL), which is the former name of the current National Institute of Information and Communications Technology (NICT), was designated as an IERS VLBI Technology Development Center (TDC) by the International Earth Rotation Service (IERS) in 1990. Since then, we have been continuously engaged in VLBI technology development for over 30 years, including the transition of designation name from IERS-TDC to IVS-TDC in 1999. As one of the activities of the IVS-TDC, we publish the newsletter "IVS NICT-TDC News (formerly, IVS CRL-TDC News)" at least once a year in order to inform the VLBI community about various VLBI-related technology developments in Japan. The newsletter series is available online at https://www2.nict.go.jp/sts/stmg/ivstdc/news-index.html. Table 1 shows the list of staff members contributing to this component.

1. Kashima Space Technology Center, National Institute of Information and Communications Technology
2. Usuda Deep Space Center, Japan Aerospace Exploration Agency

Table 1 Staff Members of NICT TDC as of January 2019 in alphabetical order.

HASEGAWA, Shingo	KAWAI, Eiji
KONDO, Tetsuro	MIYAUCHI, Yuka
SEKIDO, Mamoru	TAKEFUJI, Kazuhiro
TSUTSUMI, Masanori	UJIHARA, Hideki

2 General Information

The main topic of the 2019–2020 period was an intercontinental VLBI experiment for precise frequency comparison between Italy and Japan. The scientific results were reported by Pizzocaro et al. [1] and its analysis was reported by Sekido et al. [2]. Here we focus on the technical side of the experiments.

3 VLBI between Japan and Italy

We have carried out a series of geodetic VLBI experiments in 2018–2019 on an approximately 9,000-km baseline between portable 2.4-m VLBI antennas, named MARBLE. MARBLE1 was installed in Medicina, Bologna, Italy and MARBLE2 in Koganei, Tokyo. The Kashima 34-m antenna in Kashima was used as a reference station. We installed vertical polarization receivers at both of the MARBLEs and vertical and horizontal polarization receivers at the Kashima 34-m antenna. Four 1-GHz frequency bands specified within the total receiving range of 3.2 GHz to 14.4 GHz were simultaneously extracted; then, we observed 21–25 quasars repeatedly for about 30 hours in a single session. After the observation, linear polarization corrections were applied considering the parallactic angle and dispersive delay correction due to the ionospheric effect. As a result, we have successfully performed a bandwidth synthesis over the frequency range of 9.0-GHz width from 4.8 GHz to 13.8 GHz resulting in an effective bandwidth of 3.1 GHz.

4 Candidate Radio Sources

Correlated fluxes of most quasars are weak due to the 9,000-km long baseline between Japan and Italy. In a first test experiment, we chose good candidates from the radio catalog of the Astro-geocenter[1]. We picked up 115 radio sources, which have more than 1.0 Jy of total flux, from −10 deg to +90 deg declination, the 35% from the top in terms of total flux. In the series of frequency transfer sessions, about 27 sources were selected from ICRF sources by considering detected correlated flux in the observations.

5 Data Transfer and Correlation

A single session of the frequency comparison experiment lasted about 30 hours, and the amount of data for three stations was 240 TB (60 TB for a single polarization). We transferred single polarization data from Medicina to Kashima via UDT/IP protocol with jive5ab[2] at an average data rate at 5 Gbps. Then, correlation processing was performed by software correlator GICO3 as soon as the transfer finished. It took about one week for processing all scans of a single session. We routinely performed such sessions about 20 times.

6 Polarization Synthesis after Correlation

The large parallactic angle difference between Japan and Italy causes a misalignment of the linear polarization angle; consequently, this leads to a degradation of the signal-to-noise ratio (SNR). We needed to synthesize two polarization outputs to compensate the loss of SNR. The pseudo-Stokes-I observable is given by the

[1] http://astrogeo.org/vlbi/solutions/

[2] https://github.com/jive-vlbi/jive5ab

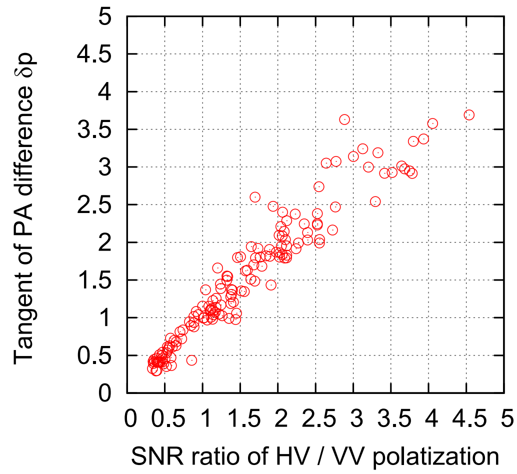

Fig. 1 A comparison of the SNR ratio of the polarization pairs of the Kashima 34-m and Medicina 2.4-m antennas and the tangent of the parallactic angles difference in a session.

following equation [5]:

$$I = \left(\overline{H_a \star H_b} + \overline{V_a \star V_b}\right)\cos(\delta p) + \left(\overline{H_a \star V_b} - \overline{V_a \star H_b}\right)\sin(\delta p).$$

Here, V and H indicate linear polarization with their suffixes corresponding to stations (a,b). δp is the difference of the parallactic angle between two stations. Since the compact antenna installed in Medicina has a single vertical polarization receiver, data of H_b is not available. Hence, we used half of pseudo-Stokes-I obtained by synthesizing two polarization cross products using the following equation:

$$I/2 = \left(\overline{V_a \star V_b}\right)\cos(\delta p) + \left(\overline{H_a \star V_b}\right)\sin(\delta p).$$

Figure 1 shows a plot of the tangent of parallactic angles difference between the Kashima 34-m and Medicina 2.4-m antennas versus the SNR ratio of the two polarization pairs in a session. The aligned data on a straight line is good evidence of the validity of the polarization synthesis procedure. Moreover, one more process was required prior to the polarization synthesis. The signal paths for two polarizations (V and H) of Kashima 34-m are slightly different. Thus, their correlation results involving the different delay needed to be corrected. Figures 2 and 3 show the comparison of group delay and phase delay between $\overline{V_a \star V_b}$ and $\overline{H_a \star V_b}$. Firstly, the group delay was corrected; then, the phase delay (or phase offset) had to be corrected.

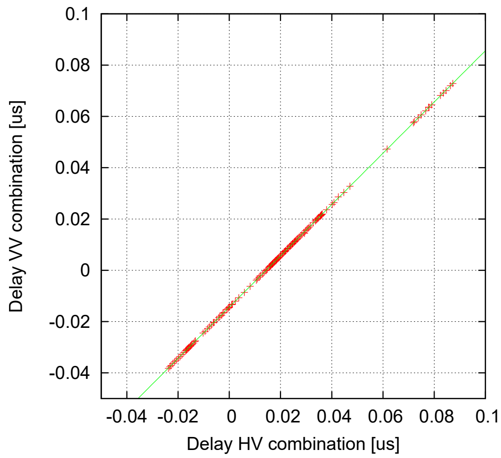

Fig. 2 A comparison of group delays between two polarization pairs (VH and VV) for the Kashima 34-m to Medicina 2.4-m baseline.

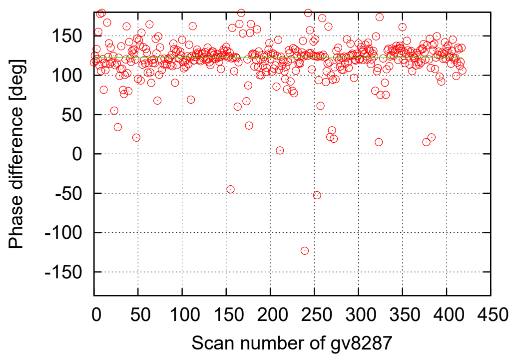

Fig. 3 Difference of phase delay between two polarization pairs (VH and VV) for the Kashima 34-m to Medicina 2.4-m baseline. The phase offset was empirically determined within 1 degree.

These processes were performed for all four 1-GHz bands correlation outputs to recover the efficiency, and the phase offset was determined within 1.0 degree. Figure 4 shows an example of the improvement of the fringe amplitudes by this polarization synthesis procedure. Thanks to the direct sampling system, no delay changes did happen during the series of observations. Once the delay difference between $\overline{V_a \star V_b}$ and $\overline{H_a \star V_b}$ was determined, it could be used for a few months (we did not evaluate how long it could keep the same state) and it was really helpful for our precise frequency comparison.

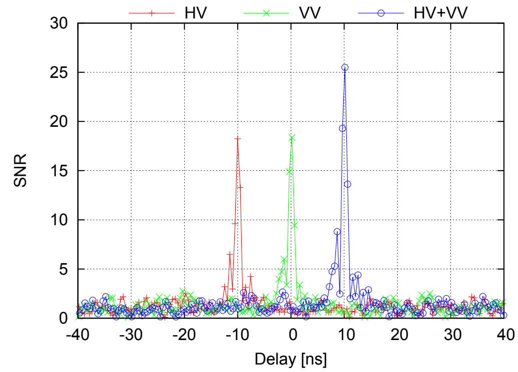

Fig. 4 An example fringe amplitude plot before and after the polarization synthesis for the Kashima 34-m to Medicina 2.4-m baseline. The SNRs improved from 18.3 and 18.7 for HV and VV to 25.7 for HV+VV after the polarization synthesis.

7 Wideband Bandwidth Synthesis with a TEC Search

An algorithm using the least-squares estimation based on a phase model was developed for determining TEC in the wide-band bandwidth synthesis (WBWS) processing [3]. The algorithm works well. However, it was difficult to apply this algorithm for data with an SNR lower than 10. In order to improve the TEC estimation at lower SNRs, we developed a TEC search-function method in addition to a least-squares (LSQ) estimation method [4]. The TEC search-function method performs iterative peak TEC search with applying several TEC values [5]. The one-sigma error, evaluated by comparison with a global ionosphere map (GIM) given by GNSS, was about 3 TECU on the Kashima–Medicina baseline (Figure 5). Even a 1.0-TECU difference causes group delay deviations as large as 17.2 ps [2]. Thus, it is important to determine accurate TEC values using a TEC search. Figure 6 shows the result of the iteratively searched TEC value on quasar 0133+476 with 110-sec integration on the Medicina–Kashima baseline. In the first step, we roughly apply TEC values from −50 to +50. Then, the final peak value is determined around the tentative peak value by a 2nd order polynomial fit (parabola fit). Figure 7 shows an example of a nice fringe plot after wideband bandwidth synthesis obtained with this procedure.

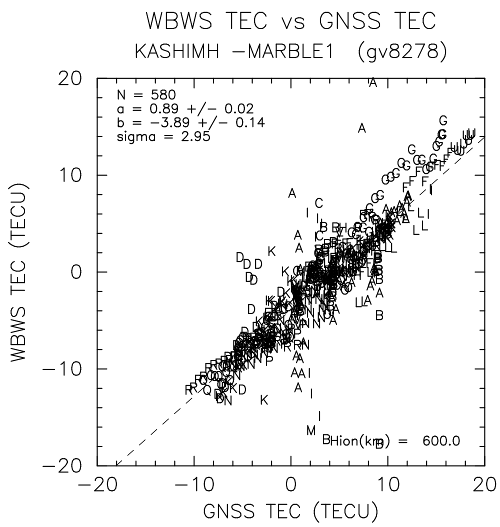

Fig. 5 A comparison between VLBI-based differential TECs by the TEC search-function method and those derived from a GNSS-based global ionosphere map. The data is for the 8,700-km Kashima–Medicina baseline.

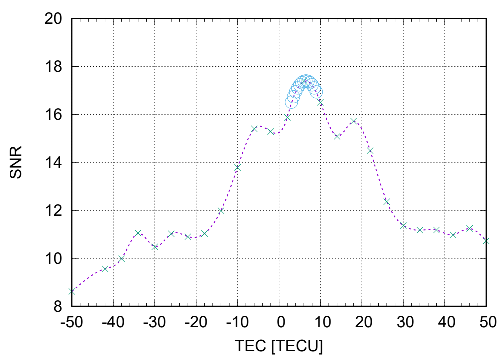

Fig. 6 Iterative search TEC peak on quasar 1144+402 in 60-sec integration on the baseline between Medicina and Kashima.

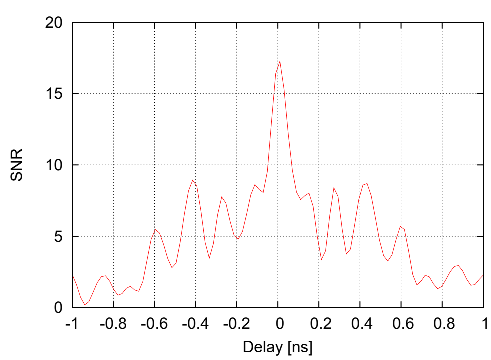

Fig. 7 A fringe plot of the same radio source as in Figure 6.

8 Development of Wideband Feeds and 2.4-m Antennas

The initial wideband feed for Gala-V, which was named IGUANA feed, was installed on the Kashima 34-m antenna at the end of 2013. The IGUANA feed was planned as a coaxial feed that is composed of IGUANA-H, a multimode horn for 6.5–16 GHz and IGUANA-L, the outer horn for 2.2–6.5 GHz. Following the installation of the IGUANA-H, the IGUANA-L was planned to be installed in later years [6]; however, the IGUANA-L was never manufactured, because the NINJA feed was newly developed for 3.2–16 GHz, which is an axial corrugated horn using lens and multimode for beam shaping. Advantages of the NINJA feed are reducing the numbers of LNAs, easy to change the beam width for other optics, and light weight; but there was a disadvantage in aperture efficiency. The radio interference under 3 GHz above S-band at Kashima was so loud and never would be quiet. Thus, in mid-2015 the IGUANA feed was replaced by the NINJA feed with OMT which can sharply cut incoming signals under 3.2 GHz. The Kashima 34-m antenna had a trolley system to exchange receiver horns. L- and S/X-band horns are set at the focal point of the antenna, but other horns are set with an offset to the focus and adjusted by the sub-reflector. Degradation by these offsets was estimated as several percent because of coma aberration.

The optics of the MARBLEs were changed from the initial 1.6-m or 1.5-m parabola dishes with Open-boundary Quad-Ridged Horn to 2.4-m Cassegrain with NINJA feeds to improve their sensitivity by three or four times. In all stations, the LNAs were not cooled because of a limited budget and development time.

The minimum frequency of the wideband feeds for Gala-V was set to 3.2 GHz. The Gala-V sampler had a maximum sampling rate of 16 Gsps and could sample RF signals up to 20 GHz; thus, the maximum frequency of the wideband feeds was planned up to 16 GHz (Figure 8). OMTs were designed for 3.2–14.4 GHz at both Port-0 and Port-1, and they had under −10 dB return loss (Port-0 can be used up to 16 GHz). If the feed and OMT had return loss over −10 dB, the near field measurement system would have made errors at the center of the calculated far field beam patterns.

The bandwidth of Gala-V is narrower than the feed and OMT, sampler, and signal transmission by RFoF

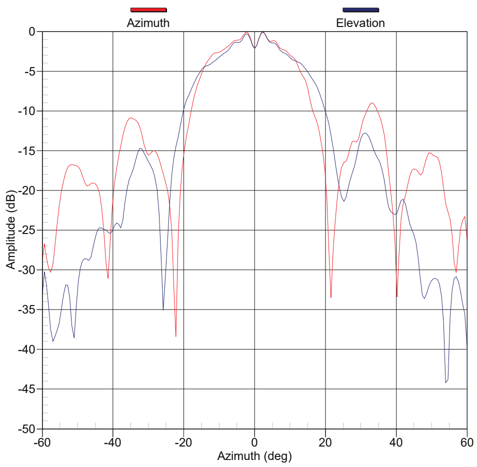

Fig. 8 Beam patterns of the NINJA feed for the MARBLEs at 16.0 GHz measured in METLAB of Kyoto University.

(RF over fiber). Maximum frequency was restricted to 14 GHz because MARBLE2 was located nearby TW-STFT (Two-Way Satellite Time and Frequency Transfer) antenna which radiates around 14 GHz for up-link. That signal was so strong to saturate LNAs of the MARBLE2. Thus, the MARBLE2 has a low-pass filter to cut TWSTFT signals and limits the frequency range used for Gala-V. Other in-band RFIs are suppressed by notch filters after LNAs at all stations, and a filter bank was added only in the MARBLE2 as a counter-measure to the RFI environment in Koganei. The filter bank of the MARBLE2 has 8-port branches and filters with different pass bands and path lengths are connected at each branch. Thus, the original phase response of the MARBLE2 receiving system is not linear over frequency. Also, OMT has different path length by 2.4 mm for Port-0 and Port-1; but Figure 2 shows a few meters of difference of path length. The RFoF in Kashima 34-m is a WDM (Wavelength Division Multiplexing) system (up to 26 GHz); thus the path length difference would come from the other part of the signal paths up to the sampler. These phase response and path length differences were compensated for in a calibration using a reference radio source.

The development of wideband antennas and VLBI activities in Kashima were terminated in 2021. But development of wideband antennas will be continued for SKA, BRAND, or other applications such as radiometers or satellite antennas in other laboratories in Japan. The 2.4-m diameter, small portable VLBI station (MARBLE) is the maximum dish size for marine container transportation. But it still has room for improvement using cooled LNAs for two or three times better sensitivity to enable VLBI observations of farther, fainter, and more compact objects. Also, high-temperature superconductor filters before the cooled LNAs may be effective to reduce RFI. Our broadband VLBI project took different oath than VGOS or SKA, like the evolution of the Galapagos Islands, but hopefully there is a marvelous future for broadband VLBI.

9 Future of Geodetic VLBI

Since the aperture areas of our compact antennas are so small, the intercontinental baseline observations with the Kashima 34-m telescope initially looked pessimistic. However, even such small antennas demonstrated nice results. Therefore, this approach may be a sustainable way for keeping on developing the large antennas. If other large, highly sensitive antennas join the observation, it improves not only the number of scans per session, but also the precise measurement of TEC; consequently, it leads to accurate results on long-distance frequency comparison and geodesy. We believe this approach might become an option for the future of geodetic VLBI.

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Onsala Space Observatory – IVS Technology Development Center Activities during 2019–2020

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Abstract We give a brief overview of the technical development related to geodetic VLBI done during 2019 and 2020 at the Onsala Space Observatory.

1 General Information

The technical development work for geodetic VLBI at the Onsala Space Observatory (OSO) was dedicated to the Onsala twin telescopes (OTT) and the Onsala 20-m telescope, see Figure 1. The main activities are summarized as follows and discussed in detail in the subsequent sections:

- A focal-finder for the OTT,
- RFI protection for the OTT,
- TPI logging for VGOS, and
- A field-system-controllable cable delay box for the S/X system on the Onsala 20-m telescope.

2 A Focal-finder for the OTT

The OTT are equipped with slightly different receiving systems. The western telescope (Ow) has a receiving system equipped with an Eleven feed covering 2–14 GHz, while the eastern telescope (Oe) has a receiving system with a Quad-Ridged Feed Horn (QRFH) covering 3–18 GHz. Both types of feeds are subject to frequency-dependent phase center positions. Thus, for optimal performance for VGOS observations, suitable compromise positions for the receivers have to be found. In the OTT installation phase, the receivers were placed at the positions that were supposed to be perfect, according to the design. But, this does not mean that these positions are really optimal. The OTT do not have motor-driven hexapods, so a performance optimization with the sub-reflector position is not easily possible. Thus, in order to test and optimize the receiver positions, a so-called focal-finder was developed to allow the complete receiver to be moved in the z-direction inside the telescope tube between -9 mm and $+26.5$ mm. This focal-finder can be installed temporarily in either of the telescope tubes and thus be used to determine the individual "optimal" positions for the VGOS frequency range by measuring the system equivalent flux density (SEFD) for different receiver positions. A photo of the focal-finder is dis-

Fig. 1 The three telescopes at Onsala used for IVS observing: Ow (left), Oe (middle), and On (right).

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OSO Technology Development Center

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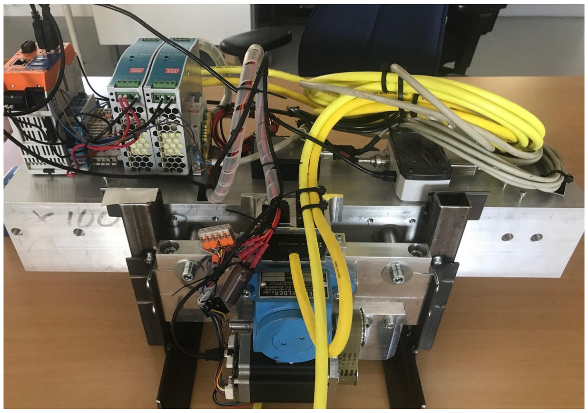

Fig. 2 Picture of the "focal-finder" for the OTT that can be installed in the telescope tube to move the receiver between −9 mm and +26.5 mm in the z-direction to optimize the focal position.

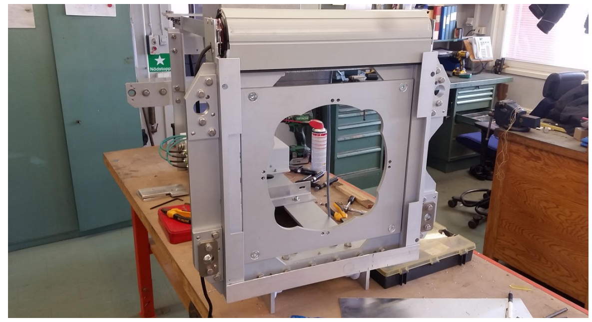

Fig. 3 RFI protection developed for the OTT receivers. The metal blinds can be activated from the VLBI field system to cover the feed horn and thus to protect against strong and potentially damaging RFI signals from, e.g., low earth orbiting radar satellites.

played in Figure 2. Due to the pandemic, the optimization of the focal position could only be done for Oe so far.

3 RFI Protection for the OTT

The OTT are equipped with broadband systems for VGOS observations. These are subject to RFI from various sources, including RFI sources on land, at sea, and in the sky. On several occasions, the OTT low noise amplifiers (LNAs) were destroyed by strong ship radar when the telescopes were looking at low elevations towards the sea, even though the LNAs are equipped with protecting diodes. As a consequence, the OTTs were out of service for several weeks while the LNAs had to be repaired. In order to minimize the risk of future damage due to ship radar, an alarm, "Oden the overseer", was implemented to automatically send warnings via e-mail to the observatory staff, in case the telescopes are looking at the open sea at low elevations.

The usual parking position for the OTT is at zero degrees of elevation towards the north, where a natural barrier in the form of a 30-m hill protects to some extent against land-based RFI. But, because the survival position of the OTT is the zenith position, it is desirable to change to a parking position at zenith. This parking position, on the other hand, is subject to radar signals emitted by remote sensing satellites, such as Sentinel-1a/b, that send rather strong C-band radar pulses. So, in order to protect the sensitive receivers of the OTT when parking at the zenith position, we developed an RFI protection system with metal blinds that can cover the feed horns inside the telescope tubes, see Figure 3. The system can be controlled directly from the VLBI field system, allowing the initiation of opening and closing before and after VGOS sessions. Due to the pandemic, so far only Ow is equipped with this RFI protection.

4 TPI Logging for VGOS

VGOS, with its broad frequency coverage and dual polarization capability, is much more sensitive to radio source structure and variation than the legacy S/X system. Thus, radio source imaging and radio source flux monitoring have become of interest. This requires monitoring of the total power values during on-going VGOS sessions. Routines were developed to allow this and to record the information in so-called extended log files.

5 A Field-system-controllable Cable Delay Box for the S/X System on the Onsala 20-m Telescope

The insertion of a calibrated piece of cable into the cable delay measurement system of the legacy S/X system of the 20-m telescope, before and after VLBI sessions, has been standard for more than 30 years at Onsala in order to determine the cable sign. This information from the "cable", "cablelong", and "cablediff" measurements is logged in the log file and used in the final data analysis. During the last 30 years or so, this was done manually as part of the session preparation and finalizing work. Due to the pandemic, the routines to run VLBI sessions needed to be adapted to allow remote operations without the need of having personnel in the control room. Thus also these cable sign measurements needed to be made possible to execute remotely. As a consequence, a field-system-controllable cable delay box was built to allow these measurements to be done remotely before and after each VLBI session.

6 Outlook and Future Plans

The plan for the upcoming two years is to continue to optimize the OTT systems for VGOS operations.

IGN Yebes Observatory Technology Development Center 2019–2020 Report

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Abstract We present the main technical developments of Yebes Observatory (IGN) in 2019 and 2020 that are related to geodetic VLBI.

1 General Information

Yebes Observatory has been a Technology Development Center of the IVS since 2015. The main areas of expertise include low noise receivers at centimeter and millimeter wavelengths, cryogenic low noise amplifiers, antennas and feeds, passive devices, cryogeny and vacuum, modules for receiver calibration, antenna control software, microwave holography for large reflector antennas, RFI detection and measurements, and topographic measurements for the local tie.

Yebes Observatory operates two radio telescopes, 13.2 m and 40 m in diameter, respectively, which are integrated in the IVS. The first one regularly runs VGOS observations, while the second one has run legacy IVS observations since 2008. The details are explained in the corresponding station report [1]. The 13.2-m radio telescope belongs to the RAEGE (Red Atlántica de Estaciones Geodinámicas y Espaciales) and it is the first operational radio telescope of the four foreseen within that network (Yebes, Santa María, Gran Canaria, and Flores) [2]. Yebes Observatory also manages two GNSS receivers: one integrated in the International GNSS Service (IGS) and a second one in the Spanish national GNSS network (Red Geodésica Nacional de Estaciones de Referencia GNSS, ERGNSS). It also runs an absolute gravimeter (FG5) and a relative superconducting gravimeter (OSG); the data collected by these gravimeters is sent to the International Geodynamics and Earth Tide Service (IGETS).

Yebes Observatory, IGN

IGN Yebes Observatory Technology Development Center

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Additionally, the project for the construction of an SLR station (YLARA project) started in late 2020, and it is expected to be finished by early January 2023. Yebes Observatory will become a GGOS core station once YLARA starts its operation in the International Laser Ranging Service (ILRS).

Finally, we plan to install a DiFX VLBI correlator for RAEGE, which could also be part of VGOS and EU-VGOS performing distributed correlation, if such scheme is finally adopted.

These activities are performed by a staff of engineers, astronomers, and technicians, with the help of the instrumentation located in the laboratories and workshops.

In the following sections we describe the most relevant technical activities performed during 2019 and 2020.

2 VGOS Broadband Receivers

Yebes Observatory was in charge of the full construction of three cryogenic VGOS broadband receivers, from the dewar and front-end (QRFH and LNAs) to the room temperature signal chain up to the input of the backends, including the PhaseCal and NoiseCal modules, the Cryogenics and Vacuum Control Unit, and the receiver control software. Two of these receivers are for the Ny-Ålesund Observatory of the Norwegian Mapping Authority (NMA) and one for the Metsähovi Observatory of the Finish Geospatial Research Institute (FGI).

These broadband receivers are cooled using a two-stage cryostat (15 and 50 K) and operate between 2 and 14 GHz in two linear polarizations. They have a receiver noise temperature below 30 K along most of the full VGOS band.

Figure 1 shows the block diagram of one such receiver in which we can see its different modules. After the cryostat, the signal is split into two sub-bands: 2.1–5.6 GHz and 3.6–11.6 GHz following Haystack's approach to avoid the saturation of the optical fiber amplifiers from strong signals in the lower part of the band. The signals—once amplified, filtered, and transported through optical fiber links to the backends room—are directed towards two identical signal conditioning modules designed and built at Yebes. These modules split the signals from both polarizations into four frequency sub-bands ready to be injected into the DBBC3. The filtering and conditioning module for the DBBC3 does not use tunable LOs and in case that the observing bands change they can be adapted by replacing the pass band filters by new ones.

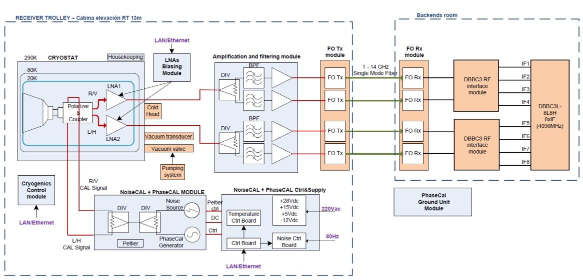

Fig. 1 Schematics of the VGOS broadband receiver for NMA and FGI.

The first NMA receiver (NMA1) was shipped in August 2019 and installed in September 2019. With respect to FGI, the VGOS receiver was shipped in October 2019 and installed in November 2019. Yebes staff was sent to each observatory to assist and provide support during the installation and commissioning of the corresponding receiver.

The receiver noise temperatures of these receivers are intercompared in Figure 2, measured in both linear polarizations along the band. It can be seen that the two receivers are almost identical with regard to noise temperature.

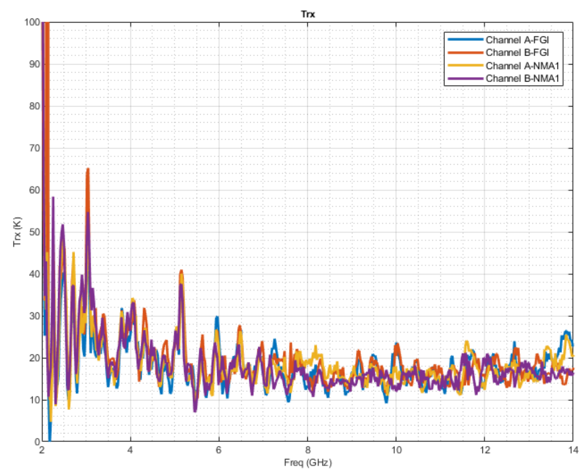

Fig. 2 Receiver noise temperatures for NMA1 and FGI.

The VGOS receivers use a cryogenics and vacuum control system which has an Ethernet connection for remote monitoring and control of both pumps (rotatory and turbomolecular), the reading of cryogenic temperature and the vacuum sensors, the control of the electrovalve, and the monitorization and control of the heat resistors and regenerators. This monitoring and control system eases the operation of the receiver from remote locations.

The second receiver for NMA (NMA2) was supposed to be intalled in 2020, but it has been delayed because it was decided to upgrade the LNAs from single-ended to balance configuration. This upgrade reduces the ripple in the receiver noise temperature curve and in the band-pass gain because balanced LNAs have much better input matching than single-ended LNAs. Additionally, 30dB directional couplers were included in the upgrade to improve the receiver noise by 3 Kelvin. It is foreseen to ship it to Ny-Ålesund in late spring 2021.

During 2020, the VGOS receiver for RAEGE Santa María station was completed. It already includes LNAs in balanced configuration, 30dB noise couplers, and a flatter envelope of the PhaseCal pulse train. Since November 2020, it is installed in the 13.2-m Yebes RAEGE VGOS radio telescope, while the Yebes VGOS receiver is being upgraded in our laboratory.

Additionally, we plan to prepare our current Up/Down converters to participate in future test observations with 1-GHz bandwidth and four R2DBEs. For this, suitable anti-aliasing filters (0.5–1.5 GHz) will be ordered.

The following upgrades are planned for the Yebes receiver during 2021:

- Revisited and improved QRFH [3]
- Balanced LNAs, to reduce the receiver noise and band-pass ripples [15]
- 30 dB noise couplers to improve receiver noise by 3 Kelvin [6]
- Updated PhaseCal AU with a flatter envelope of the pulse train
- Updated PhaseCal GU
- New post-dewar amplification unit to allow mixed mode observations (S/X and VGOS) [14]

Once the Yebes VGOS receiver is completed, the Santa María VGOS receiver will be shipped to the Azores, together with its associated backends. Then, Santa María station will join the VGOS communnity.

Finally, it has to be mentioned that, in November 2020, Yebes Observatory was contracted by HartRAO for the construction of a broadband receiver for the VGOS radiotelescope in Hartebeesthoek (South Africa). Once the receiver is finished, Yebes Observatory will have built a total of six VGOS receivers.

See [3, 4, 5, 6, 7, 8, 9, 10, 11] for more details about the VGOS receivers' development.

3 Tri-band Receiver at Santa María

The RAEGE radio telescope at Santa María is equipped with a Yebes-developed tri-band receiver, which can observe simultaneously in the bands 2.2–2.7 GHz, 7.5–9 GHz, and 28–32 GHz.

In August 2019, it suffered a failure and was shipped to Yebes for repair. It was sent back in February 2020 and was re-installed in early March 2020—just before the lockdown caused by the Covid-19 health crisis. The current receiver noise temperatures are lower than 32 K in S-band, 30 K in X-band, and 31 K in Ka-band. See [12] for details. Additionally, the Santa María station H-maser was retuned in 2020 [13].

In November 2020, the radio telescope performed joint observations of Bepi-Colombo in X/Ka together with JPL/DSN. The observations were a proof-of-concept to test if the accuracy of Doppler shift measurement can be improved by use of corrections from smaller and stiffer antennas like RAEGE VGOS ones.

During 2020, the RAEGE VGOS radio telescope underwent heavy maintenance operations, which will continue until spring 2021. It is expected to resume S/X operations by May 2021.

4 Ultra-low-noise Wide-band Amplifiers

Yebes cryogenic broadband low noise amplifiers have been extensively used in recent VGOS receivers—as well as in other VLBI observatories and even as 14-GHz-wide IF amplifiers for sub-millimeter receivers. A total of 28 amplifiers of this type were manufactured during this period, most of them already in the field.

However, an important drawback of amplifiers with such a high fractional bandwidth is the difficulty to simultaneously achieve state-of-the-art noise temperature and a good input matching, especially at the lower frequencies. This fact, combined with the poor return loss of the broadband feeds, produces ripples in the receiver noise and gain. A very advantageous solution for applications with mild power and space restrictions, as most VLBI single pixel receivers, is the use of balanced amplifiers. Yebes has excellent designs of 3 dB/90° microwave hybrids to combine with its amplifiers in a balanced configuration (see Figure 3). Since 2020, all VGOS receivers assembled in Yebes are equipped with balanced 2–14 GHz amplifiers, and some of them are being retrofitted to improved their performance.

Recent advances in this area have been driven by Yebes participation in the BRAND-EVN Radionet 4 project. The original 2-14 GHz band for VGOS was expanded to 1.5-15.5 GHz. New five-stage hybrids were developed for this band with exceptional results considering the decade fractional bandwidth. For BRAND-EVN, the balanced solution was finally preferred over the single-ended amplifier [15, 16].

An approach to further reduce the noise contribution of the hybrid in a balanced amplifier is the use of superconductors in microstrip lines. In a collaboration with Chalmers University, a prototype of a compact 4–12 GHz balanced amplifier integrating LNAs and su-

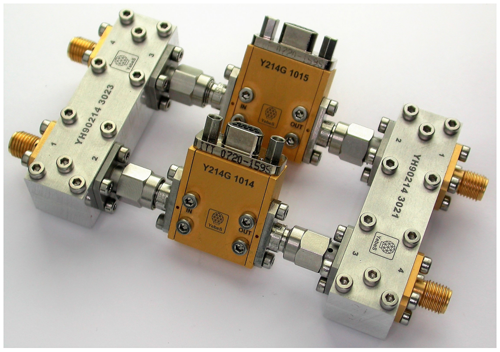

Fig. 3 Balanced Low Noise Amplifier developed in Yebes Observatory. This configuration is required for each receiver polarization channel.

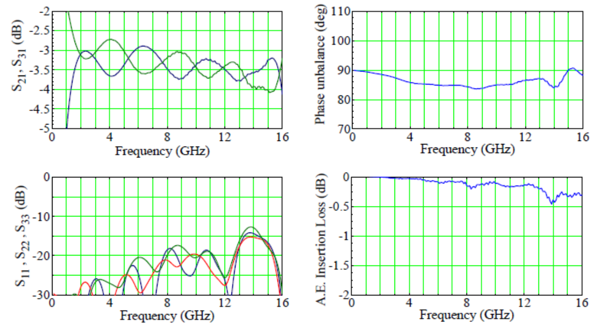

Fig. 4 Performance at 18 K of the Yebes 1.5–16 GHz cryogenic 3 dB/90° coupler for the BRAND project.

perconducting hybrids in the same block was developed, demonstrating an extremely low noise increment over the single-ended amplifier, although an operating temperature of 4 K was required [17].

5 Hardware Conversion of Linear to Circular Polarization

Most broadband receiver feeds provide dual-linear polarization. This has prevented an easy mixed-mode operation of VGOS with the legacy S/X system, which uses circular polarization. As a result, a polarization conversion is required. Two options may be considered: a hardware conversion at the front-end and a digital reconstruction of the circular polarizations at the backend.

For the implementation of the hardware option, Yebes Observatory has developed a solution based on cryogenic 3dB/90° multi-octave stripline hybrids which can be used to obtain both circular polarizations from linear polarization signals. Two designs have been manufactured: one for the 2–14 GHz band (presented in the last IVS biennial report) and another one for the 1.5–15.5 GHz band, in the frame of the BRAND-EVN Radionet 4 project. The cryogenic performance of these 2–14 GHz and 1.5–15.5 GHz broadband hybrids is very good across the whole band (see Figure 4), ensuring cross polarization below 25 dB and axial ratio below 1 dB with only a small penalty on the average noise temperature of the LNAs.

6 NoiseCal and PhaseCal Developments

All Yebes-developed VGOS receivers are equipped with a broadband noise source that can be turned ON, OFF or at 80-Hz rate under remote control. This feature is useful for amplitude calibration. The excess noise (Tcal) generated by the noise source and injected in front of the LNAs is carefully measured in the laboratory and reported. Concerning the PhaseCal Antenna Unit, the envelope of the pulse train was equalized to have a flatter spectrum.

With regard to the Cable Delay Measurement System (CDMS), a new version was installed in the 13.2-m Yebes RAEGE VGOS radio telescope in 2020. In addition, a new 5-MHz reference cable with lower temperature dependence was installed too. This cable was laid inside an insulating plastic tube, in order to reduce thermal effects on the cable itself. This set-up has been used in VGOS observations with success.

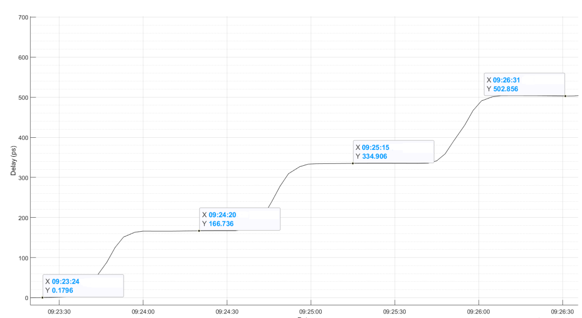

Fig. 5 CMDS test at 167-ps steps.

The system is based on a high accuracy sampling of a voltage proportional to the phase difference between the 5-MHz reference signal from the H-maser with the 5-MHz signal returned from the PhaseCal Antenna Unit, which is installed in the receiver trolley. Currently, the final version of the CDMS is under improvements for better shielded and thermal control. The goal is to provide the Yebes-developed VGOS receivers with this final version as soon as possible.

Figure 5 shows the measured delay when controlled steps of 167 ps are inserted. This test was performed in the Yebes RAEGE VGOS radiotelescope, so the whole cable run is included in the measurement, which is not the same situation as in the lab. The resolution of the system can be seen.

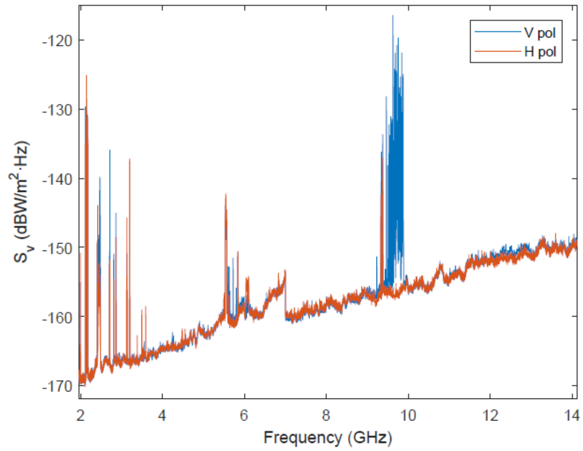

Fig. 7 Yebes RFI measurements in VGOS band at 3° elevation.

7 RFI Measurements

In 2019 and 2020, several RFI campaigns were performed with the permanent RFI measurement system (RAFITA, see Figure 6) on the roof of the lab building.

Fig. 6 Yebes RFI measurement system in the foreground and Yebes RAEGE VGOS radiotelescope in the background.

These measurements (see Figure 7) show the RFI enviroment at Yebes Observatory in the VGOS frequency range for an integrated 360° turn with the spectrum analyzer in max-hold mode. The elevation angle of the measurement was set to 3°. In additon, the RFI spectrum in the current VGOS bands A, B, C, and D were measured with better resolution and sensitivity.

In view of all these results it can be concluded that IMT, WiFi at 2.4 and 5 GHz, WiMax, fixed-service radio links, and radars at 9 GHz are the main contributors to the RFI environment.

From July to November 2020, a search for a new site of the RAEGE Gran Canaria station was carried out. RFI measurements were performed in several locations with the help of Yebes RFI portable equipment. A good candidate location was identified and the island authorities are in the process to buy the land and donate it to IGN.

Finally, the RFI shielding provided by the RAEGE radio telescope metallic servo container was evaluated, in order to check if the Santa María servo racks could be installed inside the concrete pedestal, because the container was suffering severe corrosion due to the salty environment on the island. For this purpose, the RFI environment was measured up to 4 GHz inside and outside this container when the radiotelescope was in movement. The results are shown in Figure 8. The blue trace shows the RFI generated by the servo equipment. When compared with the red trace (outside), it is clearly seen that the container is providing a good shielding. The huge RFI lines below 1 GHz are due to GMS signals. From the RFI view point, the conclusion was that it is better to keep the servo electronics inside the metallic container.

8 New Developments

In 2020, three new developments were started. The first one is a high-temperature superconducting (HTS) filter to notch the 9.4 GHz signal from radars. This design benefits from the results of the previous experi-

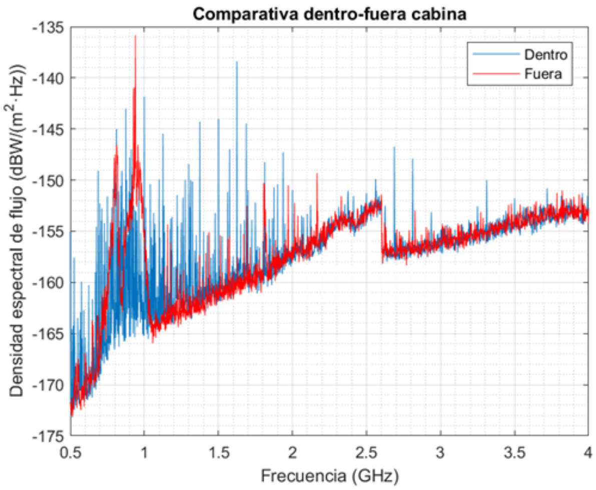

Fig. 8 RFI measurement inside (blue trace) and outside (red trace) the RAEGE servo container.

ence with the S-band HTS band-pass filter [18]. It is expected to build and test two units in 2021.

The second one is an RF-over-fiber link in the range 1–40 GHz, whose componentes were acquired. The system will be integrated and tested during 2021.

Finally, the third one is to install a DiFX VLBI correlator for RAEGE, which could also be part of VGOS and EU-VGOS performing distributed correlation, if such a scheme is adopted. We have already started with a minimal configuration to train one of the Yebes engineers and evaluate the feasiblity of this project.

Acknowledgements

Special thanks are given to all Yebes and Santa María staff for their valuable contributions to the technological developments and operations of the radio telescopes.

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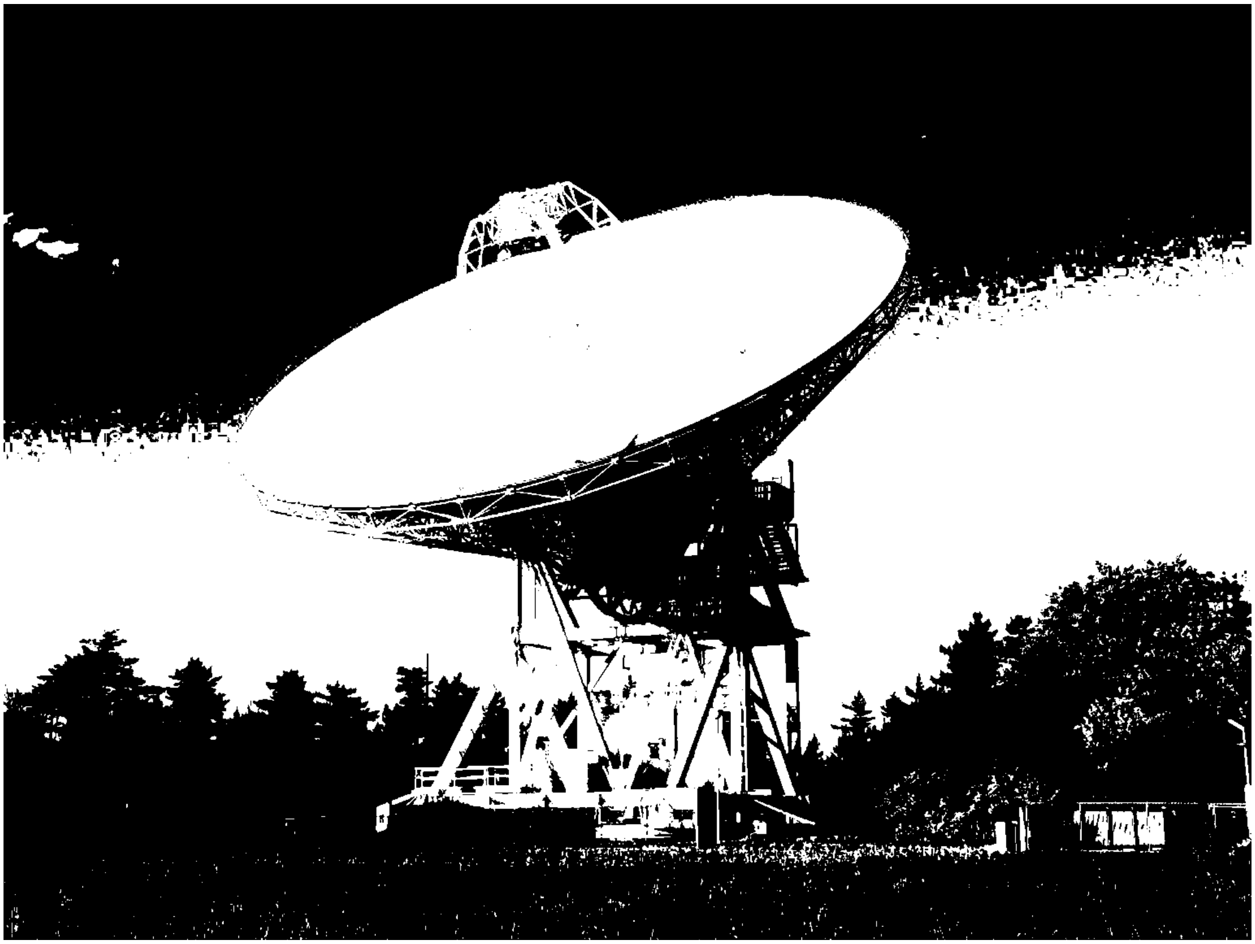
IVS Information



IVS Terms of Reference

1 Summary

1.1 Charter

The International VLBI Service for Geodesy and Astrometry (IVS) is an international collaboration of organizations which operate or support Very Long Baseline Interferometry (VLBI) components. IVS provides a service which supports geodetic and astrometric work on reference systems, Earth science research, and operational activities. IVS is a Service of the International Association of Geodesy (IAG) and of the International Astronomical Union (IAU).

1.2 Objectives

IVS fulfills its charter through the following objectives:

1. foster and carry out VLBI programs. This is accomplished through close coordination of the participating organizations to provide high-quality VLBI data and products.
2. promote research and development activities in all aspects of the geodetic and astrometric VLBI technique.
3. advance the education and training of VLBI participants through workshops, reports, and other means.
4. support the integration of new components into IVS.
5. interact with the community of users of VLBI products. IVS represents VLBI in the Global Geodetic Observing System (GGOS) of the IAG and interacts closely with the International Earth Rotation and Reference Systems Service (IERS).

In support of these objectives, IVS coordinates VLBI observing programs, sets performance standards for VLBI stations, establishes conventions for VLBI data formats and data products, issues recommendations for VLBI data analysis software, sets standards for VLBI analysis documentation, and institutes appropriate VLBI product delivery methods to ensure suitable product quality and timeliness. IVS coordinates its activities with the astronomical community because of the dual use of many VLBI facilities and technologies for both astronomy and astrometry/geodesy.

1.3 Data Products

VLBI data products contribute uniquely to these important activities:

- defining and maintaining the celestial reference frame,
- monitoring universal time (UT1),
- monitoring the coordinates of the celestial pole (nutation and precession).

These results are the foundation of many scientific and practical applications requiring the use of an accurate quasi-inertial reference frame, such as high-precision positioning, navigation, and timing. In addition IVS provides a variety of VLBI products with differing applications, timeliness, detail, and temporal resolution, such as:

- all components of Earth orientation parameters,
- terrestrial reference frame,
- baseline lengths,
- tropospheric parameters.

All VLBI data and products are publicly available in appropriate formats from IVS Data Centers.

1.4 Research

The IVS data and products are used for research in many areas of geodesy, geophysics, and astronomy, such as:

- UT1 and polar motion excitation over periods of hours to decades,
- solid Earth interior research (e.g., mantle rheology, anelasticity, libration, and core modes),
- characterization of celestial reference frame sources and improvements to the frame,
- tidal variations (solid Earth, oceanic, and atmospheric),
- improvements in the terrestrial reference frame, especially in the scale,
- climate studies (e.g., sea level change, deglaciation, and water vapor),
- regional and global geodynamics,
- general relativity.

To support these activities, there are ongoing research efforts to improve and extend the VLBI technique in areas such as:

- instrumentation, data acquisition, and correlation,
- data analysis techniques,
- spacecraft tracking and navigation (Earth-orbiting and interplanetary),
- combination of VLBI data and results with other techniques.

2 Permanent Components

IVS acquires, correlates, and analyzes VLBI data to produce geodetic, astrometric, and other results that are archived and publicized. IVS accomplishes its objectives through the following permanent components:

- Network Stations,
- Operation Centers,
- Correlators,
- Analysis Centers,
- Data Centers,
- Technology Development Centers,
- Office for Outreach and Communications,
- Coordinating Center.

2.1 Network Stations

The IVS observing network consists of high performance VLBI stations.

- Stations may either be dedicated to geodesy or have multiple uses (including astronomical observations or satellite tracking applications).
- Stations comply with performance standards for data quality and operational reliability specified by the Directing Board.
- Stations provide local tie information, timing and meteorological data to the IVS Data Centers.
- VLBI data acquisition sessions are conducted by groups of Network Stations that may be distributed either globally or over a geographical region.

2.2 Operation Centers

The IVS Operation Centers coordinate the routine operations of specific networks. Operation Center activities include:

- planning network observing programs,
- supporting the network stations in improving their performance,
- generating the detailed observing schedules for use in data acquisition sessions by IVS Network Stations,
- posting the observing schedule to an IVS Data Center for distribution and archiving.

IVS Operation Centers follow guidelines from the Coordinating Center for timeliness and schedule file formats.

2.3 Correlators

The IVS Correlators process raw VLBI data. Their other tasks are to:

- provide timely feedback to the Network Stations about data quality,
- jointly maintain the geodetic/astrometric community's media pool and transport,
- manage electronic data transfer,
- make processed data available to the Data Centers,
- regularly compare processing techniques, models, and outputs to ensure that data from different Correlators are identical.

2.4 Analysis Centers

The IVS coordinates VLBI data analysis to provide high-quality products for its users. The analyses are performed by:

- Operational Analysis Center,
- Associate Analysis Centers,
- Special Analysis Centers for Specific Observing Sessions, and
- Combination Centers.

All Analysis Centers maintain and/or develop appropriate VLBI analysis software.

Operational Analysis Centers are committed to producing results to the specifications of the IVS Analysis Coordinator and always on schedule to meet IVS requirements. In addition, Operational Analysis Centers may produce Earth orientation parameters, station coordinates, and source positions in regular intervals.

Operational Analysis Centers place their final results in IVS Data Centers for dissemination to researchers and other users. They adhere to IVS recommendations for the creation of high-quality products and their timely archiving and distribution. Any deviations that an Operational Analysis Center makes from IVS recommendations are properly documented. Operational Analysis Centers provide timely feedback about station performance. In addition to these regular services, Operational Analysis Centers may also perform any task of an Associate Analysis Center.

Associate Analysis Centers are committed to regularly submit specialized products using complete series or subsets of VLBI observing sessions. The analysis is performed for specific purposes as recognized by the Directing Board, such as exploitation of VLBI data for new types of results, investigations of regional phenomena, reference frame maintenance, or special determinations of Earth orientation parameters. The Associate Analysis Centers place their final results in IVS Data Centers for dissemination to researchers and other users. They adhere to IVS recommendations for the creation of high-quality products and their timely archiving and distribution. Any deviations that an Associate Analysis Center makes from IVS recommendations are properly documented.

Special Analysis Centers for Specific Observing Sessions have responsibility for ongoing series-related investigations of one or more existing session types. They perform detailed and comparative analyses of each session of a series within a reasonable time after correlation. In addition, they report deficits and technical complications to the observing sites, the correlators, and to the schedulers as well as to the IVS Network and Analysis Coordinators.

Combination Centers are committed to produce combination results from the individual submissions of the Operational Analysis Centers as official IVS products. For this purpose they monitor the quality of the submissions. The official IVS products include, but are not limited to, EOP time series derived from session-based results for 24-hour network sessions and one-hour Intensive sessions. Combination Centers also contribute to the generation of the official IVS input to International Terrestrial Reference Frame (ITRF) computations. The combination work is done in a timely fashion and in close cooperation with the IVS Analysis Coordinator.

2.5 Data Centers

The IVS Data Centers are repositories for VLBI observing schedules, station log files, data and products. Data Centers may mirror other Data Centers to make the distribution and maintenance of data more efficient and reliable.

- Data Centers are the primary means of distributing VLBI products to users.

- Data Centers work closely with the Coordinating Center and with the Analysis Centers to ensure that all the information and data required by IVS components are quickly and reliably available.

Data Centers provide the following functions:

- receive and archive schedule files from Operation Centers,
- receive and archive log files and ancillary data files from the Network Stations,
- receive and archive data products from the Analysis Centers,
- provide access and public availability to IVS data products for all users.

2.6 Technology Development Centers

The IVS Technology Development Centers contribute to the development of new VLBI technology for improvement of the VLBI technique. They:

- investigate new equipment and approaches,
- develop, test, and document new hardware, firmware, and software for operations,
- assist with deployment, installation, and training for any new approved technology,
- maintain and support operational equipment.

2.7 Office for Outreach and Communications

The IVS Office for Outreach and Communications (OOC) creates and maintains an outreach program to promote knowledge of the VLBI technique and the activities of the IVS, and to foster an understanding of the importance of its products for the scientific communities and the general public. The OOC is mandated with improving collaboration with regional and global organizations and institutions, including sponsor organizations and scientific associations. The OOC works together with all components of the IVS and in particular with the IVS Coordinating Center.

2.8 Coordinating Center

The IVS Coordinating Center is responsible for coordination of both the day-to-day and the long-term activities of IVS, consistent with the directives and policies established by the Directing Board. Specifically, the Coordinating Center monitors, coordinates, and supports the activities of the Network Stations, Operation Centers, Correlators, Data Centers, Analysis Centers, and Technology Development Centers. The Coordinating Center works closely with the Technology Coordinator, the Network Coordinator, and the Analysis Coordinator to coordinate IVS activities.

The primary functions of the Coordinating Center are to:

- coordinate observing programs approved by the Directing Board,
- create and maintain the master schedule of observing sessions in coordination with IVS Network Stations and astronomical observing programs,
- foster communications among all components of the IVS,
- coordinate the best use of community resources,
- develop standard procedures for IVS components,
- organize training in VLBI techniques,
- organize workshops and meetings, including IVS technical meetings,
- produce and publish reports of activities of IVS components,
- maintain the IVS information system and archive all documents, standards, specifications, manuals, reports, and publications,
- coordinate IVS outreach and educational activities,
- provide liaison with the IAU, IAG, GGOS, IERS, and other organizations,
- provide the Secretariat of the Directing Board.

2.9 Becoming a Permanent Component

IVS will accept proposals at any time to become a permanent component. Such proposals will be reviewed for approval by the Directing Board.

3 Coordinators

Specific IVS activities regarding network data quality, products, and technology are accomplished through the functions performed by three coordinators: a Network Coordinator, an Analysis Coordinator, and a Technology Coordinator.

3.1 Network Coordinator

The IVS Network Coordinator is selected by the Directing Board from responses to an open solicitation to all IVS components. The Network Coordinator represents the IVS Network Stations on the Directing Board and works closely with the Coordinating Center. The Network Coordinator is responsible for stimulating the maintenance of a high quality level in the station operation and data delivery. The Network Coordinator performs the following functions:

- monitors adherence to standards in the network operation,
- participates in the quality control of the data acquisition performance of the network stations,
- tracks data quality and data flow problems and suggests actions to improve the level of performance,
- coordinates software development for station control and monitoring.

The Network Coordinator works closely with the geodetic and astronomical communities who are using the same network stations for observations. The Network Coordinator takes a leading role in ensuring the visibility and representation of the network stations.

3.2 Analysis Coordinator

The IVS Analysis Coordinator is selected by the Directing Board from responses to an open solicitation to the IVS Analysis Centers. The Analysis Coordinator is responsible for coordinating the analysis activities of IVS and for stimulating VLBI product development and delivery. The Analysis Coordinator performs the following functions:

- fosters comparisons of results from different VLBI analysis software packages and different analysis strategies,
- encourages documentation of analysis and combination software,
- participates in comparisons of results from different space geodetic techniques,
- monitors Analysis Centers' products for high quality results and for adherence to IVS standards and IERS Conventions,
- ensures that IVS analysis and combination products from all Analysis Centers are archived and are available to the scientific community, and
- supervises the formation of the official IVS products specified by the IVS Directing Board.

The Analysis Coordinator plays a leadership role in the development of methods for generation and distribution of VLBI products so that the products reach the users in a timely manner. The Analysis Coordinator interacts with GGOS and the IERS and promotes the use of VLBI products by the broader scientific community. The Analysis Coordinator works closely with the astronomical communities who are using some of the same analysis methods and software.

3.3 Technology Coordinator

The IVS Technology Coordinator is selected by the Directing Board from responses to an open solicitation to the IVS Technology Development Centers. The Technology Coordinator performs the following functions:

- stimulates advancement of the VLBI technique,
- maintains awareness of all current VLBI technologies and ongoing development,
- coordinates development of new technology among all IVS Technology Development Centers,
- encourages technical compatibility with the astronomical community,
- encourages and oversees development of VLBI-related technical standards,
- coordinates the distribution of and access to technical documents and standards,
- helps promulgate new technologies to the IVS community.

The Technology Coordinator works closely with the astronomical community, both to maintain technical compatibility between the geodetic and astronomical communities and to take advantage of technology development activities in the astronomical community.

4 Directing Board

4.1 Roles and Responsibilities

The Directing Board sets objectives, determines policies, adopts standards, and sets the scientific and operational goals for IVS. The Directing Board exercises general oversight of the activities of IVS including modifications to the organization that are deemed appropriate and necessary to maintain efficiency and reliability. The Directing Board may determine appropriate actions to ensure the quality of the IVS products.

The Directing Board will receive and review proposals for non-IVS research programs that request IVS resources.

4.2 Membership

The Directing Board consists of representatives of the IVS components, members at-large, appointed members, and ex officio members. The members are:

Representatives of IVS Components (see below):

- Correlators and Operation Centers representative (1)
- Analysis and Data Centers representatives (2)
- Networks representatives (2)
- Technology Development Centers representative (1)

Elected by the Directing Board upon recommendation from the Coordinating Center (see below):

- Members at large (3)

Selected by Directing Board upon review of proposals from IVS Member Organizations:

- Coordinating Center Director
- Director of Office for Outreach and Communications
- Network Coordinator
- Analysis Coordinator
- Technology Coordinator

Appointed members:

- IAU representative
- IAG representative
- IERS representative

Through a reciprocity agreement between IVS and IERS, the IVS serves as the VLBI Technique Center for IERS, and as such its designated representative(s) serve on the IERS Directing Board. In turn, the IERS Directing Board designates a representative to the IVS Directing Board. This arrangement is to assure full cooperation between the two services.

Total number: 17

The members appointed by IAU, IAG, and IERS are not subject to institutional restrictions.

The six members who are the representatives of the IVS components are elected by the IVS Associate Members. All elected members serve staggered four-year terms once renewable.

At-large members are intended to ensure representation on the Directing Board of each of the components of IVS and to balance representation from as many countries and institutions and IVS interests as possible. At-large members serve two-year terms once renewable.

A Directing Board member who departs before the end of his/her term is replaced by a person selected by the Directing Board. The new member will serve until the next official elections. The position will then be filled for a full term.

An individual can only serve two consecutive full terms on the Board in any of the representative and at-large positions. Partial terms are not counted to this limit. After serving two consecutive full terms, an individual becomes eligible again for a position on the Board following a two-year absence.

The three Coordinators are selected by the Directing Board on the basis of proposals from IVS Member Organizations. On a two-thirds vote the Directing Board may call for new proposals for any Coordinator when it determines that a new Coordinator is required. Coordinators are encouraged to give at least six months notice before resigning.

4.3 Elections

Election of Board members from the IVS components shall be conducted by a committee of three Directing Board members, the chair of which is appointed by the chair of the Directing Board. The committee solicits nominations for each representative from the relevant IVS components. For each position, the candidate who receives the largest number of votes from the Associate Members will be elected. In case of a tie the Directing Board will make the decision.

4.4 Chair

The chair is one of the Directing Board members and is elected by the Board for a term of four years with the possibility of reelection for one additional term. The chair is the official representative of IVS to external organizations.

4.5 Decisions

Most decisions by the Directing Board are made by consensus or by simple majority vote of the members present. In case of a tie, the chair decides how to proceed. If a two-thirds quorum is not present, the vote shall be held later by electronic mail. A two-thirds vote of all Board members is required to modify the Terms of Reference, to change the chair, or to replace any of the members before their normal term expires.

4.6 Meetings

The Directing Board meets at least annually, or more frequently if meetings are called by the chair or at the request of at least three Board members. The Board will conduct periodic reviews of the IVS organization and its mandate, functions, and components.

5 Definitions

5.1 Member Organizations

Organizations that support one or more IVS components are IVS Member Organizations. Individuals associated with IVS Member Organizations may become IVS Associate Members.

5.2 Affiliated Organizations

Organizations that cooperate with IVS on issues of common interest, but do not support an IVS component, are IVS Affiliated Organizations. Affiliated Organizations express an interest in establishing and maintaining a strong working association with IVS to mutual benefit. Individuals affiliated with IVS Affiliated Organizations may become IVS Corresponding Members.

5.3 Associate Members

Individuals associated with organizations that support an IVS component may become IVS Associate Members. Associate Members take part in the election of the incoming members of the Directing Board representing the IVS components.

5.4 Corresponding Members

IVS Corresponding Members are individuals who express interest in receiving IVS publications, wish to participate in workshops or scientific meetings organized by IVS, or generally are interested in IVS activities. Ex officio Corresponding Members are the following:

- IAG Secretary General
- Chair of GGOS
- President of IAG Commission 1 – Reference Frames
- President of IAG Commission 3 – Earth Rotation and Geodynamics

- President of IAU Division A – Fundamental Astronomy
- President of IAU Commission A1 – Astrometry
- President of IAU Commission A2 – Rotation of the Earth
- President of IAU Commission A3 – Fundamental Standards
- President of IAU Commission B4 – Radio Astronomy
- President of URSI Commission J – Radio Astronomy

Individuals are accepted as IVS Corresponding Members upon request to the Coordinating Center.

Last modified: 24 May 2019

Links to Additional IVS Information

This page provides links to information about the individuals and groups that support IVS. Member organizations are organizations that support one or more permanent components. Permanent components are groups that formally commit to provide support in one of six categories: coordination of network operations (Operation Centers), collection of VLBI data (Network Stations), processing of raw data (Correlators), archival and distribution of data and products (Data Centers), analysis of data and generation of products (Analysis Centers), and development of new technology (Technology Development Centers).

Associate Members are individuals that are associated with a member organization and have been granted Associate Member status. Associate Members generally support IVS by participating in the activities of one or more components.

Affiliated organizations cooperate with IVS on matters of common interest but do not support a component.

Information Category	Link
Associate Members	
(listed alphabetically by last name)	https://ivscc.gsfc.nasa.gov/about/org/members/assoc_name.pdf
(listed alphabetically by their organization's country)	https://ivscc.gsfc.nasa.gov/about/org/members/assoc_org.pdf
Permanent Components	
Network Stations	https://ivscc.gsfc.nasa.gov/about/org/components/ns-list.html
Operation Centers	https://ivscc.gsfc.nasa.gov/about/org/components/oc-list.html
Correlators	https://ivscc.gsfc.nasa.gov/about/org/components/co-list.html
Data Centers	https://ivscc.gsfc.nasa.gov/about/org/components/dc-list.html
Analysis Centers	https://ivscc.gsfc.nasa.gov/about/org/components/ac-list.html
Technology Development Centers	https://ivscc.gsfc.nasa.gov/about/org/components/td-list.html
Member Organizations	https://ivscc.gsfc.nasa.gov/about/org/members/memberorgs.html
Affiliated Organizations	https://ivscc.gsfc.nasa.gov/about/org/members/affilmemberorgs.html