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International VLBI Service for Geodesy and Astrometry 2012 Annual Report

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Preface

This volume of reports is the 2012 Annual Report of the International VLBI Service for Geodesy and Astrometry (IVS). The individual reports were contributed by VLBI groups in the international geodetic and astrometric community who constitute the permanent components of IVS.

The IVS 2012 Annual Report documents the work of the IVS components for the calendar year 2012, our fourteenth year of existence. The reports describe changes, activities, and progress of the IVS. Many thanks to all IVS components who contributed to this Annual Report.

With the exception of the first section and parts of the last section (described below), the contents of this Annual Report also appear on the IVS Web site at

`http://ivscc.gsfc.nasa.gov/publications/ar2012`

This book and the Web site are organized as follows:

- The first section contains general information about IVS, a map showing the location of the components, information about the Directing Board members, and the annual report of the IVS Chair.
- The second section holds four special reports. The first report, "Short Report of IVS Working Group 5 (WG5) on Space Science Applications", presents the work of Working Group 5, which was established in 2009 to examine ways in which IVS and other VLBI networks can support planetary and space science missions to the mutual benefit of all participants. The WG5 report considers several types of spacecraft, evaluating VLBI's suitability for observing them and the expected benefits, and the report assesses the availablity of IVS observing sessions for this purpose. The second and third reports concern comparisons of two related VLBI system components — down-converters, which convert analog radio frequencies (RF) to intermediate frequencies (IF), and digital backends (DBE), which convert IF into channelized digital data that can be correlated. "VLBI Digital-Backend Intercomparison Test Report" discusses the results of the October 2012 2nd DBE intercomparison workshop, which tested and compared five DBE systems. "VLBI2010 Receiver Back End Comparison" presents tables that summarize information about two flexible down-converters and nine DBE systems as of mid-January 2013. Finally, the fourth report, "VLBI2010 Feed Comparison", presents a table and a figure that compare two VLBI2010-compliant broadband feeds and a table that compares two triband feeds that are non-compliant but can be used during the transition to VLBI2010 and also to support X/Ka CRF observations.
- The next seven sections hold the reports from the Coordinators and the reports from the IVS Permanent Components: Network Stations, Operation Centers, Correlators, Data Centers, Analysis Centers, and Technology Development Centers.
- The next section contains a compilation of publications in the field of geodetic and astrometric VLBI during 2012.
- The last section includes reference information about IVS: the Terms of Reference, the lists of Member and Affiliated organizations, the IVS Associate Member list, a complete list of IVS components, the list of institutions that contributed to this report, and a list of acronyms.

Table of Contents

About IVS

IVS Organization

Objectives

IVS is an international collaboration of organizations which operate or support Very Long Baseline Interferometry (VLBI) components. The goals are:

1. To provide a service to support geodetic, geophysical and astrometric research and operational activities.
2. To promote research and development activities in all aspects of the geodetic and astrometric VLBI technique.
3. To interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system.

The IVS

- Interacts closely with the IERS, which is tasked by IAU and IUGG with maintaining the international celestial and terrestrial reference frames (ICRF and ITRF),
- coordinates VLBI observing programs,
- sets performance standards for the observing stations,
- establishes conventions for data formats and products,
- issues recommendations for analysis software,
- sets standards for analysis documentation,
- institutes appropriate product delivery methods in order to insure suitable product quality and timeliness.

Realization And Status Of IVS

IVS consists of

- 33 Network Stations, acquiring high performance VLBI data,
- 3 Operation Centers, coordinating the activities of a network of Network Stations,
- 7 Correlators, processing the acquired data, providing feedback to the stations and providing processed data to analysts,
- 6 Data Centers, distributing products to users, providing storage and archiving functions,
- 27 Analysis Centers, analyzing the data and producing the results and products,
- 6 Technology Development Centers, developing new VLBI technology,
- 1 Coordinating Center, coordinating daily and long term activities.

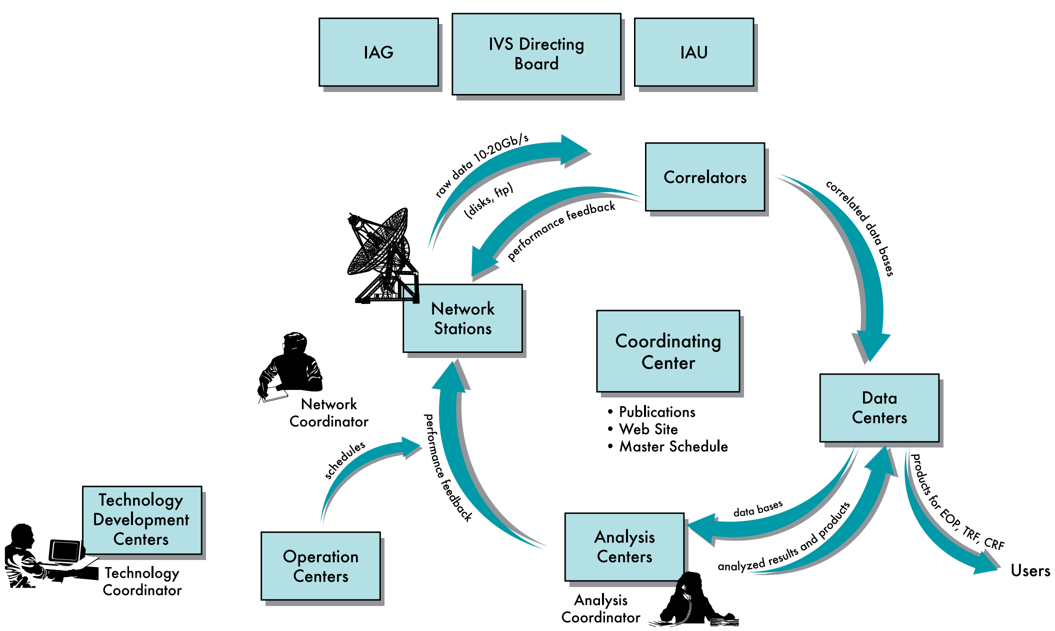
Altogether

- 83 Permanent Components, representing 43 institutions in 21 countries,
- ~280 Associate Members.

In addition the IVS has:

- Directing Board, determining policies, standards and goals; the board is composed of 15 members (elected and ex officio), including
- Coordinators for the network, analysis and technology.

ORGANIZATION OF INTERNATIONAL VLBI SERVICE



IVS Member Organizations

The following organizations contribute to IVS by supporting one or more IVS components. They are considered IVS Members. Listed alphabetically by country.

Organization	Country
Geoscience Australia	Australia
University of Tasmania	Australia
CSIRO	Australia
Vienna University of Technology	Austria
Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Geodetic Survey Division, Natural Resources Canada	Canada
Dominion Radio Astrophysical Observatory	Canada
Universidad de Concepción	Chile
Instituto Geográfico Militar	Chile
Chinese Academy of Sciences	China
Finnish Geodetic Institute, Aalto University	Finland
Observatoire de Paris	France
Laboratoire d'Astrophysique de Bordeaux	France
Deutsches Geodätisches Forschungsinstitut	Germany
Bundesamt für Kartographie und Geodäsie	Germany
Institut für Geodäsie und Geoinformation der Universität Bonn	Germany
Forschungseinrichtung Satellitengeodäsie, TU-Munich	Germany
Max-Planck-Institut für Radioastronomie	Germany
GeoForschungsZentrum Potsdam	Germany
Istituto di Radioastronomia INAF	Italy
Agenzia Spaziale Italiana	Italy
Politecnico di Milano DIIAR	Italy
Geospatial Information Authority of Japan	Japan
National Institute of Information and Communications Technology	Japan
National Astronomical Observatory of Japan	Japan
National Institute of Polar Research	Japan
Auckland University of Technology	New Zealand
Norwegian Mapping Authority	Norway
Astronomical Institute of St.-Petersburg University	Russia
Institute of Applied Astronomy	Russia
Pulkovo Observatory	Russia
Sternberg Astronomical Institute of Moscow State University	Russia
Hartebeesthoek Radio Astronomy Observatory	South Africa
Korea Astronomy and Space Science Institute	South Korea
National Geographic Information Institute	S. Korea
Instituto Geográfico Nacional	Spain
Chalmers University of Technology	Sweden
Karadeniz Technical University	Turkey
Main Astronomical Observatory, National Academy of Sciences, Kiev	Ukraine
Laboratory of Radioastronomy of Crimean Astrophysical Observatory	Ukraine
NASA Goddard Space Flight Center	USA
U. S. Naval Observatory	USA
Jet Propulsion Laboratory	USA

IVS Affiliated Organizations

The following organizations cooperate with IVS on issues of common interest, but do not support an IVS component. Affiliated Organizations express an interest in establishing and maintaining a strong working association with IVS to mutual benefit. Listed alphabetically by country.

Organization	Country
Australian National University	Australia
University of New Brunswick	Canada
FÖMI Satellite Geodetic Observatory	Hungary
Joint Institute for VLBI in Europe (JIVE)	Netherlands
Westerbork Observatory	Netherlands
National Radio Astronomy Observatory	USA

Products

The VLBI technique contributes uniquely to

- Definition and realization of the International Celestial Reference Frame (ICRF)
- Monitoring of Universal Time (UT1) and length of day (LOD)
- Monitoring the coordinates of the celestial pole (nutation and precession)

Further significant products are

- All components of Earth Orientation Parameters at regular intervals
- Station coordinates and velocity vectors for the realization and maintenance of the International Terrestrial Reference Frame (ITRF)

All VLBI data and results in appropriate formats are archived in data centers and publicly available for research in related areas of geodesy, geophysics and astrometry.

IVS Component Map

IVS Components by Country

Country	Qty.
Australia	3
Austria	1
Brazil	1
Canada	1
Chile	1
China	4
Finland	1
France	3
Germany	9
Italy	8
Japan	13
New Zealand	1
Norway	2
Russia	9
South Africa	1
South Korea	2
Spain	1
Sweden	3
Turkey	1
Ukraine	2
USA	16
Total	**83**

A complete list of IVS Permanent Components is in the IVS Information section of this volume.

Ny Ålesund
NMA
Metsähovi
Svetloe
Onsala
IAA
PUL
AIStPbU
SAI
IGGB
BKG
GFZ
MAO
FGS(BKG,IGGB)
DGFI
Wettzell
Paris
TU Vienna
Zelenchukskaya
Bordeaux
Medicina
Simeiz
INAF
Yebes
Matera
KTU
PMD
Noto
Badary
Nanshan
Mizusawa
Tsukuba
Kashima 34
Sejong
Seshan
NICT
KASI
GSI
Shanghai
Kashima 11
Koganei
Katherine
Hartebeesthoek
Yarragadee
Parkes
GA
Warkworth
Hobart
Syowa

IVS Directing Board

NAME: Harald Schuh

AFFILIATION: Vienna University of Technology, Austria

POSITION: Acting Chair and IAG Representative

TERM: ex officio

NAME: Dirk Behrend

AFFILIATION: NVI, Inc./Goddard Space Flight Center, USA

POSITION: Coordinating Center Director

TERM: ex officio

NAME: Alessandra Bertarini

AFFILIATION: University of Bonn, Germany

POSITION: Correlators and Operation Centers Representative

TERM: Feb 2011 to Feb 2015

NAME: Patrick Charlot

AFFILIATION: Bordeaux Observatory, France

POSITION: IAU Representative

TERM: ex officio

NAME: Jesús Gómez González

AFFILIATION: National Geographic Institute of Spain

POSITION: At Large Member

TERM: Feb 2011 to Feb 2013

NAME: Rüdiger Haas

AFFILIATION: Chalmers University of Technology, Sweden

POSITION: Technology Development Centers Representative

TERM: Feb 2009 to Feb 2013

NAME: Hayo Hase

AFFILIATION: Bundesamt für Kartographie und Geodäsie/TIGO, Germany/Chile

POSITION: Networks Representative

TERM: Feb 2011 to Feb 2015

NAME: Ed Himwich

AFFILIATION: NVI, Inc./Goddard Space Flight Center, USA

POSITION: Network Coordinator

TERM: permanent

NAME: Fengchun Shu

AFFILIATION: Shanghai Astronomical Observatory, China

POSITION: At Large Member

TERM: Feb 2011 to Feb 2013

NAME: Shinobu Kurihara

AFFILIATION: Geospatial Information Authority, Japan

POSITION: At Large Member

TERM: (Feb 2011) to Feb 2013

NAME: Oleg Titov

AFFILIATION: Geoscience Australia, Australia

POSITION: Analysis and Data Centers Representative

TERM: Feb 2009 to Feb 2013

NAME: Chopo Ma

AFFILIATION: NASA Goddard Space Flight Center, USA

POSITION: IERS Representative

TERM: ex officio

NAME: Gino Tuccari

AFFILIATION: Istituto di Radioastronomia, Italy

POSITION: Networks Representative

TERM: Feb 2009 to Feb 2013

NAME: Axel Nothnagel

AFFILIATION: University of Bonn, Germany

POSITION: Analysis Coordinator

TERM: permanent

NAME: Alan Whitney

AFFILIATION: Haystack Observatory, USA

POSITION: Technology Coordinator

TERM: permanent

IVS Chair's Report

Harald Schuh

Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences

With the 2012 Annual Report the IVS components report about their progress and activities which were conducted during the service's fourteenth year of existence. I would like to thank all IVS Associate Members for their contributions over the course of the year, in particular for providing their reports in time. Timely appearance of the Annual Report is always an ambitious goal and is highly appreciated for maintaining this volume as a real information exchange tool for the community and related groups. I thank the editors for the timely release.

In 2012 IVS observing activities remained at the same high level as in previous years, testament to the optimized coordination by the Coordinating Center and strong support from all components despite the limited resources and failures at a few aging radio telescopes. I would like to thank the staff of the Coordinating Center who bear much responsibility and carry a heavy burden for the entire service activities. Day-to-day work is done continuously by the Network Stations, the Correlators, the Data Centers, and the Analysis Centers and is the basis for the regular provision of precise and reliable IVS products. Here I would like to emphasize those activities performed in 2012 that go beyond the normal work load.

IVS Contribution to the Global Geodetic Observing System (GGOS)

In 2005 the intergovernmental Group on Earth Observations (GEO) was formed. This group initiated the creation of a Global Earth Observing System of Systems (GEOSS) for monitoring and understanding global change. The International Association of Geodesy (IAG) contributes to this multi-national and multi-institutional effort with the Global Geodetic Observing System (GGOS). Based on the well-established, international space-geodetic services GGOS will provide the most precise terrestrial and celestial reference frames that are needed as a stable reference to monitor any kind of changes on Earth and in space.

Integration and combination in the framework of GGOS is the main challenge for the international geodesy in this decade. GGOS goes beyond the integration of the geometric techniques (VLBI, SLR, GNSS, DORIS) as it includes also techniques measuring terrestrial gravity, the global Earth gravity field, sea level, and also the magnetic field. Thus, a consistent combination of all geometric and physical techniques will be required. GGOS plays an essential role in helping to solve environmental and societal problems. Many tasks such as establishing a unified global height system or open questions related to global change, sea level rise, or the prevention of natural hazards need precise reference frames and exact geodetic measurements. VLBI can give a critical contribution to GGOS by its relation to a quasi-inertial celestial reference frame and its unique ability to measure long-term UT1-UTC and precession/nutation. One of the IVS main tasks in 2012 was to continue its contribution as an efficient partner within GGOS. Several GGOS events were attended in 2012 with presentations about the IVS, its next generation VLBI2010 system, and the new IVS network called VGOS (VLBI2010 Global Observing System).

VLBI2010 Committee (V2C), VLBI2010 Project Executive Group (V2PEG), and VGOS (VLBI2010 Global Observing System)

In recent years the IVS has developed the concept and specifications of a next generation VLBI system called VLBI2010. The goals of the new system are to achieve (on scales up to the size of the Earth):

- 1 mm position accuracy,
- 0.1 mm/yr velocity accuracy,
- continuous observations, and
- results available in near real-time.

The VLBI2010 Committee (V2C), chaired by Bill Petrachenko, was established in 2005. It is tasked with promoting the goals set by the VLBI2010 Report released by the IVS Working Group 3 "VLBI2010: Current and Future Requirements for Geodetic VLBI Systems." All results have been summarized in the excellent VLBI2010 Progress Report with recommendations that can be used as a benchmark for new VLBI systems. Since the VLBI2010 Progress Report was finalized in spring 2009 and put on the IVS Web site (ftp://ivscc.gsfc.nasa.gov/pub/misc/V2C/TM-2009-214180.pdf) the V2C activities have continued with a lot of further simulations and technical studies. I would like to thank all members of the V2C for taking over the responsible leading role in the realization of the VLBI2010 visions.

VLBI2010 is supposed to develop not only the visions but also very detailed specifications for future VLBI systems. Now, the task for the IVS is the realization of the VLBI2010 concept. To support the implementation of VLBI2010 and to actively contact governmental entities and funding organizations the VLBI2010 Project Executive Group (V2PEG) under the leadership of Hayo Hase continued its activities in 2012. Several letters of support were sent to government bodies and funding agencies all over the world and an update of the so-called station survey was requested from the IVS network stations in December 2011. Based on this questionnaire very useful information was obtained about the status of the planning process concerning the transition to VLBI2010 at the various observing stations.

In the last years several countries have decided to develop or purchase new VLBI systems. We highly appreciate that agencies in the following countries got approval of new VLBI2010-type radio telescopes so far: Australia, China, Finland, Germany, Japan, New Zealand, Norway, Portugal, Russia, Spain, South Korea, and Sweden. Thus, already nineteen VLBI2010 antennas have been approved with more proposals under consideration or even in review in countries like France, Poland, and Saudi Arabia. With new antennas the global coverage of geodetic VLBI is getting better, but it is still far from being optimal; in particular more VLBI sites in the south-eastern quadrant would be more than welcome.

IVS Working Group 4 on "VLBI Data Structures"

The IVS Working Group on "VLBI Data Structures" chaired by John Gipson was established in September 2007 as a response to the strong need for new, common VLBI data structures. This Working Group examines the data structure currently used in VLBI data processing and develops the data structure needed in the future. WG4 is getting closed soon as all its goals w.r.t. the new data format have been achieved. What remains is the implementation into the various existing VLBI software packages.

IVS Working Group 5 on "Space Science Applications"

The mandate of the WG5 comprises the following tasks:

1. To investigate synergies in scientific and technological areas between the IVS core activities and VLBI experiments in application to planetary and space science missions.
2. To determine areas of VLBI support of planetary and space science missions where experiments conducted by the IVS (possibly together with other VLBI networks) can be mutually beneficial.
3. To investigate desirability and feasibility of establishing a mission-specific liaison between IVS and appropriate space agencies and organizations involved in planetary and space science missions.

Due to cancellations or postponement of several relevant space missions the work of WG5 was delayed, but it is anticipated to be closed in spring 2013 as the final report describing the state-of-the-art and future perspectives is about to be published.

IVS Working Group 6 on "VLBI Education and Training"

The IVS Directing Board established in March 2009 the Working Group 6 on "Education and Training" chaired by Rüdiger Haas. The general aim of IVS WG6 is to support education and training in the field of geodetic and astrometric VLBI, in order to pass on and maintain expertise in this field for the next generations.

The Terms of Reference of IVS WG6 are:

1. To establish contacts to education institutions in geodesy and geosciences worldwide with the aim to raise interest in geodetic VLBI among students.
2. To develop ideas for education material that can be distributed to education institutions.
3. To seek funding to organize training in form of, for instance, IVS summer schools for Master and PhD students.

Proposals for a VLBI school were already submitted in 2011 and it was very successfully organized in Helsinki, Finland in March 2013.

IVS Chair's Report Continued

Events and Highlights in 2012

In early March 2012, the 7th IVS General Meeting under the theme "Launching the Next-Generation IVS Network" was held in Madrid (Spain), i.e. in the country where presently the establishment of four new VLBI radio telescopes is taking place in the frame of the Spanish/Portuguese RAEGE project, chaired by Prof. Jesús Gómez-González (Instituto Geográfico Nacional, IGN). In conjunction with the General Meeting, an IVS Analysis Workshop, a V2C meeting, a V2PEG meeting, and the 27th Directing Board Meeting were organized. I would like to thank the Local Organizing Committee, Francisco Colomer (Chair), Susana García-Espada, Álvaro Santamaría, Pablo de Vicente, and Marta Calvo for the excellent organization. I thank also the session conveners and all other individuals who contributed to the great success of the meeting. The IGN is deeply acknowledged for providing the meeting facilities. We very much appreciated the great hospitality we received from our Spanish colleagues. A special highlight was certainly the official 'launch' of the new VGOS, the VLBI2010 Global Observing System, in the closing session of the 7th General Meeting.

Other highlights in terms of 2012 meetings to be mentioned here are the IVS VLBI2010 Workshop on Technical Specifications (TecSpec), in Bad Kötzting/Wettzell (Germany), March 1–2, 2012, http://www.fs.wettzell.de/veranstaltungen/vlbi/tecspec2012/index.html and the 1st International VLBI Technology Workshop, at MIT Haystack Observatory, October 22–24, 2012, http://www.haystack.mit.edu/workshop/ivtw/.

In 2012 we were able to welcome several new components to the IVS family. Metsähovi Observatory (Finland) and Sejong Station (South Korea) became new Network Stations of the IVS. Shanghai Astronomical Observatory (SHAO, China) was approved as an IVS Correlator facility, while GFZ Potsdam (Germany) was approved as IVS Associate Analysis Center. I would like to thank all new components for their support and commitment.

Summary information about all IVS events and activities is available on the IVS homepage http://ivscc.gsfc.nasa.gov and in the IVS Newsletters 32, 33, and 34. The Newsletter is an excellent means to transfer information to everybody. The editor team, Dirk Behrend, Hayo Hase, and Heidi Johnson, presented interesting and up-to-date information. They once again did an excellent job, which is highly appreciated.

The "IVS Live" tool has been further refined. It provides excellent information about ongoing VLBI sessions and can be accessed at http://ivslive.obs.u-bordeaux1.fr/. Many thanks to the Laboratoire d'Astrophysique de Bordeaux and, in particular, to Arnaud Collioud for the continued support.

Personal remarks at the end

In November 2012 I moved from Vienna, where I have worked for about 13 years, to a new position as Head of Department 1 'Geodesy and Remote Sensing' at Helmholtz Centre Potsdam – German Research Centre for Geosciences (usually called 'GFZ Potsdam'). Being still full professor at TU Wien (on leave) I am now also a full professor and Head of Section 'Satellite Geodesy' at TU Berlin. At GFZ we have already started to establish a VLBI group chaired by Robert Heinkelmann which was approved as a new IVS Associate Analysis Center in December 2012. Our main goals are VLBI observation of satellites and spacecraft as well as co-location in space (i.e., VLBI, GNSS, SLR, and DORIS on the same satellite). As was already agreed in 2011 my duty as Acting IVS Chair would finish at the first IVS Directing Board (DB) meeting after the next IVS election (which took place at the end of 2012). Thus at the DB meeting in Metsähovi in March 2013 I completed my time as IVS Chair. Axel Nothnagel (University of Bonn, Germany) got elected as new IVS Chair. I wish him and the whole IVS family a lot of success for the future.

Harald Schuh

Special Reports

Short Report of IVS Working Group 5 (WG5) on Space Science Applications

- An IVS Perspective -

Axel Nothnagel[1], Patrick Charlot[2], Veronique Dehant[3], Agnes Fienga[4], Hayo Hase[5], Lucia Plank[6], Harald Schuh[7]

[1]Institute of Geodesy and Geoinformation, University of Bonn, Germany

[2]Observatoire de Bordeaux, Bordeaux, France

[3]Royal Observatory of Belgium, Brussels, Belgium

[4]Université de Franche-Comté, Institut UTINAM, Besançon, France

[5]Bundesamt für Kartographie und Geodäsie, Germany

[6]Department of Geodesy and Geoinformation, Vienna University of Technology, Austria

[7]Department of Geodesy and Remote Sensing, GFZ German Research Centre for Geosciences, Potsdam, Germany

1. Introduction and Charter of WG5

The IVS Working Group on Space Science Applications (WG5) was established by the IVS Directing Board at its meeting in Bordeaux on 23 March 2009. The mandate of the WG5, its membership, and chairmanship have been reviewed by the IVS Board at its regular meetings.

The current mandate of the WG5 comprises the following tasks (from the charter for WG5):

- *To investigate synergies in scientific and technological areas between the IVS core activities and VLBI experiments in application to planetary and space science missions.*
- *To determine areas of VLBI support of planetary and space science missions where experiments conducted by the IVS (possibly together with other VLBI networks) can be mutually beneficial.*
- *To investigate desirability and feasibility of establishing a mission-specific liaison between IVS and appropriate space agencies and organizations involved in planetary and space science missions.*
- *The WG5 is to be co-chaired by a member of the IVS Directing Board and an external expert. The WG5 is to be composed of up to 16 persons, at least half of which should be affiliated with IVS institutes.*

The mandate of the WG5 was originally approved for the period of one year starting from April 2009. Continuation of the activities of the WG5 beyond March 2010 has been suggested by the IVS Directing Board.

A summary of the studies and discussions within WG5 done so far will be given here.

2. Preamble

Observations of satellites and spacecraft by VLBI radio telescopes in general and the IVS network in particular will be important contributions to several scientific disciplines depending on their general missions and flight paths. The methods of observing these objects are based on either group delay or phase delay measurements, predominantly in differential VLBI (D-VLBI) mode or with the astrometric phase referencing method.

Earth orbiters normally do not require observations by VLBI but these can be used in an ideal fashion to link the dynamical reference frames of the satellites with terrestrial and, most importantly, to the celestial reference frame as defined by the positions of quasars. Spacecraft en-route to the moon and subsequently orbiting the moon and possibly also landing on the moon can be and have been observed by VLBI with great success already (e.g., Goossens et al. 2011). The same applies to various spacecraft and missions to planets and outer space, mainly observed by the NASA Deep Space Network (e.g., Border 2009).

This summary describes the perspectives of future missions, possible implications, and the potential involvement of the IVS. The activities of the IVS in this field are not limited to providing the observations and initial data processing but also contain scientific data analysis and interpretation.

3. Missions

3.1 Artificial Earth Orbiters

A variety of spacecraft is in orbit around the Earth for a multitude of applications. All of them communicate on radio frequency links and may be observable with radio telescopes, thus, also being candidates for VLBI observations. Satellites with dedicated transmitters or even quasar-like beacons are another class of targets to be considered, e.g. GRASP (Nerem et al. 2011) or MicroGEM (Wickert et al. 2008, Brieß et al. 2009).

Observing these satellites with VLBI will provide invaluable information for geodetic and astrometric applications. The geodetic challenges of artificial Earth orbiters are closely related to the establishment and maintenance of reference systems. While in geodetic practice, station coordinates are usually provided in the kinematic International Terrestrial Reference Frame (ITRF) and radio source coordinates in the International Celestial Reference Frame (ICRF), positioning of space probes or the determination of planetary ephemerides rests upon dynamical theories. The link between these systems can only be established and maintained with VLBI observations of the spacecraft and preferably relative to radio sources of the ICRF.

As most of the modern geodetic techniques make use of sensors and targets in extra-terrestrial space, the main challenges for applications on Earth today are to interlink the underlying reference frames to guarantee accuracies at the mm-level with a stability of better than 0.1 mm/y. For example, orbits of GNSS (Global Navigation Satellite Systems) satellites are linked to a certain ITRF realization of observing stations on the Earth’s surface. To avoid inconsistencies and errors during measurement and calculation procedures, exact frame ties between quasi-inertial, kinematic, and dynamic reference frames have to be secured. By observing space probes alternately to radio sources with the differential Very Long Baseline Interferometry (D-VLBI) method, the relative positions of the targets to each other on the sky can be determined. As the directions to the radio sources are well known in the ICRF, it is possible with such observational configurations to link the bodies within our solar system with the ICRF. While the Earth orientation parameters (EOP), which are regularly provided by the International Earth

Rotation and Reference Systems Service (IERS), practically link the ICRF to the ITRF, the ties with the dynamic frames will be established by D-VLBI observations.

Dynamic reference frames are typically realized for each individual satellite or satellite constellation by numerical orbit integration. When it comes to the combination of various missions or follow-on satellites (e.g., the various altimetry missions), precise ties between the various frames are essential for correct and reliable results over long time periods, needed, for instance, for monitoring global change and climate variation. A typical example for such a need of consistency is the derivation of sea level heights from the altimetry missions Topex/Poseidon, Jason-1, and Jason-2, which contain a bias for each satellite that has to be removed before trends of global sea level can be determined. Today, altimeter satellites are tracked by Satellite Laser Ranging (SLR) ground stations and D-VLBI observations can provide complementary information.

3.1.1 Low Height Earth Orbiters

From a VLBI observational point of view, near-Earth orbiters are rather challenging since mutual visibility depends on the altitude of the satellite and the separation of the radio telescopes. Furthermore the satellites travel through the field of view very fast requiring radio telescopes with sufficient speed, which will, however, be guaranteed by usage of radio telescopes of the VLBI2010 class. For these satellites, continental-size VLBI observing networks are essential.

3.1.2 Medium Height Earth Orbiters

Global Navigation Satellite Systems (GNSS) are the overall representatives of medium height Earth orbiters. They have been observed with VLBI successfully in recent years (Tornatore and Haas 2009, Tornatore et al. 2011) and will permit a direct link between the terrestrial, the dynamical, and the celestial reference frames. The common field of view of two or more radio telescopes is extended for medium height Earth orbiters.

3.1.3 Geostationary Orbiters

Normally, geostationary orbiters do not have noteworthy importance in geodetic applications. However, in terms of reference frames, these satellites also deserve a closer look and some efforts to evaluate their importance in reference frame studies and time transfer applications. Observations and analysis of geostationary orbiters are hampered by frequent maneuvers to keep the orbiter in its preset box in the sky. Thus, the orbits themselves cannot be considered as being smooth over time.

3.2 Missions to the Moon

VLBI observations of orbiters of the moon have contributed important information for the determination of orbits and trajectories of spacecraft in the vicinity of the moon. In the future, VLBI will also help to position landers on the moon. As for Earth orbiters, these observations will be used to map the Moon into the known hierarchy of the established reference systems. All the lunar missions mentioned below may have valuable VLBI observation components.

SMART-1 was ESA's first mission to the moon. The purpose of tracking this satellite with VLBI methods was a demonstration of its capabilities in space applications during critical events, like the precise timing and location determination of the impact on September 3, 2006 (JIVE , 2008).

KAGUYA/SELENE. A significant milestone in lunar geodesy has been reached with the successful implementation of the Japanese SELENE (SELenological and ENgineering Explorer) mission, launched on September 14, 2007. SELENE consists of three satellites: a main satellite (MS), a relay satellite (RS), and a VLBI sub-satellite (VS), all three inserted in a coplanar orbit with an inclination near 90°. The MS had an initial 100-km-altitude circular orbit controlled by attitude maneuvers, while the RS and VS are free flyers on highly eccentric orbits with 100/880 km and 100/2400 km perigee and apogee, respectively. Besides other observing methods, same-beam differential VLBI tracking (projected accuracy 1 mm integrated over 100 sec) between RS and VS was used to precisely determine the RS orbit, which serves as the reference for the four-way Doppler measurements.

The overall goal of Kaguya/Selene is to derive an improved version of the lunar gravity field. After successfully orbiting the moon for 1 year and 8 months, the main orbiter was intentionally crashed onto the lunar surface on June 10, 2009. Data analysis is still continuing to this day (e.g., Ando et al. 2012).

For the future, a so-called inverse VLBI experiment is proposed (where artificial radio sources are located either in two landers or in one lander and the orbiter) for the lunar landing mission SELENE-2 (Kikuchi et al., 2010).

Lunar Reconnaissance Orbiter Mission. NASA's Lunar Reconnaissance Orbiter (LRO) was launched on June 18, 2009, and began its nominal mission on September 15. The spacecraft is orbiting the moon in a circular polar orbit at a mean altitude of 50 km through its one-year "primary mission", followed by a multi-year "science mission" in a modified elliptic orbit. Accurate lunar 3D-orbits of such orbiters are a prerequisite for the processing of imaging or altimetry data. Although techniques exist to improve lunar orbits from camera data and altimetry crossovers, in general the quality of the orbits plays a significant role in the realization of the lunar reference frame (http://lro.gsfc.nasa.gov/).

GRAIL. The US-mission GRAIL (Gravity Recovery and Interior Laboratory), launched on September 10, 2011, realizes the concept of inter-satellite, high-precision ranging in a planetary orbit for the first time. GRAIL's science objectives include the mapping of the gravity field for studies of lunar interior, thermal evolution, and tidal dynamics (Zuber et al., 2008). GRAIL consists of two spacecraft in lunar orbit, tracked by S-band from Earth and connected by Ka-band ranging derived from the GRACE concept.

LEO, Lunar version of GRACE. In 2007, DLR (German Aerospace Center) suggested to establish the German lunar-orbiting mission LEO (Lunar Explorations Orbiter, Jaumann et al., 2007) for comprehensive studies of the Moon, including for mapping of lunar magnetic and gravity fields. Flechtner et al. (2007, 2008) proposed to include a GRACE-type experiment with LEO, consisting of two sub-satellites to be released from LEO in lunar orbit and to be tracked from Earth by the two-way, two-frequency (X/S-band) precise range and range-rate (PRARE-L) system. Moreover, Ka-band ranging was chosen to realize a high-precision (projected accuracy 2.5 μm/s) link between the sub-satellites. Aside from the lunar gravity field, the science objectives of this experiment included geophysical parameters like crustal density, Love numbers and contributions to the reference system. The LEO mission has not been realized yet.

Remark: The US-German twin-satellite mission GRACE (Gravity Recovery and Climate Experiment) may be used as a predecessor for lunar and planetary missions applying similar concepts. GRACE (Tapley and Reigber, 2001) has two identical spacecraft using an intersatellite K-band ranging link with µm-accuracy. It was primarily designed to map the static and time-variable gravity field and has provided excellent results allowing the determination of mass transport within system Earth. The GRACE Follow-on satellites have been approved and according to present schedule will be launched in 2017.

3.3 Missions to Planets, Comets, and Other Bodies

Since the 1980s the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and recently also the Japan Aerospace Exploration Agency (JAXA) have performed D-VLBI observations during their (deep) space missions, generating data that can also be used to establish precise frame ties to major celestial frames (e.g. Hildebrand et al., 1994). Another potential network to carry out D-VLBI and suitable for spacecraft navigation is the Very Long Baseline Array (VLBA); see Lanyi et al. (2005). An interesting development is the plan of the Deep Space Network to move to the 32 GHz band for spacecraft tracking (which provides higher telemetry rates) while the astrometric community is also considering to adopt higher observing frequencies (up to 43 GHz) yielding better accuracies due to reduced source structure effects (Lanyi et al. 2010, Charlot et al. 2010, García-Miró et al. 2012). Some efforts in the development and application of phase-connection techniques are also of interest (Marti-Vidal et al., 2008).

The term D-VLBI comprises the determination of a relative position using differential observations in order to minimize common error sources like atmospheric propagation delays, antenna-specific delays, and station position inaccuracies. The configuration of the character of the spacecraft tone, the observed frequency, the antenna size, the observation network, and the achieved accuracy vary between different realizations of D-VLBI, as described by Lanyi et al. (2007). A very well developed technique performed routinely by NASA and ESA is the so-called Delta Differential One-way Ranging (ΔDOR) employing antennas of the Deep Space Network (DSN). Mainly used to support precise spacecraft navigation at the level of some nrad (e.g., Martin-Mur et al., 2006), Mars spacecraft VLBI measurements (Mars Global Surveyor, Mars Odyssey, Mars Reconnaissance Orbiter) tie the planetary ephemerides to the ICRF with an accuracy better than 1 mas (= 5 nrad) (Folkner, 2008). The reliance on special DOR-tones transmitted by the spacecraft, the need of big antennas with special receiving units, and an accuracy regulated by the group delay measurement disqualifies ΔDOR for many observations other than to deep space probes. Recent successful D-VLBI observations using the phase referencing technique of, for instance, ESA's Huygens probe landing on Titan (van 't Klooster, 2005) or within JAXA's lunar gravity mission SELENE (Liu et al., 2010) managed to overcome those restrictions. This opened up a wide range of new applications and initiated further research in D-VLBI. With the Planetary Radio Interferometry and Doppler Experiment (PRIDE), an initiative by the Joint Institute for VLBI in Europe (JIVE), Duev et al. (2012) present the VLBI spacecraft technique which has been successfully tested observing ESA's Venus Express Spacecraft. Working with almost any phase-stable radio signal from a spacecraft, observed in phase referencing mode, the PRIDE approach is applicable to virtually any deep space mission, as well as to planetary science missions and near-Earth targets (Duev et al., 2012).

VLBI tracking of Cassini, VenusExpress or MarsExpress have been already successfully used for the orbit reconstruction of the spacecraft during their flyby or orbital phases. As demonstrated by Folkner et al. (1994), the relative positions of the spacecraft observed in the projected vicinity of an extragalactic radio source with its position defined in the ICRF provide strong angular constraints for the spacecraft orbit but also for the planetary ephemerides. VLBI S/C observations are used in the adjustment of the planetary ephemerides. Even if very few VLBI data are used so far (about 0.25% of the total amount), they are the only accurate link between the orbits of the planets and the ICRF. Because of this, they are absolutely crucial for the construction of planetary ephemerides in the ICRF as required by the International Astronomical Union.

3.4 Spacecraft in Transit to Outer Space

Flybys of planets by spacecraft in transit to outer space are also a good source of information. Owing to the vicinity of the probe and its accurate tracking during this crucial phase of the mission, together with VLBI tracking, it is possible to deduce very accurate positions of the planet as the probe passes by. For gas planets, this type of observations puts a major constraint on their orbits (flybys of Jupiter and Saturn, mainly). Even if they are not numerous (less than 0.5% of the data sample), they impose 50% of the constraints brought to the Jupiter and Saturn orbits. As an example, the New Horizons mission flew by Jupiter at a distance closer than that achieved by Cassini from which the positions of Jupiter have been deduced in late 2000 by JPL. The analysis of the New Horizons radio science data during its flyby of Jupiter with an accuracy below 10 meters in geocentric distances and 5 mas in right ascension and declination give new very accurate constraints for the Jupiter orbit.

Precise ephemerides of the planets have been computed at various different institutions (Development Ephemeris (DE), JPL, see Folkner et al. 2008, Ephemerides of Planets and the Moon (EPM), IAA, see Pitjeva 2005, Integration Numerique Planetaire de l'Observatoire de Paris (INPOP), see Fienga et al. 2008) and are updated in current projects using tracking or navigation data from orbiting spacecraft or from flybys. These observations are also essential tools for monitoring the gravitational and non-gravitational forces affecting the spacecraft trajectory. These data enable the determination of planetary gravity fields with their time variations and the interpretation of the results in terms of geophysics and dynamics of solar system objects.

4. Involvement of the IVS in Space Missions

The operation of the IVS observing network and the distribution of the correlator load are controlled by the IVS Observing Program Committee (OPC). The OPC decides on observing proposals on the basis of scientific and operational merit according to the general rules of the IVS as set forth in the IVS Terms of Reference. Furthermore, the OPC discusses with the observatories and correlators involved whether observations can be carried out for the specific purpose of the proposal.

It is expected that proposals for future VLBI observing campaigns related to space science applications which require the involvement of one or more of the IVS components will be handled in the same objective resource-responsible manner. The benefits of scientific or possibly also economic developments which may help to maintain the IVS's infrastructure will remain the driving force behind any decision.

5. Concluding Remarks

The application of the VLBI technique for observing spacecraft is a valuable contribution to support space science applications as has been demonstrated by completed and ongoing projects. In the future, forthcoming missions will also draw from the strengths of the VLBI technique in general and from the expertise of VLBI scientists in particular. Geodetic and astrometric VLBI bears good chances for further developments in the area of space sciences and will provide ample opportunities for synergies. On the other hand, VLBI itself will benefit from space science applications due to external demand for technical progress and due to increased visibility in the science community.

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VLBI Digital-Backend Intercomparison Test Report

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Abstract

Issues related to digital-backend (DBE) systems can be difficult to evaluate in either local tests or actual VLBI experiments. The 2nd DBE intercomparison workshop at Haystack Observatory on 25-26 October 2012 provided a forum to explicitly address validation and interoperability issues among independent global developers of DBE equipment. This special report discusses the workshop. It identifies DBE systems that were tested at the workshop, describes the test objectives and procedures, and reports and discusses the results of the testing.

1. Introduction

As VLBI expands the scope of digital signal-processing in VLBI systems, it is important that each sub-system be validated for proper function and interoperability. While every VLBI developer strives to ensure that these criteria are met, it is often only by comparison that problems can be uncovered. One area of particular interest is digital-backend (DBE) systems, where some issues are difficult to evaluate in either local tests or actual VLBI experiments. The 2nd DBE intercomparison workshop at Haystack Observatory on 25-26 October 2012 provided a forum to explicitly address validation and interoperability issues among independent global developers of DBE equipment, and it built on the work of the first such workshop held at Haystack Observatory in May 2009. The 2012 workshop took advantage of the completion of a new Instrumentation Lab at Haystack Observatory that provided the space and signal connections needed to efficiently support the comparison exercise.

2. The DBE Systems

Five systems were assembled at Haystack for testing[1]:

1. The European 'DBBC' system, configured as a polyphase filter bank (PFB) converter[2], hereafter referred to as 'DBBC-PFB'.
2. The Chinese VLBI Data Acquisition System (CDAS) configured as 16 tunable DDCs, hereafter referred to as 'CDAS-DDC'.
3. The CDAS with polyphase filter-bank signal processing, hereafter referred to as 'CDAS-PFB'. The CDAS-PFB is a separate hardware unit from the CDAS-DDC.
4. The Japanese 'ADS3000+' system configured with 16 tunable DDC processors.

[1]The DBBC was accompanied by Gino Tuccari of INAF/IRA and Michael Wunderlich of MPIfR. The CDAS units were designed by Drs. Hong Xiaoyu, Zhang Xiuzhong, Wei Wenrun, Xiang Ying, Li Bin, Shu Fengchun, Zhu Renjie, Zhao Rongbing, Ling Quanbao, Wu Yajun, Wang Jinqing, Xue Zhuhe, Luo Jintao (all SHAO), and Chen Lan (now at Shanghai Institute of Technology). The ADS3000+ was accompanied by Hiroshi Takeuchi of JAXA and Kazuhiro Takefuji of National Institute of Information and Communications Technology. The RDBE-H was overseen by Haystack staff Chester Ruszczyk, Russ McWhirter, and Arthur Niell.

[2]The DBBC system can also be configured in a DDC configuration, which was successfully tested at the 2009 DBE intercomparison workshop but was not tested at this workshop.

5. The Haystack 'RDBE-H' PFB system, with hardware designed by UCBerkeley and NRAO-Socorro, and with firmware from Haystack and NRAO. The RDBE was configured with FPGA code version 1.4.

A detailed comparison of the systems under test, based on information gathered by Bill Petrachenko, is found in Table 1.

3. Test Objectives

The test objective was to ensure, as much as possible, that all DBE units were operating properly, including both functional and interoperability criteria. This was done by providing all units with a common frequency reference, 1pps timing signal, and broadband noise source spanning approximately 100 MHz to 2 GHz. For some testing, embedded test tones at IF frequencies 575 MHz and 961 MHz were added to the broadband noise source. The testing was divided into three specific phases:

1. Verification of compatibility with laboratory interfaces, command and control functionality, and digital-output format compatibility.
2. Single baseline cross-correlation test of each unit paired with RDBE-H unit; all station auto-correlations.
3. Simultaneous four-station zero-baseline cross-correlation of all six possible station pairs; all station auto-correlations.

4. Test Procedures

4.1. DBE Unit Setup First Day (Day 299)

Initial setup included basic testing of the compatibility of lab interfaces with equipment under test, including test recordings and verifications of recorded format, etc. Nearly the full first day of testing was devoted to this type of activity, but it resulted in the successful interfacing of all the units and successful basic operation of all units.

Prior to any testing, the units under test were set up as follows:

1. All units were supplied with a common 5 or 10 MHz reference frequency, as required.
2. All units were synchronized to a common TTL 1pps timing reference.
3. All units were set to identical UT times, as required.
4. IF levels were set appropriately by adjusting the amplification or attenuation to each unit under test.
5. Temporary test tones at 575 MHz and 961 MHz were injected into the IF as test markers (which were subsequently turned off after it was determined that the marker frequencies were appearing in the expected output channels via auto-correlation processing).
6. The CDAS-PFB and CDAS-DDC units were each connected to a Mark 5B+ with a VSI-H interface operating at a 64 MHz clock rate.

7. The RDBE-H produced 10GigE data in Mark 5B data format and was connected to a Mark 5C.
8. The DBBC produced Mark 5B data format over either a VSI-H interface to a Mark 5B+ recorder or a 10GigE interface (via Fila10G card) to a Mark 5C.
9. The ADS3000+ was connected to a K5 recorder and recorded in K5 format. The data were software-converted to Mark 5B format prior to correlation.

Each DBE unit under test included at its input a 512-to-1024 MHz anti-aliasing filter to place the recorded signal in the second Nyquist zone of the DBEs. The sampling clock for all units was 1024 MHz.

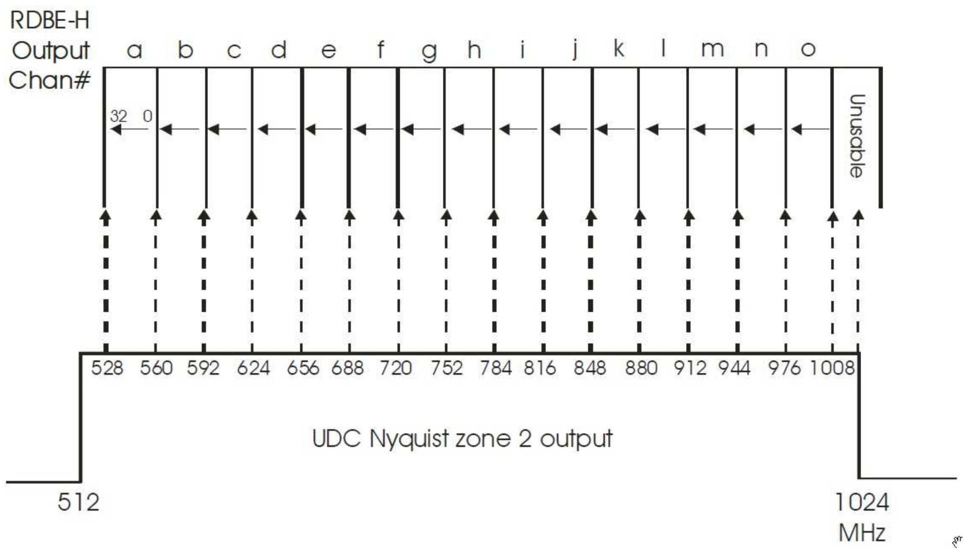

Figure 1. Relationship between input IF and digital output channels for PFB units.

4.2. Pairwise Zero-baseline Cross-correlation Tests - First Day

Following successful setup, auto-correlation and single-baseline cross-correlation tests were conducted with each unit using the RDBE-H as a reference unit. (The DBBC was tested separately with both VSI-H and Fila10G output formats.) The DBEs using a polyphase filter bank, namely RDBE, DBBC and CDAS-PFB, were configured to produce 15 useful 32 MHz baseband channels, each of which was lower sideband (LSB) with respect to the input IF (i.e. sky frequency increases in opposite direction to the IF). The frequencies that appear at DC for the 15 good channels were 1008,..., 528 MHz in steps of 32 MHz (see Figure 1). The PFB algorithm causes the 0th channel to be unusable, as indicated in Figure 1. The DBEs with flexible LOs, namely CDAS-DDC and ADS3000+ were set up with compatible channels.

For each pairwise test, ∼30 seconds of data were recorded, followed by e-transfer to standard Linux files, followed by auto-correlation and cross-correlation processing on the Haystack DiFX correlator. For each station pair, auto-correlation spectra were created for each station, as well as the zero-baseline cross-correlation results.

4.3. Four-station Zero-baseline Cross-correlation Tests - Second Day (Day 300)

A four-station zero-baseline cross-correlation test captured simultaneous data using the common broadband IF noise source to all systems under test. The setup is shown in Figure 2, where the broadband noise input is labeled 'IF' and Nyquist zone 2 filters are assumed to be internal to the individual DBE units.

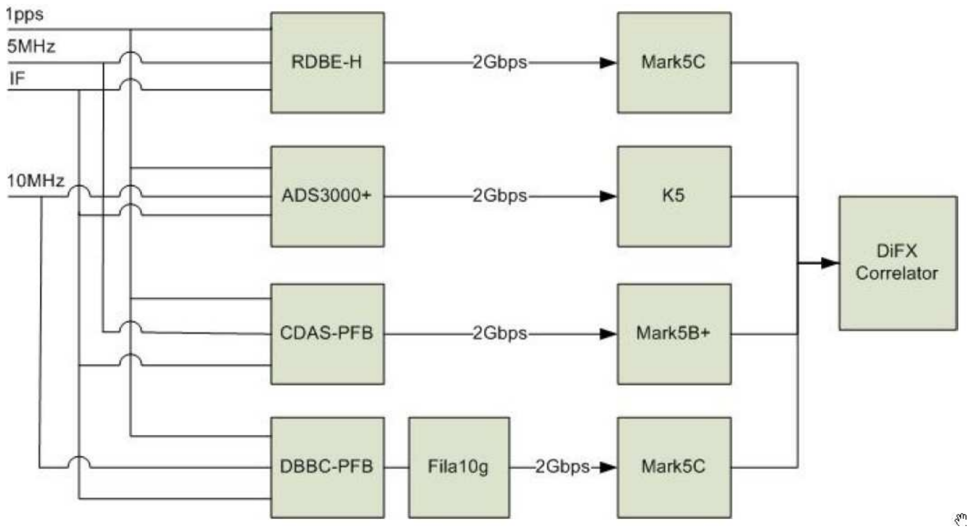

Figure 2. Setup for the zero-baseline inter-comparison test.

As before, 30 seconds of data were recorded from all four units simultaneously (with the DBBC unit operating in DDC mode with 10GigE output). No test tones were injected into the IF. The data were again e-transferred to standard Linux files, and the six cross-correlation pairs were processed on the DiFX correlator.

5. Results and Discussion

5.1. Auto-correlation Results (Figures 3 through 7)

All auto-correlation scans shown were with all test tones turned off.

Auto-correlation results shown for RDBE-H, ADS3000+ and DBBC are from Day 300 (scan 300-1657). Auto-correlation results for CDAS-DDC and CDAS-PFB are from Day 299[3]

The only significant difference between the auto-correlation results of the four units under test are the amplitude and spacing of ripples in the auto-correlation spectra, as well as the sharpness of the cutoffs at the top and bottom of the bands. These differences should not present any

[3]The CDAS-DDC was not active on Day 300. Auto-correlation results for RDBE-H, ADS3000+, and DBBC-PFB units are from the four-station scan 300-1657; auto-correlation results for CDAS-PFB for scan 300-1657 (not shown) contain a number of anomalous 'birdies' (though these 'birdies', as expected, do not propagate to the associated zero-baseline cross-correlation spectra). The cause of the 'birdies' is not known, but they were not present in the CDAS-PFB Day 299 data and may not be intrinsic to the CDAS-PFB. Hence we have elected to show the Day 299 auto-correlation for the CDAS-PFB unit. Further testing will be required to investigate the cause of these 'birdies' in the CDAS-PFB spectra for scan 300-1657.

problems for geodetic-VLBI operation or analysis, and can, in any case, be calibrated and removed if necessary.

The only problems in the set of auto-correlation of Figures 3 through 7 are in the CDAS-DDC spectra (Figure 7) that show a 'birdie' at mid-point in the auto-correlation spectra and a drop in amplitude of channel h (which covers IF frequency range 752-784; see Figure 1); separate processing of each 32 MHz output channel shows the 'birdie' to be only in channel h, which causes the apparent spectra amplitude to drop. We speculate that this problem may be due to a rounding bias in an interpolation step in the processing of that channel, but further testing is necessary to fully understand this problem.

5.2. Cross-correlation Results (Figures 8 through 14)

All zero-baseline cross-correlation results look quite nominal except for the Day 299 single-baseline result from the RDBE to CDAS-DDC (Figure 8), for which both correlation amplitudes and phases differ widely from channel to channel. Further investigation of this result has been inconclusive; post-correlation processing of single channels shows similarly low cross-correlation amplitudes as well as channel-to-channel delay differences spanning a range of almost 30 nsec, whereas equivalent delay differences among all other units (Figures 10-14) are all under $\sim$2 nsec. It is possible that the RDBE unit was malfunctioning on the day of the test, but we have no way to test this with only the single baseline of available data, and the RDBE unit behaved well on the second day of testing. At this point, we can only suggest that perhaps some sort of sampler jitter or digital-oscillator phase jitter in the CDAS-DDC may be responsible for the low correlation amplitudes, and varying internal signal path lengths may be responsible for the observed channel-to-channel delays; further testing is necessary. On the other hand, the CDAS-PFB unit, cross-correlated against DBBC-DDC, ADS3000+, and RDBE-H (as shown in Figures 10, 12 and 14, respectively) on Day 300 performed well despite observed 'birdies' in the CDAS-PFB data in scan3.

6. Summary

After several weeks of preparation and two long days of testing, including correcting various misunderstandings, fixing some hardware, and overcoming some internal networking problems, the testing was quite successful. Only one unit was found to have apparent significant problems, and another to have possible, more minor issues, and we hope that the results of this testing will help to understand and fix these problems, allowing more confidence of proper results as these DBEs move into routine VLBI observations.

This report is also available on-line at:

http://www.haystack.mit.edu/workshop/ivtw/2012.12.17_DBE_testing_memo_final.pdf

Acknowledgements

We thank everyone who participated. We hope that this exercise was useful for all of the participants, and we at Haystack were happy to be able to help support this effort.

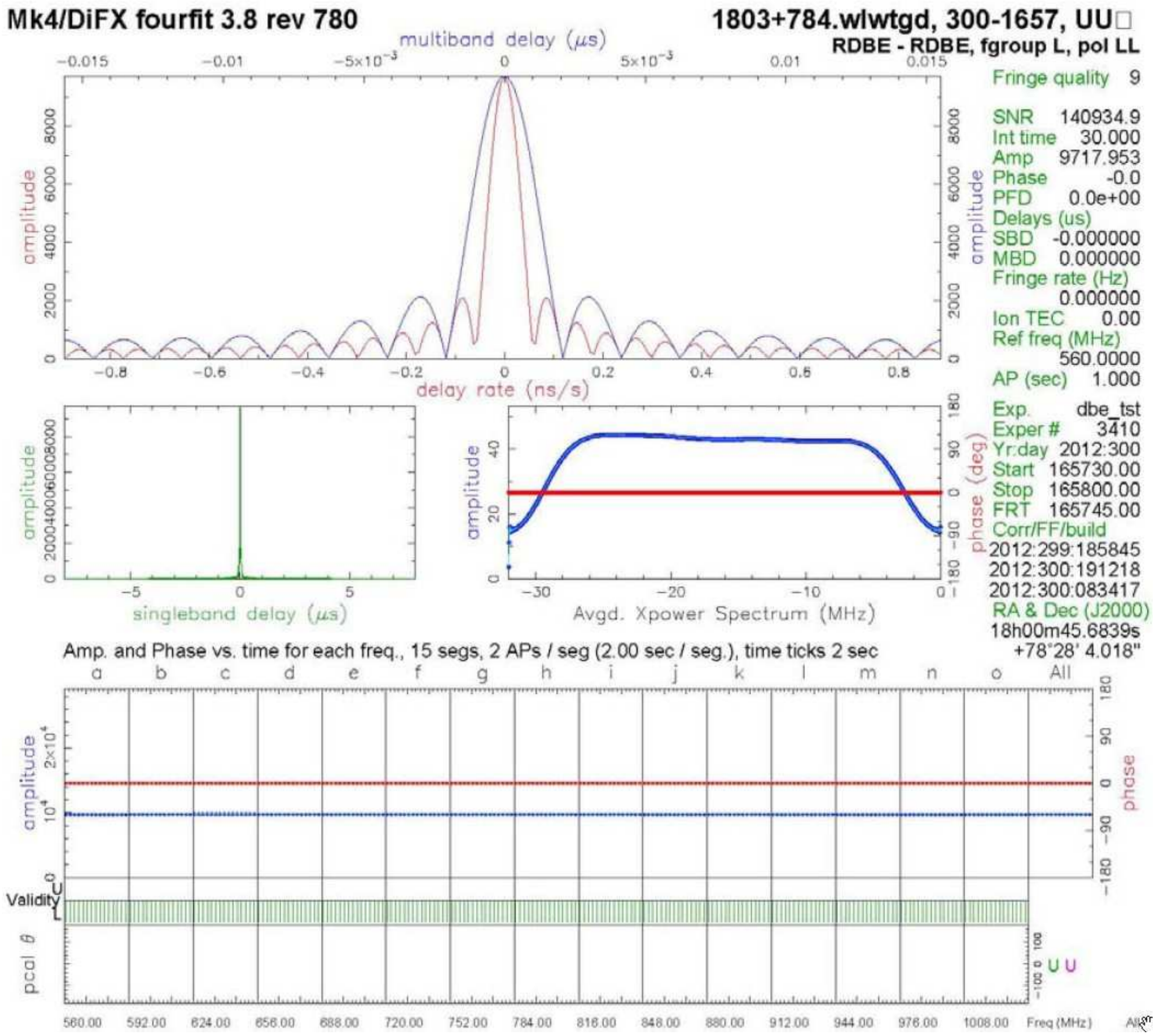

Figure 3. Auto-correlation results for RDBE-H version 1.4 (PFB algorithm).

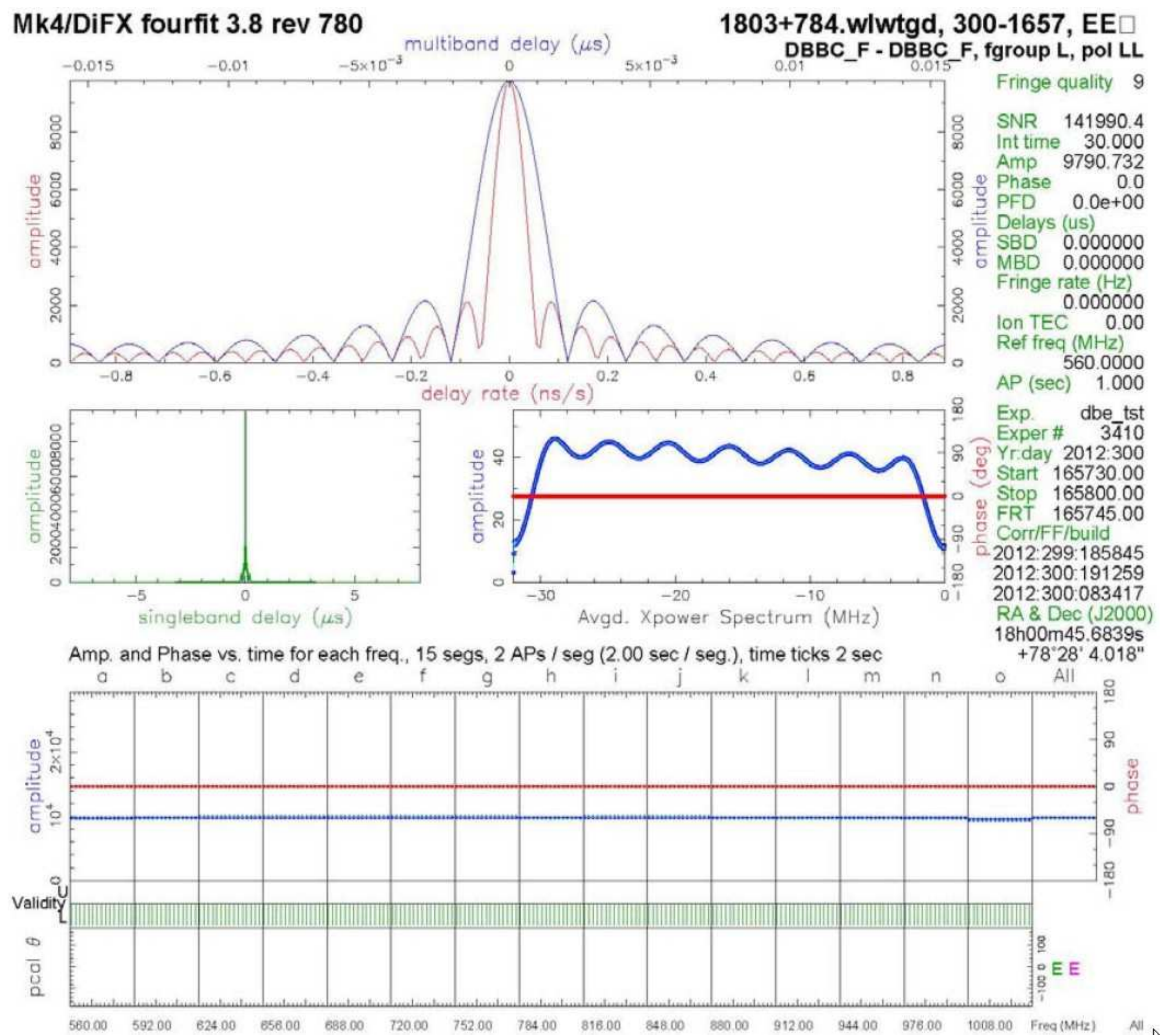

Figure 4. Auto-correlation results for DBBC-PFB w/Fila10G.

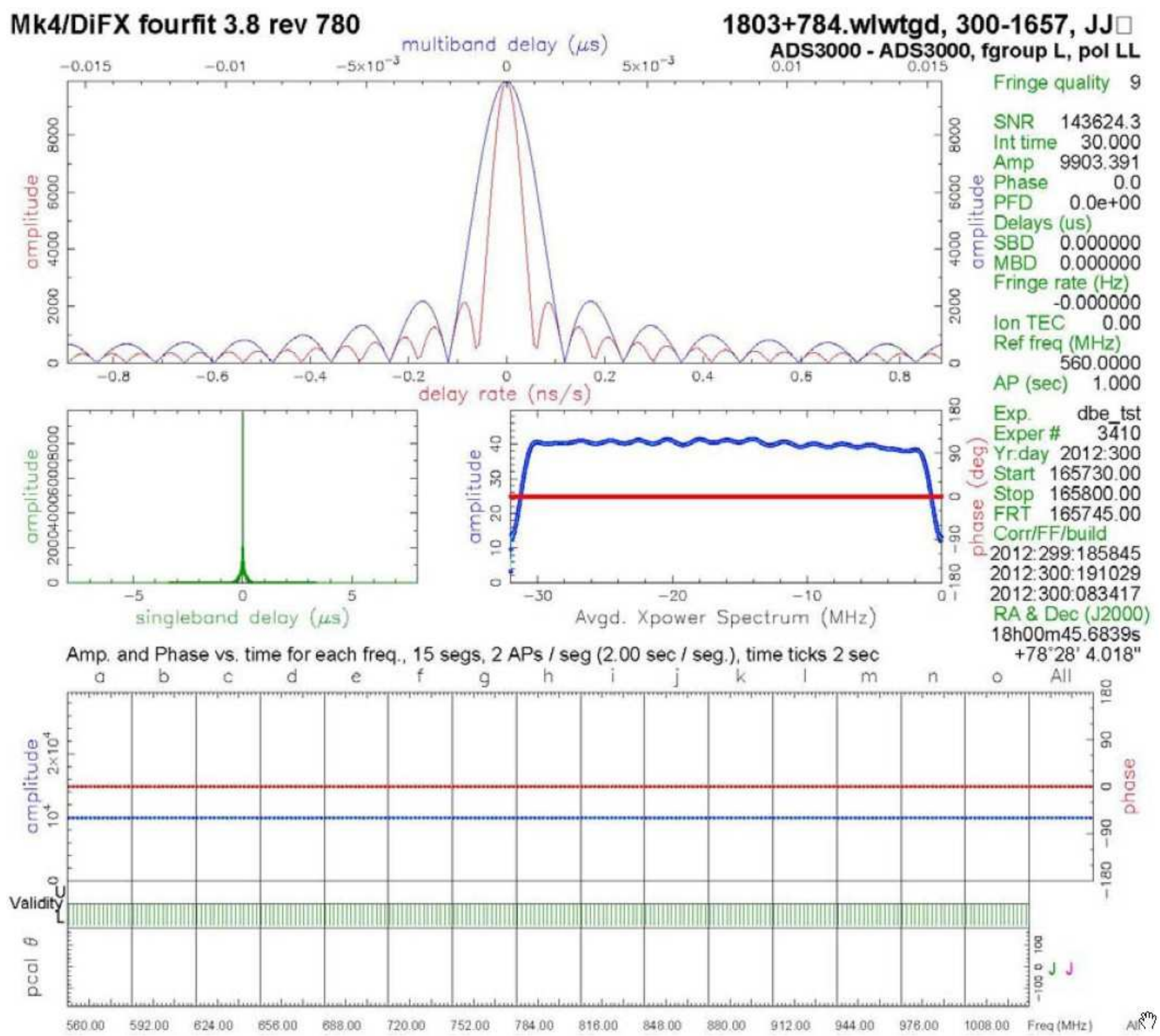

Figure 5. Auto-correlation results for ADS3000+ (DDC algorithm).

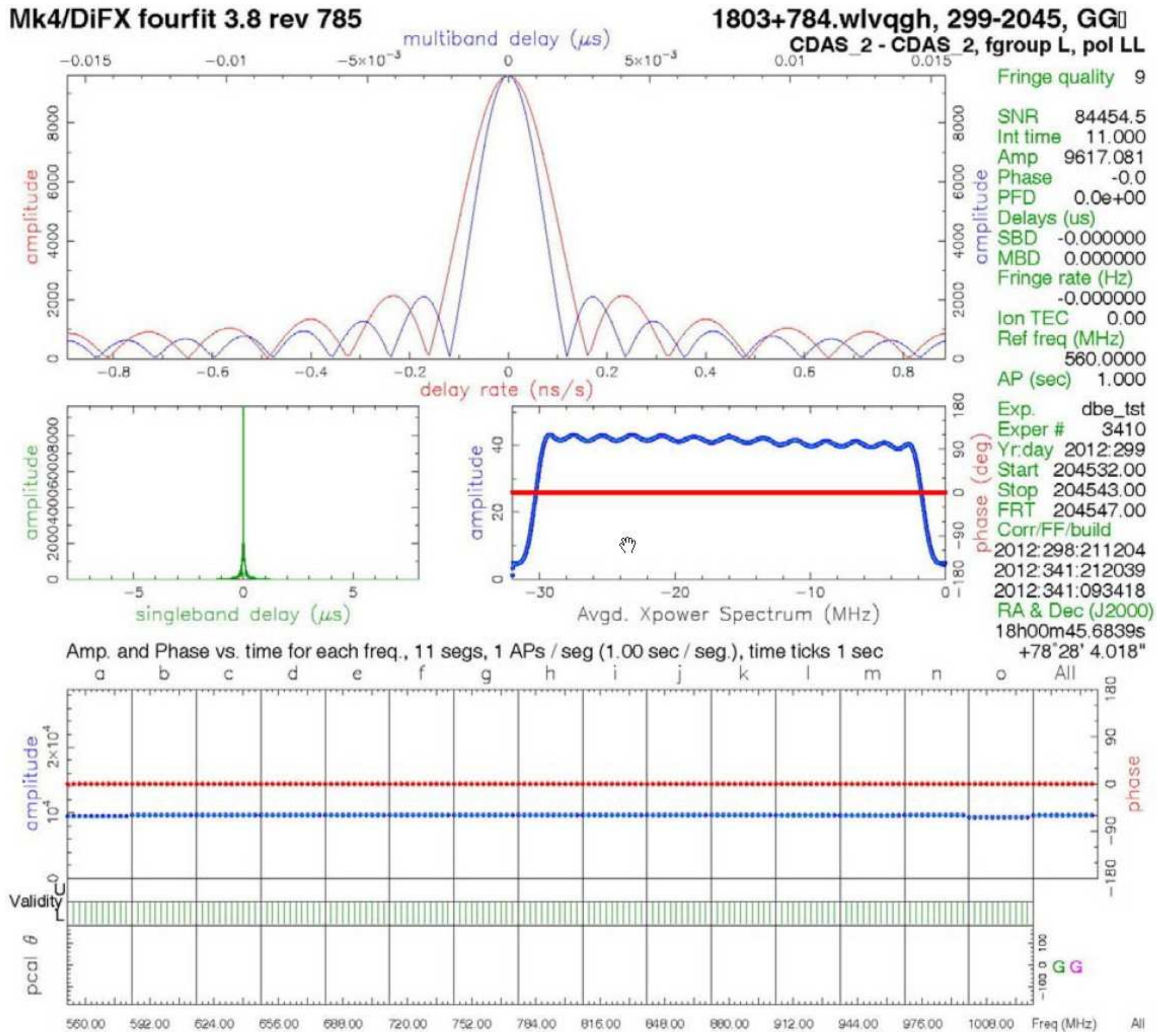

Figure 6. Auto-correlation results for CDAS-PFB.

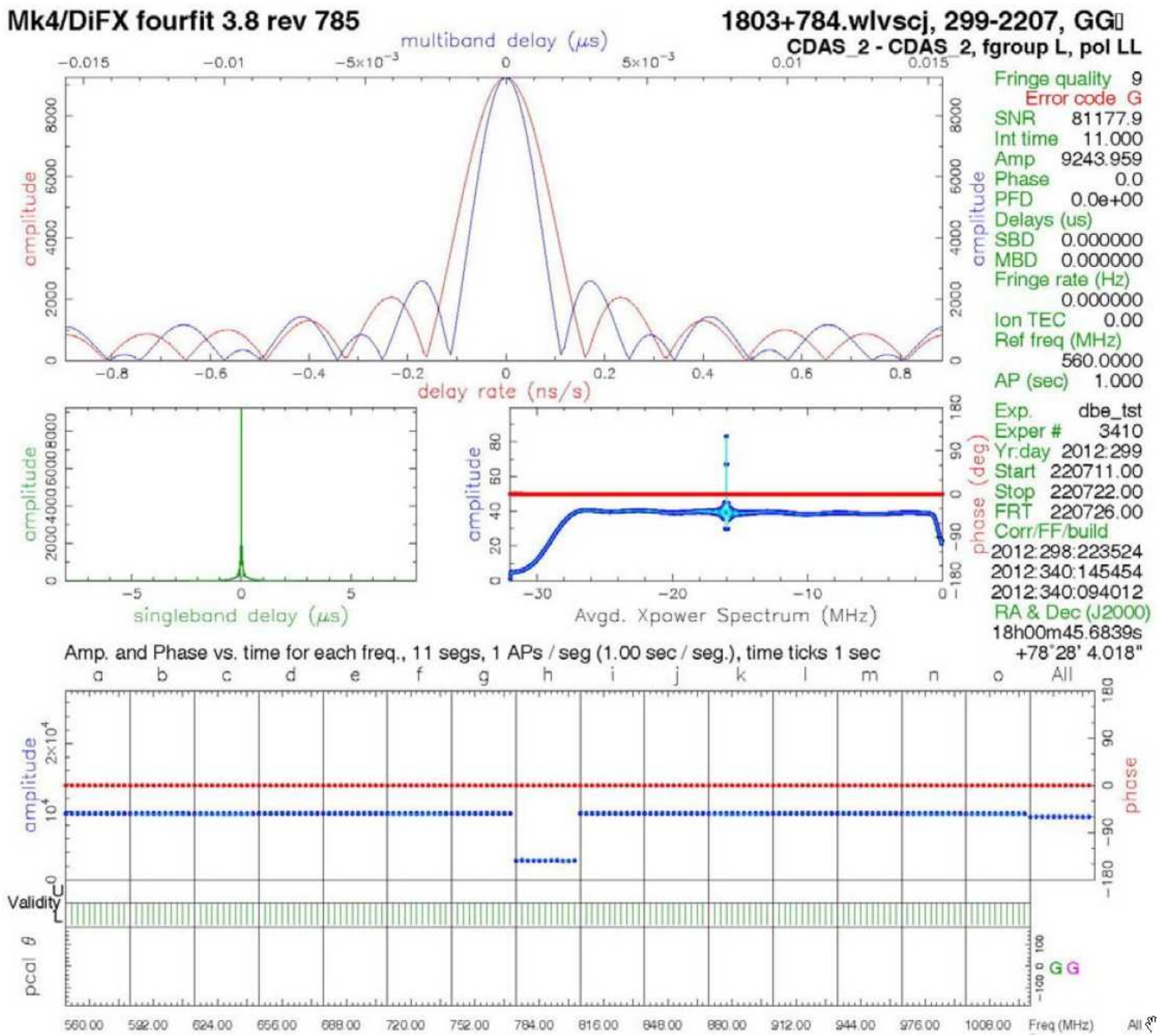

Figure 7. Auto-correlation results for CDAS-DDC.

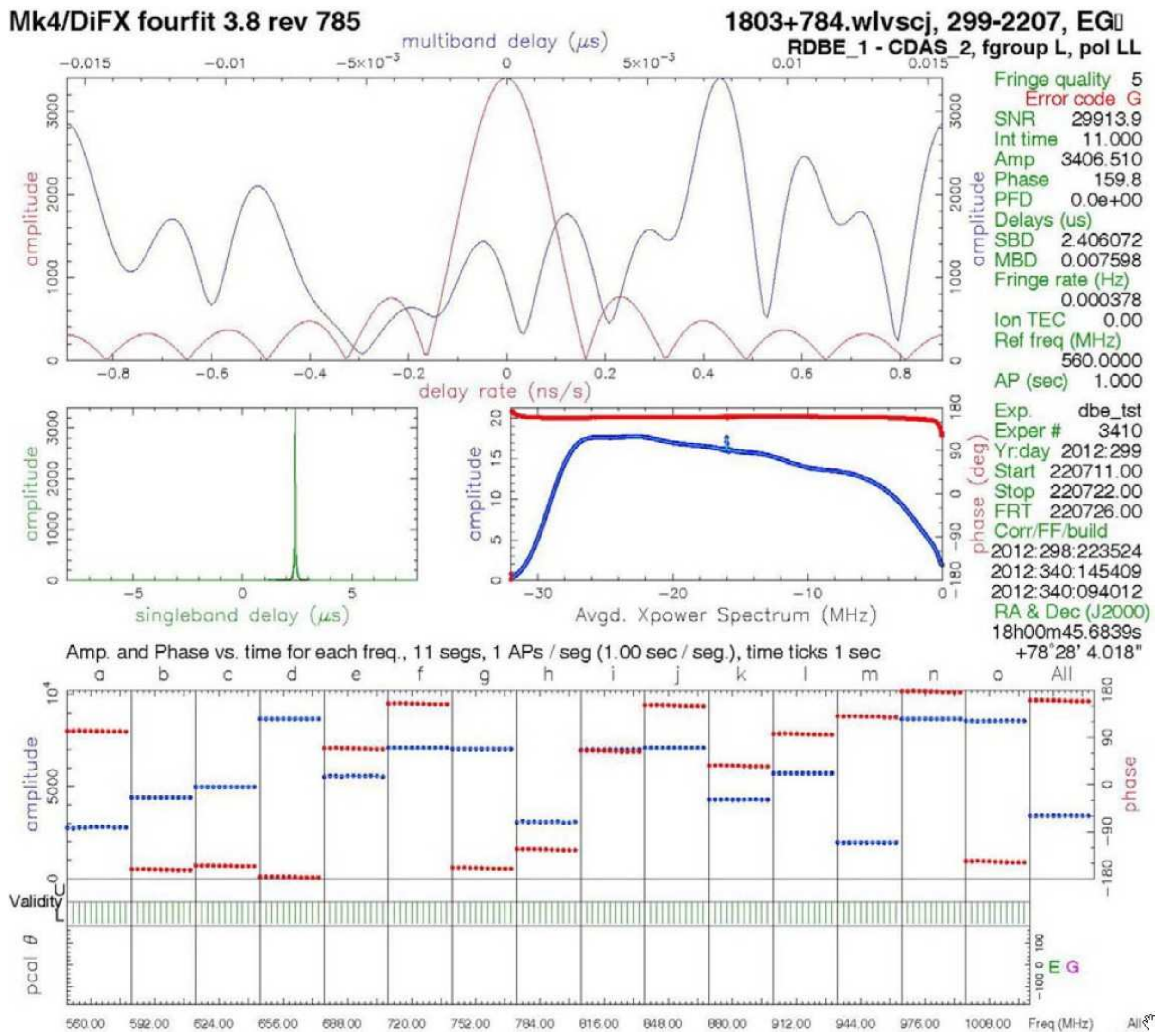

Figure 8. Zero-baseline cross-correlation results between RDBE-H and CDAS-DDC.

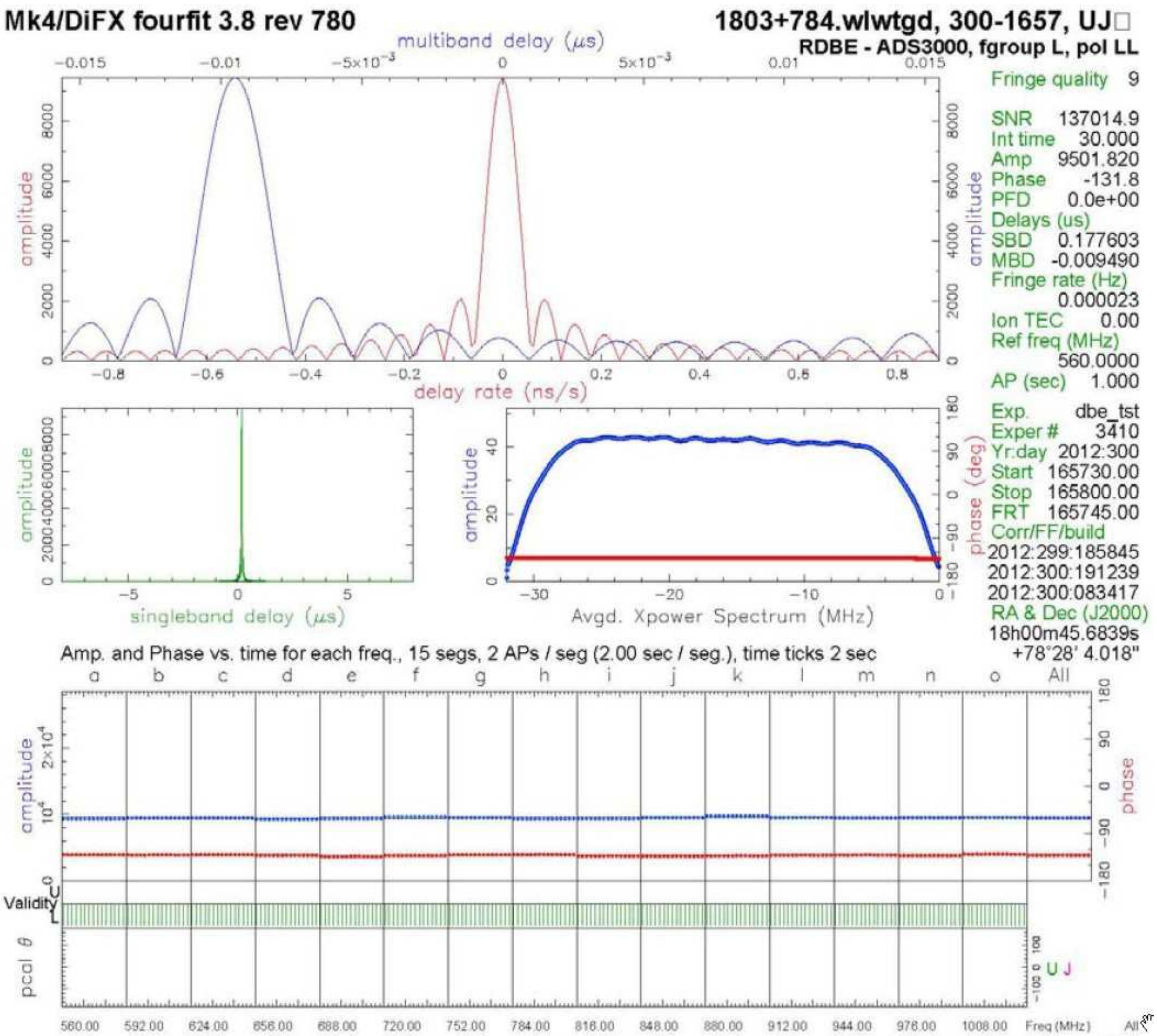

Figure 9. Zero-baseline cross-correlation results between RDBE-H and ADS3000+

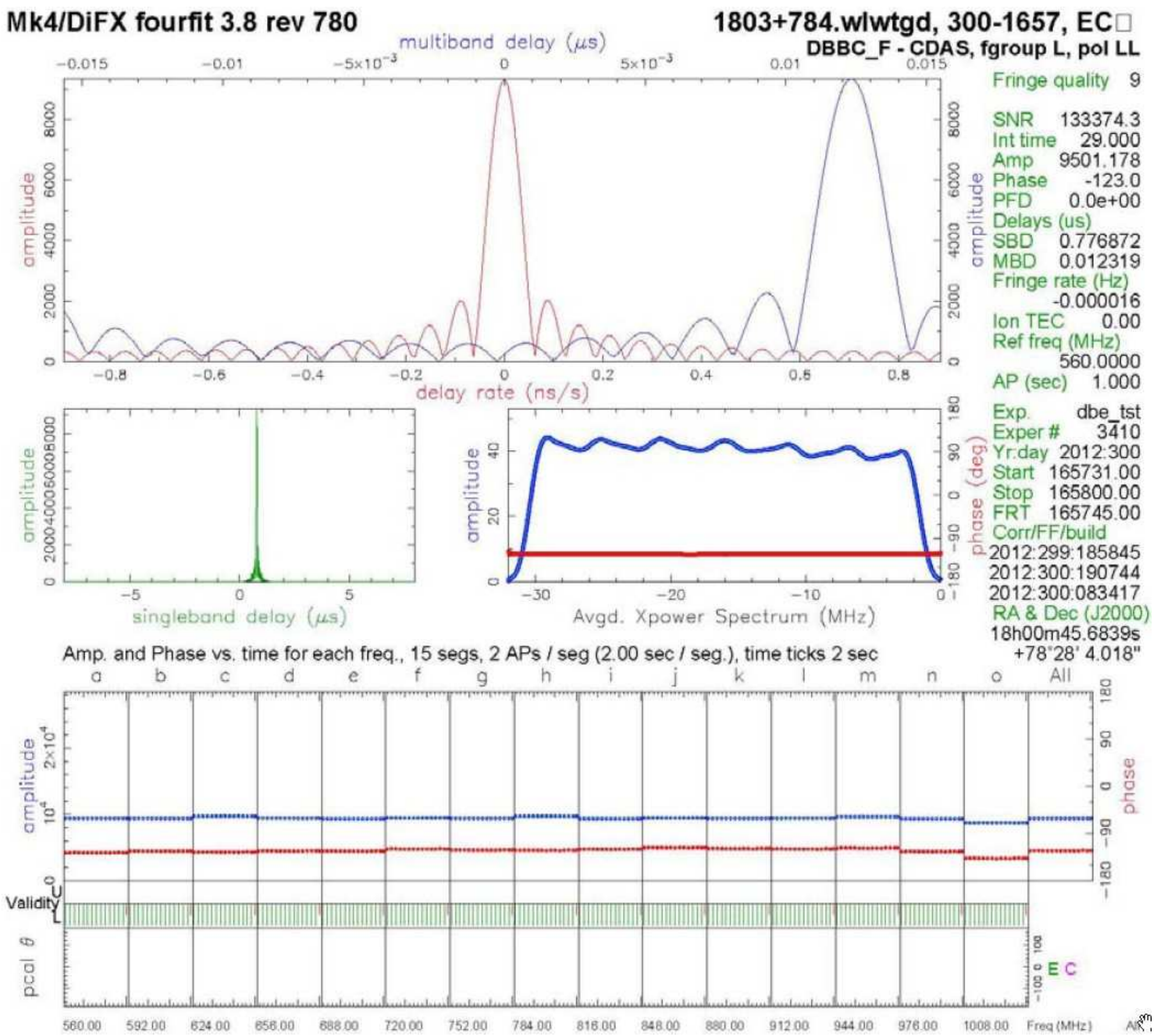

Figure 10. Zero-baseline cross-correlation results between DBBC-PFB w/Fila10G and CDAS-PFB

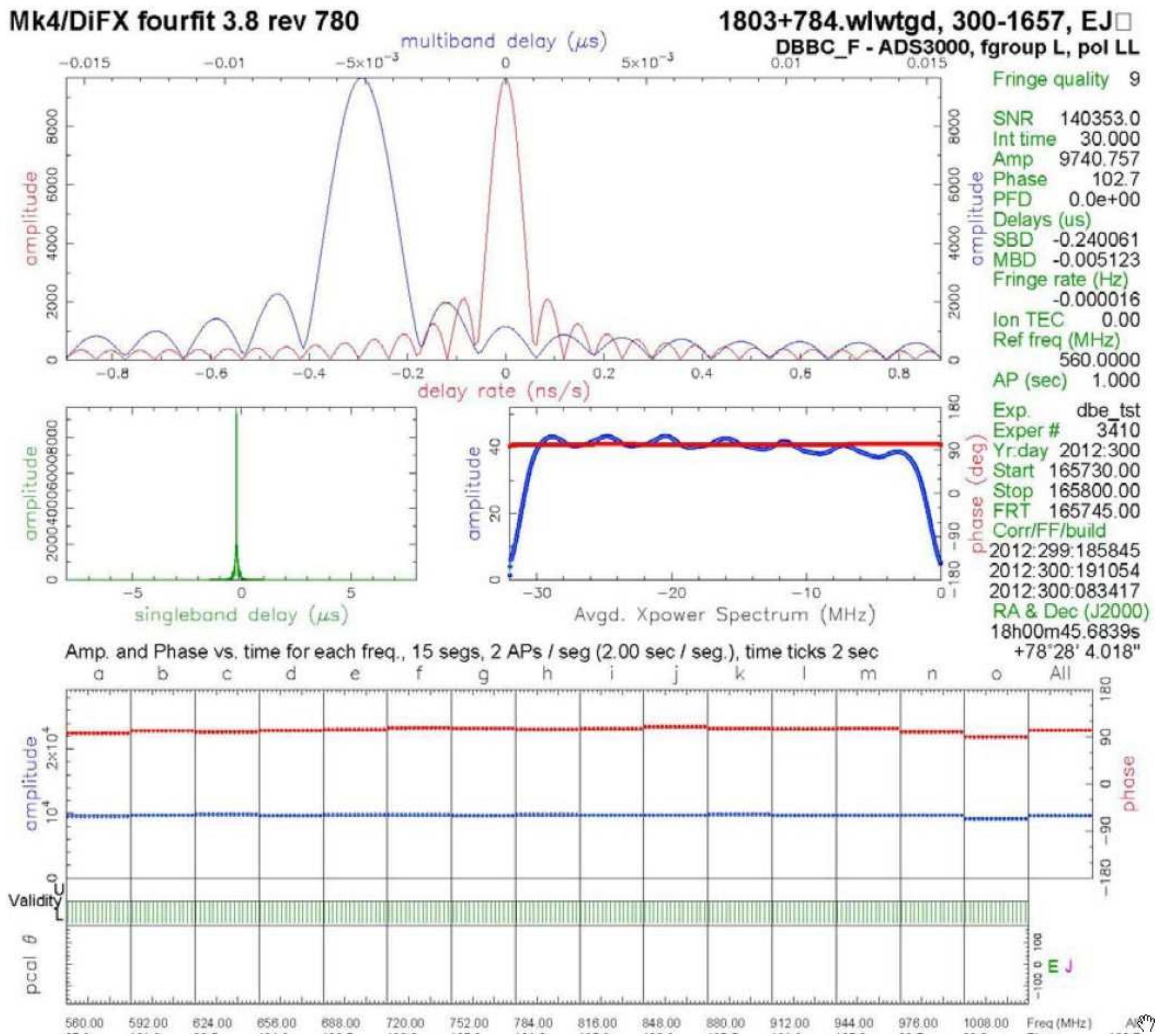

Figure 11. Zero-baseline cross-correlation results between DBBC-PFB w/Fila10G and ADS3000+.

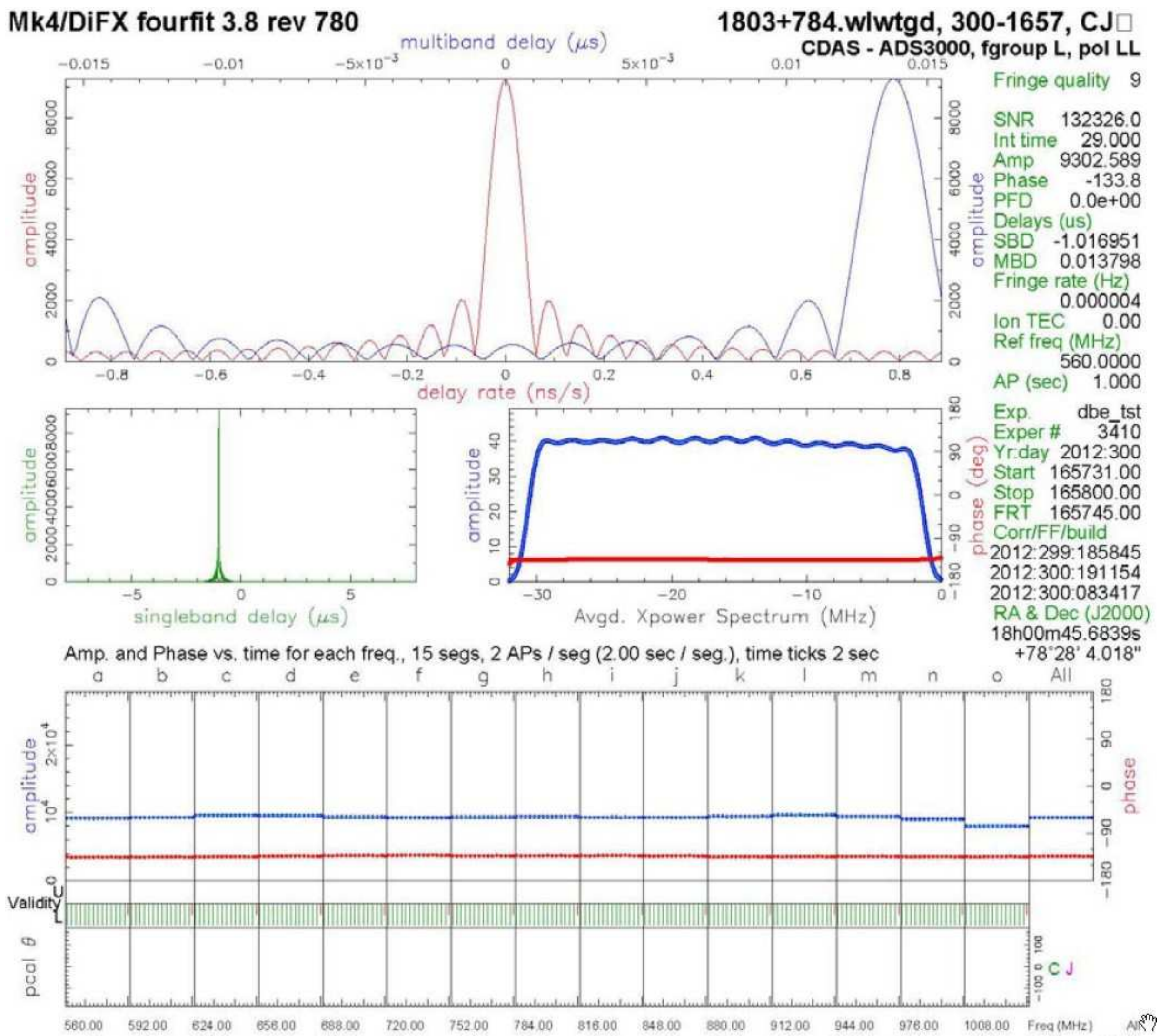

Figure 12. Zero-baseline cross-correlation results between CDAS-PFB and ADS3000+.

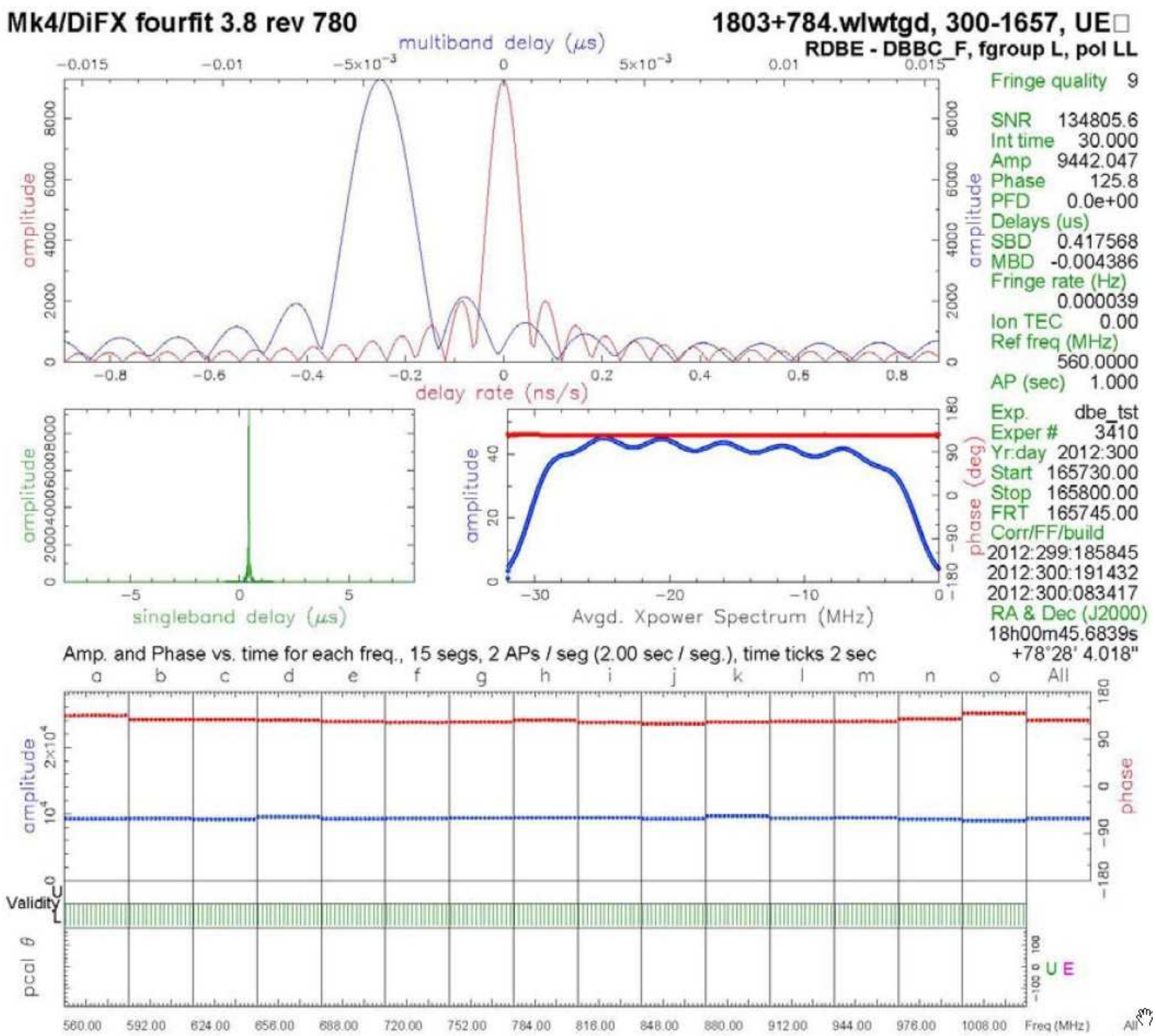

Figure 13. Zero-baseline cross-correlation results between RDBE-H and DBBC-PFB w/Fila10G.

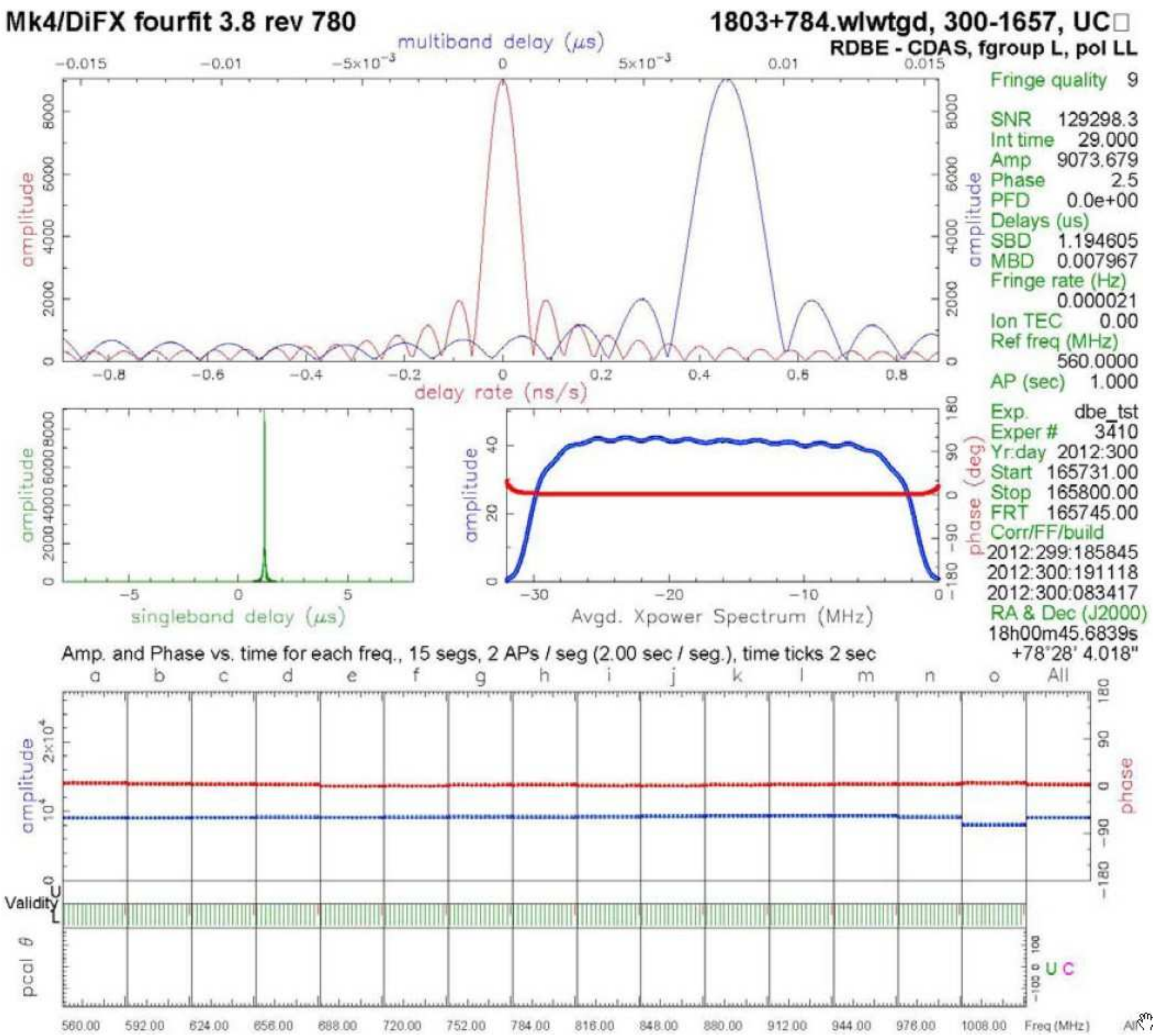

Figure 14. Zero-baseline cross-correlation results between RDBE-H and CDAS-PFB.

Table 1. DBE Feature Comparison.

Feature	RDBE-H	DBBC2010-8H8C	CDAS	ADS3000+
FPGA code version tested	1.4	14	1.0(PFB)/2.0(DDC)	10.06
IF's/Unit	2	8	4	4
Ref Freq (MHz)	5	10	5	10
Sampler resolution(bits)	8	10 at ADC	8	10 at ADC/8 at FPGA
Input Gain Set	Internal	Internal	Internal	Select 4 bits
Sampler BW (MHz)	0-1536	0-3500	50 -1024	0-2500 (-3dB@1800)
Input BW (MHz)	512	1024	512	4×512 2×1024 1×2048
PFB - Channel BW (MHz)	32	32/64	32	-
PFB - Max # channels per IF	15 usable	31/15 usable	15 usable	-
PFB - Channel selection	Flexible (16 max)	Flexible	No (but planned)	-
DDC - Channel BW (MHz)	-	1/2/4/8/16	1/2/4/8/16/32	4/8/16/32
DDC - # per unit	-	32 UL	16	16
DDC - Frequency resolution	-	$10^4(1e6/2^{20})Hz$	10kHz	1Hz
Requantization threshold (bits)	2	1, 2 or 4	1, 2 or 4	2 or 4
Real / Complex Data Output	Yes / No	Yes / Yes	Yes / No	Yes / Yes
Pcal / Total Pwr	No/Yes	Yes/Yes	Yes/Yes	No/No
Data Rate/Unit (Gbps)	2	32	2	2
Output Layer	10GigE	10GigE/VSI-H	VSI-H	VSI-H
Availability	Commercial	Commercial	Small number	Commercial
Availability Date	Now	Now	Now	Now
Upgradable	Yes	Yes	No	No
Cost/Unit	US$18K	98.6K euros	US$50K (DDC) US$10K (PFB)	US$40K

VLBI2010 Receiver Back End Comparison

Bill Petrachenko
January 21, 2013

Introduction.

VLBI2010 requires a receiver back-end to convert analog RF signals from the receiver front end into channelized digital data streams to be recorded or transmitted electronically. The back end functions are typically performed in two steps: conversion of analog RF inputs into IF bands (see Table 2), and conversion of IF bands into channelized digital data streams (see Tables 1a, 1b and 1c). The latter IF systems are now completely digital and generically referred to as digital back ends (DBEs).

In Table 2 two RF conversion systems are compared, and in Tables 1a, 1b, and 1c nine DBE systems are compared. Since DBE designs are advancing rapidly, the data in these tables are only guaranteed to be current near the update date of this document.

DBE Comparison Table (Tables 1a, 1b, 1c)

In Tables 1a, 1b and 1c nine DBEs are compared. These include:

- ***Roach-based Digital Back End (RDBE***): This DBE is the joint product of Haystack Observatory and the National Radio Astronomy Observatory (NRAO) with Haystack being responsible for the Polyphase Filter Bank (PFB) personality and NRAO for the Direct Digital Converter (DDC) personality. In the near term additional development work on the PFB personality continues at Haystack to add features such as PCAL detection and GNSS tick offset monitoring and to make a transition from real to complex mode and from Mk5B to VDIF output. In the longer term a bandwidth increase from 512 to 1024 MHz is planned in order to raise the VLBI2010 compliance from *Half* to *Full*. More information can be obtained from:
    - Arthur Niell, Haystack Observatory, aniell@haystack.mit.edu
    - Jon Romney, NRAO, jromney@aoc.nrao.edu
- ***DBBC2010-8L8C, DBBC2010-8H8C:*** This is an extension of the familiar DBBC2 developed by Gino Tuccari at INAF with boards added to handle the increased number of IF inputs specified for VLBI2010. The 8L8C version handles 512 MHz IF inputs, while the 8H8C version handles 1024 MHz IF inputs. More information can be obtained from:
    - Gino Tuccari, INAF/IRA, g.tuccari@ira.inaf.it
- ***CDAS-DDC and CDAS-PFB***: These have been developed by a team led by Xiuzhong Zhang at Shanghai Astronomical Observatory. Work continues on both systems to improve compatibility with VLBI2010. In particular plans exist to increase the efficiency of the CDAS-DDC for

VLBI2010. There is no planned commercial availability of the CDAS, but manufacture of a small number of units for use outside China may be possible. More information can be obtained from:

  - Xiuzhong Zhang, Shanghai Astronomical Observatory, xzhang@shao.ac.cn

- ***ADS3000+:*** The ADS3000+ is a joint development of NICT, JAXA/ISAS, and COSMO RESEARCH Corp. It is a DDC based system but has modes compatible with VLBI2010 if enough systems are used. More information can be obtained from:

  - Hiroshi Takeuchi, JAXA, takeuchi@isas.jaxa.jp
  - Kazuhiro Takefuji, NICT, takefuji@nict.go.jp

- ***Russian Broadband Acquisition System (BRAS):*** The BRAS DBE is being developed at IAA by Evgeny Nosov. It outputs the entire 512 MHz input IF as a single 512 MHz wide channel. More information can be obtained from:

  - Evgeny Nosov. E84@mail.ru

- ***JPL DBE:*** This DBE is being developed at JPL. It is mainly intended to support JPL VLBI activities related to deep space tracking in the Deep Space Network (DSN) including support of the X/Ka CRF. It has a unique two step channelization process where a 500 MHz input band sampled at 1280 MHz uses a PFB to produce 8 160 MHz bands which are further subdivided using DDC to channels with programmable bandwidths of less than 32 MHz. More information can be obtained from:

  - Eric Clark, JPL, jec@jpl.nasa.gov

- **XCube StreamX-VLBI (VLBI-In-a-Box):** This is a commercial system adapted to VLBI with support from NRAO and CSIRO and others. This system is a digital backend and data recorder in a single box. The system is configurable in terms of number of IO channels and FPGA and GPU compute resources. The base system has 4 bands at 512MHz with a PFB filter bank dividing it to 16, 32MHz bands. The system also has a RAW mode, and a GPU for software processing. It can be extended to 8 Channels with an additional sampler card. The recorder part can operate up to 24Gbit/s recording to removable media, or send data over Ethernet. As a recorder the StreamX VLBI is compatible with other DBE. A DDC mode and a larger PFB, 16MHz bands, are planned. In addition, data monitoring, real-time spectrometer and more are available. More information can be obtained from:

  - Mikael Taveniku, mtaveniku@x3-c.com

- It is possible that other DBEs exist that might be applicable to VLBI2010. However, at the time of preparation of this comparison, data were only available for these nine DBE's.

Heading descriptions:

- ***VLBI2010 compliant***: DBEs were qualified as either *Half* or *Full* VLBI2010 compliant. *Half* compliant implies at least eight IF inputs of 512 MHz, at least eight 32 MHz channel outputs per IF, and a total output data rate of at least 8 Gbps. *Full* implies at least eight IF inputs of 1024 MHz (could be 2*512 MHz), at least sixteen 32 MHz channels per IF, and a total output data rate of at least 16 Gbps.
- ***IF's/Unit.*** This is the number of IF inputs per unit. It is one of the factors that determine the number of units needed per VLBI2010 system.
- ***Units/VLBI2010.*** This the number of units required for a VLBI2010 system (either *Half* or *Full*).
- ***Sampler Resolution (bits).*** This is the number of bits resolution per sample.
- ***Input Gain Set.*** This is either *internal* or *external* depending on whether or not digitally controlled variable attenuators are built into the system. [Note: In the case of the ADS3000+, the gain setting is done inside the FPGA by selecting the best 4 of 8 bits to continue in the processing.]
- ***Sampler Bandwidth (GHz).*** This is the maximum frequency that can be input into the sampler without significant degradation. It determines the highest Nyquist zone that can be used.
- ***Input Bandwidth (GHz).*** This is the bandwidth of each Nyquist zone, i.e. the bandwidth that is actually processed.

The next three inputs are applicable only for systems with PFB personalities. If a PFB personality does not exist, they are left blank.

- ***PFB – Channel Bandwidth (MHz).*** This is the bandwidth of each output channel.
- ***PFB – Max # of channels per IF.*** This is the maximum number of output channels. This should normally be calculated according to Input bandwidth/PFB Channel bandwidth.
- ***PFB – Channel Selection.*** This refers to the degree of flexibility in selecting channels to be routed to the output.

The next three inputs are applicable only for systems with DDC personalities. If a DDC personality does not exist, they are left blank.

- ***DDC – Channel Bandwidth (MHz).*** This is the bandwidth of each output channel.
- ***DDC – # per unit.*** This is the number of DDC output channels per unit.
- ***DDC – Frequency resolution.*** This refers to the degree of flexibility in selecting channels to be routed to the output.
- ***Requantization Threshold.*** How many bits per output sample.
- ***Real/Complex.*** Is the output available in real or complex format or both.
- ***PCAL/Total Power.*** Is there a Pcal and/or total power function.
- ***Total Data Rate.*** This is the total data rate for all units making up the VLBI2010 system.
- ***Output layer.*** VSI-H or 10GE

- ***VDIF.*** Is VDIF output format provided? [Note. In the case of the DBE's with VSI-H outputs it is possible to generate VDIF output if these DBE's are interfaced with a VDIF-compatible recorder of 10GE converter (e.g. K5 recorder).]
- ***Availability.*** Is the DBE commercially available?
- ***Availability Date.*** At what date will the DBE be commercially available
- ***Upgradable.*** Can the VLBI2010 DBE be produced by upgrading a previous version of the DBE.
- ***Cost.*** Separated into the cost for a *Full* and/or *Half* system

Table 1a	*RDBE*	*DBBC2010-8L8C*	*DBBC2010-8H8C*
VLBI2010 Compliant	Half	Half	Full
IF's/Unit	2	8	8
Units/VLBI2010	4	1	1
Sampler resolution (bits)	8	8	10 at ADC/ 8 at FPGA
Input Gain Set	Internal	Internal	Internal
Sampler BW (MHz)	0-1536	0-2200	0-3500
Input BW (MHz)	512	512	1024
PFB - Channel BW (MHz)	32	32	32/4
PFB – Max # channels per IF	15 (16 per unit)	15 (128 per unit)	31/15 (256/128 per unit)
PFB - Channel selection	Flexible	Flexible	Flexible
DDC - Channel BW (MHz)	1/2/4/8/16/ 32/64/128	1/2/4/8/16	1/2/4/8/16
DDC - # per unit	4/4/4/4/4/4/2/1	32 UL	32 UL
DDC – Frequency resolution (Hz)	250K (15.625K)	10K (1024e6/2^31)	10K (2048e6/2^31)
Requantization threshold	2-bit	1-, 2-, or 4-bit	1-, 2-, or 4-bit
Real/Complex	Yes/Yes(2013)	Yes/Yes	Yes/Yes
Pcal/Total Pwr	Yes(2013)/Yes	Yes/Yes	Yes/Yes
Data Rate/Unit (Gbps)	2	16	32
Total Data Rate (Gbps)	8	16	32
Output Layer	10GE	10GE/VSI-H	10GE/VSI-H
VDIF	(2013)	Yes	Yes
Availability	Commercial	Commercial	Commercial
Availability Date	Now	Now	Now
Upgradable	Yes	Yes	Yes
Cost/Unit	$18K	84.7K€	98.6K€
Cost (Half VLBI2010) (Full VLBI2010)	 $72K -	 84.7K€ -	 - 98.6K€

Table 1b	***CDAS-DDC (China)***	***CDAS-PFB (China)***	***ADS3000+ (Japan)***
VLBI2010 Compliant	Yes (VSI-H)	Yes (VSI-H)	Yes (VSI-H)
IF's/Unit	4	2	4
Units/VLBI2010	4(half)/8(full)	4(half)/8(full)	4(half)/8(full)
Sampler resolution (bits)	8	8	10 at ADC/8 at FPGA/ 4 for processing
Input Gain Set	Internal	External	Inernal (see note)
Sampler BW (MHz)	50 -1024	50 -1024	0-2500 (-3dB@1800)
Input BW (MHz)	512	512	4 x 512 2 x 1024 1 x 2048
PFB - Channel BW (MHz)	-	32 /64	-
PFB – Max # of channels per IF	-	15/7	-
PFB - Channel selection	-	All	-
DDC - Channel BW (MHz)	1/2/4/8/16/32	-	4/8/16/32
DDC - # of channels per unit	16	-	16
DDC – Frequency resolution (Hz)	1 (10K)	-	1
Requantization threshold	1-,2- or 4-bit	1- or 2-bit	2- or 4-bit
Real/Complex	Yes/No	Yes/No	Yes/Yes
Pcal/Total Pwr	yes/yes	No/yes	no/no
Data Rate/Unit (Gbps)	2 (VLBI2010 mode)	4	2 (VLBI2010 mode)
Total Output Rate (Gbps)	8(half)/16(full)	16(half)/32(full)	8(half)/16(full)
Output Layer	VSI-H (10GE soon)	VSI-H (10GE soon)	VSI-H (10GE soon)
VDIF	With converter	With converter	With converter
Availability	Small number	Small number	Commercial
Availability Date	Now	Now	Now
Upgradable	Yes	Yes	Yes
Cost/Unit	$50K	$10K	$40K
Cost (Half VLBI2010) (Full VLBI2010)	$200K $400K	$40K $80K	$150K $285K

Table 1c	***BRAS (Russia)***	***JPL DBE (USA)***	***XCube (USA)***
VLBI2010 Compliant	Half	Half	Half/Full
IF's/Unit	8	2	4/8(2013)
Units/VLBI2010	1	4	1 or 2
Sampler resolution (bits)	8	10 (8 used) (@1280 Gsps)	8 (10 planned)
Input Gain Set	Internal	Internal	External
Sampler BW (MHz)	0-1600	0-2000	50-1600
Input BW (MHz)	512	500	512
PFB - Channel BW (MHz)	512	160 for internal use only	32/16(2013)
PFB - Max # of channels per IF	1	8 for internal use only	16/32(2013)
PFB - Channel selection	NA (only one 512 MHz band/IF)	All - but for internal use only	All – selectable IF
DDC - Channel BW (MHz)	-	32 or less, programmable	(2013)
DDC - # of channels per unit	-	16 complex or 32 UL	
DDC – Frequency resolution (Hz)	-	-	
Requantization threshold	2- to 8-bits	-	2-bit
Real/Complex	Yes/No	Yes/Yes	Yes/No(?)
Pcal/Total Pwr	Yes/no	Yes/Yes	Software Programmable
Data Rate/Unit (Gbps)	8	2	8/16(32)
Total Output Rate (Gbps)	8	8	8/(16)
Output Layer	10GE	10GE	Disk/10GE
VDIF	-	-	(2013, software)
Availability	Not commercial	Not commercial	Commercial
Availability Date	Mid-2013	Oct 2013	Now
Upgradable	NA	NA	NA
Cost/Unit	NA	NA	$50/70K (incl. recorder)
Cost			
(Half VLBI2010)	NA	NA	$50/$70K (incl. recorder)
(Full VLBI2010)	NA	NA	$100K/($140K)

Flexible Down Converter Comparison Table (Table 2)

In Table 2, two flexible down-converters are compared. These include:

- ***UpDown Converter (UDC)***: This flexible down-converter was designed by Alan Rogers at Haystack Observatory. It is a traditional analog design. More information can be obtained from:
    - AEE Rogers, Haystack Observatory arogers@haystack.mit.edu
        - See Mk5 Memo's 59 and 70.
- ***DBBC3:*** This flexible down-converter was designed by Gino Tuccari. It is a fully digital design with a high speed input sampler. More information can be obtained from:
    - Gino Tuccari, INAF/IRA, g.tuccari@ira.inaf.it

Heading descriptions:

- ***VLBI2010 compliant***: VLBI2010 flexible down-converters need to handle a pair of 2-14 GHz RF inputs (assumed to be both polarizations of the same signal), down-converting, with sub-MHz resolution, four pairs of 1024 MHz (or 512 MHz for *Half* compliant) bands to a Nyquist zone for sampling.
- ***Units/VLBI2010.*** This is the number of units required for a VLBI2010 system, i.e. the number of units needed to down-convert four pairs of bands.
- ***Sampler Resolution (bits).*** This is the number of bits resolution per sample.
- ***Input range (GHz).*** The input range is assumed to be 2-14 GHz for VLBI2010.
- ***BW per Output Band(GHz).*** This is assumed to be 512 MHz for *Half VLBI2010* compliant and 1024 MHz for *Full* compliant.
- ***Total # of outputs per RF input.*** This needs to be at least 4 for VLBI2010.
- ***Band selection step size.*** This needs to be at least sub-MHz, but for full compatibility with the original Haystack UpDown Converter this needs to be a sub-multiple of 0.4 MHz.
- ***Channel formation.*** Analog or digital.
- ***Total output rate.*** This is only meaningful for digital systems.
- ***Output layer.*** This is only meaningful for digital systems.

Table 2	***Up-Down Converter (UDC)***	***DBBC3***
VLBI2010 Compliant	nearly (input range and output BW need adjusting)	Full
RF Inputs/Unit	2	4
Units/VLBI2010	4	1
Sampler resolution (bits)	Analog	8 @ 28 Gsps
Input Range (GHz)	1-12 (2-14 planned)	0-14
BW per Output Band(MHz)	512 (1024 planned)	512/1024
Total # outputs per RF input	4	8
Band selection step size (MHz)	0.4	0.01
Channel Formation	Analog	DDC
Total Output Rate (Gbps)	Analog	224 per IF
Output Layer	Analog	40/100 GE
Commercially Available	Possible	orders possible in 2013
Availability Date	TBD	about 8 months after order
Upgradable	Yes	Yes
Cost/Unit	$20-25K USD	30-35K€
Cost (Full VLBI2010)	$80-100K USD	30-35K€

VLBI2010 Feed Comparison

Bill Petrachenko
February 14, 2013

Introduction.

VLBI2010 requires a feed that simultaneously has high efficiency over the full 2.2−14 GHz frequency range. The simultaneity requirement implies that the feed must operate at high efficiency over the full frequency range without the need to adjust its focal position to account for frequency dependent phase centre variations. Two feeds meet this specification:

- The Eleven Feed developed at Chalmers University. (For more information, contact Miroslav Pantaleev, miroslav.pantaleev@chalmers.se. The Eleven Feed, integrated with LNA's in a cryogenic receiver, is available as a product from Omnisys Instruments, info@omnisys.se).
- The Quadruple Ridged Flared Horn (QRFH) developed at the California Institute of Technology. (For more information please contact Ahmed Akgiray, aakgiray@ieee.org or Sander Weinreb, sweinreb@caltech.edu)

Although not VLBI2010 compliant, two triband S/X/Ka feeds are also being developed for the commissioning of VLBI2010 antennas, for S/X observations during the VLBI2010 transition period, and to support X/Ka CRF observations. The two feeds are:

- The Twin Telescopes Wettzell (TTW) triband feed developed by Mirad Microwave. (For more information please contact Gerhard Kronschnabl, Gerhard.Kronschnabl@bkg.bund.de)
- The RAEGE (Spain) triband feed developed at Yebes Observatory. (For more information please contact Jose Antonio Lopez Perez, ja.lopezperez@oan.es)

Broadband Feed Comparison.

The Eleven and QRFH broadband feeds are compared in Table 1. [See also appended notes describing table parameters.] In addition one of the most important feed parameters, the aperture efficiency was compared via simulation in a Cassegrain reflector system. The results are shown in Figure 1. There are three notable differences between the feeds:

LNAs per Polarization. Due to the differential port configuration of the Eleven Feed, each polarization output requires a network to combine the output from four antenna ports. To avoid noise degradation from the combining network, LNA's are required directly on each antenna port for a total of 4 LNA's per polarization or 8 LNA's per Eleven feed. Furthermore, since mismatches in the LNA's degrade feed performance, it is necessary that the LNA's be matched within specified limits. In contrast, the QRFH requires no combining network, only one LNA per polarization, and no LNA matching. [Note: The total number of LNA's for the Eleven Feed could be reduced to four through the use of broadband baluns. Although a broadband balun is under development at Onsala Observatory, it is not yet ready for use.]

Calibration Signal Injection. For both feeds it is possible to radiate the calibration signal directly into the feed or to couple it into the signal chain after the LNA. [See Table 1 notes for more details.] However, due to the combining network and multiple LNAs needed for the Eleven Feed, it is not practical when using this feed to inject calibration signals between the feed and LNA.

Design adaptability. The QRFH design can be optimized to match a variety of antenna optics whereas the Eleven Feed has a fixed 10-dB half-beamwidth of about 65°. To be fair, the performance of the Eleven Feed does not degrade quickly as antenna optics change so it is in fact compatible with a fair range of antenna optics. However, for the case of legacy IVS antennas requiring 10-dB half-beamwidths that are significantly different from 65°, the adaptability of the QRFH design will likely lead to improved performance.

	Eleven	*QRFH*
VLBI2010 Compatibility	Yes	Yes
Frequency range (GHz)	1.2−14	2.2−14
Polarization	Dual-Linear	Dual-Linear
Port Configuration	Differential	Single-Ended
LNAs per Polarization	4	1
LNAs per Feed	8	2
LNA Balance Requirements	1.6 dB amp 14° phase	None
Calibration Signal Injection	Radiated or post-LNA	Radiated, pre-LNA, or post-LNA
Aperture Efficiency (F/D ~ 0.375)	See Figure 1	
Ground Noise Contribution (F/D ~ 0.4)	Preliminary 10−20K, but more research is needed	< 20K (2.2−5 GHz) < 10K (5−14 GHz)
F/D Range	0.35−0.5	Adaptable for nominal 0.3−2.5
Feed 10-dB half-beamwidth	65°	Adaptable for nominal 15°−70°
Size (Half-beamwidth ~ 65°)	Diameter 210 mm height 65 mm	diameter 160 mm height 150 mm
Cost (USD)	33K (TBC)	15K

Table 1. VLBI2010 Broadband Feed comparison. Although the QRFH design is adaptable, note that the QRFH table entries for aperture efficiency, ground noise contribution, and size assume its design has been optimized for a half-beamwidth of 65°.

Notes on table parameters:

Aperture Efficiency: This is the total aperture efficiency for each feed feeding reflector optics that are nominally 0.4 F/D (65° feed half-angle). In addition to the impact of return loss, all feed sub-efficiencies including those related to beamwidth and phase center variations with frequency are accounted for in this parameter. If the feed is to be considered for an antenna system having significantly different optics, the aperture efficiency needs to be recomputed. Note that phase center variations have not been broken out as a separate table entry since, due to the directional nature of VLBI antennas, they do not impact VLBI geometric products.

Figure 1 compares the feeds as they would perform in a 12m shaped reflector system like the one manufactured by Intertronics Solutions. The version of the QRFH used in the comparison was designed specifically for these optics assuming a frequency range of 2−12 GHz; hence no data were available for a comparison in the 12−14 GHz range. [Note however that the QRFH design can easily be scaled to cover the 2.2−14 GHz range with similar performance.] The efficiency plot for the QRFH was calculated using Physical Optics software at JPL while the efficiency plot for the Eleven feed was calculated using GRASP software at Onsala Observatory. In both cases measured far field patterns were used as input. Real-world complications such as feed leg scattering have not been taken into account. From figure 1 it can be seen that the performance of the feeds is comparable with the Eleven feed having slightly higher efficiency over the 3–5 GHz band and the QRFH having slightly higher efficiency over the 9–11 GHz band.

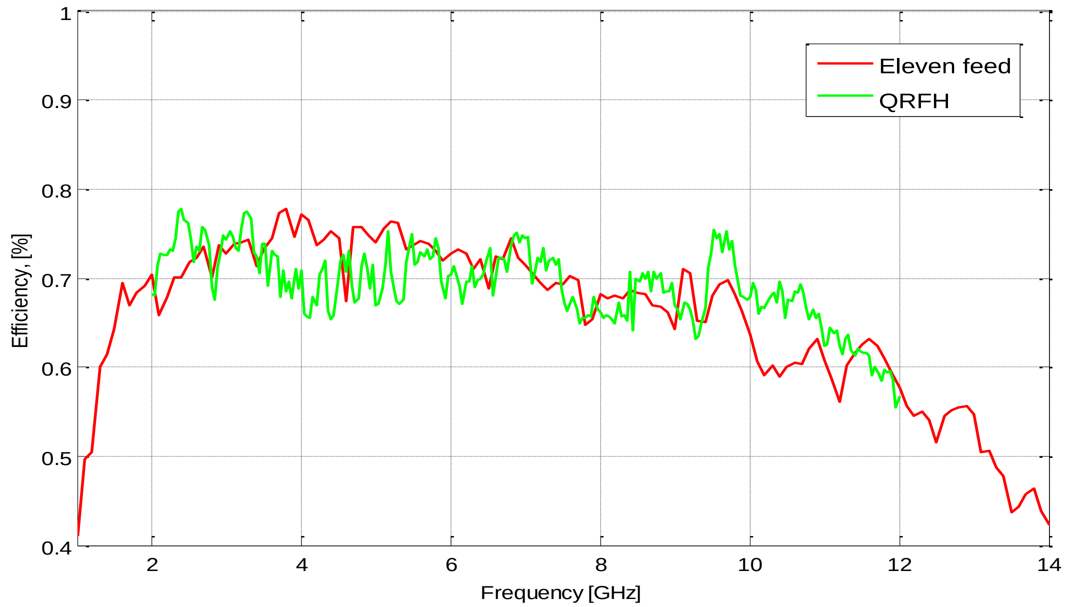

Figure 1: Comparison of the aperture efficiencies of the Eleven feed and the QRFH in a 12m Cassegrain shaped reflector antenna system. The result for the Eleven feed, red curve, is calculated with GRASP software while the result for the QRFH, green curve, is calculated with Physical Optics software. In both cases measure far field patterns were used as input. Real-world complications such as feed leg scattering have not been taken into account.

Ground Noise Contribution: This is a computation of the expected ground noise pickup when a dual-reflector antenna system is pointed at Zenith; this contribution will increase at lower elevation angles or for prime focus optics. This does not include LNA noise or thermal losses in the feed hardware.

Calibration Signal Injection: Mode of injecting calibration signals into the receiver.

- Radiated – signal is radiated into the feed via a small transmitting probe. This mode calibrates the entire signal chain but is susceptible to phase cal antenna-orientation-dependent multipath interference.
- Pre-LNA – signal is injected via microwave hardware preceding the LNA. This mode calibrates the entire signal chain and does not suffer from antenna-orientation-dependent multipath like the radiated technique but instead incurs a slight increase (~5K) in the receiver temperature.
- Post-LNA – signal is injected after the LNA so that multipath and receiver temperature increase need not be considered. However, the entire signal chain is not calibrated

Triband Feed Comparison

The Raege and Mirad feeds are compared in Table 2.

	Raege Triband	***Mirad Triband***
VLBI2010 Compatibility	No (for compatibility with S/X and X/Ka and for antenna commissioning)	No (for compatibility with S/X and X/Ka and for antenna commissioning)
Frequency range (GHz)	S: 2.2–2.7 X: 7.5–9 Ka: 28–33	S: 2.15–2.8 X: 7.0–9.5 Ka: 26.5–33
Polarization	Dual-Circular	Dual-Circular
Port Configuration	Single-Ended (use of hybrids to combine ports)	Single-Ended (use of hybrids to combine ports)
LNAs per Polarization	1	1
LNAs per Feed	6 (3 bands x 2 Pols)	6 (3 bands x 2 Pols)
LNA Balance Requirements	None	None
Calibration Signal Injection	Radiated, pre-LNA, or post-LNA	Radiated, pre-LNA, or post-LNA
Aperture Efficiency	> 70%	> 70% (70-83%)
Ground Noise Contribution	< 20 K S-band < 10 K X-band < 5K Ka-band	< 20 K S-band (17K@60°) < 10 K X-band (12K@60°) < 5K Ka-band
F/D Range	0.4	0.29
Feed 10-dB Half- Beamwidth	65°	55°
Size (DxH – mm)	190x245	Feed alone: 190x400 Feed + Waveguide: (500-900)x1250
Operating Temp (°K)	20	room temp
Cost (USD)	25K (including hybrids and Ka-band septum)	250K (including feed, waveguide and feed cone)

Table 2. Comparison of Triband Feeds.

IVS Coordination

Coordinating Center Report

Dirk Behrend

Abstract

This report summarizes the activities of the IVS Coordinating Center during the year 2012 and forecasts activities planned for the year 2013.

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

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

2. Activities during 2012

During the period from January through December 2012, the Coordinating Center supported the following IVS activities:

- Directing Board support: Coordinated, with local committees, two IVS Directing Board meetings, in Madrid, Spain (March 2012) and at the Haystack Observatory, MA, USA (October 2012). Notes from each meeting were published on the IVS Web site.

Figure 1. Attendees of the IVS Directing Board meeting held at MIT Haystack Observatory in October 2012.

- Communications support: Maintained the general IVS Web pages and the session Web pages, the e-mail lists, and the Web-based mail archive files.
- Publications: Published the 2011 Annual Report in summer/fall 2012. Published three editions of the IVS Newsletter in April, August, and December 2012. All publications are available electronically as well as in print form.
- Observing Program Committee (OPC): Coordinated meetings of the OPC to monitor the observing program, review problems and issues, and discuss changes.
- 2012 Master Schedule: Generated and maintained the master observing schedule for 2012. Coordinated VLBI resources for observing time, correlator usage, and disk modules. Coordinated the usage of Mark 5 systems at IVS stations and efficient deployment of disk modules.
- 2013 Master Schedule: Generated the proposed master schedule for 2013 and received approval from the Observing Program Committee.
- VLBI2010: Supported the activities of the VLBI2010 Committee (V2C) and the VLBI2010 Project Executive Group (V2PEG). Worked with the Local Committee and the Program Committee to prepare the VLBI2010 Workshop on Technical Specifications (TecSpec) held in Bad Kötzting, Germany in March 2012.

Figure 2. Participants of the VLBI2010 Workshop on Technical Specifications (TecSpec) held in Bad Kötzting, Germany in March 2012. More information about the workshop can be found at the URL `http://www.fs.wettzell.de/veranstaltungen/vlbi/tecspec2012/index.html`.

- Meetings: Coordinated, with the Local Committee, the seventh IVS General Meeting, held in Madrid, Spain in March 2012. Chaired the Program Committee for the meeting.

3. Staff

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

4. Plans for 2013

The Coordinating Center plans for 2013 include the following:

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
Frank Gomez	Web Manager	Web server administration, mail system maintenance, Data Center support, session processing scripts, mirror site liaison
Karen Baver	General Programmer and Editor	Publication processing programs, LaTeX support and editing, session Web page support and scripts
Kyla Armstrong	Data Technician	Publications support and Web site support

- Maintain the IVS Web site and the e-mail system.
- Publish the 2012 Annual Report (this volume).
- Coordinate, with the local committee, the seventh IVS Technical Operations Workshop to be held at the MIT Haystack Observatory, MA, USA in May 2013.
- Support Directing Board meetings in 2013.
- Coordinate the 2013 master observing schedules and IVS resources.
- Publish Newsletter issues in April, August, and December.
- Support the VLBI2010 activities of the V2C and V2PEG.

Analysis Coordinator Report

A. Nothnagel

Abstract

We present the IVS analysis coordination issues of 2012. The IVS Analysis Coordinator is responsible for generating and disseminating the official IVS products. This requires consistency of the input data by strict adherence to models and conventions. The term of the current IVS Analysis Coordinator will end on February 28, 2013.

1. General Issues

The "Thirteenth IVS Analysis Workshop" was held at the Royal Observatory of Madrid, Spain, on March 8, 2012, in connection with the 7th IVS General Meeting. In this workshop, the coordination of IVS routine data analysis was discussed as well as a number of individual items concerning geodetic and astrometric data analysis in the framework of the IVS. Due to personnel limitations at some of the analysis centers, the progress in improving the analysis software packages was slow. This is important for the necessary changes following the IERS Conventions 2010 in particular.

Concerning atmospheric gradient modeling, a decision was made by the attendees that the Chen and Herring model [1] should be the conventional model of the IVS, using the constant C = 0.0031 for estimating the hydrostatic gradient. Since the hydrostatic contribution is the biggest one and the coefficient for the total gradient contribution is only slightly different (C = 0.0032), no noticeable effect on the estimates is expected. The MacMillan model [2] produces essentially the same results, but for consistency with the analyses of the IGS, the Chen and Herring model [1] was adopted.

An unsolved problem is the issue of the sidelobe ambiguities resulting from loss of channels, e.g., due to radio frequency interference (RFI). For certain stations and sessions, this causes a loss of many observations. The only way to overcome this problem is by re-fringing the correlator output with a narrow search window (±10 ns). The author offers a little program which creates fourfit run commands with suitable search windows for a refringe. As input, it needs the listing of the post-fit residuals of the Solve program and the alist file of the aedit program. Because this requires that an analyst taking care of these observations has to extract the post-fit residuals from his solution, has to have access to the raw correlator output, and has to have some knowledge of running fourfit, the number of possible candidates for taking care of this job singlehandedly is small. It is, therefore, necessary that a suitable data flow is organized between the submitting Analysis Center and the respective correlator group.

2. IVS Operational Data Analysis and Combination

Since October 1, 2009, the operational combination has been carried out by the IVS Combination Center at the German Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt a.M. (see separate report by BKG/DGFI). The input to these combinations is datum-free (constraint-free) normal equation systems in SINEX format (Solution INdependent EXchange format) containing elements for radio source positions, Earth orientation parameters, and radio telescope coordinates.

3. Epilog

In September 2012, I gave notice to the IVS Directing Board that I will terminate my mandate as IVS Analysis Coordinator on February 28, 2013. At that time I will have served as Analysis Coordinator for more than 13 years. Thanks to the help and efforts of many individuals, it was a period of constant progress in the field of analysis and also in the field of combination products. Of course, expectations of how much progress should have been made have always been higher than could be realized. In the field of VLBI data analysis, there have been too many improvements to discuss or even mention. Concerning the combinations of the analysis results for the final IVS products, I made the first proposal to use datum-free normal equations in 2002. Although there are serious problems with filter-based solutions, I still defend my decision to go for normal equations. In the process of generating combinations for the International Terrestrial Reference Frame (e.g., ITRF2005 or ITRF2008), the IVS has always been the service that could prove and guarantee that the solutions were unconstrained. In the near future, the source positions will be handled in a consistent way together with the terrestrial reference frame and the Earth orientation parameters. Combination on the basis of datum-free normal equations containing the elements of all the parameters of the VLBI solutions will be a straightforward method without awkward constructions of the functional model between the parameters and the setting up of additional Helmert parameters as will be necessary for the solutions reported to the IERS with covariance matrices.

At the time of writing, the new IVS Analysis Coordinator, John Gipson (who works for NVI, Inc. at NASA GSFC), had already been elected by the IVS Directing Board. I am sure that John will be a capable and diligent leader of the analysis community within the IVS. I wish him good luck with all his new ideas and a good portion of persistence to motivate the IVS analysis groups to produce even better solutions in a timely fashion.

References

[1] G. Chen, and T.A. Herring (1997) Effects of atmospheric azimuthal asymmetry on the analysis of space geodetic data. J Geophys Res, Vol. 102, No. B9, pp. 20489-20502, doi: 10.1029/ 97JB01739.

[2] D. S. MacMillan (1995) Atmospheric gradients from very long baseline interferometry observations. Geoph Res Letters, Vol. 22, No. 9, pp. 1041-1044, doi: 10.1029/95GL00887.

Network Coordinator Report

Ed Himwich, Richard Strand

Abstract

This report includes an assessment of the network performance in terms of lost observing time for the 2012 calendar year. Overall, the observing time loss was about 12.3%, which is in-line with previous years. A table of relative incidence of problems with various subsystems is presented. The most significant identified causes of loss were electronics rack problems (accounting for about 21.8% of losses), antenna reliability (18.1%), RFI (11.8%), and receiver problems (11.7%). About 14.2% of the losses occurred for unknown reasons. New antennas are under development in the USA, Germany, and Spain. There are plans for new telescopes in Norway and Sweden. Other activities of the Network Coordinator are summarized.

1. Network Performance

The overall network performance was for the most part good. This year we return to reporting a detailed assessment, which was not provided for the two previous years.

This network performance report is based on correlator reports for experiments in calendar year 2012. This report includes results for the 148 24-hour experiments that had detailed correlator reports available as of March 8, 2013. The data set examined includes approximately 500,000 dual frequency observations. Results for 16 experiments were omitted because either they were correlated at the VLBA, they have not been correlated yet, or correlation reports were not available on the IVS data centers. Experiments processed at the VLBA correlator were omitted because the information provided for them is not as detailed as that from Mark IV correlators. The experiments that have not been correlated or do not have correlator reports available yet include some JADE, JAXA, OHIG, R&D, T2, and EUR experiments. In summary, roughly 90% of the data from scheduled 24 hour experiments for 2012 are included in this report. That is similar to, and actually a little more complete than, the coverage of reports for previous years.

An important point to understand is that in this report, the network performance is expressed in terms of lost observing time. This is straightforward in cases where the loss occurred because operations were interrupted or missed. However, 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.

Since stations typically observe with more than one other station at a time, the average lost observing time per station is not equal to the overall average loss of VLBI data. Under some simplifying assumptions, the average loss of VLBI data is roughly twice the average loss of station observing time. This approximation is described in the Network Coordinator's section of the IVS 2001 Annual Report. For 2012, this agrees reasonably well with the actual number of (single frequency: S or X) single baseline observations on which the correlator reported failure, approximately 21.1%, but other factors, particularly the dual frequency nature of useful geodetic observations, complicate the picture. For 2012, the actual percentage of data (dual frequency) that was not included by the analysts was approximately 28.1%. This is even larger (by approximately 34%) than the single baseline observations reported lost by the correlator. It is expected that this number should be higher because the analysts use additional criteria beyond what is discussed here to decide when to exclude observations. However, it means in effect that only about 72% of the observations we attempted to collect were useful.

For the 148 experiments from 2012 examined here, there were 1,261 station days or approximately 8.5 stations per experiment on average. This compares to 135 experiments considered in the report for 2009 (the most recent year with a detailed report), which included 1,051 station days with 7.9 stations per experiment. The increase in the number of analyzed experiments essentially just reflects that the results for more experiments were available for consideration at the time the report was written. However the increase in the number of stations per experiment is probably due to a concerted effort by the IVS Coordinating Center to make the networks in the experiments larger. The onset of operations by the AuScope and Warkworth stations helped to make this possible. Of the station days for 2012, approximately 12.3% (or approximately 155 days) of the observing time was lost. For comparison to reports from earlier years, please see Table 1.

The lost observing time for 2012 is more in-line with results from years before 2009. The results for 2009 may be artificially high due to a change in the way the results were tabulated for that year. We believe this year's calculations are more in-line with how they were made before 2009.

An assessment of each station's performance is not provided in this report. While individual station information was presented in some previous years, this practice seemed to be counterproductive. 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 improve station results. Consequently, only summary results are presented here. Detailed results are presented to the IVS Directing Board. Each station can receive the results for their station by contacting the

Table 1. Lost observing time.

Year	Percentage
1999-2000*	11.8
2001	11.6
2002	12.2
2003	14.4
2004	12.5
2005	14.4
2006	13.6
2007	11.4
2008	15.1
2009	21.5
2012	12.3

* The percentage applies to a subset of the 1999-2000 experiments.

Percentages for 2010 and 2011 are omitted, but should be 10-20%.

Network Coordinator (Ed.Himwich@nasa.gov).

For the purposes of this report, the stations were divided into two categories: **large N**: those that were included in 20 or more network experiments among those analyzed here and **small N**: those in 11 or fewer (no stations were in the 12-19 experiment range). The distinction between these two groups was made on the assumption that the results would be more meaningful for the stations with more experiments. The average observing time loss from the large N group was much smaller than the average from the small N group, 10.6% versus 25.7%. There are many more station days in the large N group than the small N group, 1,125 versus 136, so the large N group is dominant in determining the overall performance.

There are 19 stations in the large N group. Nine stations observed in 50 or more experiments. Of the 19, eight stations successfully collected data for approximately 90% or more of their expected observing time. Nine more stations collected 80% or more of the time. The two remaining stations collected data for more than about 60% of their observing time. These results are not significantly different from previous years.

There are 24 stations in the small N group. The range of lost observing time for stations in this category was 0%-100%. The median loss rate was approximately 11.3%, better than previous years.

The losses were also analyzed by sub-system for each station. Individual stations can contact the Network Coordinator (Ed.Himwich@nasa.gov) for the sub-system breakdown (and overall loss) for their station. A summary of the losses by sub-system (category) for the entire network is presented in Table 2. This table includes results since 2003 sorted by decreasing loss in 2012.

The categories in Table 2 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, and mechanical breakdowns of the antenna.

Table 2. Percentage of observing time lost by sub-system.

Sub-System	**2012**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**
Rack	21.8	6.6	8.7	11.4	16.3	5.1	6.8	5.0
Antenna	18.1	29.4	19.2	34.6	19.0	24.4	32.9	17.8
Unknown	14.2	14.2	17.7	14.9	4.0	3.3	10.1	12.6
RFI	11.8	5.9	14.8	10.4	11.6	6.2	5.0	9.3
Receiver	11.7	18.6	13.8	14.9	20.8	24.2	18.0	25.2
Miscellaneous	6.9	15.3	12.8	7.6	18.0	8.0	8.0	6.0
Recorder	5.7	2.9	4.1	4.6	3.3	8.9	11.1	10.9
Shipping	3.6	4.0	5.4	1.0	0.0	0.2	1.4	6.1
Power	2.1							
Operations	2.0	1.2	2.3	0.0	2.0	4.7	6.1	3.6
Clock	1.8	1.9	0.5	0.3	4.9	14.5	0.5	3.4
Software	0.3	0.1	0.1	0.4	0.1	0.5	0.1	0.1

Percentages for 2010 and 2011 were not calculated.

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

Miscellaneous This category includes several small 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, cables, scheduling conflicts at the stations, and errors in the observing schedule 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 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 were 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 transfer prevented the data from being correlated with the rest of the experiment'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.

Interesting results for 2012 include the fact that the largest source of losses was due to "Rack" problems, (21.8%). About half the loss in this category is associated with DBBCs, which were in use at several stations in the Southern Hemisphere. The remaining rack problems were largely due to problems at stations with aging racks for which replacement parts are hard to find. However, significant improvements were made at two of the three stations with these problems by the end of the year.

The next largest area of loss was "Antenna" problems (18.1%). This is down significantly from previous years and reflects the fact that there were no lengthy outages due to catastrophic antenna failures. Stations with significant antenna problems were Matera, Svetloe, Tsukuba, and Yarragadee.

The "RFI" losses (11.8%) were more back in-line with years before 2009. The higher value in 2009 may be related to differences in how the losses were treated that year. The stations with the most serious RFI problems were Fortaleza and Matera.

"Receiver" sub-system problems (11.7%) was lower than in previous years. For 2012 this is probably due to fewer cryogenic problems, due partly to several new stations having uncooled receivers.

The "Miscellaneous" category loss was smaller than previous years. This was to a small extent due to the fact that "Power" was broken out as a separate category this year, but this does not account for the majority of the change.

Overall, while the network operated well for the most part, there are a few notable issues (in alphabetical order of station), while some situations improved from the previous year:

- Fortleza RFI for channel SR4U caused almost 15% data loss for that station over the year. An attempt to fix this by bandpass filtering the RFI signal in the station's S-band IF did not work.
- Hobart26 is now observing without a phase calibration antenna unit.
- Hobart, Katherine, and Yarragadee have timing issues with the DBBC back-ends. These cause occasional clock breaks and data gaps when they occur. The manufacturer is investigating this issue.

- Kokee Park's damaged gearbox was repaired and was re-installed. This improved the antenna's pointing and its SEFDs but did not return them to their normal levels. There are still problems with both azimuth gearboxes, which will need to be repaired. The station replaced the AC wiring going to the telescope to prevent the cryogenic compressor from tripping off.
- The receiver at Medicina warmed up in November 2011. It is not clear when it will be repaired.
- Matera's Mark 5 samplers for S-band channels 5 and 6 have failed. Efforts are being made to locate replacements. Matera had an antenna failure that was repaired.
- After completion of its bearing repair, the Noto antenna started observing again in May 2012. Noto also repaired its BBCs, so that it has at most one or two bad BBCs now. In any event, it is expected that Noto will replace its aging VLBA4 rack with a DBBC in 2013.
- Ny-Ålesund's receiver communications were repaired using the system that the TIGO station developed for their receiver, which had the same original design.
- Svetloe had intermittent antenna problems that caused occasional data losses. Badary and Zelenchukskaya's antenna reliability has improved.
- TIGO has shown higher than normal SEFDs for several years. There has been no success in resolving this issue.
- The Tskuba32 telescope had a major structural failure and was repaired.
- Warkworth lost most of the scans scheduled for 2012 because of a maser failure, now repaired.
- The Westford azimuth antenna drives continue to trip off sometimes when the site is unattended.
- Yarragadee solved its antenna problems by installing a bandpass filter in a diplexer to eliminate the need to stow the antenna when a satellite up-link is active.

2. New Stations

There are prospects for new stations on several fronts. These include (in approximate order of how soon they will start regular observations):

- At GSFC in the USA, a new 12-m antenna has been erected and is undergoing testing. While this antenna is primarily for use in the development of the VGOS systems, it is expected that it will eventually join the network for regular observing.
- At Wettzell in Germany, construction of the new Twin Telescope Wettzell (TTW) for VGOS is underway and is expected to be commissioned in April 2013.
- At Arecibo in Puerto Rico a new 12-m antenna has been erected and is expected to be used for geodetic observing.
- In Spain/Portugal, the RAEGE (Atlantic Network of Geodynamical and Space Stations) project aims to establish a network of four fundamental geodetic stations including radio telescopes that will fulfill the VGOS specifications: Yebes (1), Canary Islands (1), and Azores (2).

- In Norway, the Norwegian Mapping Authority (NMA) has received initial funding for a project to establish a fundamental station at Ny-Ålesund, which will include a twin telescope of the Wettzell type.
- Onsala has applied for funds for a twin telescope system.
- In Russia, an effort is underway to get 12-m VGOS antennas at some of the QUASAR network sites.
- Korea is planning to build one antenna primarily for geodesy (Korea VLBI system for Geodesy, KVG) at Sejong. There is also interest in geodetic use of the Korean VLBI Network (KVN), which will consist of three stations intended primarily for astronomy.
- There is interest in India in building a network of four telescopes that would be useful for geodesy.
- Saudi Arabia is investigating having a combined geodetic observatory, which would presumably include a VLBI antenna.
- Colombia is investigating having a combined geodetic observatory, which would presumably include a VLBI antenna.

Many of these antennas may become available for use in the next few years. Efforts are being made to ensure that these antennas will be compatible with VGOS.

3. Network Coordination Activities

Network coordination involved dealing with various network and data issues. These included:

- Reviewing all experiment "ops" messages, correlator reports, and analysis reports for problems and working with stations to resolve them
- Responding to requests from stations for assistance
- Providing AuScope staff with a technical operations workshop ("Mini-TOW") for training
- Making station visits to Hobart and Warkworth for software updates and training
- Identifying network station issues and working with the IVS Coordinating Center and the stations to resolve them. This year these included:
  - Dealing with Mark 5B/5B+ ",E" scan_check errors
  - Dealing with Mark 5B/5B+ time issues
  - Preparing Mark 5 modules for use and correcting VSN problems
  - Helping stations avoid the Linux "day 49" kernel problem
  - Maintaining the FS PC kernel
- Reviewing RFI sources, selecting bandpass filters, and providing them to the sites
- Participating in development of the new VEX2 schedule file standard

- Updating RDV experiment VEX files to allow proper operation with the VLBA correlator, updating the notes file to reflect equipment set-up at different stations, and encouraging timely shipping of data
- Recognizing and reporting DBBC issues to station observing staff
- Reviewing Mark 5 recording error checks for problems and informing correlator staff and station staff
- Assisting in troubleshooting the Kokee X-band dewar failure
- Troubleshooting power supplies and identifying the correct parts for shipping
- Troubleshooting video converters and organizing shipments to stations
- Coordinating shipment of phase calibration sync trigger units to each station with a Mark 5B/5B+
- Troubleshooting phase calibration issues and coordinating parts shipments
- Providing telescope pointing analysis and advice.

4. Future Activities

Network coordination activities are expected to continue next year. The activities will largely be a continuation of the previous year's activities:

- Reviewing all experiment "ops" messages, correlator reports, and analysis reports for problems and working with stations to resolve them
- Responding to requests from stations for assistance
- Identifying network station issues and working with the IVS Coordinating Center and the stations to resolve them
- Updating Network Station configuration files
- Planning for and teaching at TOW 2013
- Other activities as needed.

IVS Technology Coordinator Report

Alan Whitney

Abstract

This report of the Technology Coordinator includes the following: 1) continued work to implement the new VLBI2010 system, 2) the 1st International VLBI Technology Workshop, 3) a VLBI Digital-Backend Intercomparison Workshop, 4) DiFX software correlator development for geodetic VLBI, 5) a review of progress towards global VLBI standards, and 6) a welcome to new IVS Technology Coordinator Bill Petrachenko.

1. VLBI2010 Progress

Progress continues towards the goal of a next-generation VLBI2010 system. Much more detailed information about VLBI2010 development is presented elsewhere in this volume; here we briefly report some of the highlights.

1.1. Development of the VLBI2010 Broadband System

The VLBI2010 system continues to be developed at several locations:

1. The VLBI2010 13-m 'twin-telescopes' installed at Wettzell will be formally inaugurated in April 2013. RMS surface accuracy is better than 60 micrometers, and the antenna and the subreflector are aligned. A tri-band feed will be installed soon, followed by measurements of G/T and pointing tests. A new broadband "Eleven" feed and accompanying receiver and recording systems are currently being installed.
2. The broadband 'QRFH' 2-14 GHz broadband feed from Caltech has been successfully tested on the VLBI2010 prototype antenna at NASA/GGAO and will soon also be installed on the Westford antenna. Experimental results for beam patterns and efficiencies closely match theoretical predictions. The QRFH feed can be easily re-designed to accommodate a wide variety of antenna geometries.
3. Digital-backend development continues in China, Europe, Japan, Russia, and the United States. A VLBI Digital-Backend Intercomparison Workshop was conducted at Haystack Observatory in October 2012 to test inter-compatibility between independently developed DBE units.
4. Mark 6 VLBI data system: The Mark 6 system is entering service at 8 Gbps. Several successful experiments have already been conducted, and the system continues to be made more robust. Routine service at 8 Gbps is expected in the first half of 2013, with expansion to 16 Gbps by the end of 2013.
5. A number of VLBI2010 data-taking sessions between Westford and NASA/GSFC were conducted during 2012, including several operating at 8 Gbps/station. Many were recorded onto four Mark 5C units at each station using RDBE backend units as data sources, at an aggregate data rate of 8 Gbps/station, but a single Mark 6 is now able to replace the four Mark 5C units. More of the processing of VLBI2010 data continues to be moved from the

Mark IV correlator to the DiFX correlator at Haystack Observatory as the DiFX correlator becomes more capable of processing VLBI2010 data.

6. DiFX correlators at MPI, Haystack Observatory, and U.S. Naval Observatory continue to be developed and used for processing geodetic VLBI data.

2. 1St International VLBI Technology Workshop at Haystack Observatory

The annual international e-VLBI workshop, the 10th of which was convened in 2011 in South Africa, was expanded in 2012 to include a broader scope of technical VLBI developments and was renamed *1st International VLBI Technology Workshop*. It was held at Haystack Observatory 22-24 October 2012 and attended by 68 participants from 17 countries.

Prior to the meeting, an intrepid group of ~20 attendees braved cold and wind to climb ~1000m-high Mt. Monadnock in nearby New Hampshire, which offered spectacular views of the New England fall foliage display.

The three-day workshop included sessions on antennas, receivers, digital backends, phase-calibration, recording, and e-VLBI, as well as some recent VLBI science achievements, and it was judged to be highly successful by all. The program and presentations from the workshop are available on-line at *http://www.haystack.mit.edu/workshop/ivtw/program.html*.

The 2nd International VLBI Technology Workshop will be held in fall 2013 in South Korea.

Figure 1. Attendees of 1st International VLBI Technology Workshop held at MIT Haystack Observatory.

3. VLBI Digital-Backend Intercomparison Workshop

The 2^{nd} International VLBI Digital-Backend Intercomparison Workshop was held at Haystack Observatory immediately following the VLBI technical workshop reported above. (The first was held in 2009.) Participants from China, Europe, Japan, and the U.S. spent two very busy days preparing equipment, recording wide-bandwidth correlated noise, and processing through the Haystack DiFX correlator to test the proper operation and intercompatibility of all the units under test. A full report of this workshop is contained elsewhere in this IVS annual report.

4. DiFX Software Correlator for Geodetic VLBI

The so-called DiFX software correlator was originally developed at Swinburne University in Australia by Adam Deller, primarily for astronomical VLBI use. The development of an economical and powerful software correlator, a dream less than a decade ago, has been made possible by the relentless march of Moore's Law to provide powerful inexpensive clustered PCs with high-speed data interconnections that can distribute and correlate VLBI data in an efficient manner. Several institutions that support geodetic VLBI correlation processing now have DiFX correlators (MPIfR, USNO, and Haystack Observatory) and have been working to augment the core DiFX software to meet the needs of geodetic VLBI. This includes the integration of much of the Mark IV post-correlation software involving data-management, output data formats, fringe finding and delay estimates, and editing/quality-assurance software. In addition, a substantial amount of work has been done to support the VDIF data-input format and to support correlation of mismatched sample rates and recording bandwidths.

5. Review of Global VLBI Standards

One of the goals of the IVS Technology Coordinator over the past 15 years has been to promote development and implementation of global standards for VLBI. During this time, the following VLBI-related standards represent some of the progress that has been made.

5.1. VEX/VEX2

VEX (VLBI EXperiment), created in the late 1990s and updated in the early 2000s, is a pseudo-language that describes the detailed configuration of each station in an experiment, as well as the schedule of observations. The scheduling process creates a VEX observation file for each experiment that describes that configuration and schedule for each station, as well as a corresponding station-specific SNAP file (Standardized Notation for Antenna Procedures, created in the 1980s) that is created to drive the Field System at each station. During an experiment, a VEX-format log file is created that aids in post-experiment correlation and post-correlation processing. VEX is now used to support a majority of geodetic VLBI observations and is also becoming quite prevalent for astronomical VLBI as well.

Over the past few years, evolving VLBI technologies and capabilities have prompted the creation of a VEX2 Task Force to update and modernize VEX to accommodate these new capabilities, particularly digital backends and VDIF data formats, in a natural way. The VEX2 specification is nearing completion and is projected to be released in early spring 2013.

5.2. VSI

The original VSI (VLBI Standard Interface) specification was created in 1999 to specify a standardized electrical data interface (dubbed VSI-H for 'VSI-Hardware') and software control interface (dubbed VSI-S for 'VSI-Software'). As a result, many of the VLBI data-recording/playback systems developed in the 2000s (Mark 5B, PC/EVN, K5, and LBA) support the VSI interface specification. In recent years, the VSI-H specification has been superseded by the industry-standard 10-Gigabit Ethernet interface that is now being widely adopted in new VLBI data systems (Mark 5C and Mark 6).

5.3. VDIF Data Format

The VLBI Data Interchange Format (VDIF) format was developed by the VDIF Task Force and subsequently ratified by the VLBI community in 2009. Designed to be fully compatible with 10Gigabit Ethernet, as well as being very flexible in terms of channelization, sample depth, sample rate, etc., it is being implemented in virtually all new VLBI data equipment. In addition, software has been implemented on several software correlators to support at least some basic VDIF modes. As more complex VDIF modes are put into use at stations, correlator software will need to develop in parallel to support them.

A VDIF2 data format, including the accommodation of arbitrary sample rates (including those that do not have an integral number of samples in a single second) is nearing completion but is not quite ready for ratification; such 'non-standard' sample rates are being designed into some of the new SKA-related systems that would like to participate in global VLBI over the next few years. The new VDIF2 standard will also relax the constraint of an integral number of filled data packets per second and will allow much more flexibility in the choice of packet lengths. Progress towards completion and ratification of VDIF2 is expected in 2013.

5.4. VTP

VLBI Transport Prototype (VTP) has been developed to specify how VDIF data frames should be streamed over standard networks such as Ethernet, and it is gaining acceptance for e-VLBI data transport and transfers. One of the primary purposes of VTP is to allow the easy identification of dropped and/or duplicated packets that might occur during the data-transmission process over high-speed networks.

5.5. VLBI Standards Website

The Web site *www.vlbi.org* has been created to act as a common source for definitions and information on VLBI standards, as well as a directory to VLBI on-line technical information located at numerous VLBI institutions around the globe. These include VEX, VSI-H, VSI-S, VDIF, VTP, and standardized VLBI file-naming conventions, as well as a VLBI technical resources page. As new standards and technical VLBI resources emerge, they will be included at this Web site.

6. Welcome to New IVS Technology Coordinator

The author will be stepping down as IVS Technology Coordinator at the end of 2012, coincident with retirement from MIT after 45 years of involvement with VLBI (although I plan to continue part-time for at least a while). It has been my great privilege to serve in this capacity and to work in this endeavor with so many wonderful and talented people over all the globe; without this great community support, my job would have been made much harder and the results less satisfactory. Thanks to you all.

Bill Petrachenko of Natural Resources Canada (NRCan) has been selected as the new IVS Technology Coordinator, beginning in 2013, and will be serving in a permanent position on the IVS Directing Board. Bill has long and deep experience in the theory and practice of VLBI and will be a great addition to the IVS team. Many of you are already familiar with the key role that Bill has played, and continues to play, in the development of VLBI2010. I have no doubt that his vision, expertise, and steadfastness will be a major force in helping to successfully steer VLBI technology development over the coming years.

Network Stations

Badary Radio Astronomical Observatory

Sergey Smolentsev, Valery Olifirov

Abstract

This report provides information about the Badary network station: general information, facilities, staff, present status, and outlook.

1. General Information

The Badary Radio Astronomical Observatory (Figure 1) was created by the Institute of Applied Astronomy (IAA) as one of three stations of the Russian VLBI network QUASAR [1].

The sponsoring organization of the project is the Russian Academy of Sciences (RAS). The Badary Radio Astronomical Observatory is situated in the Republic Buryatia (East Siberia) about 130 km east of Baikal Lake (see Table 1). The geographic location of the observatory is shown on the IAA RAS Web site (http://www.ipa.nw.ru/PAGE/rusipa.htm). The main instruments of the observatory are the 32-m radio telescope equipped with special technical systems for VLBI observations, GPS/GLONASS/Galileo receivers, a DORIS antenna, and the SLR system.

Figure 1. Badary observatory.

Table 1. The Badary observatory location and address.

Longitude	102°14′
Latitude	51°46′
Republic Buryatia	
671021, Russia	
oper@badary.ipa.stbur.ru	

2. Technical Staff

Vladimir Shpilevsky — the head of the observatory,
Roman Sergeev — the chief engineer, FS, pointing system control specialist, and
Roman Kuptsov — the engineer.

3. Technical and Scientific Information

Characteristics of the radio telescope are presented in Table 2.

Table 2. Technical parameters of the radio telescope.

Year of construction	2005
Mount	AZEL
Azimuth range	±270° (from south)
Elevation range	from $-5°$ to 95°
Maximum azimuth *	
- velocity	0.83 °/s
- tracking velocity	2.5 ′/s
- acceleration	12.0 $'/s^2$
Maximum elevation *	
- velocity	0.5 °/s
- tracking velocity	0.8 ′/s
- acceleration	12.0 $'/s^2$
Pointing accuracy	better than 10″
Configuration	Cassegrain (with asymmetrical subreflector)
Main reflector diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Main reflector shape	quasi-paraboloid
Subreflector shape	quasi-hyperboloid
Main reflector surface accuracy	± 0.5 mm
Frequency range	1.4–22 GHz
Axis offset *	3.7 ± 2.0 mm

* These values were changed to optimize the performance of the antenna system. The axis offset was measured in summer 2012 by geodesist Andrey Shamov.

4. Co-location of VLBI, GPS/GLONASS, DORIS, and SLR System

The Javad GPS/GLONASS/Galileo receiver with automatic meteorological station WXT-510 is in operation (Figure 2).

The SLR system "Sazhen-TM" (Figure 3) was mounted in July 2011. The "Sazhen-TM" SLR system was manufactured by Open Joint-stock Research-and-Production Corporation "Precision Systems and Instruments". Technical characteristics of the system are presented in Table 3. The SLR system at Badary joined ILRS in March 2012.

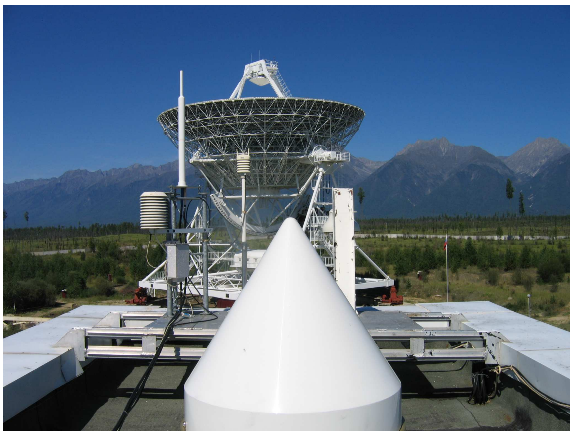

Figure 2. Javad GPS/GLONASS/Galileo receiver and DORIS beacon at the Badary observatory.

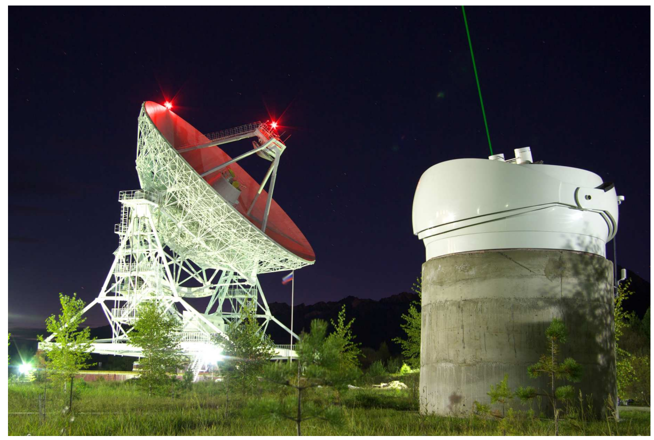

Figure 3. "Sazhen-TM" SLR system at Badary observatory.

Table 3. Technical parameters of the SLR system "Sazhen-TM".

Ranging distance, day	400-6000 km
Ranging distance, night	400-23000 km
Aperture	25 cm
Wavelength	532 nm
Beam divergence	12″
Laser pulse frequency	300 Hz
Pulse energy	2.5 mJ
Mass	170 kg
Normal points precision	1 cm
Angular precision	1-2″

5. Current Status and Activities

The Badary observatory participates in IVS and domestic VLBI observational programs. In 2012 Badary station participated in 27 diurnal IVS sessions — IVS-R4, IVS-T2, and EURO.

Badary participated in 47 diurnal sessions of the domestic Ru-E program to determine all Earth orientation parameters and in 191 one-hour Ru-U sessions for obtaining Universal Time using e-VLBI data transfer. Since July 2012, observations for the Ru-U program have been performed daily.

6. Outlook

We have the following plans for the coming year:

- To participate in IVS observations
- To carry out domestic observational programs with e-VLBI data transfer to daily obtain Universal Time and to weekly obtain Earth orientation parameters
- To carry out SLR observations of geodetic and navigation satellites
- To participate in EVN and RADIOASTRON observational sessions
- To continue geodetic monitoring of the antenna parameters
- To build foundation and to conduct survey operations for VLBI2010 antenna installation in 2014 (Figures 4 and 5).

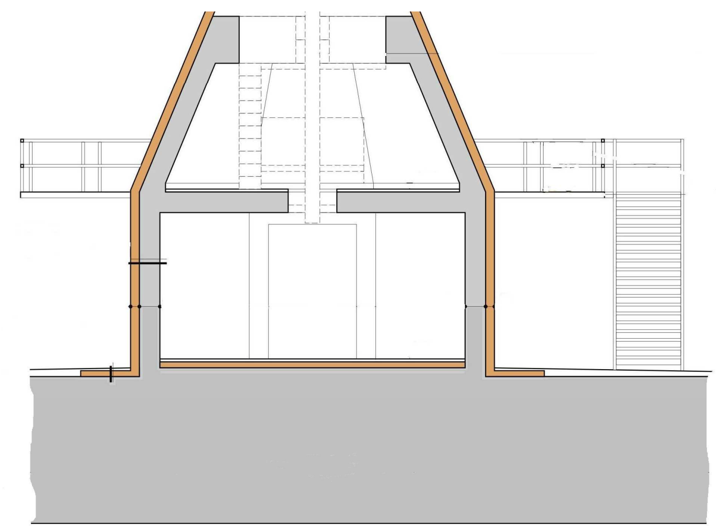

Figure 4. The foundation for RT-13 is planned to be built in 2013.

Figure 5. RT-13 is planned to be installed in 2014.

References

[1] Finkelstein A., Ipatov A., Smolentsev S. The Network “Quasar”: 2008 — 2011 // “Measuring the future”, Proceedings of the Fifth IVS General Meeting, A. Finkelstein, D. Behrend (eds.), St. Petersburg, “Nauka”, 2008. pp. 39–46.

Fortaleza Station Report for 2012

Pierre Kaufmann, A. Macílio Pereira de Lucena, Adeildo Sombra da Silva

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 until December 2012. The observing activities were resumed in May after the major maintenance that comprised the azimuth bearing replacement. The total observational experiments consisted of 103 VLBI sessions and continuous GPS monitoring recordings.

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), at the engineering school of the Mackenzie Presbyterian University in São Paulo, in agreement with the Brazilian National Space Research Institute, or INPE. The activities are currently carried out under an Agreement of Cooperation signed between NASA—representing research interests of NOAA and USNO—and the Brazilian Space Agency, or 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. The contract was extended until 2014. The counterpart of the operational costs, staff, and support of infrastructure are provided by INPE and by Mackenzie.

Figure 1. Fortaleza's 14.2-m radio telescope.

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 9.10.4. Observations are recorded with a Mark 5 system. 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, and it operates continuously. The collected data are provided to the NOAA/IGS center and to the Brazilian IBGE center. ROEN has all basic infrastructures for mechanical, electrical, and electronic maintenance of the facilities.

3. Staff

The Brazilian space geodesy program is coordinated by a Principal Investigator (PI), one of the authors (PK), who is Brazil's AEB representative in the NASA-AEB Agreement. The coordination receives support from the São Paulo office at CRAAM/Instituto and Universidade Presbiteriana Mackenzie, with administrative participation from Valdomiro S. Pereira and Lucíola Russo, CRAAM administrative manager and executive secretary, respectively. The Fortaleza Station facilities and geodetic VLBI and GPS operations are managed on site by Dr. Antonio Macilio Pereira de Lucena (CRAAE/INPE), assisted by Eng. Adeildo Sombra da Silva (CRAAE/Mackenzie), and the technicians Avicena Filho (CRAAE/INPE) and Francisco Renato Holanda de Abreu (CRAAE/Mackenzie).

4. Current Status and Activities

4.1. VLBI Observations

In the year 2012, Fortaleza carried out geodetic VLBI experiments as listed in Table 1.

Table 1. 2012 session participation.

Experiment	Number of Sessions
IVS-R1	45
IVS-R4	37
IVS-T2	04
IVS-R&D	03
IVS-RDV	03
IVS-CRF	04
IVS-CRMS	02
IVS-OHIG	05

4.2. Operational and Maintenance Activities

The summary of activities performed in the period is listed below:

1. Repair of the elevation drive base;
2. Repair and maintenance of the following equipment: cryogenic system, Mark 5 recorder, shaft encoder electronics, receiver box temperature controller, GPS time receiver, and IF distributor;
3. Maintenance and adjustment of DC azimuth and elevation motors;
4. Calibration of receiver box telemetry;
5. Operation and maintenance of geodetic GPS (NOAA within the scope of NASA contract);
6. Operation and maintenance of power supply equipment at the observatory (main and diesel driven standby); and
7. Maintenance of the Web site (http://www.roen.inpe.br) and the local server computer.

4.3. GPS Operations

The IGS network GPS receiver operated regularly at all times during 2012. Data were collected and uploaded to an IGS/NOAA computer.

5. Future Plans

Plans for the immediate future consist of the continuation of geodetic VLBI regular observations and the support of GPS receiver operations. Further progress is expected to expand data transmission via high speed national and international networks.

Goddard Geophysical and Astronomical Observatory

Ricardo Figueroa

Abstract

This report summarizes the technical parameters and the technical staff of the VLBI system at the fundamental station GGAO. It also gives an overview about the VLBI activities during the report year. The outlook lists the outstanding tasks to improve the performance of GGAO.

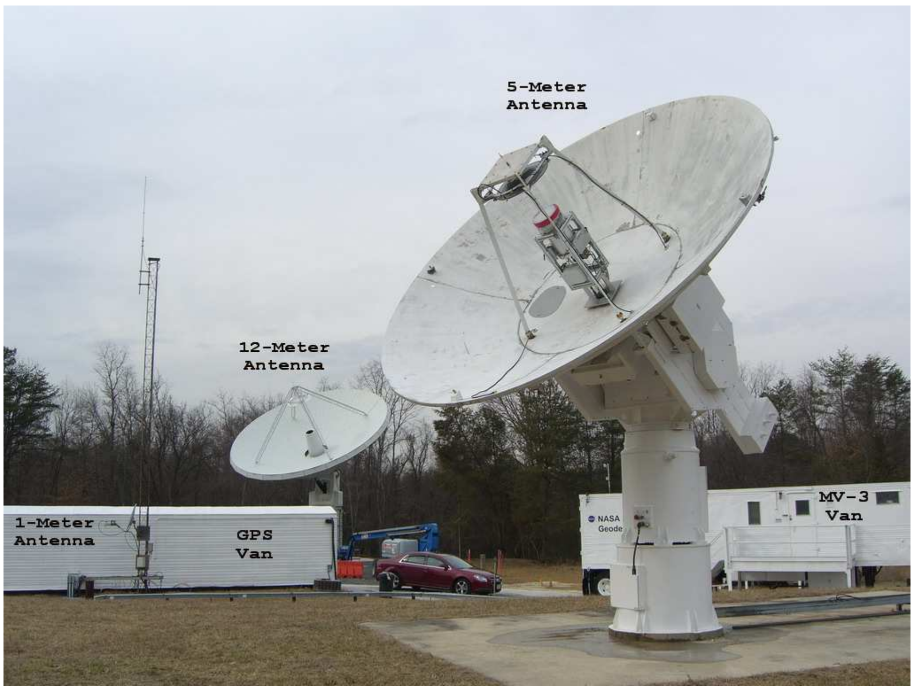

Figure 1. Goddard Geophysical and Astronomical Observatory.

1. GGAO at Goddard

The Goddard Geophysical and Astronomical Observatory (GGAO) consists of a 5-meter radio telescope for VLBI, a new 12-meter radio telescope for VLBI2010 development, a 1-meter reference antenna for microwave holography development, an SLR site that includes MOBLAS-7, the NGSLR development 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. In addition, we are 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 (Table 1).

Table 1. Location and addresses of GGAO at Goddard.

Longitude	76.4935° W
Latitude	39.0118° N
MV3 Code 299.0 Goddard Space Flight Center (GSFC) Greenbelt, Maryland 20771	
`http://cddisa.gsfc.nasa.gov/ggao/vlbi.html`	

2. Technical Parameters of the VLBI Radio Telescopes at GGAO

The 5-m radio telescope for VLBI at MV3 was originally built as a transportable station; however, it was moved to GGAO in 1991 and has been used as a fixed station. In the winter of 2002 the antenna was taken off its trailer and permanently installed at GGAO.

In October of 2010, construction of the new 12-meter VLBI2010 developmental antenna was completed. This antenna features all-electric drives and a Cassegrain feed system. Integration of the broadband receiver and the associated sub-systems is underway as a joint effort between Exelis and the MIT Haystack Observatory.

The technical parameters of the radio telescopes are summarized in Table 2.

Table 2. Technical parameters of the radio telescopes at GGAO.

Parameter	5-m	12-m
Owner and operating agency	NASA	NASA
Year of construction	1982	2010
Diameter of main reflector d	$5m$	$12m$
Azimuth range	$+/-270°$	$+/-270°$
Azimuth velocity	$3°/s$	$5°/s$
Azimuth acceleration	$1°/s^2$	$1°/s^2$
Elevation range	$+/-90°$	$5-88°$
Elevation velocity	$3°/s$	$1.25°/s(Avg.)$
Elevation acceleration	$1°/s^2$	$1°/s^2$
Receiver System		
Focus	Cassegrain	Cassegrain
Receive Frequency	$2-14GHz$	$2-14GHz$
T_{sys}	$100\,K$	$50\,K(Theoretical)$
Bandwidth	$512MHz$, 4 bands	$512MHz$, 4 bands
G/T	$26\,dB/K$	$43\,dB/K$
VLBI terminal type	CDP	VLBI2010
Recording media	Mark IV	Mark 5C

3. Technical Staff of the VLBI Facility at GGAO

GGAO is a NASA R&D and data collection facility. On April 9, 2011 the NENS contract transitioned to the SCNS contract operated by Exelis Information Systems. The staff at GGAO consists of four people under the contract. Exelis staff includes Jay Redmond and Katherine Pazamickas conducting VLBI operations and maintenance at GGAO with the support of Ricardo Figueroa and Charles Kodak.

4. Status of MV3 at GGAO

Having ceased VLBI operations in May 2007, MV3 continues on a full time basis to be a major component in the program to demonstrate the feasibility of the VLBI2010 broadband delay concept. Working under the guidance of the Exelis team, MV3's S/X components are currently in the process of being upgraded to provide additional support to the VLBI2010 System. The 2012 accomplishments for the 5-m antenna include:

- The ACU and Control Panel was completely rebuilt.
- The Cryogenic Dewar and the components required for restoration of the X-band have been located, and the wiring of the 017 box was upgraded.
- The feed assembly was repaired and is ready to be placed back on the antenna. The FSS has been recoated with a highly reflective surface.

Much of the 2012 activities at GGAO have been focused on performance testing and upgrading of the VLBI2010 12-m antenna. However, there were some other activities worth noting:

- Wideband system testing and characterization of the 12-m antenna.
- Procurement of new test equipment for characterization of the wideband RF hardware.
- Broadband Phase Cal performance testing.
- Performance testing of the 16 Gbps VLBI recording, demonstrated using Mark 6.
- Installation of the high frequency optical fiber link system.

Activities to understand antenna deformations that could potentially dilute the accuracy of the VLBI2010 system started in 2012. Initially, survey data collections were performed using the 5-m dish as the antenna to be tested and a 1-m satellite receiving dish as the phase reference. Preliminary results from 2010 data collection show that the imaging technique was able to faithfully reconstruct deformations in the aperture of the primary reflector. These deformations included GPS antennas mounted on the rim of the dish, an RF absorbing block, the offset feed Water Vapor Radiometer (WVR) cover, and the subreflector in the center of the primary as shown in Figure 2.

5. Outlook

GGAO will continue to support VLBI2010, e-VLBI, and other developmental activities during the upcoming year. Tentative plans for 2013 include:

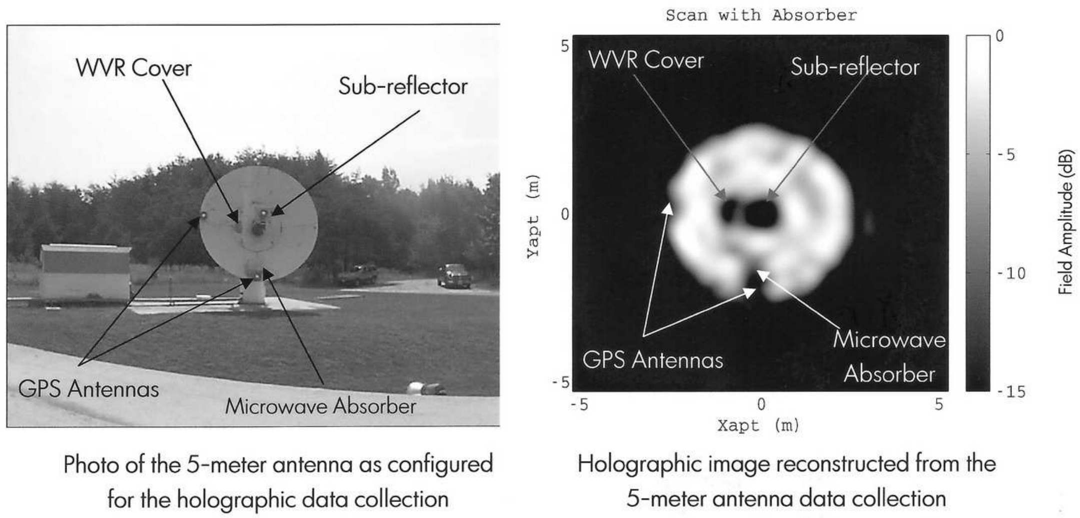

Figure 2. Holographic imaging of the 5-m antenna.

- Continue to upgrade the VLBI2010 broadband receiver system on the 12-m antenna and the new self-retractable feed positioner.
- Conduct IVS observations using the Mark 5C and Mark 6 recorders to demonstrate the VLBI2010 capabilities.
- Continue testing of the new broadband phase calibrator for the VLBI2010 system.
- Continue the upgrade of the 5-m antenna and initiate testing of the S/X band.
- Continue the use of the RDBEs, Mark 5Cs, and Mark 6s, replacing the DBE1s and Mark 5B+s.
- Continue to measure the baseline between the 5-m and the 12-m antennas for position ties to the reference frame.
- Try to understand the source of the elevation creep, which appears to have stopped.
- Try to understand why the antenna will not move in elevation under computer control when first started up on cold mornings.

Hartebeesthoek Radio Astronomy Observatory (HartRAO)

Marisa Nickola, Mike Gaylard, Jonathan Quick, Ludwig Combrinck

Abstract

HartRAO provides the only fiducial geodetic site in Africa, and it participates in global networks for VLBI, GNSS, SLR, and DORIS. This report provides an overview of geodetic VLBI activities at HartRAO during 2012, including the conversion of a 15-m alt-az radio telescope to an operational geodetic VLBI antenna.

1. Geodetic VLBI at HartRAO

Hartebeesthoek is located 65 kilometers northwest of Johannesburg, just inside the provincial boundary of Gauteng, South Africa. The nearest town, Krugersdorp, is 32 km away. The telescope is situated in an isolated valley which affords protection from terrestrial radio frequency interference. HartRAO currently uses a 26-meter 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 telescope is co-located with an ILRS SLR station (MOBLAS-6), an IGS GNSS station (HRAO), and an IDS DORIS station (HBMB) at the adjoining South African National Space Agency Earth Observation (SANSA EO) site. HartRAO is a full member of the EVN.

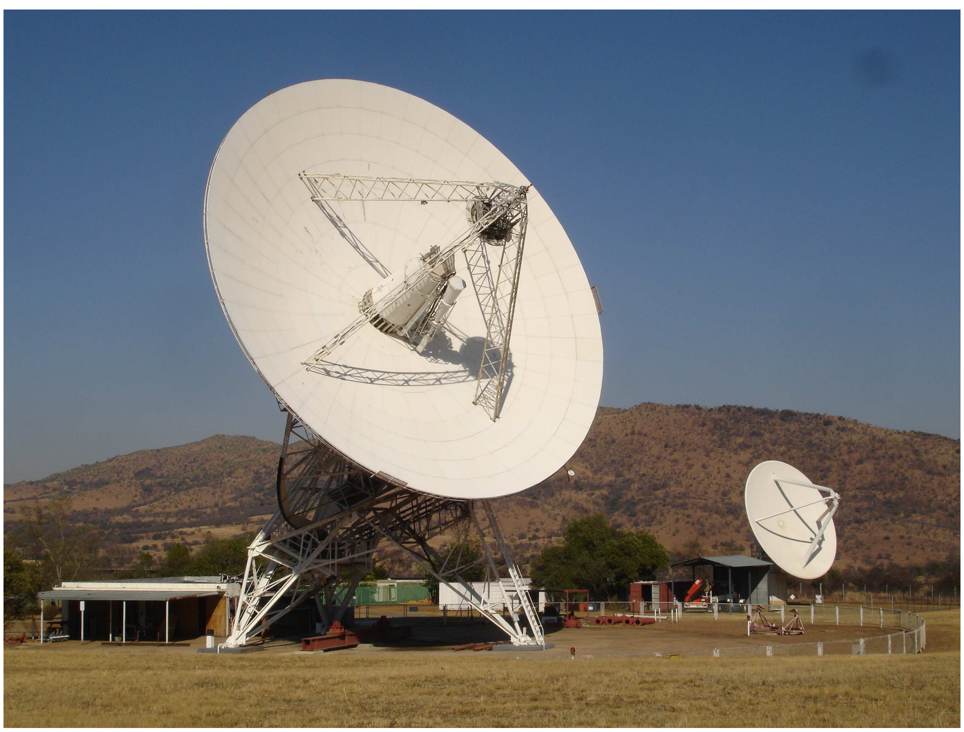

Figure 1. The HartRAO 26-m observing a source during R1551 on September 11, 2012, with the 15-m operating in tag-along mode as part of a commissioning test. (Credit: M. Gaylard)

2. Technical Parameters of the 26-m and 15-m Telescopes of HartRAO

Table 1 contains the technical parameters of the HartRAO 26-m and 15-m radio telescopes, while Table 2 contains technical parameters of the HartRAO 26-m and 15-m receivers. The current data acquisition system consists of a Mark 5 terminal and a Mark 5B+ recorder. Another two Mark 5B+ recorders are used, one with the 15-m and one for e-transfer of data. Two DBBC terminals have been acquired and will replace the Mark 5 terminal once FS support is available and recorders have been upgraded to Mark 5C. Three hydrogen masers are available for use, namely the iMaser 72, which is currently employed during geodetic VLBI, as well as two spares - EFOS-28 and the resuscitated EFOS-6.

Table 1. Antenna parameters.

Parameter	**HartRAO 26-m**	**HartRAO 15-m**
Owner and operating agency	HartRAO	HartRAO
Year of construction	1961	2007
Radio telescope mount	Offset equatorial	Az-El
Receiving feed	Cassegrain	Prime focus
Diameter of main reflector d	25.914 m	15 m
Focal length f	10.886 m	7.5 m
Focal ratio f/d	0.42	0.5
Surface error of reflector (RMS)	0.5 mm	1.6 mm
Short wavelength limit	1.3 cm	2 cm
Pointing resolution	0.001°	0.001°
Pointing repeatability	0.004°	0.004°
Slew rate on each axis	HA: 0.5° s^{-1}	Az: 2° s^{-1}
	Dec: 0.5° s^{-1}	El: 1° s^{-1}

Table 2. 26-m and 15-m receiver parameters. The degraded performance of the 26 m is due to the use of the dichroic reflector for simultaneous S- and X-band VLBI.

	26-m Dish		**15-m Dish**	
Parameter	**X-band**	**S-band**	**X-band**	**S-band**
Feeds	dual CP conical	dual CP conical	stepped horn	wide-angle coaxial corrugated horn
Amplifier type	cryo HEMT	cryo HEMT	cryo HEMT	cryo HEMT
T_{sys} (K)	52	40	40	42
S_{SEFD} (Jy)	849	1190	1400	1050
PSS (Jy/K)	16.3	29.8	35	25
3 dB beamwidth (°)	0.096	0.418	0.16	0.57

3. Current Status

Conversion of the 15-m KAT prototype to an operational telescope for geodetic VLBI started on March 30, 2012 with the installation of the S/X (2.3 and 8.4 GHz) prime-focus cryogenic receiver. On June 6, 2012, during cooled operation, the 15-m co-observed the radio galaxy 3C123 in test mode, together with the 26-m. As part of its commissioning, the 15-m participated in four R4 sessions during October and November 2012, and it produced data of acceptable quality. On November 29, it joined in Ultra-Rapid sessions for the determination of EOP. The last of these three sessions for 2012, UR1203 on December 17, was run remotely from home by Jonathan Quick. The 26-m had already started participating in Ultra-Rapid sessions with Tsukuba, Japan, at the end of August 2012, but the 15-m is capable of much faster slewing rates, making it ideally suited for these types of observations. The 15-m can also observe down to horizon level in all directions, whereas the equatorially-mounted 26-m has limited sky coverage to the south. Currently, geodetic VLBI data from all sessions, barring the RDV sessions, are being e-transferred to the correlators. Telescope time allocation for geodetic VLBI consisted of 59 24-hour experiments in 2012 (Table 3). Table 4 lists the HartRAO station staff who are involved in geodetic VLBI. Jonathan Quick (VLBI friend) provides technical support for the Field System as well as for hardware problems.

Table 3. Geodetic VLBI experiments in which HartRAO participated during 2012.

Experiment	Number of Sessions
R1	29
RD	8
CRDS	7
T2	6
CRF	3
OHIG	3
RDV	3
Total	59

Table 4. Staff supporting geodetic VLBI at HartRAO.

Name	Function	Program
L. Combrinck	Program Leader	Geodesy
J. Quick	Hardware/ Software	Astronomy
R. Botha	Operator	Geodesy
J. Grobler	Operator	Technical
L. Masongwa	Operator	Technical
R. Myataza	Operator	Technical
M. Nickola	Logistics/ Operations	Geodesy
P. Stronkhorst	Operator	Technical
C. Zondi	Operator	Technical

4. Future Plans

The idea is to lighten the 26-m antenna's workload considerably, offloading as many of the geodetic VLBI observations as possible onto the quick-slewing, all-sky seeing 15 m. We are actively pursuing implementation of VLBI2010, for which extra funding will be needed. HartRAO will be represented by radio astronomer Alet de Witt in the IAU's working group aimed at creating the next generation full-sky celestial reference frame (ICRF3). A tide gauge and seismometer will be added to the 2012 installation of a new GNSS station at Gough Island. Lunar Laser Ranger (LLR) refurbishment and design will proceed during 2013.

Figure 2. 15-m XDM's S/X receiver package being hoisted into position for prime-focus installation. (Credit M. Gaylard)

Figure 3. The 15-m, with cryogenically cooled receiver, co-observing radio galaxy 3C123 together with the 26-m. (Credit M. Gaylard)

Figure 4. On August 7, these visitors enjoyed the first snow at HartRAO since the NASA days in the 1960s. (Credit: F. Majola)

Figure 5. Ludwig Combrinck with the GNSS antenna installed on Gough Island in the South Atlantic Ocean.

Acknowledgements

The Space Geodesy Programme is an integrated program, combining VLBI, SLR, and GNSS, and it is active in several collaborative projects with GSFC, JPL, and GFZ (Potsdam) as well as numerous local institutes. Collaboration also includes CNES/GRGS/OCA and the ILRS community in a Lunar Laser Ranger (LLR) project with local support from the University of Pretoria and the National Laser Centre (CSIR), among others. General information as well as news and progress on geodesy and related activities can be found at `http://geodesy.hartrao.ac.za/`.

AuScope VLBI Project and Hobart 26-m Antenna

Jim Lovell, John Dickey, Brett Reid, Jamie McCallum, Stas Shabala, Christopher Watson, Simon Ellingsen, Anthony Memin

Abstract

This is a report on the activities carried out at the three AuScope VLBI observatories and the Hobart 26-m antenna. In 2012 the three AuScope 12-m antennas at Hobart (Hb), Katherine (Ke), and Yarragadee (Yg) completed their first full year of operations as an array. The Hobart 26-m antenna (Ho) continued to make a contribution to IVS, providing overlap with the Hb time series. In total the AuScope antennas and the Hobart 26 m observed for 146 antenna days in 2012.

In this report we also briefly highlight our research activities during 2012 and our plans for 2013.

1. VLBI Facilities

As part of AuScope (www.auscope.org.au), the University of Tasmania (UTAS) operates the AuScope VLBI Array (Lovell et al., 2013), three radio telescopes on the Australian continent (Figure 1), located near Hobart (Tasmania), Yarragadee (Western Australia), and Katherine (Northern Territory). Newly derived telescope coordinates are presented in Table 1. The AuScope telescopes closely follow the International VLBI Service VLBI2010 specification for the next generation of telescopes for geodesy (Petrachenko et al., 2009) or provide an upgrade path to meet the specification where it is not currently possible to do so.

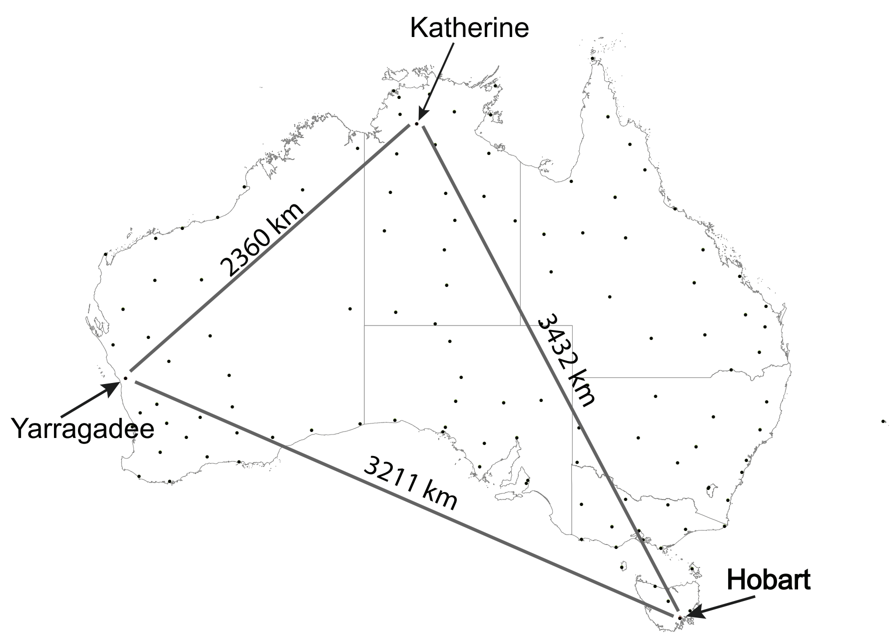

Figure 1. The geographical distribution of VLBI and GNSS infrastructure for AuScope. The locations of the new 12-m telescopes are labeled, and the new GNSS sites are indicated by filled dots.

Table 1. Calculated positions for the three AuScope VLBI antennas at epoch 2012.0, ITRF2005 datum (Lovell et al., 2013). The first uncertainty represents the average formal error in an individual measurement. The second uncertainty corresponds to weighted scatter about the best estimate.

Hobart 12 m (Hb)	
No. Sessions	82
Latitude (d m s)	$-42\,48\,20.0621 \pm (0.0006, 0.0012)$
Longitude (d m s)	$147\,26\,17.3070 \pm (0.0006, 0.0012)$
Height (m)	$40.967 \pm (0.019, 0.036)$
Katherine 12 m (Ke)	
No. Sessions	24
Latitude (d m s)	$-14\,22\,31.6679 \pm (0.0006, 0.0004)$
Longitude (d m s)	$132\,09\,08.5439 \pm (0.0007, 0.0006)$
Height (m)	$189.262 \pm (0.021, 0.017)$
Yarragadee 12 m (Yg)	
No. Sessions	14
Latitude (d m s)	$-29\,02\,49.7226 \pm (0.0012, 0.0006)$
Longitude (d m s)	$115\,20\,44.2576 \pm (0.0013, 0.0013)$
Height (m)	$248.236 \pm (0.040, 0.029)$

The new Hobart telescope (Hb) is co-located with the existing 26-m telescope (Ho) to preserve the more than 20 year VLBI time series at the site. Midway between the 26-m and 12-m telescopes is the HOB2 GNSS installation which has been a core site of the International GNSS Service (IGS) since its conception. A hut capable of housing a mobile gravimeter is also co-located on the site. The Yarragadee telescope (Yg) provides a far western point on the continent and is co-located with multiple existing geodetic techniques including SLR, GNSS, DORIS, and gravity. The Katherine site (Ke) is new and provides a central longitude, northern site. The telescope at Katherine is co-located with a new GNSS site that forms part of the AuScope GNSS network.

Each AuScope VLBI observatory is equipped with a main reflector that is 12.1 m in diameter. The telescope specifications include: 0.3 mm of surface precision (RMS), fast slewing rates (5 deg/s in azimuth and 1.25 deg/s in elevation), and acceleration (1.3 deg/s/s). All three sites are equipped with dual polarization S- and X-band feeds with room temperature receivers covering 2.2 to 2.4 GHz at S-band and 8.1 to 9.1 GHz at X-band. System Equivalent Flux Densities (SEFDs) are 3500 Jy in both bands. Data digitization and formatting is managed by the Digital Base Band Converter (DBBC) system, and data are recorded using the Mark 5B+ system. Each site is equipped with a Hydrogen maser time and frequency standard.

All three observatories were designed and constructed to be remotely controlled and monitored to keep operating costs at a minimum. Operation of the AuScope VLBI array is being carried out from a dedicated operations room on the Sandy Bay campus of the University of Tasmania.

2. Staff

Staff at UTAS consist of academics, Professor John Dickey (director), Dr. Simon Ellingsen, Dr. Christopher Watson, and Professor Peter McCulloch. Dr. Jim Lovell is Project Manager for the AuScope VLBI project. Dr. Jamie McCallum, Dr. Stas Shabala, and Dr. Anthony Memin are Australian Research Council Super-Science Fellows who are carrying out research aimed at improving geodetic solutions in the southern hemisphere. Mr. Brett Reid is the Observatory Manager whose position is funded by the university. In addition we have an electronics technical officer, Mr. Eric Baynes. For operation of the observatories during geodetic observations we rely heavily on support from astronomy PhD and postgraduate students. Logistical and maintenance support at Katherine is provided by Mr. Martin Ephgrave and at Yarragadee by Mr. Randall Carman and team at the MOBLAS5 SLR station.

3. AuScope VLBI Project Status

The Hobart telescope began IVS observations in October 2010 with Yarragadee and Katherine joining in May and June 2011 respectively. 2012 was the first full year that all three telescopes participated in IVS sessions.

The AuScope VLBI array is currently funded for operations at the level of 70 observing days per year until the end of 2014. The Hobart 26-m antenna will continue to participate in IVS sessions at the level of six days per year to assist in the maintenance and enhancement of the Celestial Reference Frame in the southern hemisphere.

4. Geodetic VLBI Observations

In 2012 the AuScope and Hobart 26-m antennas participated in 72 IVS sessions for a total of 146 antenna days of observing. A summary of the sessions is presented in Table 2.

Table 2. AuScope and Hobart 26-m antenna participation (number of days) in IVS sessions in 2012.

Session	Antenna			
	Ho	Hb	Ke	Yg
APSG		1	1	
AUSTRAL		4	4	4
CRDS	1	6	3	3
OHIG		3		
R1	5	18	17	15
R4	5	16	18	19
T2		1	1	1
Total	11	49	44	42

5. Research Activities

5.1. Source Structure

A key area of research over the past year has involved investigating the effects of quasar structure and evolution on geodetic solutions. In particular, we have begun using the IVS flux density data to track quasar evolution. Some promising metrics have been obtained for assessing the effects of quasar evolution on source position stability as evaluated by geodetic software. We plan to develop this work further in the coming year, with the ultimate goal of helping schedulers decide which quasars should be included in a given IVS session. Other related projects include a better calibration of the IVS flux density data, and simulation-based evaluation of the effects of quasar evolution on geodetic measurements.

5.2. Non-tidal Deformation

Taking into account the deformation of the Earth due to a range of well-known geophysical processes is required to accurately resolve VLBI solution parameters including EOPs and station coordinates. Models describing the dominant tidal signals (solid Earth tides, pole tide, and ocean tide loading) are routinely employed following the International Earth Rotation and Reference Systems Service recommendations. However to achieve greater accuracy at the millimeter level, non-tidal deformations must also be considered.

To this aim we investigated the effect induced by high-frequency non-tidal ocean loading at 18 Australian geodetic GPS sites. We found that correcting for this effect improved the daily geodetic observation scatter by up to 15% in 61% of the studied vertical coordinate time series (mean improvement about 6−8%). Another project has involved the investigation of hydrologically induced deformation which has a highly spatially correlated regional signature. The temporal variability in surface gravity, as deduced from the Gravity Recovery And Climate Experiment (GRACE) data, will help to extract the seasonal signal that will be compared to the geodetic time series. We aim to assess the improvement in station coordinates and the impact on other parameter estimates when including these non-tidal deformations in VLBI solutions.

5.3. Antenna Structural Deformation Study

In order to realize the full potential of the telescopes and achieve positional accuracy at the millimeter level, several sources of systematic error must be understood and mitigated. One such error source is structural deformation of the telescopes themselves, particularly due to the effects of thermal expansion. In 2013 we will embark on a high precision survey of the Hobart 12-m telescope in order to provide an insight into the structural behavior of the telescope. We will use the Australian Geophysical Observing System (AGOS) robotic telescope monitoring infrastructure, including a Leica TDRA6000 total station and an array of temperature sensors deployed over the telescope to study how the structure responds to the diurnal temperature cycle. We will compare our observations with modelled estimates obtained through computer modelling of the telescope with the final aim of establishing a corrective model for the AuScope telescopes to mitigate the effect in our geodetic analysis.

References

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Kashima 34-m Radio Telescope

Mamoru Sekido, Eiji Kawai

Abstract

The Kashima 34-m radio telescope has been continuously operated and maintained by the National Institute of Information and Communications Technology (NICT) as a facility of the Kashima Space Technology Center (KSTC) in Japan. This brief report summarizes the status of this telescope, the staff, and activities during 2012.

1. General Information

The Kashima 34-m radio telescope (Figure 1, left) was constructed as a main station of the "Western Pacific VLBI Network Project" in 1988. The telescope has been used not only for geodetic experiments but also for astronomical observations and spacecraft tracking under collaboration with National Astronomical Observatory of Japan (NAOJ), Kagoshima University, Institute of Space and Astronautical Science (ISAS), and other related institutes. The 34-m antenna was damaged by the big earthquake that occurred in north east Japan on March 11, 2011, and its operation was stopped for repair work until the end of March 2013.

The Kashima 34-m station is located about 100 km east of Tokyo in Japan. The Kashima 11-m radio telescope and the International GNSS Service station (KSMV) (Figure 1, right) are also co-located in the Kashima Space Technology Center. The station is maintained by the Space-Time Measurement Project of the Space-Time Standards Group, NICT.

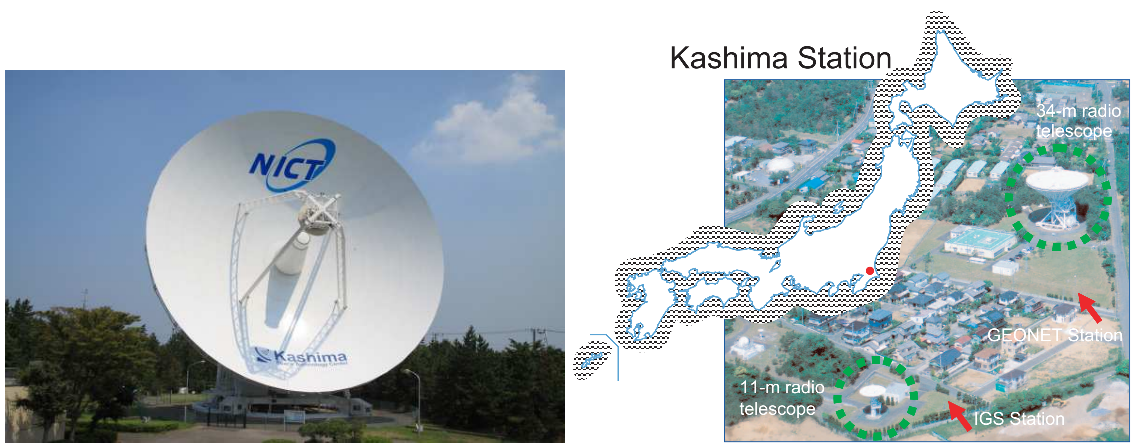

Figure 1. Left panel is a picture of the 34-m diameter radio telescope. Right panel indicates the location of Kashima KSTC in Japan and locations of 34-m antenna, 11-m antenna, and the GNSS station (KSMV) at the site.

2. Component Description

The receiver equipment of the Kashima 34-m radio telescope is summarized in Table 1 and Table 2. For radio frequency interference (RFI) mitigation, a high temperature superconductor

Table 1. Main specifications of the 34-m radio telescope.

Main reflector aperture	34 m
Latitude	N 35° 57' 21.27"
Longitude	E 140° 39' 36.33"
Height of AZ/EL intersection above sea level	43.7 m
Height of azimuth rail above sea level	26.9 m
Antenna design	Modified Cassegrain
Mount type	AZ-EL mount
Drive range azimuth	±270° from the North
Drive range elevation	7°-90°
Maximum speed azimuth	0.8°/sec
Maximum speed elevation	0.64°/sec
Maximum operation wind speed	13 m/s

Table 2. The receiver specifications of the 34-m radio telescope.

Band	frequency (MHz)	Trx (K)	Tsys (K)	Efficiency	SEFD (Jy)	Polarization
L	1405-1435	18	45	0.68	200	L/R
S	2193-2350	19	72	0.65	340	L/R
X-n (∗)	8180-9080	40	48	0.68	210	L/R
X-wL(#)	8180-9080	40	67	0.68	300	L/R
X-wH(#)	7860-8360	-	67	0.68	300	L/R
K	22000-24000	105	141	0.5	850	L
Ka	31700-33700	85	150	0.4	1100	R
Q	42300-44900	180	350	0.3	3500	– (†)

∗ : 8 GHz narrow band LNA . # : 8 GHz wide band LNA. † : No Polarizer

(HTS) band-pass filter (2193 - 2473 MHz) for S-band [1], and a conventional band-pass filter (1405 - 1435 MHz) for L-band have been used since 2008.

3. Staff

The engineering and technical staff of the Kashima Station are listed in Table 3.

4. Current Status and Activities

Recent status and activities related to the 34-m radio telescope in the NICT VLBI group are as follows:

Repair of Azimuth Wheel and Rail Cracking damage to the azimuth wheel, which is due to the big earthquake, was found in an inspection. Repair work to replace the azimuth wheels and rails is in progress and will finish at the end of March 2013.

Table 3. The engineering and technical staff of the Kashima station.

Name	Responsibility
KAWAI Eiji	Operations and maintenance.
SEKIDO Mamoru	Operations, maintenance, and coordination of development.
ICHIKAWA Ryuichi	Maintaining GNSS observation systems.
TAKEFUJI Kazuhiro	Development and experiments of wideband VLBI system.
UJIHARA Hideki	Designing of new wideband feed.
TSUTSUMI Masanori	Computer network and computer systems.
HASEGAWA Shingo	Computers for K5 system and supporting data conversion for e-transfer of IVS VLBI sessions.

IVS sessions The 34-m antenna could not participate in IVS sessions since 2011 because of the damages. In April 2013, the 34-m station will return to observing in the IVS sessions as it used to do.

Data transport of international and domestic VLBI observations has been made via e-transfer, rather than a physical shipping of recorded data disks. Depending on the request, Mark 5 data or K5 data are prepared and provided to IVS correlators from our data server, which is accessible from the Internet with a 1 Gbps connection.

Development of New Wideband Feed The main project of the VLBI group in NICT is a VLBI application for frequency comparison between distant atomic frequency standards. For pursuit of this project, a wideband observation system semi-compliant with a VLBI2010 system is under development. Due to some restriction, we decided to fix four observation frequency bands (3.2-4.2 GHz, 4.8-5.8 GHz, 9.6-10.6 GHz, and 12.8-13.8 GHz) for the new observation system. A new wideband feed system for this frequency selection is being designed. It will replace the original C-band receiver. The C-band receiver was already removed in June 2012, and the new wideband feed system will be installed in 2013.

5. Future Plans

The 34-m station will come back to operation after the first quarter in 2013. As mentioned in the former section, the new wideband feed is going to be installed, and a new optical wideband signal transmission system is to be installed for that. A new direct sampling system, which converts an analog RF signal to digital data without frequency conversion by taking advantages of the aliasing effect of sampling, is going to be employed experimentally for wideband observing. More details about technology development at NICT will be found in the NICT Technology Development Center Report, this volume.

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Kashima and Koganei 11-m VLBI Stations

Mamoru Sekido, Eiji Kawai

Abstract

Two 11-m VLBI antennas at Kashima and Koganei are continuously operated and maintained by the National Institute of Information and Communications Technology (NICT). This report summarizes the status of these antennas, the staff, and the activities in 2012.

1. General Information

Figure 1. 11-m VLBI antennas at Kashima (left) and Koganei (right).

Two 11-m VLBI antennas at Kashima and Koganei (Figure 1) have been operating for the monitoring of crustal deformation of the Tokyo metropolitan area (Key Stone Project) since 1995 [1]. After the regular VLBI sessions with the KSP VLBI Network terminated in 2001, the 11-m VLBI stations at Kashima and Koganei have mainly been used for research and technical developments.

2. Component Description

The antenna parameters of Kashima-11 and Koganei-11 are summarized in Table 1. The band-pass filters for S-band (2215-2375 MHz) have been installed since 2010 for RFI mitigation at both stations. A phase calibration signal (P-cal) of 5 MHz interval has been used instead of a 1 MHz interval at these KSP stations.

Table 1. The antenna parameters of the 11-m antennas.

		Kashima	Koganei
Antenna Type		Cassegrain type	
Diameter of the Main Reflector		11 m	
Mount Style		Az El mount	
Latitude		N 35° 57' 19.46"	N 35° 42' 37.89"
Longitude		E 140° 39' 26.86"	E 139° 29' 17.06"
Height of Az/El intersection above sea level		62.4 m	125.4 m
Input Frequency [MHz]	S band	2212 ∼ 2360	2212 ∼ 2360
	X Low band	7700 ∼ 8200	7700 ∼ 8200
	X High band	8180 ∼ 8680	8100 ∼ 8600
Local Frequency [MHz]	S band	3000	3000
	X Low band	7200	7200
	X High band	7680	7600
SEFD [Jy]	X-band	5700	9500
	S-band	3300	5500

2.1. Kashima-11

The original design of these antennas was identical. However, the frequency of the first local oscillator of X-H band at the Kashima 11-m station was changed by 80 MHz in 2008, so that the observation frequency range became the same as that of the Kashima 34-m station. A compact hydrogen maser atomic time standard was installed in November 2011. Since then the reference signal of the Kashima 11-m station has been provided from this frequency standard. Also, a precise temperature control box (PTCB: Figure 2) has been used since 2010 to keep the environmental temperature of the reference signal distribution unit, which is sensitive to temperature variation, constant. The PTCB can keep the air temperature variation in the box within a few tenths of degrees, while the room temperature around the PTCB varies in the range of a few degrees under the control of a standard air conditioner.

Figure 2. Precise temperature control box located at Kashima 11-m Station.

2.2. Koganei-11

The reference signal (5 MHz) has been provided from an H-maser standard, which has been synchronized to the UTC(NICT), through the optical loop-back controlled reference signal transmission system since 2009 [2]. Therefore the clock of the Koganei 11-m station is highly stable, and its rate is maintained to be close to zero with respect to the UTC.

3. Staff

The 11-m antenna stations at Kashima and Koganei are operated and maintained by the members of the Space-Time Standards Laboratory. The staff members contributing to the operation and maintenance of the 11-m antennas are as follows:

- AMAGAI Jun (Okinawa): has supported Antenna System and Timing Systems at the Koganei 11-m station. He moved to Okinawa Electromagnetic Technology Center in July 2012.
- HASEGAWA Shingo (Kashima): Maintenance of computer system.
- ICHIKAWA Ryuichi (Koganei, Tokyo): Maintenance of meteorological sensors and IGS receivers.
- KAWAI Eiji (Kashima): Overall antenna system.
- SEKIDO Mamoru (Kashima): Operation and overall maintenance of the VLBI systems.
- TAKEFUJI Kazuhiro (Kashima): Operation and maintenance of data acquisition system.

The operation and maintenance of the 11-m VLBI station at Koganei have been also supported by the Space Weather and Environment Informatics Laboratory and the Space Communication Systems Laboratory at the Koganei Headquarters of NICT.

4. Current Status and Activities

The two 11-m antennas have been used for a variety of VLBI sessions and single dish sessions as follows:

International and Domestic VLBI Observation for Geodesy: The Kashima region was widely affected by the big earthquake that occurred on March 11, 2011 in the north east area of Japan. Fortunately the Kashima 11-m and Koganei 11-m stations were not seriously damaged. These two antennas have been participating in IVS-T2, APSG, and JADE sessions since 2011. These participations are important for monitoring the change of the global positions of the Kashima and Koganei stations after the earthquake.

Data transport of international and domestic VLBI observations are made via e-transfer, rather than via physical shipping of recorded data disks. Depending on the request, Mark 5 data or K5 data are stored and provided to the correlator from our data server, which is accessible from the Internet with a 1 Gbps connection.

VLBI Experiments for Frequency Comparison: The Space-Time Standards Laboratory is in charge of keeping the national standard time of Japan and is developing optical frequency standards for the primary frequency standards of the next generation. The main mission of the VLBI group of NICT is the development of a VLBI system that could be used for frequency comparison between optical frequency standards at intercontinental distances. For this purpose, a new VLBI system with small diameter antenna pairs and a wideband observation system are under development [3]. Before the new VLBI system becomes available, test experiments with the 11-m antenna pair will have been conducted several times for a feasibility study of frequency comparison.

Astronomical Observation: A flare up of the galactic center Sgr-A* of our galaxy is predicted to occur in the summer of 2013 by Glissen et al. [4]. Based on the proposal by Miyoshi et al. [5] and Tsuboi et al. [5], monitoring observations of the flux variations of Sgr-A* in S/X-band were conducted in June, October, and December in 2012. The observations will be continued until the fall of 2013 at least.

Receiving the Down-link Signal from STEREO Spacecraft: The Koganei 11-m antenna has been used to download data from the STEREO spacecrafts[1] in cooperation with the Space Weather and Environment Informatics Laboratory of NICT. When VLBI sessions or maintenance work were not scheduled, the Koganei 11-m antenna has been mostly used for tracking the STEREO.

5. Future Plan

The antenna performance of the Koganei 11-m antenna is about 60% with respect to that of the Kashima 11-m antenna. The reason for this degradation is not known yet. We are going to investigate the reason and to recover the performance of the Koganei 11-m antenna to the same level with that of Kashima 11-m.

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Kokee Park Geophysical Observatory

Ron Curtis

Abstract

This report summarizes the technical parameters of the VLBI system at the Kokee Park Geophysical Observatory and provides an overview of the activities that occurred in 2012.

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.

2. Technical Parameters

The receiver is of NRAO (Green Bank) design (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.

Timing and frequency is provided by a Sigma Tau Maser with a NASA NR Maser providing backup. Monitoring of the station frequency standard performance is 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 people employed by ITT Exelis under the SCNS contract to NASA for the operation and maintenance of the observatory. Chris Coughlin, Lawrence Chang, Kiah Imai, and Ron Curtis conduct VLBI operations and maintenance. Ben Domingo is responsible for antenna maintenance, with Amorita Apilado providing administrative, logistical, and numerous other support functions. Kelly Kim also supports VLBI operations and maintenance during 24-hour experiments and as backup support.

4. Mission Support

Kokee Park has participated in many VLBI experiments including IVS R4 and R1. KPGO also participates in the RDV experiments. KPGO averaged two experiments of 24 hour duration each week, with daily Intensive experiments in 2012. After the earthquake in Japan in March 2011, KPGO began supporting the INT2 weekend Intensive experiments while data from the Tsukuba VLBI station was being analyzed for weekend Intensive experiment support. The KPGO support of the weekend Intensive experiments concluded in April 2012.

Kokee Park also hosts other systems, including a 7-m PEACESAT command and receive antenna, 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.

Table 1. Technical parameters of the radio telescope at KPGO.

Parameter	Kokee Park
owner and operating agency	USNO-NASA
year of construction	1993
radio telescope system	Az-El
receiving feed	primary focus
diameter of main reflector d	$20m$
focal length f	$8.58m$
f/d	0.43
surface contour of reflector	$0.020 inches rms$
azimuth range	$0 \ldots 540°$
azimuth velocity	$2°/s$
azimuth acceleration	$1°/s^2$
elevation range	$0 \ldots 90°$
elevation velocity	$2°/s$
elevation acceleration	$1°/s^2$
X-band (reference $\nu = 8.4GHz, \lambda = 0.0357m$)	$8.1 - 8.9\,GHz$
T_{sys}	$40\,K$
$S_{SEFD}(CASA)$	$900\,Jy$
G/T	$45.05\,dB/K$
η	0.406
S-band (reference $\nu = 2.3GHz, \lambda = 0.1304m$)	$2.2 - 2.4GHz$
T_{sys}	$40\,K$
$S_{SEFD}(CASA)$	$665\,Jy$
G/T	$35.15\,dB/K$
η	0.539
VLBI terminal type	VLBA/VLBA4-Mark 5
Field System version	9.11.1

5. Recent Activities

In January 2012, ITT Exelis support personnel from the Goddard Space Flight Center made a trip to KPGO and, working with local KPGO staff, were successful in repairing the failed NASA NR-1 Maser. The NASA NR-1 Maser remains in its backup role to the Sigma Tau Maser for timing and frequency at KPGO.

The PEACESAT mission came to an end near the end of 2011. In March 2012, KPGO staff and NOAA personnel performed the de-orbit maneuvers of the GOES-7 spacecraft to formally end the PEACESAT support at KPGO.

The KPGO 20-m antenna has been in service for 20 years and is starting to show signs of its age and obsolescence. In March 2012, the KPGO 20-m antenna construction contractor, GD Satcom, made a site visit to assess some observed anomalies in the 20 m's mechanical operation. There is noticeable axial play in the 20 m's azimuth bearing, and it is outside of design specifications but still capable of supporting the VLBI mission. The most significant impact of the axial play is increased wear on the azimuth bull gear teeth caused by the azimuth drive pinions as a result of the degraded tooth mesh with the axial play of the bearing. The GD Satcom engineers indicated that the wear on the azimuth bull gear teeth will eventually result in the 20-m antenna falling out of mission support capability. Actions are being planned to extend the 20 m mission support life-cycle given the current degraded condition of the azimuth bearing and its impacts.

On June 18, 2012, we started our scheduled experiments while our receiver was in the process of re-cooling. As the receiver re-cooled, we noticed that the X-band was not present in our local monitoring systems. We verified the missing X-band with the USNO correlator and began troubleshooting. We reached out to NRAO and NVI for their insights and quickly narrowed the issue down to a failed LNA in the dewar of the receiver. The normal process would be to pull the receiver box and work on removing the dewar with the receiver box in the workshop. With the current rusted state of the receiver box focus rails, bringing the receiver box to the ground and then having to re-focus after re-installation presented substantially increased complexity to the repair efforts. After assessing the side panel access to the receiver box, we were able to partially disassemble some components from the dewar and carefully remove the dewar itself to examine it on an operations building workbench. The practice in previous years was to send the dewar back to NRAO for servicing, which probably would have resulted in an extended period of downtime. After discussing the process with NRAO, we felt comfortable in working on the dewar ourselves. We opened the dewar and verified a failed XR LNA with a short to ground on Stage 1. NRAO had an identical custom built spare on their shelf that they shipped overnight to us to replace the failed LNA. While waiting for the arrival of the replacement LNA, we used our time to clean other components in the cryogenic system and replace worn components as necessary in preparation for re-installation in the receiver box. Some of this work was previously planned including the running of a new 30A circuit up to the helium compressor on the elevation platform, replacing old transducers, replacing a damaged refrigerator, and replacing an aging vac-ion pump. We received the replacement LNA late on June 26 and began work on the dewar first thing in the morning on June 27. We installed the replacement LNA in the dewar and it tested nominal. We worked through some Kokee weather issues and completed the dewar reinstallation into the receiver box and verified nominal status for all components. We re-cooled the receiver into nominal 15K and 50K stage ranges and reached temperature levels we had never previously seen. We discussed this with NRAO and NVI, and we came to the conclusion that we fixed what might have been a bad thermistor connection when we installed the replacement LNA. The readings we are seeing now are very good and nominal. On the morning of June 28 we verified the new LNA readings after it had been cooled for 24 hours, and all were in nominal ranges. We started observing session R4539 at scan 180-2202 upon our return to operational status. After session I12181, we adjusted the bias on the XR LNA per NRAO direction to optimize the X-band performance. The extended team effort by KPGO staff, NRAO, NVI, and remote ITT Exelis support personnel made it possible to identify the problem and get the issue resolved in a little over a week.

The e-transfer of the INT1 sessions from KPGO to USNO were performed over microwave infrastructure provided by the Pacific Missile Range Facility (PMRF) and connecting KPGO to

DREN. Plans to migrate to a dedicated fiber connection to DREN at PMRF have been delayed due to damage to the fibers by a wild fire. MIT is working with the Hawaii Intranet Consortium (HIC) and DREN to improve the KPGO e-transfer rate. Long term plans are still to make real-time VLBI data transfers from KPGO a reality.

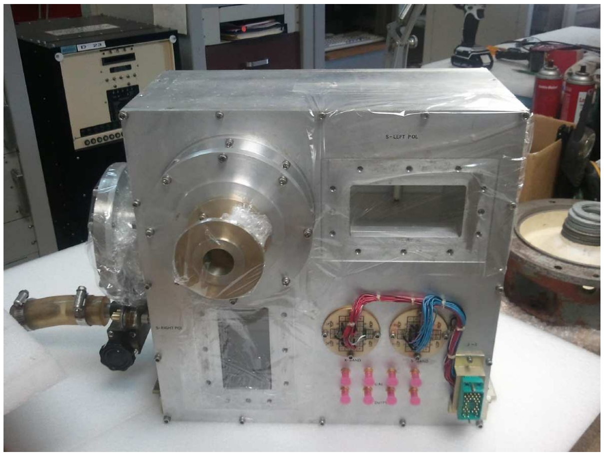

Figure 1. 20-m S/X dewar.

Figure 2. LNA repair.

6. Outlook

GD Satcom is scheduled to make a site visit to KPGO to implement some changes to the KPGO 20-m antenna configuration in an effort to reduce the wear on the azimuth bull gear teeth due to the axial play in the azimuth bearing. Those changes include re-alignment of the azimuth drives to improve teeth mesh between the azimuth pinions and the bull gear. They will also tune the servo system to decrease the acceleration and deceleration of both the azimuth and elevation drive systems.

KPGO is making progress in efforts to upgrade the 20-m antenna signal path to VLBI2010 specifications. The RDBE and up-down converter components of a new digital backend system have been delivered to KPGO from MIT. There have been some discussions on implementing the digital backend components with the existing 20-m antenna S/X feed, and progress on that is currently limited by Mark 5C recorder capabilities at both KPGO and correlators. KPGO staff, ITT Exelis personnel at GSFC, USNO personnel, and MIT have begun planning the final design and installation of a new broadband front end for the KPGO 20-m antenna.

PMRF is working on repairs to the fiber runs that were damaged by a wild fire. Those repairs are expected to be completed in the first half of 2013, and progress on establishing a dedicated fiber path to HIC/DREN for KPGO e-transfers can continue next year.

In September 2012, USNO personnel made a site visit to KPGO to assess possible locations and local environmental impacts of constructing a next generation VLBI antenna. KPGO will continue to assist USNO in an effort to establish a next generation VLBI telescope at KPGO.

Matera CGS VLBI Station

Giuseppe Bianco, Giuseppe Colucci, Francesco Schiavone

Abstract

This report describes the status of the Matera VLBI station. Also, in an overview of the station, some technical characteristics of the system, and staff addresses are given.

1. General

Figure 1. The Matera "Centro di Geodesia Spaziale" (CGS).

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 at CGS. Fully integrated into the worldwide network, SAO-1 was in continuous operation from 1983 up 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 and replaced 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 876 sessions up through December 2012.

In 1991 we started GPS activities, participating in the GIG 91 experiment and installing at Matera a permanent GPS Rogue receiver. In 1994 six TurboRogue SNR 8100 receivers were purchased in order to create the Italian Space Agency GPS fiducial network (IGFN). At the moment 12 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).

In 2000 we started activities with an Absolute Gravimeter (FG5 Micro-G Solutions). The gravimeter operates routinely at CGS, and it 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 extended CGS' involvement also to remote sensing activities for present and future missions (ERS-1, ERS-2, X-SAR/SIR-C, SRTM, ENVISAT, and COSMO-SkyMed).

Figure 2. MLRO in action.

2. Technical/Scientific Overview

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 EFOS-8 H-maser from Oscilloquartz is used as a frequency source for VLBI.

Table 1. Matera VLBI Antenna Technical Specifications.

Input frequencies	S/X	2210−2450 MHz / 8180−8980 MHz
Noise temperature at dewar flange	S/X	<20 K
IF output frequencies	S/X	190−430 MHz / 100−900 MHz
IF Output Power (300 K at inp. flange)	S/X	0.0 dBm to +8.0 dBm
Gain compression	S/X	<1 dB at +8 dBm output level
Image rejection	S/X	>45 dB within the IF passband
Inter modulation products	S/X	At least 30 dB below each of two carriers at an IF output level of 0 dBm per carrier
T_{sys}	S/X	55/65 K
SEFD	S/X	800/900 Jy

3. Staff

The list of the VLBI staff members of the Matera VLBI station is provided in Table 2.

Table 2. Matera VLBI staff members.

Name	Agency	Activity	E-Mail
Dr. Giuseppe Bianco	ASI	Space Geodesy Manager	giuseppe.bianco@asi.it
Francesco Schiavone	e-geos	Operations Manager	francesco.schiavone@e-geos.it
Giuseppe Colucci	e-geos	VLBI contact	giuseppe.colucci@e-geos.it

4. Status

In 2012, 52 sessions were observed. Figure 3 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 had been 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]-[3].

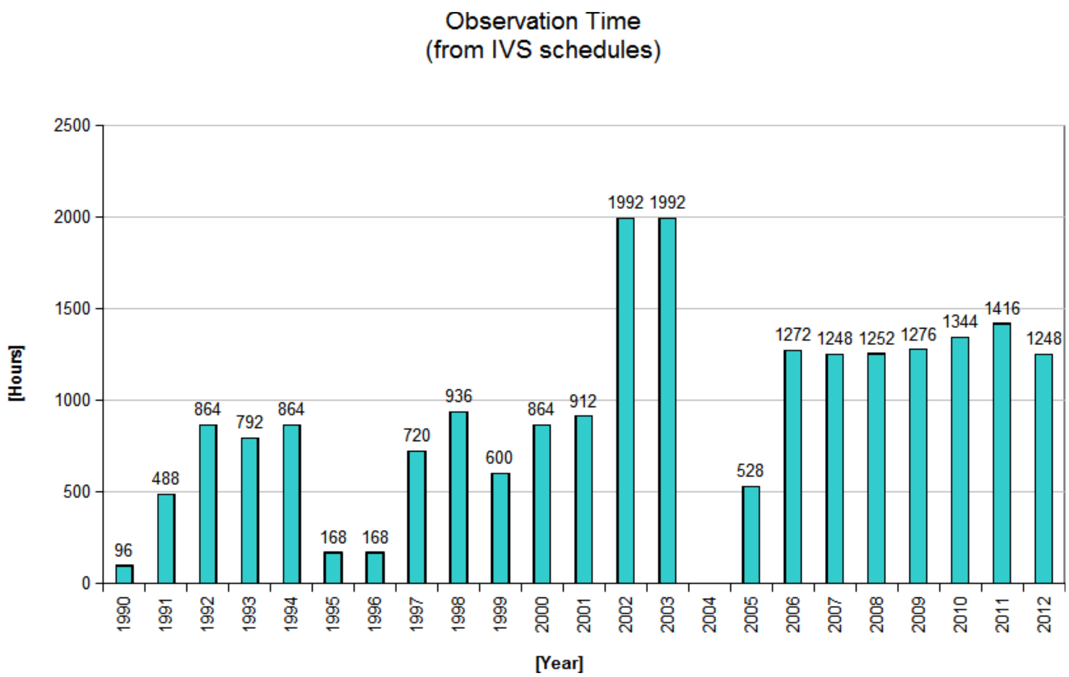

Figure 3. Acquisitions per year.

5. Outlook

In order to plan the eventual building of a VLBI2010 system, the fund raising investigation process has been started. At this moment it is not clear when the budget for starting the project will be ready.

In May 2012, the remaining two azimuth wheels were replaced. The other two were replaced in 2008 and 2009 respectively.

The process of purchasing a new H-Maser has been already started. The delivery of the new unit is planned for 2013.

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The Medicina Station Status Report

Alessandro Orfei, Andrea Orlati, Giuseppe Maccaferri

Abstract

General information about the Medicina Radio Astronomy Station, the 32-m antenna status, and the staff in charge of the VLBI observations is provided. In 2012, the data from geodetic VLBI observations were acquired using the Mark 5A recording system with good results. Updates of the hardware were performed 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 1985 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.

2. Antenna Description

The Medicina antenna has Cassegrain optics, consisting of a primary mirror that is 32 m in diameter and a secondary mirror, called the subreflector, of convex shape and approximately 3 m in diameter. The subreflector, mounted on a quadrupod, is placed opposite the primary mirror and focuses the radio waves at its center, where the receiver system is located. For some observing frequencies, a simplified optical system is enough. The subreflector is therefore shifted from its normal position, and the receiving system is placed at the primary focus. This is the case for the S-X observations. The antenna can operate in the range between 327 MHz and 22 GHz.

The receivers are cooled with cryogenic techniques to improve the system sensitivity. The antenna's operative receiver is easily changed; only a few minutes are needed to change the observing frequency. A recent picture of the antenna is shown in Figure 1.

3. The Staff

Many scientists and technicians take care of the observations. However, a limited number are dedicated to maintaining and improving the reliability of the antenna during the observations: Alessandro Orfei is the Chief Engineer, expert in microwave receivers, and Andrea Orlati, Software Engineer, takes care of the observing schedules and regularly implements SKED, DRUDG, and the Field System. In 2012, Giuseppe Maccaferri took a half-time contract. Marco Bartolini and Simona Righini have been temporary included in the staff, helping Andrea Orlati for the VLBI preparation and observation.

Figure 1. View of the Medicina 32-m dish taken during geodetic VLBI observations. Note that the subreflector is shifted to allow the use of the S/X receiver located in the primary focus of the radio telescope.

4. Current Status and Activities

The Mark 5C board and the DBBC have been delivered. At the time of this report they are on the way to be integrated in the observing system.

A new Helium pipeline and new cryogenic compressors have been installed on the antenna.

The new H-maser has been successfully tested at the factory. It will be delivered before the end of February.

The driving system of the subreflector is going to be re-engineered; installation, tests, and commissioning are expected to occur during autumn 2013.

The upgrade of the fiber optic link to 10 Gb/s is complete. A full bandwidth (without data drop) e-VLBI observation has been carried out. IVS data correlated in Bonn are regularly transferred off-line through optical fiber.

5. Geodetic VLBI Observations

In 2012, Medicina took part in 22 24-hour routine geodetic sessions (namely two IVS-T2, 17 IVS-R4, one R&D, and two EUROPE experiments).

Metsähovi Radio Observatory - IVS Network Station

Minttu Uunila, Nataliya Zubko, Markku Poutanen, Juha Kallunki, Ulla Kallio

Abstract

In 2012, Metsähovi Radio Observatory together with Finnish Geodetic Institute officially became an IVS Network Station. Eight IVS sessions were observed during the year. Two spacecraft tracking and one EVN X-band experiment were also performed. In 2012, the Metsähovi VLBI equipment was upgraded with a Digital Base Band Converter, a Mark 5B+, a FILA10G, and a FlexBuff.

1. General Information

Aalto University Metsähovi Radio Observatory and Finnish Geodetic Institute (FGI) are two separate institutes which together form the Metsähovi IVS Network Station. Metsähovi Radio Observatory operates a 13.7 meter radio telescope at the premises of Aalto University at Metsähovi, Kylmälä, Finland about 35 km from the university campus. In the same area, near Metsähovi Radio Observatory, there is the Metsähovi Research Station of FGI.

Figure 1. Metsähovi Radio Observatory.

2. Component Description

The Metsähovi Radio Observatory has been operational since 1974. The telescope was upgraded in 1992-1994. The radome was replaced with a new one, and new surface panels were installed. Metsähovi together with FGI started observing IVS T2 and EUROPE sessions in 2004. Approximately six to eight sessions are observed per year. The antenna speed of the Metsähovi antenna is 1.2 degrees per second. The surface accuracy of the present telescope is 0.1 mm (rms). The geodetic VLBI receiver of Metsähovi uses right circular polarization and 8.15-8.65 and 2.21-2.35 GHz frequency bands. Astronomical orbservations are also carried out. Metsähovi is known for its long-term quasar monitoring. Astronomical VLBI observations are carried out with the 22 GHz receiver.

2.1. Metsähovi Fundamental Station

Finnish Geodetic Institute (FGI) is running the Metsähovi Fundamental Station. It is a part of the IAG GGOS Core station network. The instrumentation includes geodetic VLBI (in co-operation with Aalto University), Satellite Laser Ranging (SLR), DORIS, GNSS, and absolute and superconducting gravimeters. Currently, instrumentation is being renewed based on special funding from the Ministry of Agriculture and Forestry. During the next five years, the plan includes e.g. a new VLBI2010 compatible radio telescope. FGI is committed to maintain and develop Metsähovi as a geodetic fundamental station.

3. Staff

FGI is responsible for the geodetic VLBI observations and is the owner of the S/X receiver. The radio telescope is owned and operated by the Aalto University, and an annual agreement is made on its use for geodetic VLBI sessions. It is not possible to increase the number of annual sessions (currently six to eight), because the telescope is mainly used for astronomical observations. Operation during the geo-VLBI sessions and technical questions are handled jointly; all other technical work, telescope maintenance, and maintenance of instrumentation and data connections are done by the personnel of the radio telescope.

Metsähovi personnel working with geodetic VLBI observations in 2012 are listed in Table 1. Dr. Elizaveta Rastorgueva-Foi is in charge of all VLBI observations at Metsähovi. The theses are listed in the sub-section: Data analysis. The preparation, operation of GeoVLBI observations, and submission of data are provided by staff from FGI. The personnel engaged in the work are listed in Table 2.

Table 1. Metsähovi Radio Observatory personnel involved in geodetic VLBI observations during 2012.

Name	Title	Responsibility
Lic.(tech.) Juha Kallunki	Laboratory manager	VLBI equipment, NEXPReS
M.Sc.(tech.) Ari Mujunen	Laboratory manager	NEXPReS
Dr. Elizaveta Rastorgueva-Foi	VLBI friend	VLBI observations
M.Sc. Minttu Uunila	Doctoral candidate	VLBI equipment
M.Sc.(tech.) Petri Kirves	Operating engineer	Receivers
Tomi Salminen	Research assistant	NEXPReS

Table 2. FGI personnel involved in geodetic VLBI observations during 2012.

Name	Title	Responsibility
Prof. Markku Poutanen	Head of the Department of Geodesy and Geodynamics	Metsähovi research station
Dr. Nataliya Zubko	Senior research scientist	preparation of GeoVLBI sessions, operation of GeoVLBI observations, e-transfer of data
M.Sc. Veikko Saaranen	Special research scientist	operation of GeoVLBI observations
M.Sc. Ulla Kallio	Senior research scientist	Local ties measurements
M.Sc. Simo Marila	Research scientist	operation of GeoVLBI observations

4. Current Status and Activities

4.1. Geodetic VLBI Experiments

Metsähovi together with FGI observed eight IVS sessions in 2012. Also two spacecraft tracking experiments were performed. Metsähovi radio antenna contributed to the following EURO and T2 IVS sessions: EUR115, EUR116, EUR117, EUR118, T2082, T2083, T2084, and T2086. Most of the observations were achieved properly. However, some technical problems also occurred during the observations. In particular, within the EUR115 session, the problems with antenna slewing appeared a few times, so most of the scans were not recorded. Besides, time differences between the Field System and the formatter clocks were found during some sessions. Troubles with the Mark 5 recording system happened, but because the observations are simultaneously recorded with two independent systems, namely Mark 5 and PC-EVN, all the observations were successfully recorded. For the period of 2012, most of the sessions were observed without antenna cable calibration, due to technical reasons. Therefore, the possible changes in the cable's length were not monitored. Most of the sessions were correlated at the Bonn correlator. The data were sent there via e-transfer using the Tsunami protocol. In accordance with the correlation reports, the amounts of correlated observations varied from 60% to 80%.

4.2. Technical Activities and Issues

In December 2012, Metsähovi successfully tested the new equipment consisting of DBBC and Mark 5B+ during a Venus Express spacecraft tracking experiment. Also the new standalone FILA10G together with the new FlexBuff data storage computer developed in the EU NEXPReS project were successfully deployed.

4.2.1. BBC/DBBC Status

The status of the old VLBI hardware is not as good as it could be: some rack BBCs are broken. Two of the broken BBCs were repaired, and now a total of 12 BBCs are being used in the experiments. The repair was done by replacing the BBC's oscillator chain with a $300 synthesizer. The DBBC ordered from Hat-Lab arrived in September with the standalone FILA10G. Also, a new Mark 5B+ arrived in spring of 2012. We successfully tested the new equipment in parallel with the old equipment in December 2012.

4.2.2. Recording Systems

We have developed a new DAQ system, the FlexBuff, using COTS components. Local UDP streaming performance tests were performed with wirespeed 10GE. Long (30 minute) tests demonstrated the ability to write at maximum wire speed with zero packet loss. Writing to 34 disks without a network (using local machines), the architecture can handle 40 Gbps, and it can always handle $>$ 30 Gbps. We have fixed our Mark 5A 1 Gbps recording problems by changing an R25 resistor to a 27-ohm resistor in the Mark 5A I/O board. We also purchased a Mark 5B+ system, which is now ready to be used.

4.2.3. Other Technical Issues at Metsähovi

Metsähovi has been suffering from the old formatter being out of sync during various sessions. After deploying the Mark 5B+ and the DBBC these problems will vanish. Because the phase cal box is temperature dependent, and because there has been a lot of drifting and phase jumps, the box will be temperature stabilized. A phase coherence problem due to the 5 MHz reference signal was found and corrected with a new 5 MHz distribution unit. The 1PPS distributor destroyed the Metsähovi 1PPS going to the old VLBI equipment. A new distributor has been purchased.

4.3. Data Analysis

In 2010 FGI and Metsähovi Radio Observatory received four-year funding from Academy of Finland to start geodetic VLBI data analysis. During 2012 one doctoral dissertation (Guifré Molera Calvés: “Radio spectroscopy and space science with VLBI radio telescopes for Solar System research”) and one master’s thesis (N. Kareinen: “Geodetic Very Long Baseline Interferometry and the effects of Tohoku Earthquake — Case analysis of Tsukuba station”) were finished. In addition one doctoral dissertation (M. Uunila: “Improving geodetic VLBI: UT1 accuracy, latency of results and data quality monitoring”) was sent to the pre-examination process in late 2012. Data analysis at FGI is performed by N. Zubko. The research of stochastic model selection for GeoVLBI data analysis has been done. Also, the project of source structure study and its influence on estimated geodetic VLBI parameters has been started with E. Rastorgueva-Foi from Metsähovi Radio Observatory. Diego Meschini is responsible for correlation.

4.3.1. Local Ties between VLBI and GPS at Metsähovi

The local ties measurements between the co-located instruments at Metsähovi are provided by Ulla Kallio. A local tie between IGS station METS and the VLBI antenna reference point was regularly performed with kinematic GPS measurements during the geo-VLBI campaigns starting in 2008. Testing shows that a millimeter level accuracy can be achieved in local tie vector determination with the kinematic GPS method. In July 2012, the local tie vector between the new Doris and Regina (GPS) antennas was determined by Thomas Donal and Jean-Claude Poyard (IGN) in June 2012. The local tie between Regina and VLBI was measured in July with kinematic GPS during the EUROPE-118 geo-VLBI session. The SINEX file of the tie vector is available.

5. Outlook

In the upcoming years Metsähovi will continue spacecraft tracking experiments and participating in IVS sessions together with FGI. Five T2 and two EUROPE sessions have been scheduled for Metsähovi in 2013. The FlexBuff development and geodetic VLBI data analysis will continue in 2013.

Acknowledgements

Both the FGI and Metsähovi teams acknowledge support from the Academy of Finland (grant number 135101).

VERA Geodetic Activities

Takaaki Jike, Yoshiaki Tamura, Makoto Shizugami, VERA group

Abstract

This report briefly describes the geodetic activities of VERA in the year 2012. The regular geodetic observations are 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 JADE of GSI and IVS-T2. The raw data of the T2 and JADE sessions are electronically transferred to the Bonn, Haystack, and GSI correlators via Internet.

Gravimetric observations are carried out at the VERA stations. An SG was installed at Mizusawa and placed in the vicinity of the VERA antenna in order to monitor vertical displacement at the end of 2008, and the observations continued throughout the year. Also at the VERA-Ishigakijima station, continuous operation of the SG started in 2012.

The crustal movements generated by the 2011 earthquake off the Pacific coast of Tohoku continued during 2012, and displacement of the VERA-Mizusawa position by post-seismic creeping continued.

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-Ishigakijima antenna is shown in Figure 1. The VERA array is controlled from the Array Operation Center (AOC) at Mizusawa via Internet.

The primary scientific goal of VERA is to reveal the structure and the dynamics of our galaxy by determining three-dimensional force field 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 S and X, K (22 GHz), and Q (43 GHz). Geodetic observations are made in S/X- and K-bands. Q-band is currently not used for geodesy. Only a single beam is used 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. Lengths of baselines range from 1000 km to 2272 km. The skyline at Ogasawara station ranges from 7° to 18° because it is located at the bottom of an old volcanic crater. The northeast 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 with low elevation. Since 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 K and Q bands. These stations, as well as Iriki station, are frequently hit by strong typhoons. The wind speed sometimes reaches up to 60–70 m/s.

2. Component Description

Parameters of the antennas and the front- and back-ends are summarized in Tables 2 and 3, respectively. Two observing modes are used in geodetic observations. One is the VERA internal

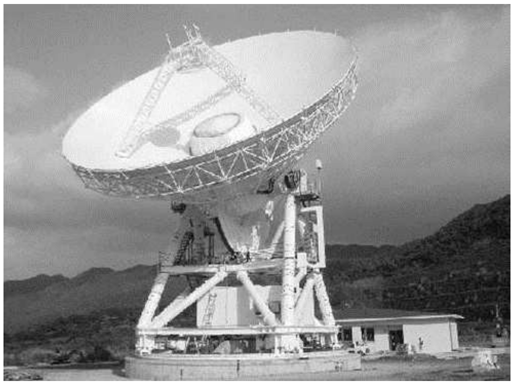

Figure 1. VERA-Ishigakijima 20-m antenna.

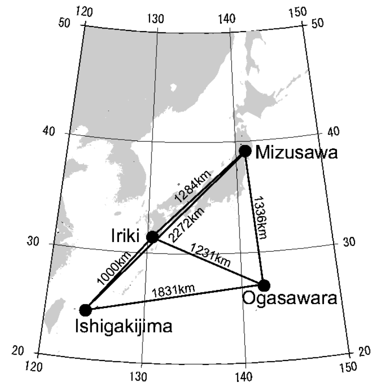

Figure 2. Locations of the VERA stations.

Table 1. General information.

Sponsoring agency	Mizusawa VLBI Observatory, National Astronomical Observatory of Japan	
Contributing type	Network observing station	
Location	Mizusawa	141° 07' 57".199 E, 39° 08' 00".726 N, 75.7 m(sea level)
	Iriki	130° 26' 23".593 E, 31° 44' 52".437 N, 541.6 m(sea level)
	Ogasawara	142° 12' 59".809 E, 27° 05' 30".487 N, 223.0 m(sea level)
	Ishigakijima	124° 10' 15".578 E, 24° 24' 43".834 N, 38.5 m(sea level)

mode in K-band with the recording rate of 1 Gbps. The other is the conventional S/X-band mode with K5-VSSP. JADE, which is GSI's domestic observation project, and IVS-T2 sessions belong to this class. Only Mizusawa and Ishigakijima participated in these sessions.

Table 2. Antenna parameters.

Diameter	20-m	Slew	Azimuth	Elevation
Mount	Az-El	range	-90° – 450°	5° – 85°
Surface accuracy	0.2mm(rms)	speed	2.1°/sec	2.1°/sec
Pointing accuracy	<12"(rms)	acceleration	2.1°/sec^2	2.1°/sec^2

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

3. Staff

Noriyuki Kawaguchi is the director of Mizusawa VLBI Observatory. The geodesy group consists of Seiji Manabe (scientist, retired in March 2012), Yoshiaki Tamura (scientist), Takaaki Jike (scientist), and Makoto Shizugami (engineer).

Table 3. Front-end and back-end parameters.

Front-end					
Frequency band	Frequency range (GHz)	Receiver temperature	Polarization	Receiver type	Feed
S	2.18–2.36	100° K	RHC	HEMT	Helical array
X	8.18–8.60	100° K	RHC	HEMT	Helical array
K	21.5–24.5	39±8° K	LHC	HEMT (cooled)	Horn
Back-end					
Type	Channels	BW/channel	Filter	Recorder	Deployed station
VERA	16	16 MHz	Digital	DIR2000	four VERA
K5-VSSP	16	4 MHz	Analog BBC	HDD	Mizusawa Ishigakijima

4. Current Status and Activities

4.1. VLBI

VERA observes seven days per week. The 24-hour geodetic sessions are allocated twice 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 and Ishigakijima participate in JADE by GSI or IVS-T2 sessions in S/X-band on a once-a-month basis. 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 IVS reference frame. The reason for the shift of the observing frequency band from S/X-band to K-band is to avoid the strong radio interference by cellular phone in S-band, particularly at Mizusawa. The interfering signal which has line spectra is filtered out. However, this filtering considerably degrades the system noise temperature. It is likely that the S-band observing will become 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 S/X-band is 500 at most. It has been confirmed that the K-band observations are far more precise, although no correction is made for ionospheric delay. In fact, standard deviations of the individual determinations of the antenna positions in K-band are less than half of those in S/X-band.

In order to link the VERA network to the international reference frame, VERA continues participation in the IVS-T2 sessions by using the Mizusawa and Ishigakijima stations. In 2012, a long maintenance period during October to December was allocated, during which the azimuth, elevation, and feed rotator motors were overhauled. Therefore, the period when VERA carried out regular VLBI observations was from January to September. We participated in six T2 sessions and in four JADE sessions. VERA internal geodetic observations were carried out 18 times. The final estimation of the geodetic parameters are derived by using the software developed by the VERA team.

4.2. Other Activities

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. Four water level gauges surrounding the SG were used for monitoring the groundwater level. The preliminary results show that gravity variation due to the variation of the water table can be corrected as accurately as the 1μgal level. The SG was newly installed also in the VERA Ishigakijima station, and observing was started in January 2012. This observing aims at solving the cause of the slow slip event which occurs frequently around the Ishigaki island.

5. State of the Crustal Movement after the March 11, 2011 Earthquake at Mizusawa

After the 2011 earthquake off the Pacific coast of Tohoku (Mw=9.0) [Epoch=11 March 2011, 14:16:18 JST], VERA-Mizusawa was displaced by co-seismic crustal movement and post-seismic creeping. Also, during 2012, the creeping continued, although the speed declined (Figure 3). According to the newest analysis, the co-seismic steps are North=-1.274 m, East=2.337 m, and Up=-0.128 m in the horizontal coordinate system, and the displacement by creeping amounts to North=-0.258 m, East=0.756 m, and Up=0.067 m.

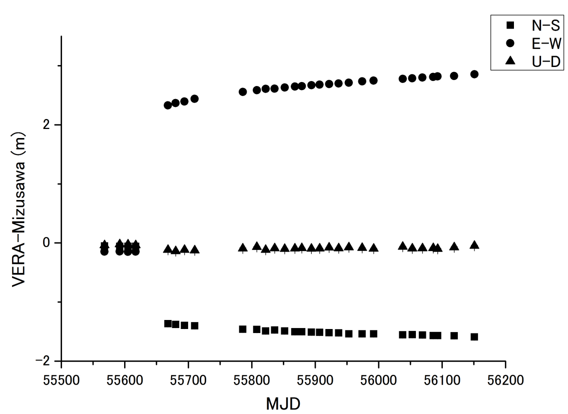

Figure 3. Movements of VERA-Mizusawa after 2011.

6. Future Plans

Now, the examination which increases the recording rate to 4 Gbps from 1 Gbps is being carried out. Furthermore, the examination for changing the recording system from tape recorder to HDD is also being implemented. With these changes, regular operation of a new software correlator is due to begin.

Noto Station Status Report

G. Tuccari, S. Buttaccio, P. Cassaro, C. Contavalle, G. Nicotra, L. Nicotra, C. Nocita, L. Papaleo, M. Paternó, P.R. Platania, F. Schilliró

Abstract

The Noto VLBI station was fully operational in 2012, and the upgrade projects could be restarted, involving mainly the receiver area. Another important improvement was the activation of the 1 Gbps network.

1. Frequency Agility

A frequency agility system is in the design phase. The system will install a set of receivers in the antenna secondary focus so that the receivers will automatically become operative within a few minutes. The primary focus will receive a revised version of the SXLP receiver that was developed some years ago but was never used due to the difficult mechanical operations required to implement it. This frequency agility project has been funded, and the activities started in summer 2012. The C, K, Q, and W receivers will be placed in the secondary focus in fixed position to make it possible to switch between them in a very short time. The W band will be covered by a revised version of a receiver acquired from IRAM. This solution is particularly convenient because it can be implemented as part of the vertex room reconstruction. The receiver will require specialized installation because it is filled with liquid helium in order to cool it down to the 4K stage, and the helium must remain in its tank while the antenna moves through a 0 to 90 degree range of elevation. Noto could join the millimeter VLBI network as soon as it becomes operational.

2. Fiber Optics Connection

A fiber optics link for e-VLBI activities has been activated by the GARR (Italian Academic and Research Network), and it is now operating at a 1 Gbps data rate since March 2012. An upgrade increasing the connection rate up to 10 Gbps is planned to become available in the next few months. The new connection permitted Noto to participate in the e-VLBI EVN observations and greatly reduced the need to send disk packs to the correlators for the IVS sessions.

3. VLBI2010 at the Station

The Noto station will participate in VLBI sessions with the legacy antenna until it is possible to install a VLBI2010 12-m antenna. Operations in this technology require adoption of a broadband receiver and a dedicated backend. The first is under construction with a prototype feed. This receiver covers the range 2-14 GHz and, apart from the first amplification stages, is fully digital. Indeed no analog down-conversion is included for the entire band covered up to 14 GHz. In order to adapt the feed to the 32-m antenna optics, an additional tertiary mirror is planned, to be installed on the antenna surface during the observation periods. The final destination for this receiver is a 12-m fast slewing VLBI2010 compliant antenna.

The DBBC2 backend in Noto was partly upgraded to DBBC2010. This requires the installation of a total number of eight 1 GHz bandwidth IFs to provide a total number of boards able to support eight wideband PFB (Polyphase Filter Bank) elements, for a minimum total aggregate output data rate of 32 Gbps. A FILA10G Ethernet interface, which is already operational at several EVN stations, is required to produce 32 Gbps output; producing more than 32 Gbps output requires additional interfaces. Such a board will be installed in Noto in 2013, with the completion of the DBBC2010 upgrade.

The DBBC3 project financed by Radionet started in July 2012. This project will produce the newest front-backend system compliant with EVN32Gbps and VLBI2010. The new system will provide the entire dual polarization VLBI2010 14 GHz broadband coverage in full digital fashion, including the support for data processing and multiple 40G network capability. It will also include burst modes and a buffer/recording system, which is an alternative to other VLBI high data rate recorders and which is able to support external disk-packs at 32-64-128 Gbps. A DBBC3 schematic block view is shown in Figure 1.

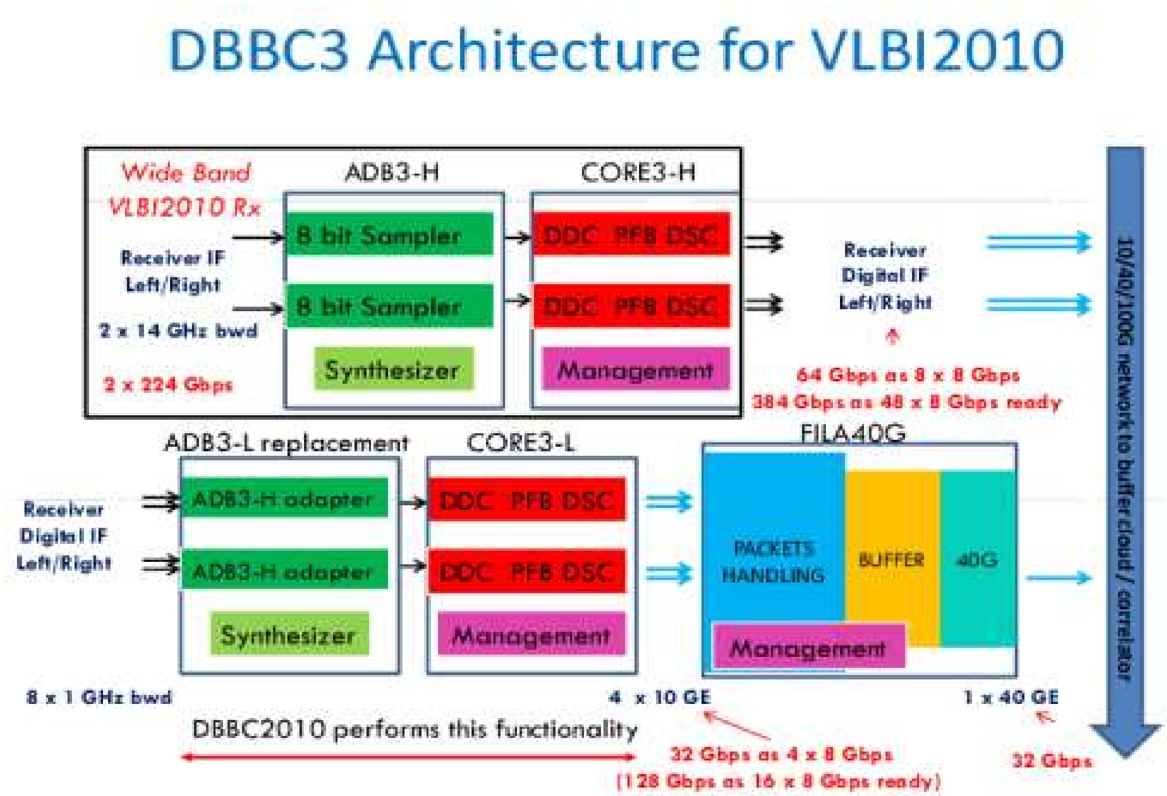

Figure 1. DBBC3 schematic block view.

4. Observations

Noto was scheduled for one 24-hour session per month, starting from February 2012, when the antenna was again operational after the azimuth track replacement. The scheduled experiments have been: EUROPE-116, CRF67, EUR117, EUR118, T2084, EUR119, T2085, CRF70, T2086, EUR120, and CRF71. Due to the high number of inoperative, old analog baseband converters, the efficiency was not as desired. A great effort was made to reactivate the maximum possible number of such units, but the actual solution to the problem will come with the operational introduction of the upgraded DBBC backend, in the first half of 2013.

Ny-Ålesund Geodetic Observatory

Moritz Sieber

Abstract

In 2012 the 20-m telescope at Ny-Ålesund, Svalbard, operated by the Norwegian Mapping Authority (NMA), took part in 163 out of 168 scheduled sessions of the IVS program. Since spring, all data was transferred by network, and the receiver monitoring computer was replaced by a bus-coupler. In autumn, the NMA received building permission for a new observatory from the Governor of Svalbard. The bidding process and first construction work for the infrastructure will start in 2013.

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, in Kings Bay, at the west side of the island of Spitsbergen. This is the biggest island in the Svalbard archipelago. In 2012, Ny-Ålesund was scheduled for 122 24-hour VLBI sessions, including R1, R4, EURO, RD, T2, and RDV sessions, and 46 one-hour Intensives within the Int3 program.

In addition to the 20-meter VLBI antenna, the Geodetic Observatory has two GPS antennas in the IGS system and a Super Conducting Gravimeter in the Global Geodynamics Project (GGP) installed at the site. The French-German AWIPEV research base in Ny-Ålesund operates a DORIS station. In October 2004, a GISTM (GPS Ionospheric Scintillation and TEC Monitor) receiver was installed at the Mapping Authority's structure in the frame of ISACCO, an Italian research project on ionospheric scintillation observations, led by Giorgiana De Franceschi of the Italian Institute of Volcanology and Geophysics (INGV). Another Real-Time Ionospheric Scintillation (RTIS) Monitor was set up by the NMA in November 2012.

2. Component Description

The antenna, which has a 20 m diameter, is intended for geodetic use and receives data in S- and X-band. Its design and construction are similar to those at Green Bank and Kokee Park. A rack with 14 video-converters, a Mark IV decoder, and a Mark 5 sampler streams the data to a Mark 5B+ recorder. A Mark 5A 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.

3. Staff

The staff at Ny-Ålesund consists of four people employed at 75%, which means that three full-time positions are covered. Each position goes with a two-year contract that can be extended up to 12 years, but on average people stay three to four years. The observatory is part of the Geodetic Division of the Mapping Authority with the main office at Hønefoss (near Oslo).

In summer 2012, Carl Petter married and moved with his wife Carina to the mainland – Congratulations! By end of 2012, Kent Roskifte had been recruited as a new operator, and Moritz will take over the role of station manager after Carl Petter. See Table 1 for an overview.

Figure 1. Wedding scene in Kongsfjorden (Photo: Linda Bakken).

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

Hønefoss	Section Manager	Reidun Kittelsrud
	Technical Manager	Leif Morten Tangen
Ny-Ålesund	Station Manager	Carl Petter Nielsen (until 2012.12.31)
	Engineer	Geir Mathiassen
	Engineer	Kent Roskifte (from 2013.01.01)
	Engineer	Moritz Sieber
	Engineer	Åsmund Skjæveland

4. Current Status and Activities

Monitoring After the former receiver monitoring system (based on a 386-board) stopped working after 16 years, we were looking for alternatives. TIGO ran into similar problems with their hardware in 2009 and had good experiences with a solution based on a Beckhoff BK9000 bus-coupler. We kindly were provided with their bits of software (which saved us a great deal of trouble and headache, so thanks a lot!) which fit into our environment.
For the documentation-wiki, at the station some scripts do a good job of generating graphs of the sessions' midob-data and thus provide both current data and their recent development not just for the FS-computer.

Session Performance After spurious phase-cal signals of unknown origin, the phase-cal unit was replaced during the maintenance-week in October. No bigger problems were observed afterwards, but the cable is probably beginning to wear out, also.
Four Int3 sessions were not observed due to a crack in one of the support pillars for the sub-

reflector at Tsukuba-32m. Seshan, which participated instead, was not available for those four dates.
An overview of sessions with trouble and their explanations can be found in Table 2. All other sessions were observed according to schedule.

Table 2. Sessions with trouble.

EUR115	general problem with schedule, updated on late notice
R1525	not ready after scheduled maintenance period (installing receiver monitor). The Int3-Intensive on the same day was replaced by a J-schedule on late notice
R1530	fieldsystem PC hard disk trouble slowing down the RAID and everything else
R4534	receiver warming up during last six hours
R1539	last six hours warm
RDV93	late start due to cooling down receiver
R4553	FS crashed due to bug in rxcom (the station's program doing the communication via TCP/Modbus with the receiver monitor). Restarted, but lost 15 minutes or so
R1559	late start, too late getting schedule
R4560	no data for two hours
R1564	warm receiver during the whole session

E-Transfer All measurement data is transferred by network to the correlators now, to Socorro with the great help of Haystack, which buffers the data. This is a great improvement since the ground handling of outbound freight from SAS Cargo and FedEx in Oslo recently became less and less reliable.

New Instrumentation At the end of April, NavSys AS started broadcasting RTCM3.x-data for customers of the CPOS-service in the Kings Bay area. Now the positioning accuracy has increased to a few centimeters, without the need to establish a reference station for each measurement.
The Norwegian Mapping Authority established two of its own instruments: another Real-Time Ionospheric Scintillation (RTIS) monitor at the end of November and an absolute gravimeter co-located to the existing superconducting gravimeter at the end of December.

New Observatory After the budget was granted in 2011, the Governor of Svalbard approved the impact analysis of the new observatory project. Construction work for the road will start in 2013, in parallel with the tendering process.

5. Future Plans

After the iron-values for one of the two azimuth gears showed high and increasing values in the past, it was decided to replace the gearbox with a spare, which will take place during the scheduled maintenance week in March. Later in 2013 the road construction work to the new observatory's location will start. Due to the arctic climate and environmental protection plans, this has to wait until summer.

German Antarctic Receiving Station (GARS) O'Higgins

Alexander Neidhardt, Christian Plötz, Thomas Klügel

Abstract

In 2012, the German Antarctic Receiving Station (GARS) O'Higgins contributed to the IVS observing program with four observation sessions. Maintenance and upgrades were made, and a new replacement dewar is under construction in the observatory at Yebes, Spain.

1. General Information

The German Antarctic Receiving Station (GARS) is jointly operated by the German Aerospace Center (DLR) and the Federal Agency for Cartography and Geodesy (BKG, under the duties of the Geodetic Observatory Wettzell (GOW)). The Institute for Antarctic Research Chile (INACH) coordinates the activities and logistics. The 9-m radio telescope at O'Higgins is mainly used for the downloading of remote sensing data from satellites ERS-2 (mission ended in September 2012) and TanDEM-X, for the control and monitoring of spacecraft telemetry, and for geodetic VLBI. In 2012, the station was manned by DLR staff the entire year and by BKG staff only in January and the beginning of March for the VLBI observations. The VLBI campaign in November-December 2012 had to be canceled due to the reduced staffing situation. Besides engineers and operators from DLR and BKG, a team for maintaining the infrastructure (e.g. power and generation of fresh water) was present all year.

Over the last years, special flights using "Hercules C-130"-aircrafts and small "Twin Otter DHC-6"-aircrafts as well as transportation by ship were organized by INACH in close collaboration with the Chilean Army, Navy, and Airforce and with the Brazilian and Uruguayan Airforce in order to transport staff, technical material, and food for the entire campaign from Punta Arenas via Base Frei on King George Island to O'Higgins on the Antarctic Peninsula. Due to the fact that the conditions for landing on the glacier are strongly weather dependent and involve an increasing risk, transport of personnel and cargo is always a challenging task. Arrival and departure times strongly depend on the climate conditions and on the logistic circumstances.

After the long Antarctic winter the VLBI equipment at the station has to be initialized. Damages resulting from the winter conditions or strong storms have to be identified and repaired. Shipments of each kind of material, such as spare parts or upgrade kits, have to be carefully prepared in advance.

On location at the site the following instruments are operated:

- An H-Maser, an atomic Cs-clock, a GPS time receiver, and a Total Accurate Clock (TAC) to offer time and frequency.
- Two GNSS receivers, both operating in the frame of the IGS network, while one receiver is additionally part of the Galileo CONGO network. The receivers worked without failure in 2012.
- A meteorological station providing pressure, temperature, humidity, and wind information, as long as the extreme conditions did not disturb the sensors.

- A radar tide gauge which was installed in 2012. The radar sensor itself is referenced to space by a GPS antenna mounted on top and referenced to the Earth via the local survey network. The radar gauge is operated only during the Antarctic summer.
- An underwater sea level gauge for permanent monitoring of water pressure, temperature, and salinity, which was replaced in 2012.

The 9-m radio telescope is designed for a dual purpose:

- Performing geodetic VLBI, and
- Receiving data from and sending commands to remote sensing satellites, mainly ERS-2 and TanDEM-X.

Figure 1. The 9-m radio telescope of GARS O'Higgins.

2. Technical Staff

The members of staff for the operation, maintenance, and upgrade of the VLBI system and other geodetic devices are summarized in Table 1.

Table 1. Staff – members.

Name	Affiliation	Function	Working for
Johannes Ihde Ulrich Schreiber	BKG BKG	interim head of the GOW (till February 2012) head of the GOW (since March 2012)	GOW GOW
Christian Plötz	BKG	electronic engineer	O'Higgins (responsible), RTW
Christian Schade	BKG	geodesist	O'Higgins operator, SLR
Reiner Wojdziak	BKG	software engineer	O'Higgins, IVS Data Center Leipzig
Andreas Reinhold	BKG	geodesist	partly O'Higgins operator
Thomas Klügel	BKG	geologist	administration for O'Higgins, laser gyro and local systems Wettzell
Rudolf Stoeger	BKG	geodesist	logistics for O'Higgins
Alexander Neidhardt	FESG	head of the RTW group and VLBI station chief	RTW, TTW (partly O'Higgins, laser ranging)
Gerhard Kronschnabl	BKG	electronic engineer	RTW, TTW (partly TIGO and O'Higgins)

3. Observations in 2012

GARS participated in the following sessions of the IVS observing program during the Antarctic summer campaign (January-March 2012):

- IVS-T2081 February 14 - 15, 2012.
- IVS-OHIG76 February 15 - 16, 2012.
- IVS-OHIG77 February 28 - 29, 2012.
- IVS-OHIG78 February 29 - March 1, 2012,

The observations were recorded with Mark 5A. The related data modules were carried from O'Higgins to Punta Arenas by the staff on their way back. From Punta Arenas, the disk units were shipped by regular air freight back to Wettzell and then to the correlator in Bonn, Germany.

4. Maintenance

The extreme environmental conditions in the Antarctic require special attention to the GARS telescope and the infrastructure. Corrosion frequently results in problems with connectors and capacitors. Defective equipment needs to be detected and replaced. The antenna, the S-X-band receiver, the cooling system, and the data acquisition system have to be activated properly. A COM-server was replaced by a RS232 converter. The existing GNSS receiver Leica GRX1200GGPRO was replaced by another Leica GRX1200+GNSS. A problem is the low transfer rates (often with only 50 kbps) on the communication connection, so that Internet and phone access was reduced. The Web cams are also regularly maintained.

The defective tide gauge was dismounted. A new system was tested in the workshop and installed in cooperation with the Chilean military base and the service team of the DLR. The radar tide gauge was installed for the duration of the campaign and dismounted before the Antarctic winter.

The construction of the new dewar is in progress in order to replace the original O'Higgins dewar. This one has to be evacuated permanently by a turbo molecular pump to maintain the required vacuum due to a leakage.

5. Technical Improvements

The new Symmetricon NTP-server was installed and put into operation. A new meteorological mast was raised and populated with the required sensors. A new data logger for the meteorological data was put in operation. The new meteorological station was also integrated into the automated data acquisition, graphical interfacing, and NASA Field System.

The remote control of complete VLBI-sessions could be extended. Using the newly developed Wettzell software, the O'Higgins Field System can be controlled over a secure Internet connection from Wettzell. This is a key feature to extend the operation periods in GARS O'Higgins.

A new NAS server was installed and activated.

6. Upgrade Plans for 2013

The replacement dewar will be completed. A dedicated plan should offer a shared, interleaved observation of satellites (DLR) and VLBI sources (BKG) during the whole year. Some antenna motors must be replaced, and a gear needs to be inspected. There are further plans to replace the receiver with a more suitable, smaller, and more easily maintained system, similar to the TWIN tri-band-receiver. This needs to be planned and designed.

Onsala Space Observatory – IVS Network Station

Rüdiger Haas, Gunnar Elgered, Johan Löfgren, Tong Ning, Hans-Georg Scherneck

Abstract

During 2012 we participated in 40 IVS sessions. As in the previous four years, we used the majority of the sessions that involved both Onsala and Tsukuba to do ultra-rapid dUT1 observations together with our colleagues in Tsukuba. We observed one four-station ultra-rapid EOP session together with Tsukuba, Hobart, and HartRAO. We also observed the RadioAstron satellite and several GLONASS satellites using the Onsala 25-m telescope.

The highlight in 2012 was that our proposal to the Knut and Alice Wallenberg Foundation to establish a twin-telescope system at Onsala in accordance with the VLBI2010 recommendations was accepted.

1. General Information

The Onsala Space Observatory is the National Facility for Radioastronomy in Sweden with the mission to support high-quality research in radio astronomy and geosciences. The geoscience instrumentation at Onsala includes equipment for geodetic VLBI, GNSS, a superconducting gravimeter, several radiometers for atmospheric measurements, both GNSS-based and pressure sensor based tide gauges, and a seismometer. The Onsala Space Observatory can thus be regarded as a fundamental geodetic station. Figure 1 shows an aerial photo with the location of all of its observational infrastructure. The area planned for the future Onsala Twin Telescope is highlighted, too.

The staff associated with the IVS Network Station at Onsala remained the same as reported in last year's report. Contact information is found on `www.chalmers.se/rss/oso-en/`.

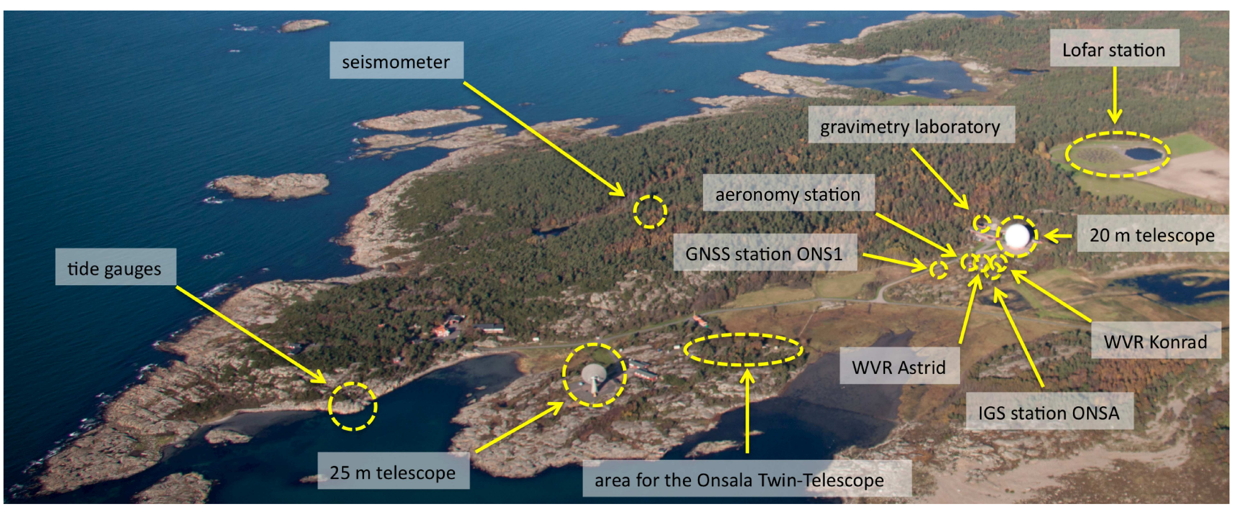

Figure 1. Aerial photo of the Onsala Space Observatory with the location of all observational infrastructure. The area planned for the future Onsala Twin Telescope is highlighted as well. The distance between the 20-m telescope and the 25-m telescope is approximately 600 m.

2. VLBI Observations for Geodesy and Space Navigation

During 2012 Onsala was involved in five IVS observing series, EUROPE, R1, T2, RD, and RDV, see Table 1. Observations were acquired during 40 IVS sessions. The success rate of our observations was very high, and in all but two of the sessions that have been correlated so far, the percentage of scheduled Onsala observations that could be used in the IVS analysis of a session exceeded the average percentage for the stations in that session. All experiments were recorded with our Mark IV VLBI rack and recorded on the Mark 5A unit. For all experiments except one, the data were recorded in parallel on the PCEVN-computer that is daisy-chained to the Mark 5A unit. This made it possible to e-transfer the data offline to the respective correlators at Bonn and Haystack. The only experiment where a Mark 5-module needed to be shipped was RDV94, which is supposed to be correlated at Soccoro.

We used the majority of the R1- and RD-sessions involving both Onsala and Tsukuba to perform ultra-rapid dUT1 observations. In these cases the Onsala data were e-transferred in real-time to the Tsukuba correlator using the Tsunami protocol. The data were correlated with the corresponding data from the Tsukuba station in near real-time, followed by a near real-time analysis to determine dUT1. Using this automated strategy, dUT1 results were determined already during the ongoing VLBI observations using a “sliding window” approach.

On December 17-18 we observed the first four-station ultra-rapid EOP experiment, together with Tsukuba, HartRAO, and Hobart. The experiment was successful, and polar motion and dUT1 were determined in ultra-rapid mode, i.e. during the ongoing session.

We continued to test our digital VLBI system which consists of a DBBC and a Mark 5B+ recorder. For several experiments the observational data were recorded in parallel with the analog system and the digital system. The Bonn correlator supported these tests and correlated the data. Based on these tests we could improve our IF-distribution and optimize the performance of the digital system. Fringes with the digital system were found for several experiments, and the Bonn correlator prepared several databases including Onsala both as an analog and as a digital station.

We again participated in observations for space craft navigation. In January we observed a session to determine the orbit of the RadioAstron satellite. In April we performed an experiment to observe GLONASS satellites.

Radio interference due to UMTS mobile telephone signals continued to be a disturbing factor for the S-band observations. We started to systematically map the RFI environment at the observatory between 2 and 26 GHz.

3. Monitoring Activities in 2012

We continued with the monitoring activities as described in previous annual reports:

Vertical height changes of the telescope tower.

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

Table 1. VLBI observations for geodesy and space navigation at Onsala during 2012. Information is given on whether the data were e-transferred in real-time (RT) and/or off-line (OL) and to which correlator, whether modules were shipped to a correlator, and whether ultra-rapid dUT1 (UR-dUT1) results were produced. The final column gives general remarks and/or information on the percentage of the scheduled Onsala observations that were used in analysis (as reported in the IVS session Web pages' analysis reports), compared to the station average percentage per experiment.

Exper.	Date	E-transfer		Mod.	UR-	General remarks, % of scheduled observations
		RT	OL	ship.	dUT1	used in analysis (according to IVS analysis reports).
R1-514	01.03	–	Bonn	–	–	Onsala: 96.1% (station average: 95.2%)
R1-515	01.09	–	Bonn	–	–	Onsala: 94.5% (station average: 92.1%)
RA-01-14	01.14	–	JIVE	–	–	OK, RadioAstron observations, 2 h
EUR-115	01.16	–	Bonn	–	–	Onsala: 27.9% (station average: 17.8%)
R1-517	01.23	–	Bonn	–	–	Onsala 72.9% (station average: 61.9%)
RD-12-01	01.24	–	Hays	–	–	Onsala: 96.8% (station average: 95.2%)
R1-518	01.30	–	Bonn	–	–	Onsala: 81.7% (station average: 71.8%)
R1-520	02.13	Tsuk	Bonn	–	yes	Onsala: 94.0% (station average: 89.5%)
T2-081	02.14	Tsuk	Bonn	–	yes	Onsala: 78.8% (station average: 63.2%)
R1-526	03.26	–	Bonn	–	–	Onsala: 96.5% (station average: 85.0%)
EUR-116	03.28	–	Bonn	–	–	Onsala: 68.8% (station average: 50.1%)
G-0402	04.02	–	JIVE	–	–	OK, Glonass observations, 6 h
R1-527	04.02	–	Bonn	–	–	Onsala: 84.7% (station average: 69.8%)
RD-12-02	04.03	–	Hays	–	–	Onsala: 90.0% (station average: 85.2%)
R1-528	04.10	Tsuk	Bonn	–	yes	Onsala: 63.1% (station average: 68.0%)
R1-532	05.07	Tsuk	Bonn	–	yes	Onsala: 94.2% (station average: 92.0%)
T2-083	05.08	Tsuk	Bonn	–	yes	Onsala: 80.9% (station average: 61.8%)
EUR-117	05.09	–	Bonn	–	–	Onsala: 73.8% (station average: 54.8%)
R1-539	06.25	Tsuk	Bonn	–	–	Onsala: 64.0% (station average: 43.9%)
R1-540	07.02	–	Bonn	–	–	Onsala: 76.6% (station average: 58.8%)
EUR-118	07.03	–	Bonn	–	–	Onsala: 73.0% (station average: 53.3%)
R1-545	08.06	Tsuk	Bonn	–	yes	Onsala: 92.4% (station average: 88.2%)
R1-546	08.13	Tsuk	Bonn	–	yes	Onsala: 96.1% (station average: 90.9%)
RDV-94	08.22	–	–	Socc	–	Onsala: 88.1% (station average: 69.0%)
R1-548	08.27	Tsuk	Bonn	–	yes	Onsala: 92.8% (station average: 91.4%)
RD-12-06	08.28	Tsuk	Hays	–	yes	Onsala: 81.1% (station average: 82.9%)
EUR-119	09.03	–	Bonn	–	–	Onsala: 78.7% (station average: 63.9%)
R1-549	09.04	Tsuk	Bonn	–	yes	Onsala: 92.6% (station average: 86.4%)
R1-550	09.10	Tsuk	Bonn	–	yes	Onsala: 94.5% (station average: 92.5%)
T2-085	09.11	Tsuk	Bonn	–	yes	not correlated yet in Bonn
R1-552	09.24	–	Bonn	–	–	Onsala: 81.3% (station average: 76.7%)
RD-12-07	09.25	–	Hays	–	–	Onsala: 96.6% (station average: 95.4%)
R1-553	10.01	Tsuk	Bonn	–	yes	Onsala: 91.7% (station average: 87.4%)
RD-12-08	10.02	Tsuk	Hays	–	yes	Onsala: 93.4% (station average: 92.0%)
R1-554	10.10	Tsuk	Bonn	–	yes	Onsala: 91.5% (station average: 85.4%)
R1-555	10.15	Tsuk	Bonn	–	yes	Onsala: 92.3% (station average: 87.1%)
EUR-120	11.22	–	Bonn	–	–	not correlated yet
R1-561	11.26	Tsuk	Bonn	–	yes	Onsala: 91.3% (station average: 82.2%)
RD-12-09	11.27	–	Hays	–	–	not correlated yet
R1-563	12.10	Tsuk	Bonn	–	yes	Onsala: 92.5% (station average: 82.3%)
RD-12-10	12.11	Tsuk	Hays	–	yes	not correlated yet
UR-12-03	12.17	Tsuk	–	–	yes	ultra-rapid EOP with four stations
R1-564	12.18	Tsuk	Bonn	–	yes	Onsala: 94.0% (station average: 90.1%)

Microwave radiometry.

One water vapor radiometer, Konrad, was in operation continuously during 2012 observing in a so-called sky-mapping mode. The second water vapor radiometer, Astrid, was operated for shorter periods in the winter and spring but then had to be upgraded and repaired. The mechanical pointing and the switches for the calibration of the 31 GHz channel were repaired, and since November 2012 Astrid has been operational again.

Calibration of pressure sensor.

We continued to calibrate the Onsala pressure sensor using a Vaisala barometer borrowed from the Swedish Meteorological and Hydrological Institute (SMHI). This instrument was installed at Onsala in late 2002 and has been calibrated at the SMHI main facility in Norrköping every 1–2 years since then. The latest calibration was on October 11, 2011. Since the installation of a new VLBI pressure sensor in 2008, the agreement between the Onsala pressure sensor and the SMHI pressure sensor has been on the level of ± 0.1 hPa.

Sea-level monitoring.

The GNSS-based tide gauge was operated continuously at its new location. A tide gauge based on pressure sensors was operated next to it throughout the year. However, the pressure based tide gauge was damaged by lightning in the summer and was out of operation for about two months.

Superconducting gravimetry.

The superconducting gravimeter operated continuously during 2012 and produced a highly precise record of gravity variations. Further information on the superconducting gravimeter can be found on `http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html`.

Absolute gravimetry.

We supported visiting absolute gravity measurement campaigns by the University of Hannover (Germany) and Lantmäteriet, the Swedish mapping, cadastral, and land registration authority.

Seismological observations.

The seismometer owned by Uppsala University and the Swedish National Seismic Network (SNSN) was moved from the gravimeter laboratory to a new dedicated underground site on the observatory premises. The new location has the advantage of being less disturbed by man-made seismic noise.

4. Outlook

The Onsala Space Observatory will continue to operate as an IVS Network Station and to participate in the IVS observation series. For 2013, we plan to participate in 40 IVS sessions, and we envisage completing the transition from our analog to our digital VLBI system. We also will continue our efforts concerning the ultra-rapid EOP project, together with our colleagues in Japan, South Africa, and Australia.

A major part of our activities in 2013 will be the Onsala Twin Telescope project that starts officially in January 2013. The plan is to build two new 12-m diameter radio telescopes following the VLBI2010 recommendations. In parallel to these efforts, we will operate the 20-m telescope for geodesy during an overlapping period together with the twin telescope.

Parkes 2012 IVS Report

John Reynolds

Abstract

This report presents the status of the Parkes Observatory in 2012, as well as our future plans.

1. Status

The Parkes Observatory participated in three 24-hour IVS sessions during 2012, compared to six in the previous year. All three sessions were recorded using the station's Mark 5b system and were generally successful, including one recorded using a relatively new "IF3" observing configuration.

A significant development was that data for two of these sessions were transferred electronically to the correlator at USNO. The intention is that such transfers become more routine during 2013.

Parkes also continues to support a program led by Leonid Petrov (ADNET Systems/GSFC) of hybrid astronomy/geodesy observations, refining the locations of several Southern Hemisphere radio stations that are equipped with neither dual S/X receiving systems nor IVS-compatible recording systems. This program also aims to identify additional calibrator sources in the Southern Hemisphere for "densification" of the ICRF in the South.

2. Future Plans

The outlook for 2013 and beyond continues to be a little uncertain owing to scheduling constraints arising from changes to the Parkes Operations model that could impact the availability of the dual S/X receiver. See http://www.atnf.csiro.au/management/atuc/2012feb/docs/carretti_ATUC_1202.pdf for details. This is currently constraining the number of IVS sessions in which Parkes can participate. We are continuing to work with our Australian colleagues to ensure that the S/X receiver and recording systems remain available and that the active participation of Parkes in IVS observing programs continues to be both valued and supported.

Korea Geodetic VLBI Station, Sejong

Baek Donghyun, Yi Sangoh, Oh Hongjong, Han Sangchul

Abstract

The Sejong VLBI station officially joined the IVS as a new Network Station in 2012. This report summarizes the activities of the Sejong station during 2012. The following are the activities at the station. 1) VLBI test observations were carried out with the Tsukuba 34-m antenna of the GSI in Japan. As a result, the Sejong antenna needs to improve its efficiency, which is currently in progress. 2) A survey to connect the VLBI reference point to GNSS and ground marks was conducted. 3) To see the indirect effects of RFI (Radio Frequency Interference) at this place, we checked the omni-direction (AZ 0° to 360°, EL fixed at 7°) for RFI influence.

1. General Information

The Sejong station is the first geodetic VLBI station in the Republic of Korea which is dedicated to geodetic purposes only. The station is located about 120 km south of Seoul, in the middle of Sejong City, which serves as a new administrative capital. The Sejong antenna is 22 meters in diameter, and its slew speed is 5°/sec in both azimuth and elevation; its specifications have been designed for the possible addition of other small antennas in the future.

The observatory was constructed on the top of a small mountain in Sejong City, which was officially approved as a new town in July 2012. The city is a newly designated administrative capital city planned by the government, and it will be developed in phases over the next 20 years. The Sejong VLBI station was previously called “KVG” (Korea VLBI system for Geodesy) which was named after the project purpose in its initial stage. However, now “Sejong Station” is the official title to prevent possible confusion in addressing the station.

National Geographic Information Institute (NGII, http://ngii.go.kr) manages the observatory, and Table 1 shows the staff members of the Sejong station. A newly appointed site director, Mr. Baek Dong Hyun, started work in November 2012, and Mr. Joo Hyun Hee, who showed outstanding work in Sejong VLBI construction, was transferred to another group. Staff at the observatory carry out the VLBI observation, baseline analysis, international cooperation including the IVS, antenna maintenance, and management of the observatory.

Table 1. Staff members of the Sejong station.

Name	Function	e-mail
Baek Donghyun	Site Director	baekdh@korea.kr
Yi Sangoh	S/W engineer	sangoh.yi@korea.kr
Oh Hongjong	H/W engineer	stockoh11@korea.kr
Han Sangchul	Antenna system	hsc4907@korea.kr

2. Sejong VLBI System

The Sejong VLBI configuration is listed in Table 2. The IVS letter codes and the CDP and DOMES numbers have been newly registered during this year. The antenna has the Cassegrain

Figure 1. VLBI 22-m antenna, monument pillars 1 - 4, GNSS, and UCP (Unified Control Point) layout.

shape, and the 22-m main reflector consists of 200 rectangular aluminium panels. Each panel has four elevation adjustments at the edge of the panel, so that the antenna main reflector surface can be properly arranged.

Technical parameters of the receiver are presented in Table 3. However, some items are omitted due to the antenna efficiency improvement work. The Sejong station uses the Field System (version FS-9.10.4) and a K5 data recorder.

3. Activities in 2012

3.1. VLBI Observation

The Sejong antenna carried out several fringe tests with the Tsukuba 34-m antenna in Japan. A few observations failed to get fringes due to a wrong setting for time synchronization. After that we successfully got fringes from all channels in the S and X bands. As a result, the Sejong antenna needs to improve its antenna efficiency, which is currently in progress.

3.2. Co-location

We performed a ground survey that used four pillars to tie the cross point of the axes of the VLBI antenna to the Sejong GNSS monument. Figure 2 shows the local tie layout in the site. The antenna reference position was calculated by a 3D circle fitting method, with measurement of the distances from the pillars to the reflection sheet on the antenna surface. Therefore, a ground network consisting of VLBI, GNSS, and the pillars was established. Monitoring for the antenna reference position and ground subsidence of the new site will regularly be done by local tie survey.

Table 2. Sejong Antenna parameters.

Parameters	Sejong VLBI
IVS letter codes	Sejong (Kv)
CDP number	7368
DOMES number	23907S001
Location	127°18'E, 36°31'N Elevation 177 m
Diameter of main reflector	22 m
Antenna type	Shaped Cassegrain
Aperture efficiency	about 60%
Pointing accuracy	0.0131°
Reflector surface accuracy	86μm
Operation range	AZ: ±270° EL: 0 ∼ 90°
Slew speed	5°/sec (AZ and EL)
FS Version	9.10.4
Data acquisition Rack/Recorder	K4/K5

Table 3. Receiving system of the Sejong VLBI system.

Bands	S	X	K	Q
Freq. [GHz]	2.1-2.6	8.0-9.0	21-23	42-44
Receiver noise temp.	< 20K	< 30K	< 50K	< 80K
Polarization	R,L	R,L	R,L	R,L
First LO Freq.	NONE	NONE	13.5 GHz	33.9 GHz
First IF Freq.	NONE	NONE	8-10 GHz	8-10 GHz
IF Pout/BW	-50 dbm/500 MHz			
Phase noise@1KHz	-120 dBc/Hz			
Reference Freq.	100 MHz			

3.3. RFI Monitoring

Even at the Sejong site, RFI is unavoidable. We scanned all directions (AZ 0° to 360°) at a fixed elevation of 7° to see the maximum values in S band (2.2 ∼ 2.4GHz). Figure 3 shows the change of signal power. It shows that most RFI is detected over 2.3 GHz. It is also direction-dependent. In other words, there was more RFI coming from the north direction.

4. Future Plans

We will take on the following activities in 2013: 1) The Sejong station, as a new IVS Network Station in 2012, will participate in regular IVS sessions. 2) Antenna efficiency improvement is currently in progress. 3) After that, we will proceed to join IVS observing as soon as possible by contacting the IVS Coordinating Center. 4) A local tie survey is also planned.

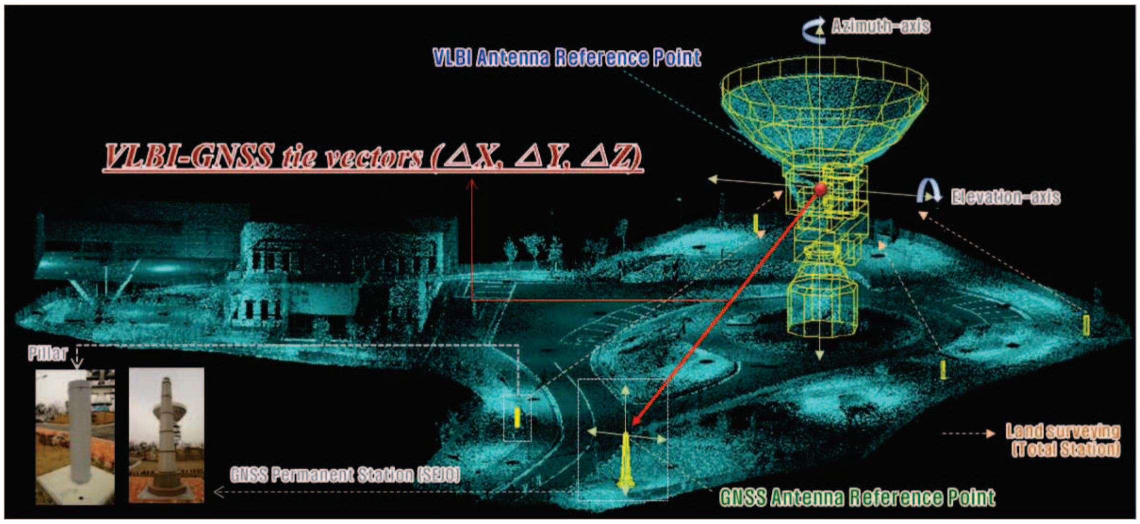

Figure 2. Facilities for local ties at the Sejong station.

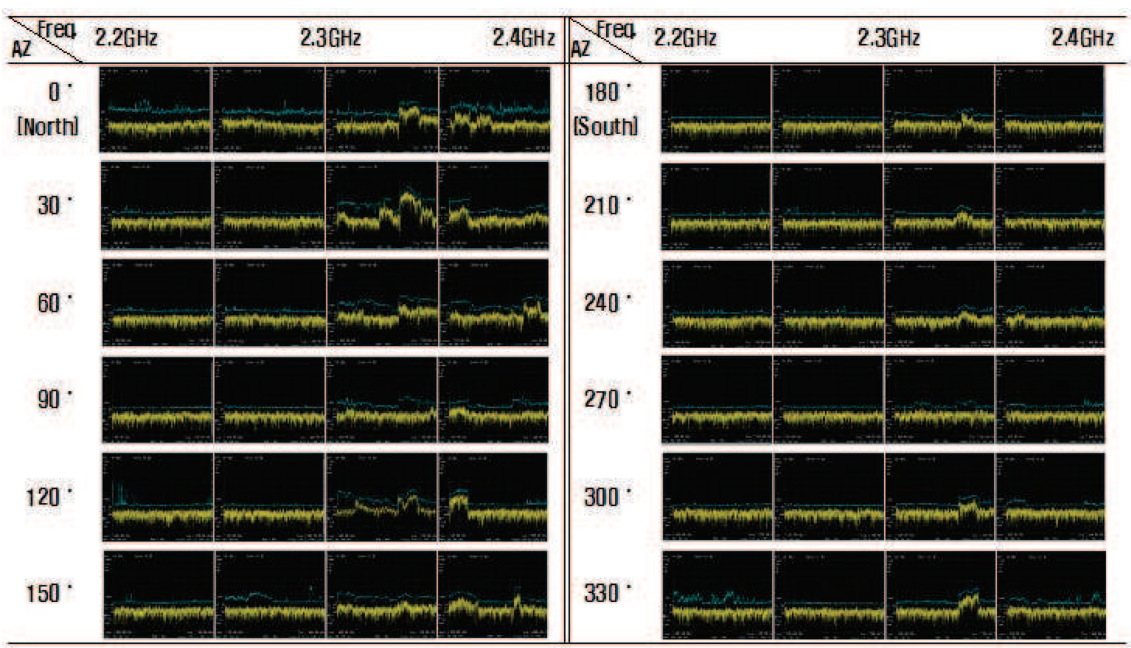

Figure 3. RFI measurement results using a spectrum analyzer.

Sheshan VLBI Station Report for 2012

Bo Xia, Zhiqiang Shen, Xiaoyu Hong, Qingyuan Fan

Abstract

This report summarizes the observing activities at the Sheshan station (SESHAN25) in 2012. It includes international VLBI observations for astrometry, geodesy, and astrophysics and domestic observations for satellite tracking. We also report on updates and on development of the facilities at the station.

1. General Information

The Sheshan VLBI station (SESHAN25) is located at Sheshan, 30 km west of downtown Shanghai. It is hosted by the Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS). A 25-meter radio telescope is in operation at 1.3, 3.6/13, 5, 6, and 18 cm wavelengths. The Sheshan VLBI station is a full member of the IVS and EVN. The SESHAN25 telescope takes part in international VLBI sessions in astrometric, geodetic, and astrophysics research. Apart from its international VLBI activities, the telescope spent a large amount of time on the Chinese Lunar Project, including the test observations and the tracking campaign of Chang'E-2.

Figure 1. SESHAN25 Radio Telescope.

2. VLBI Observations in 2012

In 2012, SESHAN25 participated in 19 IVS sessions (including six INT3 Intensive sessions). SESHAN25 also participated in the EVN sessions in February and October. Because of a VSI-C card problem, there were no fringes found in R1539 and R1540. In the Chinese Chang'E-2 Lunar Exploration Project, SESHAN25 observed the Chang'E-2 satellite for two or three sessions per week.

3. Development and Maintenance of Sheshan Telescope in 2012

A new pcal unit for S/X band was installed in December 2012. The pcal was injected before the LNA and after the feed. The pcal unit's input is 10 MHz from the H Maser. The pulse intervals can be adjusted by FS to 500 KHz, 1 MHz, 2 MHz, 5 MHz, or 10 MHz. Most of the time it works in 1 MHz mode.

We performed routine maintenance of our antenna from May to June. It included changing the gear box, painting, and control room decoration.

4. The Staff of the Sheshan VLBI Station

Table 1 lists the group members of the Sheshan VLBI Station. The staff are involved in the VLBI program at the station with various responsibilities.

Table 1. The staff of the Sheshan VLBI Station.

Name	Background	Position & Duty	Contact
Xiaoyu HONG	Astrophysics	Director, Astrophysics	xhong@shao.ac.cn
Qingyuan FAN	Ant. control	Chief Engineer, Antenna	qyfan@shao.ac.cn
Zhiqiang SHEN	Astrophysics	Head of VLBI Division	zshen@shao.ac.cn
Zhuhe XUE	Software	Professor, FS	zhxue@shao.ac.cn
Quanbao LING	Electronics	Senior Engineer, VLBI terminal	qling@shao.ac.cn
Bin LI	Microwave	Technical friend, Receiver	bing@shao.ac.cn
Tao AN	Astrophysics	Astrophysics	antao@shao.ac.cn
Bo XIA	Electronics	VLBI friend, VLBI terminal	bxia@shao.ac.cn
Hong YU	Ant. control	Associated Professor, Antenna	yuhong@shao.ac.cn
Li FU	Ant. mechanics	Engineer, Antenna	fuli@shao.ac.cn
Jinqing WANG	Electronics	Engineer, Antenna	jqwang@shao.ac.cn
Lingling WANG	Software	Engineer, VLBI terminal	llwang@shao.ac.cn
Rongbing ZHAO	Software	Engineer, VLBI terminal	rbzhao@shao.ac.cn
Weiye ZHONG	Microwave	Engineer, Receiver	wyzhong@shao.ac.cn
Wei GOU	Electronics	Engineer	gouwei@shao.ac.cn
Linfeng YU	Electronics	Engineer	lfyu@shao.ac.cn
Yongbin JIANG	Electronics	Engineer	jyb@shao.ac.cn
Yunxia Sun	HVAC	Engineer, Refrigeration	sunyunxia@shao.ac.cn
Xiaocong Wu	Electronics	Engineer	wuxc@shao.ac.cn
Wen Guo	Electronics	Engineer	gw@shao.ac.cn
Jian Dong	Ant. Control	Engineer	dongjian@shao.ac.cn

5. Outlook

In 2013, the Sheshan radio telescope will take part in 14 24-hour IVS sessions and 12 INT-3 sessions.

Simeiz VLBI Station - Geodetic and Astrophysical Study

A.E. Volvach

Abstract

This report gives an overview about the geodetic VLBI activities at the Simeiz station. It also summarizes the seasonal and long-term variability of the Black Sea level near Yalta, Odessa, Ochakov, and Katsively.

1. General Information

The Simeiz VLBI Station (also known as CRIMEA in the geodetic community), operated by Radio Astronomy Laboratory of Crimean Astrophysical Observatory, is situated on the coast of the Black Sea near the village Simeiz, 20 km west of the city Yalta in the Ukraine (Figure 1).

Figure 1. Simeiz VLBI station.

The fundamental geodynamics area "Simeiz-Katsively" is also situated on the coast of the Black Sea near the village Simeiz. It consists of two satellite laser ranging stations, a permanent GPS receiver, a sea level gauge, and the radio telescope RT-22. All of these components are located within 3 km (Figure 2).

Figure 2. The geodynamics area “Simeiz-Katsively”.

RT-22, the 22-meter radio telescope which was set in operation in 1966, is among the five most efficient telescopes in the world. Various observations in the centimeter and millimeter wave ranges are being performed with this telescope now and will be performed in the near future. First VLBI observations were performed in 1969 on the Simeiz (RT-22) — Green Bank (RT-43, USA) intercontinental baseline. RT-22 is equipped with radiometers at the 92 cm, 18 cm, 13 cm, 6 cm, 3.5 cm, 2.8 cm, 2.3 cm, 2.0 cm, 13.5 mm, and 8 mm wavelengths.

2. The Black Sea Level

The 22-m radio telescope RT-22 is located 80 m from the edge of the Black Sea. The geodynamics area “Simeiz-Katsively” consists of two satellite laser ranging stations, a permanent GPS receiver, a sea level gauge, and the radio telescope RT-22 (Nesterov and Volvach, 2002). All these components are located within 3 km. The Yalta level gauge is located near Yalta, 20 km east of RT-22.

A temporal spectrum of the Black Sea level variations and a possible relation between this spectrum and dynamics of changes in the position of the CRAO RT-22 as an element of the European geodynamic VLBI network are discussed in [1].

Using some results of the international geodynamic VLBI program for 1994 — 2011, the coordinates of the station Simeiz have been determined. The measurement results for the Simeiz RT-22 coordinates are compared with long-term monthly-averaged measurements for the Black

Sea level which are performed at the stations located in Odessa, Ochakov, Sevastopol, Yalta, and Katsively. All the stations of the sea level measurements have a different water flow, which gives the opportunity to explore global geodynamic processes and a relationship between them and a solar activity cycle. A spectrum of sea level variations at various points shows the presence of periods from one to 11 and 22 years. Results are presented in Table 1.

Table 1. The main periods of the Black Sea level variations.

Station	Period (month)	Value of periodogram
Ochakov	6	376
(1986-2005)	12	5000
	14	624
	17	675
	20	698
	40	743
Odessa	6	146
(1945-2010)	12	12839
	20	1799
	28	1346
	44	2851
	53	1777
	99	1761
	132	2806
	396	3173
Yalta	6	225
(1992-2003)	10	282
	12	1420
	14	586
	21	358
	29	643
Katsively	6	363
(1992-2009)	12	1986
	17	594
	40	754

The periods for each station's level are estimated separately with the use of wavelet analysis (Figure 3).

3. Current Status and Activities

During last year the Space Geodesy and Geodynamics stations regularly participated in the International Network programs — IVS, the International GPS Service (IGS), and the International Laser Ranging Service (ILRS).

During the period of January 1 – December 31, 2012, the Simeiz VLBI station participated in 12 24-hour geodetic sessions. Simeiz regularly participated in the EUROPE and T2 series of

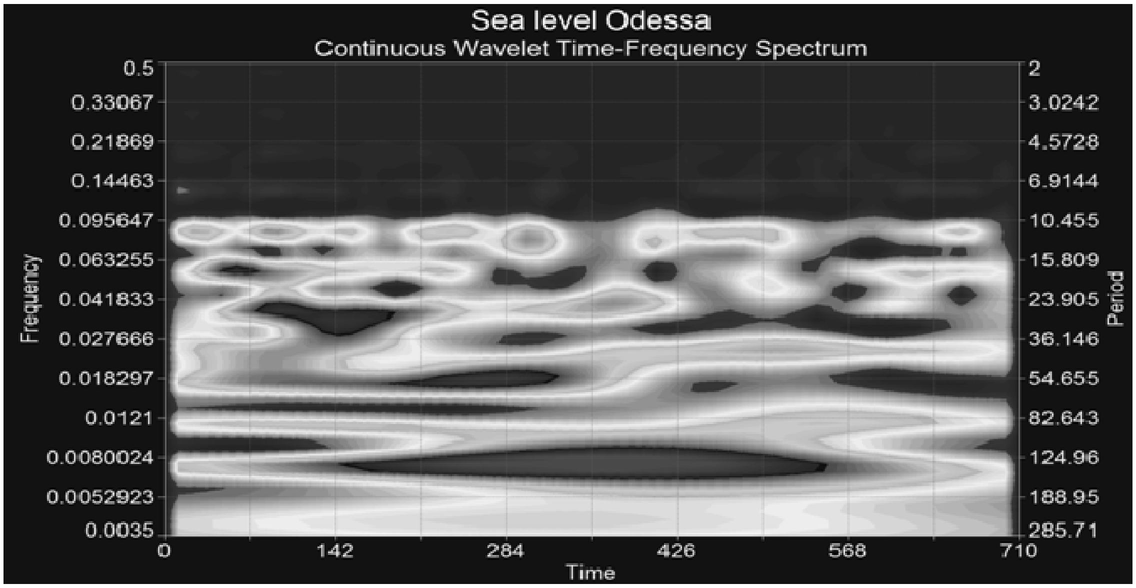

Figure 3. Wavelet analysis of the sea level in Odessa.

geodetic sessions.

Use of the Simeiz antenna is shared with the "Radioastron" program: the testing of the ground-based segment of the Radioastron mission at wavelengths of 1.35 cm.

In accordance with the scientific cooperation between Ukraine and Russia, the Simeiz (radio astronomy laboratory) team held a series of studies for the preparation of the operation of the ground segment of the "RadioAstron" mission. Using the 22-m radio telescope RT-22, the team prepared the scientific program of measurements, a substantial part of which is the study of the compact structures in the extragalactic sources. For testing of the model of the ground segment of "Radioastron", RT-22 of Crimean Astrophysical Observatory in Simeiz and RT-70 (P-2500) in Evpatoria jointly conducted ground-based VLBI test experiments at 1.35 cm [2].

4. Future Plans

Our plans for the coming year are the following: to put into operation the VLBI Data Acquisition System DBBC, to upgrade the laser of the SLR Simeiz-1873 station, and to set up a new GPS station near the Simeiz VLBI station.

References

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Svetloe Radio Astronomical Observatory

Sergey Smolentsev, Ismail Rahimov

Abstract

This report summarizes information about the Svetloe Radio Astronomical Observatory activities in 2012. Last year, a number of changes took place in the observatory to improve some technical characteristics and to upgrade some units to their required status. The report provides an overview of current geodetic VLBI activities and gives an outlook for the future.

1. General Information

The Svetloe Radio Astronomical Observatory (Figure 1) was created by the Institute of Applied Astronomy (IAA) as the first station of the Russian VLBI network QUASAR [1].

The sponsoring organization of the project is the Russian Academy of Sciences (RAS). The Svetloe Radio Astronomical Observatory is situated near the village Svetloe, in the Priozersky district, Leningrad Region (Table 1). The geographic location of the observatory is shown on the IAA RAS Website: *http://www.ipa.nw.ru/PAGE/rusipa.htm*. The main instruments of the observatory are the 32-m radio telescope equipped with special technical systems for VLBI observations, GPS/GLONASS/Galileo receivers, and the SLR system.

Figure 1. Svetloe observatory.

Table 1. Svetloe Observatory location and address.

Longitude	29°47′
Latitude	60°32′
Leningrad region, Priozerski district	
188833 Russia	
rahimov@osvtl.spb.ru	

2. Technical Staff

Prof. Ismail Rahimov — the head of the observatory,
Vladimir Tarasov — the chief engineer,
Tatiana Andreeva — the engineer, and
Andrey Mikhailov — FS, pointing system control specialist.

3. Technical and Scientific Information

Table 2. Technical parameters of the radio telescope.

Year of construction	2000
Mount	AZEL
Azimuth range	±270° (from south)
Elevation range	from −5° to 95°
Maximum azimuth *	
- velocity	0.83 °/s
- tracking velocity	2.5 ′/s
- acceleration	12.0 $'/s^2$
Maximum elevation *	
- velocity	0.5 °/s
- tracking velocity	0.8 ′/s
- acceleration	12.0 $'/s^2$
Pointing accuracy	better than 10″
Configuration	Cassegrain (with asymmetrical subreflector)
Main reflector diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Main reflector shape	quasi-paraboloid
Subreflector shape	quasi-hyperboloid
Main reflector surface accuracy	± 0.5 mm
Frequency range	1.4–22 GHz
Axis offset *	5.5 ± 2.0 mm

* These values were changed to optimize the performance of the antenna system. The axis offset was measured in summer 2011 by geodesist Andrey Shamov.

4. Co-location of VLBI, GPS/GLONASS, and SLR System

The Topcon GPS/GLONASS/Galileo receiver with meteo station WXT-510 is in operation (Figure 2).

Figure 2. Topcon GPS/GLONASS/Galileo receiver at Svetloe observatory.

The SLR system "Sazhen-TM" (Figure 3) was mounted in October 2011 and joined ILRS in March 2012.

The technical characteristics of the system are presented in Table 3.

Figure 3. "Sazhen-TM" SLR system at Svetloe observatory.

5. Current Status and Activities

The Svetloe observatory participates in IVS and domestic VLBI observing programs. In 2012, Svetloe station participated in 28 diurnal IVS-R4, IVS-T2, and EURO sessions and in 18 IVS Intensive sessions.

Table 3. Technical parameters of the SLR system “Sazhen-TM”.

Ranging distance, day	400-6000 km
Ranging distance, night	400-23000 km
Aperture	25 cm
Wavelength	532 nm
Beam divergence	12″
Laser pulse frequency	300 Hz
Pulse energy	2.5 mJ
Mass	170 kg
Normal points precision	1 cm
Angular precision	1-2″

Svetloe participated in 47 diurnal sessions of the domestic Ru-E program for determining all Earth orientation parameters, and in 36 one-hour Ru-U sessions to obtain Universal Time using e-VLBI data transfer.

6. Outlook

We have the following plans for the coming year:

- To participate in IVS observations
- To carry out domestic observing programs to obtain Universal Time with e-VLBI data transfer and Earth orientation parameters once a week
- To carry out SLR observations of geodetic and navigation satellites
- To participate in EVN and RADIOASTRON observing sessions
- To continue geodetic monitoring of the antenna parameters.

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JARE Syowa Station 11-m Antenna, Antarctica

Yuichi Aoyama, Koichiro Doi, Kazuo Shibuya

Abstract

In 2012, the 52^{nd} and the 53^{rd} Japanese Antarctic Research Expeditions (hereinafter, referred to as JARE–52 and JARE–53, respectively) participated in five OHIG sessions — OHIG76, 78, 79, 80, and 81. These data were recorded on hard disks through the K5 terminal. Only the hard disks for the OHIG76 session have been brought back from Syowa Station to Japan, in April 2012, by the icebreaker, Shirase, while those of the other four sessions are scheduled to arrive in April 2013. The data obtained from the OHIG73, 74, 75, and 76 sessions by JARE–52 and JARE–53 have been transferred to the Bonn Correlator via the servers of National Institute of Information and Communications Technology (NICT). At Syowa Station, JARE–53 and JARE–54 will participate in six OHIG sessions in 2013.

1. General Information

To investigate polar science, the National Institute of Polar Research (NIPR) is managing Japanese Antarctic Research Expeditions (JAREs). The 31 members of JARE–53 overwintered at Syowa Station, East Ongul Island, East Antarctica in 2012.

Syowa Station has become one of the key observation sites in the Southern Hemisphere's geodetic and geophysical networks (shown in Figure 1), as reported in [1]. As part of these geodetic measurements, the JAREs have been operating the 11-m S/X–band antenna at Syowa Station (69.0°S, 39.6°E) for geodetic VLBI experiments since February 1998. A total of 102 quasi-regular geodetic VLBI experiments were performed by the end of 2012.

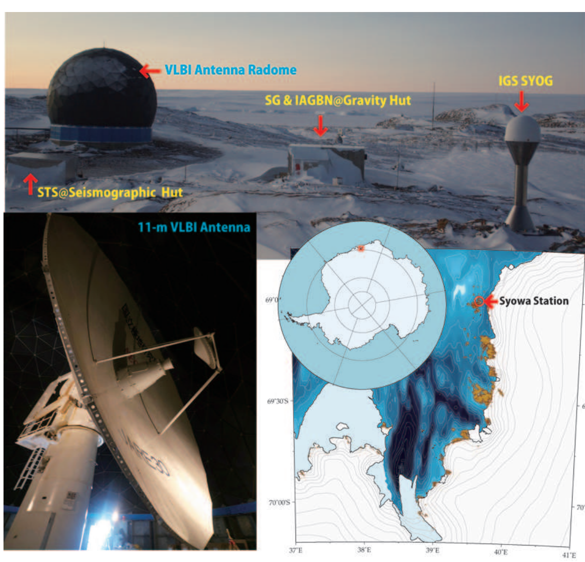

Figure 1. Syowa VLBI antenna.

Figure 2. Syowa VLBI staff of JARE–53, H. Hayakawa (right) and T. Yoshioka (left).

2. Component Description

For VLBI, the Syowa antenna is registered as IERS Domes Number 66006S004 and as CDP Number 7342. The basic configuration of the Syowa VLBI front-end system has not changed from the description in [2]. Syowa's K4 recording terminal had been fully replaced by K5 simultaneously with the termination of the SYW session at the end of 2004. Syowa has participated in the OHIG sessions in the austral summer season since 1999. Data transfer through an Intelsat satellite link from Syowa Station to NIPR has been available since 2004. However, its recent bandwidth is about 2 MB, and its effective speed of FTP transfer is about 100kB/sec which is too slow to transfer the huge VLBI data practically.

3. Staff of the JARE Syowa Station 11-m Antenna

The Syowa Station 11–m antenna is operated and maintained by JARE and NIPR. The staff members are listed in Table 1. OHIG sessions in 2012 were performed primarily by the staff of JARE–53 as shown in Figure 2. The staff of JARE–52 supported them in the OHIG76 session, in order to hand the operation and maintenance of the 11–m antenna over to JARE–53 as their successor.

Table 1. Staff members.

Name	Affiliation	Function
Kazuo SHIBUYA	NIPR	Project coordinator
Koichiro DOI	NIPR	Liaison officer
Yuichi AOYAMA	NIPR	Liaison officer
Syunsuke IWANAMI	Tomakomai Nationl College of Technology	Chief operator of JARE–52
Shinobu TAKAHIRA	NEC	Antenna engineer for JARE–52
Hideaki HAYAKAWA	NIPR	Chief operator of JARE–53
Takeshi YOSHIOKA	NEC	Antenna engineer for JARE–53

JARE–52: February 2011 – January 2012 JARE–53: February 2012 – January 2013

4. Current Status and Activities

4.1. Notes on System Maintenance

There used to be two hydrogen masers, Anritsu RH401A HM–1001C and HM–1002C at Syowa Station. Since a failure had occurred in the HM–1002C, it had been repaired and overhauled at Anritsu Co., Ltd. in Japan between April and October 2011. We attempted to return the HM–1002C to Syowa Station immediately. However, it was impossible to transport it, because the icebreaker, Shirase, could not approach Syowa Station in the 2011/2012 austral summer season due to dense and thick sea ice. Then the HM–1002C was turned back to Japan in April 2012 and was maintained at Anritsu Co., Ltd. until October 2012. Although we planned to re-install the HM–1002C at the Syowa Station again in the 2012/2013 austral summer season, we had to abandon its re-installation, because Shirase could not approach Syowa Station for a second consecutive year.

The other hydrogen maser, HM–1001C, has operated for VLBI observations since January

2011. On March 11, 2011, its ion pump was interrupted, and an uninterruptible power supply (UPS) for the HM–1002C was broken down by instability in both the voltage and the frequency of the generator for power supplies at Syowa Station. Since then, the ion pump has been interrupted occasionally. In 2012, such interruptions, which caused a low vacuum inside the HM–1001C and attenuated the hydrogen maser oscillator, occurred on February 25, August 15, September 2, and November 20. The JARE–53 staff had to form a high vacuum and to check the hydrogen maser generation at all such times. They also checked that there was no apparent difference in 1 PPS and 10 MHz between HM–1001C and GPS whenever they restarted the HM–1001C. For the purpose of lightening these work loads, we have purchased a new hydrogen maser, which is miniaturized to be carried on the helicopter. We will install the new one in Syowa Station in the next austral summer.

Write errors sometimes occurred during data recording to HDD of the K5 system, so that the K5 system froze. These were caused by inadequate setting for the ATA transfer mode. Starting with OHIG81, we configured the ATA transfer mode with UDMA66; therefore such problems were solved.

A system for delay calibration (D–Cal) recording is independent of the K5 system. D–Cal signals used to be recorded at the start and the end of each Syowa scan onto the floppy disk (FD) by using a Basic program based on the old NEC PC. However, timing to record D–Cal came to be unsynchronized with each Syowa scan since the updating of SKED in 2010. We have not modified this program yet. In addition, the FD drive broke down in November 2012, so that we could not record D–Cal during OHIG79-81. The broken FD drive was replaced by a spare in January 2013, and D–Cal signals resumed being stored on FD.

4.2. Session Status

Table 2 summarizes the status of processing as of December 2012 for the sessions after 2011. The OHIG sessions involved Fortaleza (Ft), O'Higgins (Oh), Kokee Park (Kk), TIGO Concepción (Tc), Hobart 26-m antenna (Ho), Hobart 12-m antenna (Hb), HartRAO (Hh), Warkworth (Ww), and Syowa (Sy). In 2005, Syowa joined the CRD sessions, but after 2006, Syowa participated only in OHIG sessions. Syowa took part in five OHIG sessions in 2012.

K5 HDD data brought back from Syowa Station were transferred to NICT servers and converted to the Mark 5 format data there. The converted data were transferred from the NICT servers to the Bonn Correlator by FTP.

4.3. Analysis Results

As of December 2012, Syowa had contributed 93 sessions starting in May 1999. According to the results analyzed by the BKG IVS Analysis Center, the length of the Syowa–Hobart baseline is increasing with a rate of 55.5 ± 1.1 mm/yr. The Syowa–HartRAO baseline shows a slight increase in its length with a rate of 12.3 ± 1.1 mm/yr. The Syowa–O'Higgins baseline also shows a slight increase, although its rate is only 2.4 ± 1.1 mm/yr. Detailed results from the data until the end of 2003 as well as comparisons with those from other space geodetic techniques were reported in [3].

Table 2. Status of OHIG sessions as of December 2012.

Code	Date	Station	Hour	Correlation	Solution	Notes
OHIG70	2011/Feb/02	Sy, Hb, Hh, Ho, Kk, Oh, Tc	24 h	Yes	Yes	J52 †1
OHIG71	2011/Feb/08	Sy, Hb, Hh, Kk, Oh, Tc	24 h	Yes	Yes	†1
OHIG72	2011/Feb/09	Sy, Hh, Kk, Oh, Tc	24 h	No	No	†1
OHIG73	2011/Nov/01	Sy, Ft, Kk, Ww	24 h	Yes	Yes	†1
OHIG74	2011/Nov/08	Sy, Ft, Kk, Tc, Ww	24 h	Yes	Yes	
OHIG75	2011/Nov/09	Sy, Ft, Kk, Tc, Ww	24 h	Yes	Yes	
OHIG76	2012/Feb/15	Sy, Ft, Hh, Kk, Oh, Tc	24 h	Yes	Yes	J53
OHIG77	2012/Feb/28	Ft, Kk, Oh, Tc	24 h	–	–	†2
OHIG78	2012/Feb/29	Sy, Ft, Hh, Kk, Oh, Tc	24 h	–	–	
OHIG79	2012/Nov/06	Sy, Ft, Hb, Kk, Tc	24 h	–	–	
OHIG80	2012/Nov/07	Sy, Ft, Hb, Kk, Tc	24 h	–	–	
OHIG81	2012/Nov/14	Sy, Hb, Hh, Kk, Tc	24 h	–	–	

J52: JARE–52, op S. Iwanami eng S. Takahira
J53: JARE–53, op H. Hayakawa eng T. Yoshioka
†1 : Large clock offset occurred.
†2 : Syowa canceled participation in OHIG77 experiment because of malfunction of HM–1001C.

5. Future Plans

Dismantling the current Syowa VLBI antenna is scheduled for the 2015/2016 austral summer season. Because Shirase could not approach Syowa Station for two consecutive years, this schedule will possibly be postponed. We presented a proposal to budget for new VLBI2010 antenna construction in 2018. We will make every effort until this proposal is approved.

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Status of the TIGO VLBI Station in Concepción

Hayo Hase, Cristian Herrera, Felipe Pedreros, Octavio Zapata, Pedro Pino

Abstract

The main activities at the TIGO VLBI station during 2012 have been 120 successful VLBI sessions and the investigation of an alternate site for TIGO for future operation.

1. General Information

Since 2002, TIGO has been located in the terrain of the Universidad de Concepción (longitude 73.025 degrees West, latitude 36.843 degrees South), in Concepción, Chile.

The TIGO project is carried out on the basis of governmental decree 489, which considers four Chilean institutions as project partners for the German Federal Agency of Cartography and Geodesy (BKG). Two Chilean partners had left in 2004 and 2007, and by the end of 2011 the Universidad de Concepción, as the main partner, had to recall its commitment to the TIGO project. Hence with the beginning of 2012 only one Chilean partner remained for the German BKG: the Instituto Geográfico Militar. The TIGO project lacks management to achieve financial support by the Chilean government. A temporary financial aid from BKG allowed for continuous operation in 2012 and 2013. Without full Chilean support, Germany is obliged to find new partners elsewhere and to look for an alternate site for its future operation. The candidate site is the Instituto Argentino de Radioastronomía (IAR) near La Plata in Argentina.

2. Component Description

The IVS Network Station TIGOCONC constitutes the VLBI part of the Geodetic Observatory TIGO, which was designed to be a fundamental station for geodesy. Hence, the VLBI radio telescope is co-located to an SLR telescope (ILRS site), a GPS/Glonass permanent receiver (IGS site), and other instruments such as a seismometer, a superconducting gravimeter, and an absolute gravity meter.

The atomic clock ensemble of TIGO consists of three hydrogen masers, three cesium clocks, and four GPS time receivers realizing the Chilean contribution to the Universal Time scale (Circular T, BIPM).

The technical parameters of the TIGO radio telescope as published in [1] have not been changed.

3. Staff

The 2012 VLBI staff consisted of four persons, as listed in Table 1. Felipe Pedreros left TIGO in July to work for one year at the South Pole station. He was replaced by Pedro Pino. Octavio Zapata reduced his obligations from full-time to half-time for the second part of the year.

Figure 1. 2012 VLBI Staff: Herrera, Zapata (until December), Pedreros (until July), and Hase. Not shown in the photo is Pedro Pino, who replaced Felipe Pedreros.

Table 1. TIGO-VLBI support staff in 2012.

Staff	Function	Email	Remark
Hayo Hase	Head	hayo.hase@tigo.cl	
Cristian Herrera	Informatic Engineer	cristian.herrera@tigo.cl	
Felipe Pedreros	Telecommunications Engineer	felipe.pedreros@tigo.cl	until July 2012
Octavio Zapata	Telecommunications Engineer	octavio.zapata@tigo.cl	until December 2012
Pedro Pino	Electronic Engineer	pedro.pino@tigo.cl	since August 2012
all VLBI operators		vlbistaff@tigo.cl	

4. Current Status and Activities

4.1. IVS Operation

During 2012, TIGO was scheduled to participate in 120 regular IVS sessions. Three 24-hour additional participations had been carried out within the TANAMI-project [2]. Table 2 gives an overview about the participation of TIGOCONC in 2012. Out of 123 requested observation days, 120 could be observed successfully, reaching an efficiency of 97%. The main reasons for data loss have been related to technical problems in the refrigerating system of the receiver, recording problems on bad data carriers, and unexpected delays in the customs clearance procedure of data carriers.

Table 2. TIGO's IVS observation statistics for 2012.

Name	R1xxx	R4xxx	OHIGxx	T2	RD	TANAMI	Total IVS
# of Exp.	52	52	6	2	8	3	**123**
Correlated	50	52	5	2	8	3	**120**
No result	2	0	1	0	0	0	**3**

4.2. Search for New Site for TIGO

Some conversations between Germany and Argentina concerning a future cooperation for the operation of a Geodetic Observatory have been fruitful. A potential site for TIGO was identified at the Instituto Argentino de Radioastronomía (IAR) near La Plata in Argentina. From July to October 2012 investigations into the radio frequency situation at IAR were carried out. From the data of one month of continuous monitoring, it was concluded that the proposed site is suitable for future VLBI observations [3]. During November 2012 three engineers from IAR visited TIGO in order to become familiar with the necessities of this observatory (Figure 2).

Figure 2. Visit of technical staff from IAR in November 2012: Guillermo Gancio, Augusto Cassino, and Daniel Perilli.

5. Future Plans

The VLBI activities in 2013 will be focused on:

- Execution of the IVS observing program for 2013, and
- Preparation and disassembling of TIGO for its transportation to a new site.

References

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Tsukuba 32-m VLBI Station

Ryoji Kawabata, Shinobu Kurihara, Yoshihiro Fukuzaki, Jiro Kuroda, Tadashi Tanabe, Yasuko Mukai, Takashi Nishikawa

Abstract

The Tsukuba 32-m VLBI station is operated by the Geospatial Information Authority of Japan. This report summarizes activities of the Tsukuba 32-m VLBI station in 2012. More than 200 sessions were observed with the Tsukuba 32-m and other GSI antennas in accordance with the IVS Master Schedule of 2012. We have started installing the observing facilities that will be fully compliant with VLBI2010 for the first time in Japan.

1. General Information

The Tsukuba 32-m VLBI station (TSUKUB32, Figure 1) is located at the Geospatial Information Authority of Japan (hereafter GSI) in Tsukuba Science City, which is about 50 km to the northeast of the capital of Japan, Tokyo. GSI has three regional stations besides TSUKUB32: SINTOTU3, CHICHI10, and AIRA, which form a geodetic VLBI network in Japan covering the whole country (Figure 2).

GSI carried out the domestic VLBI session series called "JADE (JApanese Dynamic Earth observation by VLBI)". The main purposes of the JADE series are to maintain the reference frame of Japan and to monitor the plate motions for the advanced study of crustal deformations around Japan. Additionally, Mizusawa (VERAMZSW) and Ishigakijima (VERAISGK), which are part of the VERA network of the National Astronomical Observatory of Japan (NAOJ), and Kashima (KASHIM11) and Koganei (KOGANEI) 11-m stations, which belong to the National Institute of Information and Communications Technology (NICT), have also participated in some JADE sessions.

Figure 1. Tsukuba 32-m VLBI station.

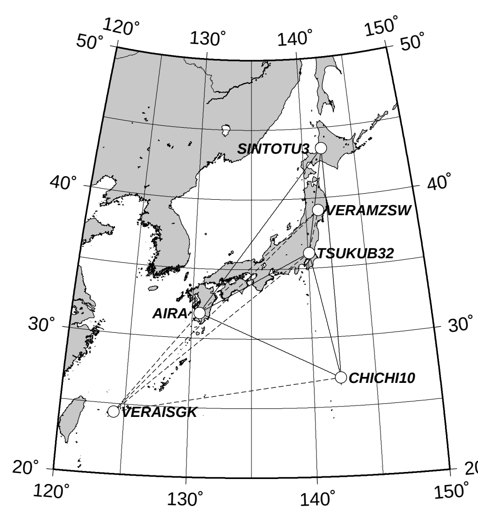

Figure 2. Geodetic VLBI network in Japan.

2. Component Description

The specifications of the Tsukuba 32-m antenna are summarized in Table 1.

Table 1. Tsukuba 32-m antenna specifications.

Owner and operating agency	Geospatial Information Authority of Japan
Year of construction	1998
Radio telescope mount type	Az-El
Antenna optics	Cassegrain
Diameter of main reflector	32 m
Azimuth range	10 – 710°
Elevation range	5 – 88°
Az/El drive velocity	3°/sec
Tsys at zenith (X/S)	50 K / 65 K
SEFD (X/S)	320 Jy / 360 Jy
RF range (X1)	7780 – 8280 MHz
RF range (X2)	8180 – 8680 MHz
RF range (X3)	8580 – 8980 MHz
RF range (S with BPF)	2215 – 2369 MHz
Recording terminal	K5/VSSP32, ADS3000+ with DDC

3. Members

Table 2 lists the regular members belonging to the GSI VLBI observation group. Misao Ishihara and Kensuke Kokado moved to another division at the beginning of April. Therefore, Tadashi Tanabe has become the director of our division. Routine operations were mainly performed under contract with Advanced Engineering Service Co., Ltd. (AES).

Table 2. Member list of the GSI VLBI group.

Name	Main Function
Tadashi TANABE	Supervisor
Jiro KURODA	Management, Co-location
Yoshihiro FUKUZAKI	Installation of VLBI2010 system
Shinobu KURIHARA	Correlation, Analysis, IVS Directing Board member
Ryoji KAWABATA	Observation, Co-location
Kazuhiro TAKASHIMA	Research
Yasuko MUKAI	Operation (AES, Co., Ltd)
Takashi NISHIKAWA	Operation (AES, Co., Ltd)
Toshio NAKAJIMA	System engineer (I-JUSE)

4. Current Status and Activities

4.1. Geodetic VLBI Observations

The regular sessions in the IVS Master Schedule which were observed by using GSI antennas are shown in Table 3. TSUKUB32 participated in 87 domestic and international 24-hr VLBI sessions, and in 131 Intensive 1-hr sessions for dUT1 measurement in 2012. TSUKUB32 could not participate in the IVS sessions from the end of February to March due to the repair of some cracks in the supporting structures of the subreflector as mentioned in Section 4.2. Some IVS-CRF sessions were observed by TSUKUB32 this year. The other GSI antennas, SINTOTU3, CHICHI10, and AIRA, participated not only in domestic sessions but also in some international sessions.

Table 3. The number of regular sessions observed by using GSI antennas in 2012. The numbers in parentheses show those of canceled sessions listed in the IVS Master Schedule.

Sessions	TSUKUB32	SINTOTU3	CHICHI10	AIRA
IVS-R1	44(4)	–	–	–
IVS-R4	9(3)	–	–	–
IVS-T2	6(1)	–	7	7
APSG	2	2	2	2
VLBA	5	–	–	–
IVS-R&D	9(1)	–	–	–
IVS-CRF	3	–	–	–
JADE	8	7	4	4
JAXA	1	–	1	1
IVS-INT2	88	–	–	–
IVS-INT3	43	–	–	–
Total	218	9	14	14

4.2. Repair of Tsukuba 32-m Antenna

At the end of February, we investigated the TSUKUB32 antenna in order to find the cause of a reduction of main beam efficiency in K-band especially at low elevation angles, which was reported by our research collaborator, Tsukuba University. After the investigation, some cracks were found on the joint parts of the subreflector supporting structure, which could cause the change of the subreflector position depending on the elevation angle. TSUKUB32 could not participate in the IVS sessions for just over one month, until we repaired these cracks and reinforced the joint parts by using iron covers at the end of March.

4.3. Fringe Tests with Sejong 22-m Antenna

The Sejong 22-m antenna, which is the first geodetic VLBI antenna in Korea, was constructed and became an IVS network station in 2012. TSUKUB32 had some fringe tests with the Sejong antenna in order to check the Sejong antenna system before participating in the IVS sessions. After some tests, we managed to detect fringes in both S and X-band (Figure 3).

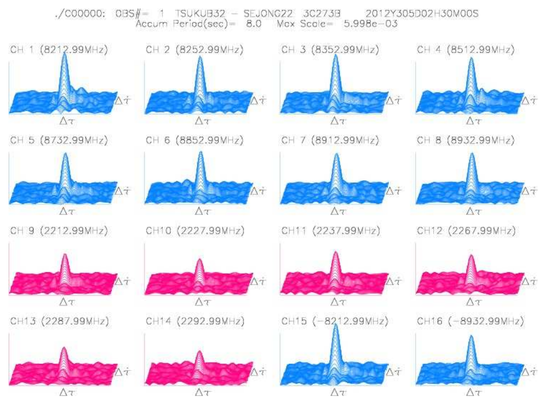

Figure 3. Fringes in X-band (blue) and S-band (red) found in the experiment on October 31.

5. VLBI2010 Project in GSI

We have entered into contracts with some manufacturers for a new antenna and necessary components for GSI VLBI2010 observing facilities. The GSI VLBI2010 station is now planned to be installed at a candidate site in Ishioka city located about 17 km northeast from Tsukuba (Figure 4), and it will be compliant with all requirements for VLBI2010 specification. The site has stable foundation ground and is in a relatively RFI-quiet environment. We considered special features of the antenna structure and the location of the survey pillars so that we can efficiently perform a local-tie survey with a GNSS observation point, which is also planned to be installed at the same site.

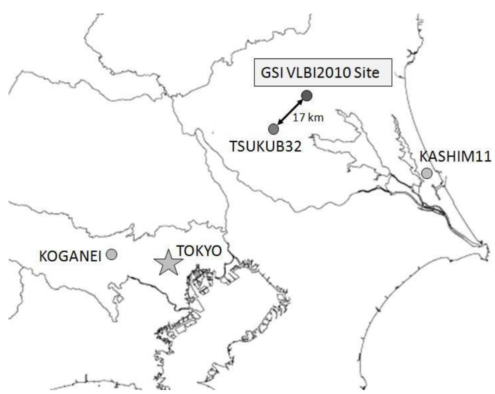

Figure 4. Location of the candidate site for the GSI VLBI2010 station.

Warkworth 12-m VLBI Station: WARK12M

Stuart Weston, Hiroshi Takiguchi, Tim Natusch, Lewis Woodburn, Sergei Gulyaev

Abstract

The Warkworth 12-m radio telescope is operated by the Institute for Radio Astronomy and Space Research (IRASR) at AUT University, Auckland, New Zealand. Here we review the characteristics of the 12-m VLBI station and report on a number of activities and technical developments in 2012.

1. General Information

Table 1: Specifications of the Warkworth 12-m antenna.

Antenna type	Dual-shaped Cassegrain
Manufacturer	Cobham/Patriot, USA
Main dish Diam.	12.1 m
Secondary refl. Diam.	1.8 m
Focal length	4.538 m
Surface accuracy	0.35 mm
Pointing accuracy	$18''$
Mount	alt-azimuth
Azimuth axis range	$90^\circ \pm 270^\circ$
Elevation axis range	4.5° to 88°
Azimuth axis max speed	5°/s
Elevation axis max speed	1°/s

The WARK12M VLBI station is located some 60 km north of the city of Auckland, near the township of Warkworth. Specifications of the Warkworth 12-m antenna are provided in Table 1. The radio telescope 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 baseband converter (DBBC) developed by the Italian Institute of Radio Astronomy. The station frequency standard is a Symmetricom Active Hydrogen Maser MHM-2010 (75001-114). Mark 5B+ and Mark 5C data recorders are used for data storage and streaming of recorded data off site through the network. The observatory network is directly connected to the national network KAREN (Kiwi Advanced Research and Education Network) via a 1 Gbps fiber link to the site [1].

2. Component Description

2.1. 12-m Antenna: Progress and Issues

The new L-Band feed was designed by Cobham, USA and installed in May 2012 (Figure 1). It is located behind the secondary mirror at the prime focus, so for L-band observations the secondary mirror has to be removed.

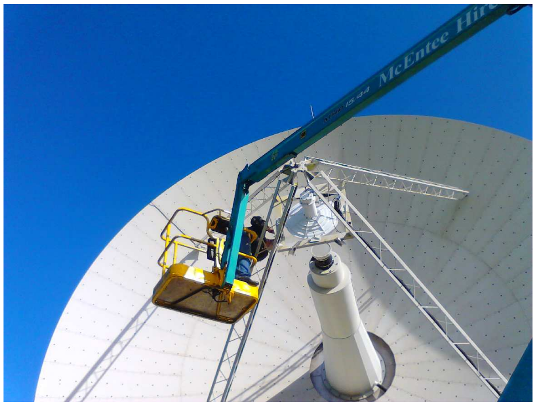

Figure 1: The new L-Band feed installed at prime focus on the 12 m. Credit: S. Weston.

In late 2012, the Hydrogen maser developed a fault, and it had to be returned to Symmetricom. It is expected to be back and operational in February-March 2013. This has severely impacted our station's participation in IVS and LBA observations from late 2012 to date. Another problem was connected with the jack screw elevation bearing; this was finally repaired in early February 2013. This would appear to have been caused by poor initial assembly, with the grease passage way blocked by the protective plastic membrane not having been removed prior to assembly. The DBBC has had new filters installed to the input IF's for the L-band; this will allow the RF to be received directly with no mixing. We are working on finishing the L-band backend for LBA sessions in 2013. We have undertaken a big tidy up of the racks to try to make the systems more manageable; all systems not required in the 12-m system racks have been moved to the 30 m computer room across the road to help reduce the heat sources within the 12-m control room because the maser resides here.

2.2. 30-m Antenna: Progress and Issues

The 30-m Cassegrain beam-waveguide NEC antenna was used by Telecom NZ after construction in 1984. It was handed over to AUT in 2010. Renovation of the 30 m started in 2011. Old azimuth and elevation motors have been removed and replaced with new ones (see Figure 2). A new control system from Control Techniques, UK, very similar to the system used on the 12 m, was installed. A new cable wrap system was installed, and new cables have been pulled through. In mid-February 2013 Mark Godwin will be on-site to commission the new control system. A bolt replacement program by a local rigging contractor has started. We are in the process of negotiating a maintenance contract with them for both the 30 m and the 12 m. Additional DBBC and Mark 5C equipment have been ordered for the 30 m. Work continues on using the existing satellite receiver in C-Band, but we are also talking with other parties about receiver systems. Obviously we would like to have L, S, C, and X but are unsure of the waveguide optics.

2.3. Warkworth Network

We continue to e-transfer data to the correlators. We have installed a new 10Gbit switch in the 30 m computer room. This provides fiber point to point connectivity between the DBBC and Mark 5C via the Fila10G interface and gives us a 10Gbit backbone at the observatory. The network topography was changed so that the 12 m is now a spur from the 30 m KAREN POP. Warkworth now has a direct IP presence on KAREN, so data transfers should no longer go through the University Campus (of mutual benefit to us and campus LAN users). It is hoped with the upgrades taking place with the KAREN network that we will have 10Gbps international connectivity to/from the observatory in the near future. The 30 m building has been wired with cat6 and fiber has been installed from the computer room to the pedestal room beneath the dish where the wave guide terminates. In addition, equipment has been installed for distribution of 1PPS and 10 MHz from

Figure 2: The 30 m: Top left, one of the old azimuth motors being replaced. Top right, Tim and Takiguchi having finished replacing one of the elevation motors. Bottom left, an example of the corrosion we have to get on top of. Bottom right, with the new motors and control system we are now able to move the dish once again. Image Credit: S. Weston.

the maser at the 12 m over to the 30 m pedestal room using a Symmetricom RF via fiber system.

3. Current Status and Activities

In March 2012 we had a visit by Gino Tuccari with Jim Lovell and Jamie McCallum from Hobart for a mini workshop about the DBBC, looking at diagnoses and issue resolution. Later in the year during September Ed Himwich also paid a visit, during which he installed the new Field System DBBC support components. Now when we run Drudg, the generated schedule .prc file contains the appropriate commands to program and setup the DBBC. We have successfully installed SDK 9.2 on our Mark 5B to support disk packs larger than 8 TB. We now have a station pool of five 16 TB disk packs which we will be using for LBA and the AUSTRAL experiments with AuScope antennas in Australia. In addition to the IVS and LBA observations, the WARK12M is now also a tracking station for SpaceX on their supply missions to the International Space Station.

3.1. Co-operative Observation

Co-operative observation for geodetic purposes with NICT (Japan) and University of Tasmania (Australia) started. The baseline of WARK12M and KASHIM11 is a long north-south baseline of over 8,000 km. The first observation of the WARK12M-KASHIM11 baseline was carried out in April 2012 and the baseline length has been determined as 8,075,003,545±150 mm. By repeating the observation, we expect to obtain information about the relative tectonic motion of Japan and New Zealand. Also, we are working to establish the ability to derive EOP ultra-rapidly by utilizing this baseline, existing UT1 products (such as from the IVS INT2 sessions), and data transfers by high-speed network. The University of Tasmania operates three 12-m radio telescopes located in Hobart (HOBART12), Yarragadee (YARRA12M), and Katherine (KATH12M) under the AuScope project [2]. These three telescopes and WARK12M are located on the Australian tectonic plate and consequently are ideally placed for measurements of intra-plate deformation. WARK12M-AuScope observations started in July 2012. Monthly 24-h observations and a series of multi-day observations together with AuScope antennas will be scheduled from early 2013.

Figure 3 shows the baseline length changes of the Warkworth-Hobart baseline derived from both GNSS and VLBI data sources for the epoch 2011-2013. We checked all of the baselines of AuScope and WARK12M. GNSS results indicate a small intra-plate deformation. On some baselines current VLBI results appear to be in disagreement with the GNSS data. At this stage it is not possible to comment further on this discrepancy due to the statistically small number of VLBI observations. Our proposed co-operative observations will add vital data points, reduce the noise, and compensate for this current VLBI weakness.

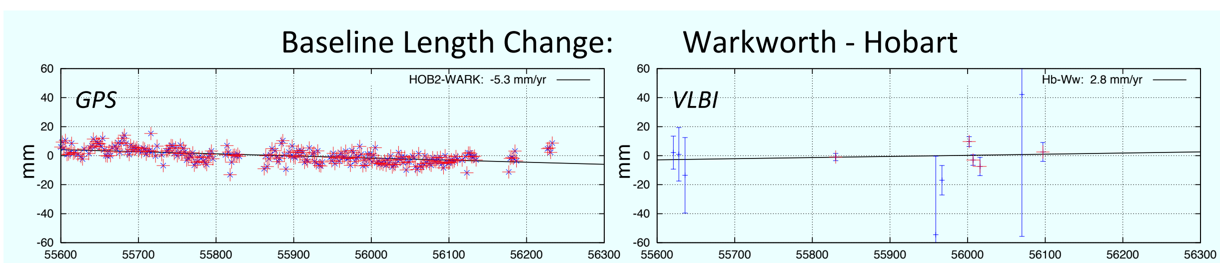

Figure 3: The baseline length changes of the Warkworth-Hobart baseline derived from both GNSS and VLBI data sources for the epoch 2011-2013. GNSS results were produced by analysis of the GNSS data (IGS: alic, auck, hob2, karr, kat1, yarr + PositioNZ: wark) using the GAMIT/GLOBK software package. VLBI baseline behavior was determined from results produced by the IVS analysis center. The difference of color indicates whether these data were used (red) for the calculation of the change rate or excluded (blue).

References

[1] Weston, S., Natusch, T., Gulyaev, S., Radio Astronomy and e-VLBI using KAREN. *In Proceedings of the 17th Electronics New Zealand Conference*, 2010. Preprint arXiv:1011.0227.

[2] Lovell, J. E. J., McCallum, J. N., Reid, P. B., McCulloch, P. M., Baynes, B. E., Dickey, J. M., Shabala, S. S., Watson, C. S., Titov, O., Ruddick, R., Twilley, R., Reynolds, C., Tingay, S. J., Shield, P., Adada, R., Ellingsen, S. P., Morgan, J. S., Bignall, H. E., The AuScope geodetic VLBI array, *Journal of Geodesy*, 1-12. doi:10.1007/s00190-013-0626-3, 2013.

Westford Antenna

Mike Poirier

Abstract

Technical information is provided about the antenna and the VLBI equipment at the Westford site of the Haystack Observatory and about changes to the systems since the IVS 2011 Annual 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 ~70 km northwest of Boston, Massachusetts, the antenna is part of the MIT Haystack Observatory complex.

Figure 1. The radome of the Westford antenna.

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 Off Route 40 Westford, MA 01886-1299 U.S.A.	
http://www.haystack.mit.edu	

The Westford antenna was constructed in 1961 as part of the Lincoln Laboratory Project West Ford that demonstrated the feasibility of long-distance communication by bouncing radio signals off a spacecraft-deployed belt of copper dipoles at an altitude of 3600 km. In 1981 the antenna was converted to geodetic use as one of the first two VLBI stations of the National Geodetic Survey Project POLARIS. Westford has continued to perform geodetic VLBI observations on a regular basis since 1981. Westford has also served as a test bed in the development of new equipment and techniques now employed in geodetic VLBI worldwide. Funding for geodetic VLBI at Westford is provided by the NASA Space Geodesy Program.

2. Technical Parameters of the Westford Antenna and Equipment

The technical parameters of the Westford antenna, which is shown in Figure 2, are summarized in Table 2.

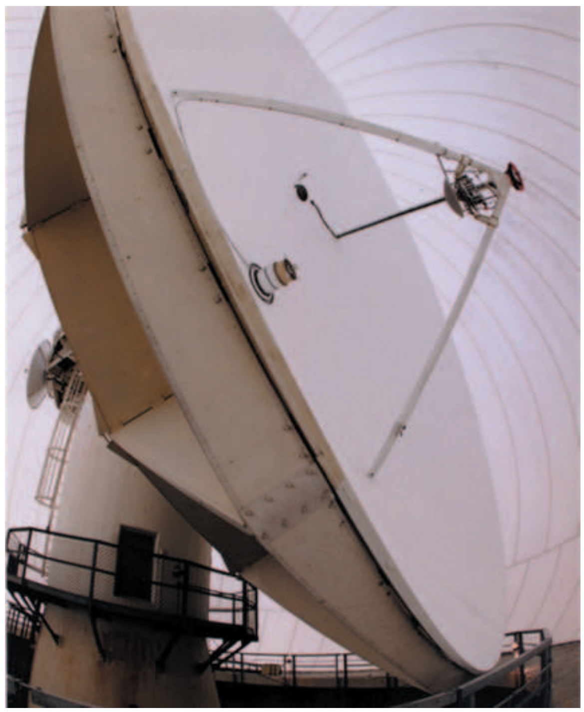

Figure 2. Wide-angle view of the Westford antenna inside the radome. The VLBI S/X receiver is located at the prime focus. The subreflector in front of the receiver is installed when observing with the TAL receiver (see Section 4), which is located at the Cassegrain focus.

The antenna is enclosed in a 28-meter diameter air-inflated radome made of 1.2 mm thick Teflon-coated fiberglass—see Figure 1. When the radome is wet, system temperatures increase by 10–20 K at X-band and by a smaller amount at S-band. The major components of the VLBI data acquisition system are a Mark IV electronics rack, a Mark 5B recording system, and a Pentium-class PC running PC Field System version 9.10.2. The primary frequency and time standard is the NR-4 hydrogen maser. A CNS Clock GPS receiver system provides a 1 pps reference clock to which the maser 1 pps is compared.

Westford also hosts the WES2 GPS site of the IGS network. A Dorne-Margolin chokering antenna is located on top of a tower ∼60 meters from the VLBI antenna, and a LEICA GRX1200 Reference Station receiver acquires the GPS data.

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	
S/X feed location	primary focus	
focal length	5.5 meters	
antenna mount	elevation over azimuth	
antenna drives	electric (DC) motors	
azimuth range	$90^\circ - 470^\circ$	
elevation range	$4^\circ - 87^\circ$	
azimuth slew speed	3° s^{-1}	
elevation slew speed	2° s^{-1}	
	X-band system	*S-band system*
frequency range	8180-8980 MHz	2210-2450 MHz
T_{sys} at zenith	50–55 K	70–75 K
aperture efficiency	0.40	0.55
SEFD at zenith	1400 Jy	1400 Jy

3. Westford Staff

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

Chris Beaudoin	broadband development
Joe Carter	antenna servo support
Brian Corey	VLBI technical support
Kevin Dudevoir	pointing system software
Dave Fields	technician, observer
Alex Burns	technician, observer
Glenn Millson	observer
Arthur Niell	principal investigator
Michael Poirier	site manager
Colin Lonsdale	site director

4. Standard Operations

From January 1, 2012, through December 31, 2012, Westford participated in 46 standard 24-hour sessions. Westford regularly participated in IVS-R1, IVS-R&D, and RD-VLBA observations.

Use of the Westford antenna is shared with the Terrestrial Air Link (TAL) Program operated by the MIT Lincoln Laboratory. In this project Westford serves as the receiving end on a 42-km long terrestrial air link designed to study atmospheric effects on the propagation of wideband communications signals at 20 GHz.

5. Research and Development

In its role as a test bed for VLBI development, the Westford antenna was implemented several times during the year with the VGOS broadband feed assembly and used successfully as the second element of the interferometer with the GGAO 12-m VGOS system.

The first VGOS geodetic observations were scheduled and observed in October. Two six-hour sessions were run on successive days. The initial results agree at the few millimeter level, consistent with the expected performance of the two systems [1].

The antenna was also equipped with the Mark 6 prototype data recorder for a demonstration of 16 Gbps recording capability [2]. The equipment has been left in place for additional Mark 6 testing and development.

6. Outlook

Westford is expected to participate in seventy-three 24-hour sessions in 2012. We also plan to support five 24-hour VGOS sessions along with the occasional fringe test, e-VLBI experiments, and the continuing VGOS broadband development program.

Westford is planning to upgrade the PC Field System and to complete the pointing system upgrade which will facilitate compatibility with the VGOS/MCI system to be installed on the Westford antenna.

The Westford broadband system will see several upgrades in 2013, including improvements to the dewar, implementation of noise diode calibration, and separation of the RF signal path into two bands to reduce sensitivity to S-band RFI.

Acknowledgements

I would like to thank Arthur Niell, Christopher Beaudoin, and Chester Ruszczyk for their contributions to this report.

References

[1] Niell et al, Haystack Analysis Center Report, this volume.

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

Alexander Neidhardt, Gerhard Kronschnabl, Raimund Schatz

Abstract

In the year 2012, the 20-m radio telescope at the Geodetic Observatory Wettzell, Germany again contributed very successfully to the IVS observing program. Technical changes, developments, improvements, and upgrades were made to increase the reliability of the entire VLBI observing system. In parallel, the new Twin radio telescope Wettzell (TTW) got the first feedhorn, while the construction of the HF-receiving and the controlling system was continued.

1. General Information

The 20-m Radio telescope in Wettzell (RTW) is an essential component of the Geodetic Observatory Wettzell (GOW) and is jointly operated by Bundesamt für Kartographie und Geodäsie (BKG) and Forschungseinrichtung Satellitengeodäsie (FESG) of the Technische Universität München (Technical University Munich). In addition to the RTW, an ILRS laser ranging system, several IGS GPS permanent stations, a large laser gyroscope G (ringlaser), as well as the associated local techniques such as time and frequency, meteorology, and super conducting gravity meter are also operated. Also, the building of the first fully VLBI2012 compliant Twin telescope at the location of the GOW is currently in the final phases. It should extend the observation possibilities according to the new technical suggestions of the IVS Working Group 3 (WG3).

Within the responsibility of the GOW are also the TIGO system in Concepción, Chile, operated mainly together with the Universidad de Concepción (see the separate report about TIGO), and the German Antarctic Receiving Station (GARS) O'Higgins at Antarctica, operated together with the German Space Center (DLR) and the Institute for Antarctic Research Chile (INACH) (see the separate report about O'Higgins).

2. Staff

The staff of the GOW consists of 34 members (excluding students) for operations, maintenance, repair issues, and improvement and development of the systems. The staff operating RTW is summarized in Table 1. One additional engineer is in a position which is funded by the "Novel EXploration Pushing Robust e-VLBI Services" (NEXPReS) project in cooperation with the Max-Planck-Institute for Radioastronomy (MPIfR), Bonn. It was also possible to support the student operators to work within development projects and internships.

3. Observations in 2012

The 20-m RTW has been supporting the geodetic VLBI activities of the IVS, and partly other partners, such as the EVN, for almost 30 years. All successfully observed sessions in the year 2012 are summarized in Table 2. After the repair of the bearings in 2010 the RTW is again completely in all schedules as before, and except for some problems with the gears and the servo system, which are also overaged, the telescope is in a very good and stable state. The main priority in operations

Table 1. Staff members of RTW.

Name	Affiliation	Function	Mainly working for
Ulrich Schreiber	BKG	head of the GOW (until March 2012)	GOW
Reiner Dassing together with	BKG	interim head of the GOW (from April 2012)	GOW
Johannes Ihde	BKG	interim head of the GOW (from April 2012)	GOW
Alexander Neidhardt	FESG	head of the RTW group and VLBI station chief	RTW, TTW (partly O'Higgins, laser ranging development)
Erhard Bauernfeind	FESG	mechanical engineer	RTW
Ewald Bielmeier	FESG	technician	RTW
Gerhard Kronschnabl	BKG	electronic engineer	RTW, TTW (partly TIGO and O'Higgins)
Christian Plötz	BKG	electronic engineer	O'Higgins, RTW
Raimund Schatz	FESG	software engineer	RTW
Walter Schwarz	BKG	electronic engineer	RTW (partly O'Higgins and WVR)
Reinhard Zeitlhöfler	FESG	electronic engineer	RTW
Martin Ettl	FESG/MPIfR	IT and computer scientist	NEXPReS (EU FP7)
Jan Kodet	FESG	applied physical engineer	Reference systems (DFG)
Yvonne Klingl	FESG/BKG	student	Operator WLRS/RTW
Gerhard Mühlbauer	FESG/BKG	student (April to December 2012)	Operator WLRS/RTW
Daniel Prexler	FESG/BKG	student	Operator WLRS/RTW
Johannes Vogl	FESG/BKG	student (April to September 2012)	Operator RTW/WLRS, VLBI project work

was participation in all daily one-hour INTENSIVE-sessions (INT) in order to determine UT1-UTC. For these sessions the complete data transfer is done with e-VLBI techniques. RTW now also routinely uses the increased Internet connection capacities of 1 Gbit/sec for the e-transfers to Bonn, Tsukuba, and Haystack for the 24h sessions. Following the implementation of a Field System extension for remote control, weekend INTENSIVEs were partly done in the new observation modes by remote attendance, remote control from students at the laser ranging system (WLRS), or completely unattended.

In addition to the standard sessions RTW was also active for other special observations such as the tracking of the ESA Venus Express spacecraft and RadioAstron satellite for the EVN. Another participation in the EVN network was made with the monitoring of the supernova SN2011dh in M51. These sessions were coordinated by the Joint Institute for VLBI Europe (JIVE).

Table 2. RTW observations in 2012.

program	number of 24h-sessions
IVS R1	52
IVS R4	51
IVS T2	7
IVS R&D	10
RDV/VLBA	6
EUROPE	6
total	**132**
total (in hours)	**3168**

special program	number of 1h-sessions
1h-INT1(Kokee-RTW)	229
1h-INT2/K(Tsukuba-RTW)	153
1h-INT3/K(Tsukuba-RTW-NyAl)	40
ESA VENUS Express	6
EVN RadioAstron	62
EVN sopernova monitoring	10
total (in hours)	**454**

4. Technical Improvements and Maintenance

Regularly, tasks and maintenance days (obtaining replacements for the hardware, 8-pack repairs, gear maintenance, exchange of motors after they reach their lifetime, NASA Field System updates, cryo-system maintenance, servo replacements, and improvements for e-VLBI issues) were scheduled for the usual maintenance work. The components of the servo system are overage and not available on the market anymore. Therefore it was possible to commission a replacement of the whole system and to upgrade to a similar, modern technique such as is installed in the Twin telescopes. The upgrade will be done in the middle of 2013. Upgrades and repairs were also necessary for the Mark IV data acquisition rack. The revision of the replacement dewar systems for Wettzell and O'Higgins were commissioned to be done by the cooperation partners at the observatory at Yebes in Spain, where specialists update the systems to the state-of-the-art.

The usage of the EVN-PC for e-Transfer was continuously extended. In addition e-Transfer for the 24h sessions to Bonn, Haystack, and Washington was installed and tested at rates up to 600 Mbit per second. A combination of the Mark 5 software "fuseMk5" and the communication protocol "Tsunami" was used on a regular Mark 5B system. Meanwhile all R1 sessions were regularly sent to the Bonn correlator using e-VLBI techniques, which reduced the shipping costs tremendously. In parallel with that, all Mark 5 systems were updated or upgraded.

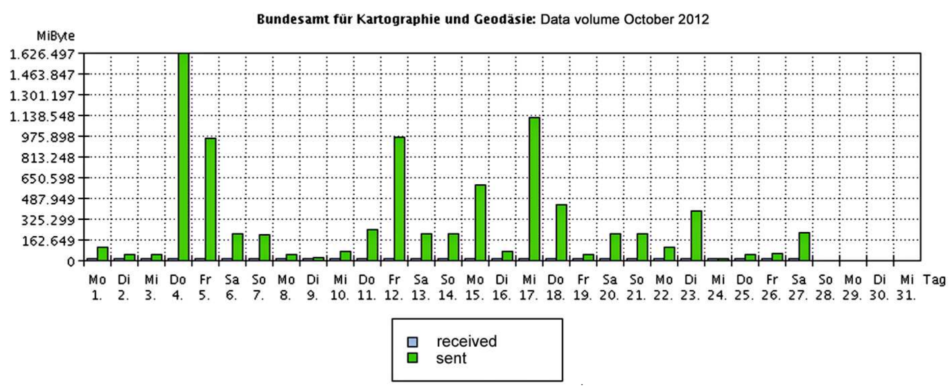

Figure 1. Example of the transfer volume with e-VLBI from the 20-m radio telescope.

The usage of the new Digital Baseband Converters (DBBC) progressed. They were tested, calibrated, and adjusted again. Several test data were correlated at the Bonn correlator to check the functionality and quality. Additionally new CoMo boards were ordered to upgrade to a standard version of the equipment. The development is still in progress.

The remote control software "e-RemoteCtrl" was also extended, mainly by the TUM. In close cooperation with the developers of the NASA Field System and with other test sites at Australia (e.g. Hobart, Katherine, and Yarragadee), new features were established. The deliveries were on time, so the newly implemented authentication and authorization with user roles could be successfully tested. The AuScope network and the Wettzell site already use the software routinely. During the days off around the new year the Wettzell radio telescope was completely remotely controlled including the preparation of the data transfer. Students at the laser ranging system regularly used the software to control the radio telescope in parallel with the laser observation to optimize shift times. The software development is funded in task 3 of work package 5 of the NEXPReS project and is performed in cooperation with the MPIfR.

As a pilot study, ideas for a permanent survey of the telescopes were realized to enable reference movements, which are surveyed with a total station and 20 to 30 reflectors in the back-structure. First software models for the calculation of the positions and the surveying were implemented.

The broadband RFI- and data acquisition for the RFI surveys for a possible new location for the TIGO system in La Plata, Argentina was prepared in Wettzell. Therefore an RFI measuring system was implemented and developed to allow a broadband analysis of dual-polarized RFI signals with an omnidirectional antenna.

Another new field is the preparation of the tracking of global navigation satellites. Therefore new amplifier and receiver boards were implemented, which can be used after the waveguides for S- and X-band to receive the L-band of the satellite. Additionally the software from the laser ranging system was changed to create schedules for the NASA Field System, which can be used to track the satellites with the 20-m radio telescope, using one-second orbit sampling points.

5. The TWIN Radio Telescope Wettzell (TTW)

The Twin Telescope Wettzell project is Wettzell's realization of complete VLBI2010 conformity. While the construction of the buildings and telescopes was the main focus in recent years, the year 2012 was used to install parts of the interior and to commission the final elements for the receiving system. Therefore at the beginning of 2012, the final review of the telescopes was completely possible without any critical issues. Both telescopes are now completely controllable and movable. After that the first installations, such as air conditioning, helium flex-lines, and communication cable to the operator building, were made by the Wettzell team. In the operator building all server racks are now mounted and partly populated with hardware and computers. The network was installed and configured to build up a separate network enclave for VLBI.

A big milestone was the final review of the first three-band feedhorn (triband horn from the company Mirad, Switzerland for S/X/Ka-band). The first test results offered an excellent receiving performance in combination with the ring-focus antennas of Twin. There were some delays with the final review of the dewar, as amplifiers for the S-band, provided by the BKG, became defective during the tests. They had to be shipped back to the vendor.

A final design review for the second horn of the broadband feedhorn was held in June 2012. The second horn is an "Elevenfeed" from Omnisys, Sweden, which allows tunable frequency bands between 2 and 14 GHz. The reviewers were able to decide on the constructive parameters, and construction of the feedhorn started.

A special task was the organization of the IVS VLBI2010 workshop for technical specifications for March 2012. Local organizers were the BKG and the FESG/TUM. Several new technical issues were discussed and presented during this meeting. More than 80 participants from geodetic fields, industry, and science attended the very successful meeting.

6. Plans for 2013

During 2013, dedicated plans are:

- Upgrading the gear, servo, and control system of the 20-m radio telescope,
- Inaugurating the first Twin telescope in April, and
- Finalizing the NEXPReS developments.

Instituto Geográfico Nacional of Spain

Francisco Colomer, Susana García–Espada, Jesús Gómez–González,
José Antonio López–Fernández, Álvaro Santamaría–Gómez, Pablo de Vicente

Abstract

This report updates the description of the space geodesy facilities of the Spanish National Geographic Institute (IGN). The current 40-m radio telescope at Yebes, a network station for IVS, has performed geodetic VLBI observations regularly since September 2008. In addition to this, the project to establish an Atlantic Network of Geodynamical and Space Stations (RAEGE) is progressing with the construction of the first antenna, which is being erected at Yebes.

1. General Information: the IGN Facilities at Yebes

The National Geographic Institute of Spain (Instituto Geográfico Nacional, Ministerio de Fomento), has run geodetic VLBI programs at Yebes Observatory since 1995 and now operates a 40-m radio telescope which is a network station for IVS. Yebes Observatory is also the reference station for the Spanish GNSS network and holds permanent facilities for gravimetry. A new VLBI2010-type antenna is being built at Yebes as part of the RAEGE project.

2. IGN Staff Working on VLBI Projects

Table 1 lists the IGN staff who are involved in space geodesy studies and operations. The VLBI activities are also supported by other staff such as receiver engineers, computer managers, telescope operators, secretaries, and students.

Table 1. Staff in the IGN VLBI group (e-mail: **vlbitech@oan.es**).

Name	Background	Role	Address*
Francisco Colomer	Astronomer	VLBI Project coordinator	IGN
Susana García–Espada	Engineer	geoVLBI expert	CAY
Jesús Gómez–González	Astronomer	Deputy Director for Astronomy, Geophysics, and Space Applications	IGN
José Antonio López–Fdez	Engineer	Yebes and RAEGE Director	CAY
Javier López–Ramasco	Geodesist	Geodesist	CAY
Álvaro Santamaría	Geodesist	Geodesist	CAY
Pablo de Vicente	Astronomer	VLBI technical coordinator	CAY

Addresses:

IGN: Instituto Geográfico Nacional. Calle General Ibañez de Ibero 3, E–28003 Madrid, Spain.

CAY: Centro Astronómico de Yebes. Apartado 148, E–19080 Guadalajara, Spain.

3. Status of Geodetic VLBI Activities at IGN

The 40-m radio telescope has participated in 37 sessions (five EURO, 12 R4, 19 R1, and one T2). Data to be correlated in Bonn (R1 experiments) and in WACO (R4) are transferred by Internet using the tsunami protocol.

The relative position of the reference points of the different space geodetic instruments is a key issue in the realization of the International Terrestrial Reference Frame. Following the works started in 2011 to realize such local ties at Yebes, simulations were carried out to estimate the Invariant Reference Point (IRP) coordinates of the 40-m radio telescope at the Yebes Observatory. From those simulations the authors showed the extent to which the precision of the estimated IRP coordinates depends on the number, the quality, and the geometry of the survey observations. Based on these results, an automated system will be set up at the Yebes Observatory in the future in order to determine the IRP of the 40-m radio telescope with a precision better than 1 mm (Santamaría-Gómez et al., 2012).

Using the estimated coordinates in a common terrestrial frame, we have obtained the relative vector between the reference points of the GPS station and the 14-m and 40-m VLBI radio telescopes. As a preliminary assessment of the local tie survey, the estimation of the position and the velocity in the ITRF2008 is used to derive the relative vector between these three instruments at the Yebes Observatory. In the absence of systematic errors in the VLBI, the GPS, and the terrestrial survey observations, local tie surveys, and ITRF-derived relative vectors should agree.

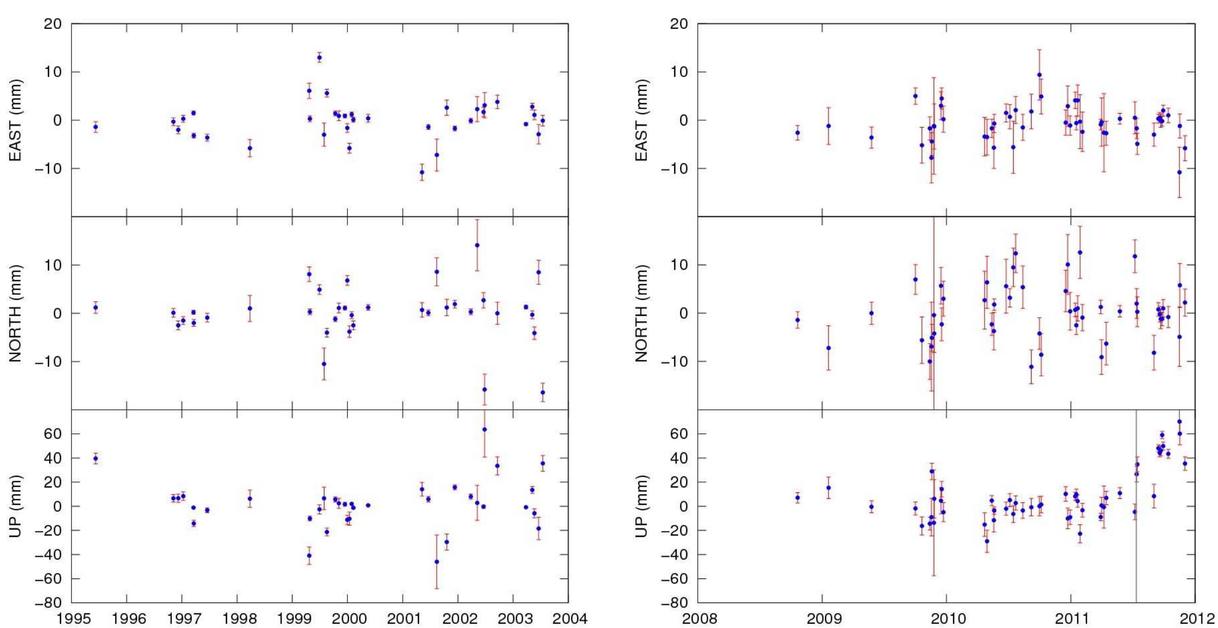

Figure 1. Residuals of the VLBI radio telescope positions at Yebes Observatory. Left: 14-m. Right: 40-m.

The subreflector of the 40-m radio telescope has been kept fixed to its optimum position for an elevation of 45^o for sessions since July 12, 2011. A position offset was therefore discovered in the time series, and the radio telescope coordinates were estimated before and after the discontinuity. The radio telescope velocity was constrained between both segments. After the change of the focus, a significant offset of approximately 4.6 cm was found in the vertical coordinate (see Figure 1).

4. Project RAEGE

IGN, together with its Portuguese colleagues in DSCIG (Azores Islands), continues the construction of a network of four new Fundamental Geodynamical and Space Stations. The RAEGE project has been described in previous IVS Annual Reports. The first antenna is being erected in Yebes (see Figure 2), and the construction of a tri-band (S/X/Ka) receiver and optics, developed at Yebes Labs, is also progressing. It is expected to be completed and to start operation in 2013. Activities have also started at RAEGE's Santa María site with the construction of the concrete tower and the infrastructure facilities. The assembly of the steel backstructure is anticipated for June 2013. On September 17, 2012, an official inauguration ceremony kicked off the start of construction. The event took place in the presence of local authorities as well as regional government representatives. The infrastructure project includes the construction of the main control building, a building for power distribution, a social facilities building (to be built in a second phase), and access roads. The Santa María site will include a completely isolated gravimetry pavilion, buried in a small hill, on top of which a permanent GNSS station will be installed.

Figure 2. Left: RAEGE telescope under construction at Yebes. Lifting of the azimuth cabin. Right: Work for the RAEGE telescope in Santa María (Azores Islands).

5. Meetings

IGN hosted the 7th IVS General Meeting "Launching the Next-Generation IVS Network" on March 4-9 2012, at the premises of the Royal Observatory of Madrid. A total of 150 participants (see Figure 3) from 25 countries representing 65 institutions submitted 120 abstracts, delivering 60 oral presentations and 50 poster presentations, available at:

`http://www.oan.es/gm2012/show-presentations-pdf.php`.

Figure 3. Participants in the 7th IVS General Meeting are photographed in front of the IGN 40-m radio telescope at Yebes Observatory.

References

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[5] Santamaría–Gómez A., García–Espada S., Haas R., López–Ramasco J., "Estimation of the invariant reference point: first steps at Yebes". 2012. IVS 2012 General Meeting Proceedings. CP-2012-217504. In press.

Zelenchukskaya Radio Astronomical Observatory

Sergey Smolentsev, Andrei Dyakov

Abstract

This report summarizes information about Zelenchukskaya Radio Astronomical Observatory activities in 2012. Last year a number of changes took place in the observatory to improve some technical characteristics and to upgrade some units to the required status. The report provides an overview of current geodetic VLBI activities and gives an outlook for the future.

1. General Information

The Zelenchukskaya Radio Astronomical Observatory (Figure 1) was created by the Institute of Applied Astronomy (IAA) as one of three stations of the Russian VLBI network QUASAR [1].

The sponsoring organization of the project is the Russian Academy of Sciences (RAS). The Zelenchukskaya Radio Astronomical Observatory is situated in Karachaevo-Cherkesskaya Republic (the North Caucasus) about 70 km south of Cherkessk, near Zelenchukskaya village (Table 1). The geographic location of the observatory is shown on the IAA RAS Website: *http://www.ipa.nw.ru/PAGE/rusipa.htm*. The main instruments of the observatory are the 32-m radio telescope equipped with special technical systems for VLBI observations, the SLR system, and the GPS/GLONASS/Galileo receivers.

Figure 1. Zelenchukskaya observatory.

Table 1. The Zelenchukskaya Observatory location and address.

Longitude	41°34′
Latitude	43°47′
Karachaevo-Cherkesskaya Republic 369140, Russia ipazel@mail.svkchr.ru	

2. Technical Staff

Andrei Dyakov — the head of the observatory,
Dmitry Dzuba — FS, pointing system control specialist, and
Anatoly Mishurinsky — front end and receiver support specialist.

3. Technical and Scientific Information

Table 2. Technical parameters of the radio telescope.

Year of construction	2003
Mount	AZEL
Azimuth range	±270° (from south)
Elevation range	from −5° to 95°
Maximum azimuth *	
- velocity	0.83 °/s
- tracking velocity	2.5 ′/s
- acceleration	12.0 $'/s^2$
Maximum elevation *	
- velocity	0.5 °/s
- tracking velocity	0.8 ′/s
- acceleration	12.0 $'/s^2$
Pointing accuracy	better than 10″
Configuration	Cassegrain (with asymmetrical subreflector)
Main reflector diameter	32 m
Subreflector diameter	4 m
Focal length	11.4 m
Main reflector shape	quasi-paraboloid
Subreflector shape	quasi-hyperboloid
Main reflector surface accuracy	± 0.5 mm
Frequency range	1.4–22 GHz
Axis offset *	3.6 ± 2.0 mm

* These values were changed to optimize the performance of the antenna system. The axis offset was measured in summer 2012 by geodesist Andrey Shamov.

4. Co-location of VLBI, GPS/GLONASS, and SLR System

The Javad GPS/GLONASS/Galileo receiver with meteo station WXT-510 is in operation (Figure 2). The SLR system "Sazhen-TM" (Figure 3) of the Zelenchukskaya observatory joined ILRS in March 2012. The technical characteristics of the system are presented in Table 3.

Figure 2. Javad GPS/GLONASS/Galileo receiver at the Zelenchukskaya observatory.

Figure 3. "Sazhen-TM" SLR system at the Zelenchukskaya observatory.

Table 3. Technical parameters of the SLR system "Sazhen-TM".

Ranging distance, day	400-6000 km
Ranging distance, night	400-23000 km
Aperture	25 cm
Wavelength	532 nm
Beam divergence	$12''$
Laser pulse frequency	300 Hz
Pulse energy	2.5 mJ
Mass	170 kg
Normal points precision	1 cm
Angular precision	$1\text{-}2''$

5. Current Status and Activities

The Zelenchukskaya observatory participates in IVS and domestic VLBI observational programs. In 2012, Zelenchukskaya station observed in 27 diurnal IVS sessions — IVS-R4, IVS-T2, and EURO.

Zelenchukskaya participated in 47 diurnal sessions of the Ru-E program and in 171 one-hour Ru-U sessions using e-VLBI data transfer. Since July 2012, observations for the Ru-U program have been performed daily.

6. Outlook

We have the following plans for the coming year:

- To participate in IVS observations
- To carry out domestic Ru-U and Ru-E observational programs with e-VLBI data transfer
- To carry out SLR observations of geodetic and navigation satellites
- To participate in EVN and RADIOASTRON observational sessions
- To continue geodetic monitoring of the antenna parameters
- To build a foundation and to conduct survey operations for VLBI2010 antenna installation in 2014 (Figures 4 and 5).

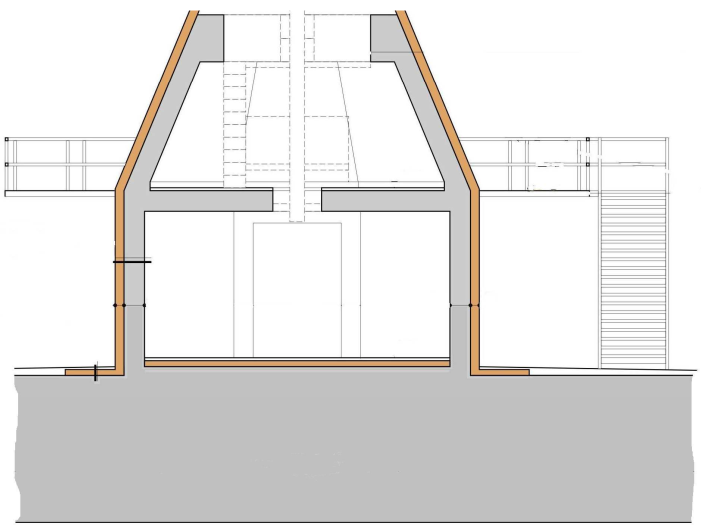

Figure 4. Foundation for RT-13, planned to be built in 2013.

Figure 5. RT-13 is planned to be installed in 2014.

References

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Operation Centers

The Bonn Geodetic VLBI Operation Center

A. Nothnagel, A. Müskens

Abstract

In 2012, the IGGB Operation Center has continued to carry out tasks for organizing and scheduling the observing sessions of the IVS-T2, IVS-OHIG, IVS-INT3, and EUROPE series.

1. Center Activities

The IGGB VLBI Operation Center is located at the Institute of Geodesy and Geoinformation of the University of Bonn, Nussallee 17, D-53115 Bonn, Germany. It has been organizing and scheduling VLBI observing sessions for more than twenty years. The observing series organized and scheduled in 2012 are very similar to those in 2011.

- **Measurement of Vertical Crustal Motion in Europe by VLBI (EUROPE)**
  In Europe, a series of special sessions has been scheduled for the determination of precise station coordinates and for long term stability tests. This year, six sessions with Ny-Ålesund, Onsala, Metsahovi, Svetloe, Zelenchukskaya, Badary, Effelsberg, Wettzell, Simeiz, Medicina, Matera, Noto, and Yebes (YEBES40M) were scheduled employing the frequency setup of 16 channels and 4 MHz bandwidth in fan-out mode (identical to the setup of the IVS-T2 sessions).
- **IVS-T2 Series**
  This series has been observed roughly every second month (seven sessions in 2012) primarily for maintenance and stabilization of the VLBI terrestrial reference frame as well as for Earth rotation monitoring as a by-product. Each station of the global geodetic VLBI network is scheduled to participate at least once per year in the T2 sessions. In view of the limitations in station days, priority was given to stronger and more robust networks with many sites over more observing sessions. Therefore, generally 15 to 20 stations have been scheduled in each session. The processing is carried out with the DiFX software correlator. The scheduling of these sessions has to take into account that a sufficient number of observations should be planned for each baseline of these global networks. The recording frequency setup is 16 channels and 4 MHz channel bandwidth.
- **Southern Hemisphere and Antarctica Series (OHIG):**
  In February 2012, three sessions of the Southern Hemisphere and Antarctica Series with the Antarctic stations Syowa (Japanese) and O'Higgins (German) plus Fortaleza, Hobart, HartRAO, and Kokee have been organized. Furthermore, OHIGGINS was also included successfully in the T2081 session. The (southern) winter O'Higgins burst was scheduled and observed but without the stations of O'Higgins and Warkworth for various reasons. The purpose of these sessions is the maintenance of the VLBI TRF and the monitoring of Earth rotation as a by-product. The recording frequency setup is 16 channels and 4 MHz channel bandwidth. Due to the fact that Syowa is not able to deliver the recorded data for nearly one year after the observations, the correlation and the generation of the databases is delayed considerably.

- **UT1 Determination with Near-real-time e-VLBI (INT3):**
  The so-called INT3 sessions included the telescopes of Ny-Ålesund, Tsukuba and Wettzell for weekly UT1 determinations with rapid processing time. Since August 2007, these sessions have been scheduled to start every Monday morning at 7:00 a.m. UT.

  The operations of the INT3 series are directly linked to data transmission and correlation since the raw VLBI observation data of the three sites is directly transferred to the Bonn Correlator by Internet connections to speed up delivery of the results. The transmission rate is about 100 Mb/s for Ny-Ålesund (limited due to the use of a radio link for the first part of the distance) and 400-600 Mb/s from Tsukuba and Wettzell. The correlation is solely carried out with the DiFX software correlator.

  In 2012, 45 sessions were observed and transmitted successfully. 90% of the sessions were correlated and the databases were delivered within the first five hours after the end of the observations. A further 5% were completed within 10 hours. The rest took between 10 and 48 hours due to difficulties with networking hardware and/or station and processor problems. In March and April, Seshan participated in some INT3 sessions replacing Tsukuba, which could not observe due to maintenance activities. Since then Seshan has taken part in INT3 sessions periodically.

2. Staff

Table 1. Personnel at IGGB Operation Center.

Arno Müskens	+49-228-525264	mueskens@mpifr.de
Axel Nothnagel	+49-228-733574	nothnagel@uni-bonn.de

CORE Operation Center Report

Cynthia C. Thomas, Daniel MacMillan

Abstract

This report gives a synopsis of the activities of the CORE Operation Center from January 2012 to December 2012. The report forecasts activities planned for the year 2013.

1. Changes to the CORE Operation Center's Program

The Earth orientation parameter goal of the IVS program is to attain precision of at least 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 had been upgraded to Mark 5. Due to the efficient Mark 5 correlator, the program continues to be dependent on station time and media. The following are the network configurations for the sessions for which the CORE Operation Center was responsible in 2012:

- IVS-R1: 52 sessions, scheduled weekly and mainly on Mondays, five to eleven station networks
- RDV: Six sessions, scheduled evenly throughout the year, 15 to 16 station networks
- IVS-R&D: Ten sessions, scheduled monthly, seven to eight station networks

2. IVS Sessions from January 2012 to December 2012

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

- IVS-R1: In 2012, the IVS-R1s were scheduled weekly with five to eleven station networks. During the year, 18 different stations participated in the IVS-R1 network, but there were only eight stations that participated in at least half of the scheduled sessions—Wettzell (52), Tigo (50), Ny-Ålesund (46), Tsukuba (44), Fortaleza (44), Westford (36), HartRAO (29), and Kokee (28). Urumqi was tagged along to one IVS-R1 session for testing in preparation for joining the IVS-R1 network during 2013.

  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 recording to the results as short as possible. The time delay goal is a maximum of 15 days. 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.

- RDV: There are six bi-monthly coordinated astrometric/geodetic experiments each year that use the full 10-station VLBA plus up to six geodetic stations.

  These sessions are being coordinated by the geodetic VLBI programs of three agencies: 1) USNO performs repeated imaging and correction for source structure; 2) NASA analyzes this 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 2012, as decided by the IVS Observing Program Committee, was to support observations close to the Sun.

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

Table 1 gives the average formal errors for the R1, R4, RDV, and T2 sessions from 2012. The R1 session formal uncertainties are not significantly different from the 2010-2011 errors. The R4 uncertainties for 2012 sessions are much better than for 2011 or 2010. This improvement is due in part to the better performance of stations in 2012; in 2012, 22 sessions lost one or more stations from the original scheduled network, while there were 37 such sessions in 2011. R1 uncertainties for 2012 (as well as for 2011) are worse than for 2010. This is most likely due to the contribution of TSUKUB32 to the EOP solution estimates. Since the Japanese earthquake in March 2011, we have been estimating the position of TSUKUB32 for each observing session. This weakens its contribution to EOP. If we use a GPS a priori model to obtain the post-earthquake behavior at Tsukuba, then the formal uncertainties are reduced by 10-20%. We will be applying this model in the next GSFC operational quarterly solution.

RDV uncertainties are not significantly different among the three years from 2010 to 2012. The RDV formal errors are significantly better than the formal errors from any of the other experiment series. This is due to the larger number of RDV stations as well as better global geometry. T2 EOP uncertainties are markedly better in 2012 than for 2010-2011. For comparison, we also included the formal uncertainties for the CONT11, which are much better than any of the networks discussed above that observed in 2012.

Table 2 shows EOP differences with respect to the IGS series for the R1, R4, RDV, T2, and CONT11 series. The WRMS differences were computed after removing a bias, but estimating rates does not affect the residual WRMS significantly. The R1 and R4 series show approximately the same WRMS agreement in x-pole and y-pole for 2012 as for these series since 2000. The R1s are worse for x-pole, which is most likely due to the treatment of TSUKUB32 in solutions as discussed above. Adopting the improved GPS a priori model strategy mentioned above improves the agreement with IGS by 20%. The polar motion biases of the R1 and R4 sessions relative to IGS differ by 10-20 μas, which is at the level of the uncertainty (1-2 sigma) of the bias estimates. The biases for the six RDV sessions are significantly smaller. Perhaps there is a network bias between the RDV and the R1/R4 networks, but this would require further investigation. Of all the series, the RDV series has the best WRMS agreement of x-pole and y-pole with IGS estimates in 2012 as well as for all sessions since 2000. There are really too few RDV and T2 sessions to give significance to the WRMS differences for 2012 compared with the difference for full series from 2000-2012. For comparison with the 2012 sessions discussed here, we included the statistics for the 15 CONT11 sessions. The WRMS agreement with IGS is much better because 1) the network has better geometry; 2) short-term scatter is always smaller than long-term scatter, and 3) the performance of stations was most likely better because of the increased station checkout that is done for the R&D continuous session experiments.

Table 1. Average EOP Formal Uncertainties for 2012.

Session Type	Number	X-pole (μas)	Y-pole (μas)	UT1 (μs)	DPSI (μas)	DEPS (μas)
R1	51 (52)	73(67,62)	63(65,58)	3.4(3.1,2.4)	110(113,116)	44(46,46)
R4	5l (52)	70(84,96)	67(75,85)	2.8(3.2,3.3)	124(161,172)	49(65,70)
RDV	3 (6)	48(49,44)	48(46,44)	2.5(2.6,2.1)	68(75,67)	28(30,28)
T2	4 (7)	91(100,93)	69(107,101)	4.5(5.0,5.2)	166(216,192)	63(79,75)
CONT11	15 (15)	39	38	1.7	42	17

For the number of sessions in 2012, the number of sessions processed at this time is given, with the number of observed sessions in parentheses. For the other columns, the values in parentheses are for 2011, followed by the values for 2010.

Table 2. Offset and WRMS Differences (2012) Relative to the IGS Combined Series.

		X-pole		Y-pole		LOD	
Session Type	Number	Offset (μas)	WRMS (μas)	Offset (μas)	WRMS (μas)	Offset (μs/d)	WRMS (μs/d)
R1	52(562)	-64(9)	107(95)	42(13)	88(88)	1.5(0.3)	14(16)
R4	52(560)	-42(-23)	109(113)	32(15)	113(111)	3.4(1.8)	17(18)
RDV	6(78)	15(59)	97(82)	24(5)	55(66)	0.3(-0.5)	10(14)
T2	4(81)	-80(3)	234(145)	152(2)	61(122)	13.8(1.7)	11(20)
CONT11	15	42	36	9	29	7.0	7

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

4. The CORE Operations Staff

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

5. Planned Activities during 2013

The CORE Operation Center will continue to be responsible for the following IVS sessions during 2013.

- The IVS-R1 sessions will be observed weekly and recorded in a Mark 5 mode.
- The IVS-R&D sessions will be observed ten times during the year.
- The RDV sessions will be observed six times during the year.

Table 3. Key Technical Staff of the CORE Operations Center.

Name	Responsibility	Agency
Dirk Behrend	Organizer of CORE program	NVI, Inc./GSFC
Brian Corey	Analysis	Haystack
Ricky Figueroa	Receiver maintenance	ITT Exelis
John Gipson	SKED program support and development	NVI, Inc./GSFC
Frank Gomez	Software engineer for the Web site	Raytheon/GSFC
David Gordon	Analysis	NVI, Inc./GSFC
Ed Himwich	Network Coordinator	NVI, Inc./GSFC
Dan MacMillan	Analysis	NVI, Inc./GSFC
Katie Pazamickas	Maser maintenance	ITT Exelis
David Rubincam	Procurement of materials necessary for CORE operations	GSFC/NASA
Braulio Sanchez	Procurement of materials necessary for CORE operations	GSFC/NASA
Dan Smythe	Tape recorder maintenance	Haystack
Cynthia Thomas	Coordination of master observing schedule and preparation of observing schedules	NVI, Inc./GSFC

NEOS Operation Center

David Hall, M.S. Carter

Abstract

This report covers the activities of the NEOS Operation Center at USNO for 2012. The Operation Center schedules the IVS-R4 and the INT1 Intensive experiments.

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 2012, the operational IVS-R4 network included VLBI stations at Kokee Park (Hawaii), Wettzell (Germany), Ny-Ålesund (Norway), TIGO (Chile), 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 eight to twelve 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 — Svetloe baseline so that Svetloe can be used as an alternate for Wettzell should it be needed. Odd-day Intensives were scheduled with the scheduling technique used since 2000; even-day Intensives were scheduled with a new, experimental scheduling technique.

The Operation Center updated its 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.

Table 1. Experiments Scheduled during 2012.

Number	Session Type
52	IVS-R4 experiments
230	Intensives

2. Staff

K. A. Kingham, D. M. Hall, and M. S. Carter are the only staff members of the NEOS Operation Center. Dr. Kerry Kingham retired at the beginning of June, and Mr. Hall assumed his duties. 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 Astro/Geo Correlator

Simone Bernhart, Walter Alef, Alessandra Bertarini, Laura La Porta, Arno Müskens, Helge Rottmann, Alan Roy

Abstract

The Bonn Distributed FX (DiFX) correlator is a software correlator 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.

1. Introduction

The Bonn correlator is hosted at the MPIfR[1] in Bonn, Germany. It is operated jointly by the MPIfR and the BKG[2] in cooperation with the IGG[3]. It is a major correlator for geodetic observations and astronomical projects, for instance those involving pulsar gating, millimeter wavelengths, and astrometry.

2. Present Correlator Capabilities

The Distributed FX correlator[4] was developed at Swinburne University in Melbourne, Australia by Adam Deller (and other collaborators). It has been adapted to the VLBA operational environment by Walter Brisken and the NRAO staff, and it has been developed for a number of years by the worldwide DiFX developers group. DiFX in Bonn is installed and running on a High Performance Compute Cluster (HPC cluster).

Features of the software correlator cluster are:

- 60 nodes (eight compute cores each)
- four TFlops in the Linpack benchmark test
- 20 Gbps Infiniband interconnection
- 11 RAIDs (about 480 TB storage capacity)
- one control node for correlation (*fxmanager*)
- one computer (*frontend*) for executing parallelized jobs on the cluster, e.g., post-correlation applications
- one control computer (*appliance*) for installing and monitoring the cluster
- closed loop rack cooling

The correlator cluster is connected via 20 Gbps Infiniband to 14 Mark 5 units[5] used for playing back the data. If more than 14 playback units are required, and in the case of e-VLBI, data are copied to the raid systems prior to correlation. All Mark 5 units can play back all types of Mark 5 data (A/B/C). The disk-modules in the Mark 5 are controlled via NRAO's mk5daemon program. The available functionality includes all necessary functions such as recording the directories of the modules, resetting and rebooting the units, and module conditioning.

[1] `http://www3.mpifr-bonn.mpg.de/div/vlbicor/index_e.html`
[2] `http://www.bkg.bund.de/`
[3] `http://www.gib.uni-bonn.de/`
[4] DiFX: A Software Correlator for Very Long Baseline Interferometry using Multiprocessor Computing Environments, 2007, PASP, 119, 318
[5] `http://www.haystack.mit.edu/tech/vlbi/mark5/`

A summary of the capabilities of the DiFX software correlator is presented in Table 1.

Table 1. Correlator capabilities.

Playback Units	
Number available	14 Mark 5 (four Mark 5A, two Mark 5B, and eight Mark 5C)
Playback speed	1.5 Gbps
Formats	Mark 5A, Mark 5B, and VDIF
Sampling	1 bit and 2 bits
Fan-out (Mark 5A)	1:1, 1:2, and 1:4
No. channels	$\leq$ 16 USB and/or LSB
Bandwidth/channel	(2, 4, 6, 8, and 32) MHz
Signal	Single- and dual-frequency; all four Stokes parameters for circular and linear polarization
Correlation	
Geometric model	CALC 9
Phase cal	Phase-cal extraction of all tones in a sub-band simultaneously
Pre-average time	Milliseconds to seconds
Spectral channels	Maximum number of FFT tested 2^{18}
Export	FITS export. Interface to Mk IV data format which enables the use of geodetic analysis software and the Haystack fringe fitting program.
Pulsar	Pulsar with incoherent dedipersion

3. Staff

The people in the Geodesy VLBI group[6] at the Bonn correlator are:
Arno Müskens - group leader and scheduling of T2, OHIG, EURO, and INT3 sessions.
Simone Bernhart - e-transfer supervision and operations, experiment setup and evaluation of correlated data, and media shipping.
Alessandra Bertarini - experiment setup and evaluation of correlated data for both astronomy and geodesy, digital baseband converter (DBBC) testing, APEX fringe testing, Friend of the correlator.
Laura La Porta - experiment setup and evaluation of correlated data, DBBC testing, and programming for automated preparation of correlation reports.

The people in the astronomical group at the Bonn correlator are:
Walter Alef - head of the VLBI technical department, computer systems and cluster administration.
Alan Roy - deputy group leader, support scientist (water vapor radiometer, technical assistance, development of FPGA firmware for linear to circular polarization conversion, and project manager for equipping APEX for millimeter VLBI).
Helge Rottmann - software engineer for correlator development and operation, cluster administration, DBBC and RDBE control software, and Field System.

[6] http://www3.mpifr-bonn.mpg.de/div/vlbicor/geodesy/index.html

Heinz Fuchs - correlator operator, responsible for the correlator operator schedule, daily operations, and media shipping.
Hermann Sturm - correlator operator, correlator support software, media shipping, and Web page development.
Rolf Märtens - technician maintaining cluster hardware and Mark 5 playbacks.
Michael Wunderlich - engineer, development, and testing of DBBC components.
Jan Wagner - PhD student, support scientist for APEX, DBBC development, and DiFX developer.
Armin Felke - FPGA programming for DBBC.
Gino Tuccari - guest scientist from INAF, DBBC development, and DBBC project leader.
David Graham - consultant (technical development, DBBC development, and testing).

4. Status

Experiments: In 2012, the Bonn group correlated 51 R1, six EURO, five T2, five OHIG, 43 INT3, and 16 astronomical experiments.

e-VLBI: On average $\geq 60\%$ of the stations do e-transfer, and the number still increases. E.g., in the T2086 session, 16 stations participated in the observations, and 11 of them sent their data via high-speed network connection. The average amount of e-transferred data per week ranges from 4 to 6 TB considering only the regular INT3 and R1 experiments. Most transfers are done using the UDP-based Tsunami protocol.

The total disk space available for e-VLBI data storage at the correlator is currently about 125 TB. The Web page that shows current active e-transfers and helps to coordinate transfer times and rates on a first come-first served basis[7], has been extended by information about the storage capacity at the three correlators in Washington, Haystack, and Bonn. The envisaged upgrade of the existing 1 Gbps Internet connection in order to meet the requirements of the higher observing rate foreseen within VLBI2010 has not yet been realized due to still existing issues concering funding. However, the transfer Web page currently seems well adopted by the community and even though meanwhile more than 60% of the stations nowadays transfer their observational data via Internet, we have merely been facing minor problems - if any - due to bandwidth limitations.

DiFX software correlator: A graphical user interface was installed on the DiFX control computer, which simplifies the use of the software correlator.

A branch version of the DiFX software correlator for RFI mitigation has been developed as part of a PhD project. DiFX RFI suppression via filtering fast off-source fringe rates is complete[8]. While it reduces ringing by RFI along UV plane tracks, it has proven ineffective at removing a residual constant RFI power in the affected channels, and it is not as powerful as the method for Focal Plane Array RFI excision also included in the DiFX library.

DBBC: The Bonn group is involved in the development of the DBBC for the European VLBI Network (EVN) and geodesy. The DBBC is designed as a full replacement for the existing analog BBCs. The following stations have already bought one or more DBBCs: APEX, AuScope (Australia), Effelsberg, Onsala, Pico Veleta, Yebes, Wettzell, and Warkworth. Most of those DBBCs are already in regular use. High data rate modes with 2 and 4 Gbps are being tested. First test observations at 2 Gbps and 4 Gbps were performed in June 2012 (at Yebes, Effelsberg, and Onsala).

[7] `http://www3.mpifr-bonn.mpg.de/cgi-bin/showtransfers.cgi`
[8] `http://www.radionet-eu.org/fp7wiki/lib/exe/fetch.php?media=jra:albius:rfifringefilter_pub.pdf`

Regular testing with geodetic observations is performed for DBBCs at Onsala and Wettzell.

In the summer of 2012, a project to develop the next generation DBBC called DBBC3 was started. In the first stage, a system which can handle 4 GHz bandwidth will be developed (DBBC3-L). In the second stage, the DBBC3-H will be able to sample the full frequency range of 1 to 14 Ghz without any downconversion required.

APEX: The Bonn VLBI group has equipped the APEX telescope for VLBI observations at 1 mm. The first successful fringe test took place in May 2012 on 3C 279 at 229 GHz with SMA (Hawaii) and SMTO (Arizona). The fringe spacing achieved was 29 microarcseconds, adequate to resolve the expected diameter of the shadow of the event horizon of 47 microarcseconds in Sgr A*. A fringe plot of these observations is shown in Figure 1.

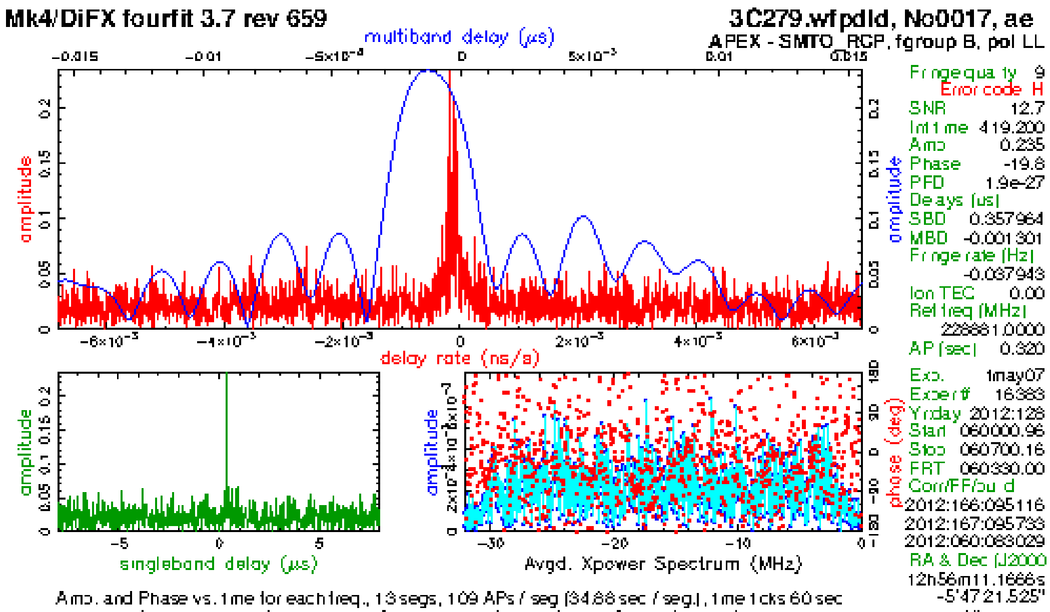

Figure 1. Successful 1 mm fringe tests performed in March 2012, baseline APEX- Submillimeter Telescope Observatory (SMTO, Arizona), on 3C 279. The fringe spacing was 29 microarcseconds, the finest yet achieved.

5. Outlook for 2013

DiFX Correlator: The planning to replace the now five-year-old cluster with a more modern system will begin.

e-VLBI: e-transfer tests with other antennas are planned or ongoing.

DBBC: DBBC testing in the EVN stations that recently acquired DBBCs will continue. Wide bandwidth modes are also under test. Development of the DBBC3 will take place.

APEX First real observations will take place at APEX in March 2013.

Phasing up ALMA The group is involved in an international project to add array phasing capability to ALMA. This will enable its use as an extremely sensitive station in 1 mm VLBI experiments.

Haystack Observatory VLBI Correlator

Mike Titus, Roger Cappallo, Brian Corey, Kevin Dudevoir, Arthur Niell, Alan Whitney

Abstract

This report summarizes the activities of the Haystack Correlator during 2012. Highlights include finding a solution to the DiFX InfiniBand timeout problem and other DiFX software development, conducting a DBE comparison test following the First International VLBI Technology Workshop, conducting a Mark IV and DiFX correlator comparison, more broadband delay experiments, more u-VLBI Galactic Center observations, and conversion of RDV session processing to the Mark IV/HOPS path. Non-real-time e-VLBI transfers and engineering support of other correlators continued.

1. Introduction

The Mark IV and DiFX VLBI correlators of the MIT Haystack Observatory, located in Westford, Massachusetts, are supported by the NASA Space Geodesy Program and the National Science Foundation. They are dedicated mainly to the pursuits of the IVS, with a smaller fraction of time allocated to processing radio astronomy observations for the Ultra High Sensitivity VLBI (u-VLBI) project. The Haystack correlators serve as development systems for testing new correlation modes, for hardware improvements such as the Mark 6 system, and in the case of the Mark IV, for diagnosing correlator problems encountered at Haystack and at the identical correlator at the U.S. Naval Observatory. This flexibility is made possible by the presence on-site of the team that designed the Mark IV correlator hardware and software. Some software support is provided to the Max Planck Institute for Radioastronomy in Bonn, Germany, for DiFX processing of IVS sessions.

2. Summary of Activities

2.1. DiFX Cluster Developments

Efforts to diagnose InfiniBand fabric timeout errors which manifested themselves at high record rates (1 Gb/sec and above) have come to fruition through an understanding that the particular model of InfiniBand cards installed in the Mark 5 playback units were the cause. New cards were procured and tested, and they appear to mitigate the problem. Cards were ordered and installed in all the capable Mark 5 units. Various other DiFX related debugging projects were conducted, and problems were corrected.

2.2. DiFX Software Support

Initially mysterious problems with multiband delay (mbd) scatter in many DiFX correlated sessions from Bonn led to an investigation at Haystack. Data for session R1543 were transferred from Bonn to Haystack and correlated on the Haystack Mark IV for comparison. This revealed a problem with time registration of delay polynomials in the difx2mark4 conversion software. The problem was corrected but not before $\sim$ 120 sessions were affected. Fortunately, the delays can be corrected in the databases; as of the end of 2012, NASA Goddard and BKG had corrected approximately half of the databases.

2.3. DiFX-Mark IV Correlator Comparison of Experiment R1543

As a by-product of the diagnosis of the difx2mark4 problem, a comparison between DiFX and the Mark IV correlator was conducted. Results show that mbd differences compare favorably between all combinations of crossings. The full analysis of this comparison be found at *http://cira.ivec.org/dokuwiki/doku.php/difx/difx2mark4*

2.4. Broadband Delay

Major broadband delay tests were conducted in January, May, and October 2012. January had a plethora of tests, and May and October featured six-hour "geodetic quality" schedules being run at the GGAO 12-m and Westford antennas to fully test the VLBI2010 system. Various other tests were conducted over the year, including overlapping bands, zoom mode (Mark IV vs. broadband), a source transit experiment, a DBE1/Mark 5B+ vs. RDBE/Mark 5C comparison, and others.

2.5. DBE Comparison Test

Following the First International VLBI Technology Workshop held at Haystack in October, a DBE Compatibility Testing Workshop was hosted by Haystack staff. DBEs from Haystack, China, Japan, and Europe were compared to test interoperability. All units participating in the workshop were successfully compared. A report of the results can be found at *http://www.haystack.mit.edu/workshop/ivtw/index.html*. As a by-product of this test Haystack provided the DiFX correlation setup to Seshan in order for them to duplicate the Haystack results. This can be used for future debugging of their DBE on their DiFX installation.

2.6. Galactic Center Observations

Further u-VLBI observations of the Galactic Center with dual polarization at all sites were recorded and correlated in 2012. Also, results were published for the ground-breaking observations made in 2011 of the center of the galaxy M87 that spatially resolved the base of the jet in that source. Fringe searching to the MPI/Onsala/ESO sponsored APEX antenna in Atacama, Chile, was successful. These searches were conducted in Bonn, but searches for the participating U.S. stations were done at Haystack. In the near future other new antennas will be tested and added to the u-VLBI array, which will greatly increase its resolution.

2.7. RDV Fringe-fitting

Test fringe-fitting of the RDV sessions correlated on the NRAO DiFX correlator described last year showed favorable results compared to the traditional NRAO AIPS package. Thus, processing them through the Mark IV/HOPS path has become the routine production process. A summary of this work can be found at *http://www.oan.es/gm2012/pdf/poster_id_117.pdf*

2.8. e-VLBI

Non-real-time transfers have continued. Data from nineteen experiments were transferred to Haystack this year from seventeen stations (seven in Japan, four in Western Europe, two in Australia, two in South America, one in Crimea, and one in South Africa): Kashima11, Koganei, Tsukuba, Chichijima, Ishigaki, Aira, Mizusawa, Onsala, Ny-Ålesund, Wetzell, Noto, Hobart, Yaragadee, Fortaleza, Tigo (via Bonn), Crimea (via Bonn) and HartRAO. e-VLBI transfers have significantly increased this year due to an upgrade of Haystack's connectivity to the Internet which has enabled data transfer rates up to 1.4 Gb/sec.

2.9. Experiments Correlated

Production processing on the Mark IV correlator continues amidst all the DiFX development. In 2012, thirty-four geodetic VLBI experiments were processed, at least in part, on the Haystack Mark IV correlator, including ten R&Ds, six T2s, one AUST, and the aforementioned R1543 experiment. The remaining 16 were various tests. The other test experiments included the broadband experiments and fringe tests and an assortment of other projects, some of which were mentioned in the summary above. As usual, smaller tests were not included in the above count because they were too small to warrant individual experiment numbers.

2.10. Current/Future Hardware and Capabilities

As of the end of 2012 the Mark IV correlator was comprised of seven Mark 5A units, seven station units, seven Mark 5B units (DOMs) with their associated correlator interface boards (CIBs), 16 operational correlator boards, two crates, and miscellaneous other support hardware. We have the capacity to simultaneously process all baselines for 11 stations in the standard geodetic modes, provided the aggregate recordings match the above hardware matrix. Note that all experiments up to 15 stations have been done in one pass due to the ability to share playback units between stations which do not co-observe. Six of the playback units are accessible to the six-server (12 cores each) DiFX cluster.

In 2013 we hope to transition to the software correlator, only keeping the hardware correlator alive in support of USNO until their transition to a software correlator, which is expected in late 2013.

3. Staff

Staff who participated in aspects of Mark IV, DiFX, Mark 5/6, and e-VLBI development and operations include:

3.1. Software Development Team

- John Ball - Mark 5A/5B; e-VLBI.
- Roger Cappallo - real-time correlator software and troubleshooting; system integration; post processing; Mark 5B/5C/6; Linux conversion; e-VLBI; DiFX correlator development.
- Geoff Crew - DiFX correlator development, post processing software; Mark 6.
- Kevin Dudevoir - correlation; maintenance/support; Mark 5A/5B/5C; e-VLBI; Linux conversion; correlator software and build system development; computer system support/development; DiFX correlator development.
- Jason SooHoo - e-VLBI; Mark 5A/5B/5C/6; computer system support.

- Chester Ruszczyk - e-VLBI; Mark 5A/5B/5C.
- Alan Whitney - system architecture; Mark 5A/5B/5C/6; e-VLBI .

3.2. Operations Team:

- Peter Bolis - correlator maintenance.
- Alex Burns - playback drive maintenance; Mark 5 installation and maintenance; general technical support; replacement for Dave Fields (see below).
- Brian Corey - experiment correlation oversight; station evaluation; technique development.
- Dave Fields - playback drive maintenance; Mark 5 installation and maintenance; general technical support; retired in December 2012.
- Glenn Millson - correlator operator.
- Arthur Niell - technique development.
- Don Sousa - correlator operator; experiment setup; tape library and shipping.
- Mike Titus - correlator operations oversight; experiment setup; computer services; software and hardware testing.
- Ken Wilson - correlator maintenance; playback drive maintenance; general technical support.

4. Conclusion/Outlook

A full transition to the DiFX software correlator is expected in early 2013. Operational testing of the complete VLBI2010 system is expected to start in early 2013. Testing and implementation of new digital back ends and recording systems will continue.

IAA Correlator Center

Igor Surkis, Voitsekh Ken, Alexey Melnikov, Vladimir Mishin, Nadezda Sokolova, Violet Shantyr, Vladimir Zimovsky

Abstract

The activities of the six-station IAA RAS correlator include regular processing of national geodetic VLBI programs Ru-E, Ru-U, and Ru-F. The Ru-U sessions have been transferred in e-VLBI mode and correlated in the IAA Correlator Center automatically since 2011.

The DiFX software correlator is used at the IAA in some astrophysical experiments.

1. Introduction

The IAA Correlator Center is located at and staffed by the Institute of Applied Astronomy in St. Petersburg, Russia.

The IAA Correlator Center is devoted to processing geodetic, astrometric, and astrophysical observations made with the Russian national VLBI network Quasar.

Figure 1. View of the six-station ARC correlator, showing four racks containing (left to right) signal distribution and synchronization system (SDSS) and three Mark 5B playback units, two correlator crates and KVM, three correlator crates, and one more cabinet with SDSS and three Mark 5B playback units.

2. Component Description

The ARC (Astrometric Radiointerferometric Correlator) (Figure 1) was the main data processing device in the IAA Correlator Center in 2012. The ARC was designed and built in the IAA RAS in 2007 - 2009. The correlator has an XF design and is based on FPGA technology.

The ARC is a six-station, 15-baseline correlator. It is able to process up to 16 frequency channels on each baseline, for a total of 240 channels. The correlator accesses two-bit VLBI signals with 32 MHz maximal clock frequency. The maximal data range from each station is 1 Gbit per second. The correlator requires VSI-H input VLBI signals, and it is equipped with Mark 5B playback terminals.

Since 2011 the DiFX software correlator has been used in some astrophysical experiments. The DiFX is installed at the IAA on a Sun Fire X4450 Server as a virtual machine under the VMware.

3. Staff

- Voitsekh Ken — GPU software developer;
- Alexey Melnikov — software developer, DiFX processing, scheduler of the Ru-sessions;
- Vladimir Mishin — software developer, data processing;
- Nadezda Sokolova — software developer;
- Violet Shantyr — software developer, post processing;
- Igor Surkis — leading investigator, software developer;
- Vladimir Zimovsky — leading data processing;
- Ekaterina Medvedeva — data processing;
- Alexander Salnikov — leading e-VLBI data transfer;
- Ilya Bezrukov — e-VLBI data transfer;

4. Current Status and Activities

The ARC correlator was used for processing all of the national geodetic VLBI observations in the IAA Correlator Center in 2012. The RUE and RUU geodetic VLBI sessions were observed in IAA RAS.

The three-station 24-hour RUE sessions for EOP determination were observed one time per week, as in 2011.

The two-station one-hour sessions for UT1-UTC determination in e-VLBI mode were carried out one time per week up to June 2012 and one time per day starting in July 2012. The RUU sessions were executed on cold station receivers, with a frequency channel bandwidth of 8 MHz and a total bitrate of 256 Mbps, and on warm receivers, with a frequency channel bandwidth of 16 MHz and a total bitrate of 512 Mbps. The data transfer speed from station to correlator was improved in 2012, and near to realtime correlation processing with a data bitrate of 256 Mbps was achieved.

In 2012, the DiFX software correlator became the main tool for a spectral radio source observation processing routine. We have started regular observing program Ru-P in 1.35 cm band and

18 cm band. Target sources are Orion KL, W49N, W3OH, and W75, and the experiment bitrate is 32 Mbps. The processing time for one second of real data is about eight seconds with DiFX using current facilities on a Sun Fire X4450 Server and its virtual machines under the VMware. The output data has a resolution from 1024 to 4096 spectral channels. Several experiments were observed with station Simeiz: RU0069, RU0083, RU0084, RU0087, and RU0088. These were 1.35 cm band sessions. Data from the Simeiz station were transferred via Internet directly to IAA's server, then processed with DiFX. We also used DiFX in test experiments of a new wideband DAS: a single IF channel of 512 MHz width with 2 Gbps total bitrate was successfully processed using DiFX.

5. Future Plans

The design of a new FX software correlator intended for the new small antenna VLBI network in comformance with VLBI2010 was started in 2012 at IAA RAS. The correlator design is supposed to process up to 16 Gb/s data stream from each of up to six observatories. VLBI data are recorded from four frequency bands with bandwidth up to 1024 MHz in one circular polarization or up to 512 MHz in two linear polarizations using 2-bit sampling. The input data format is VDIF. The correlator computes cross-spectra with a resolution up to 4096 spectral channels, and it extracts up to 16 phase calibration tones in each frequency band of each station. The correlator's hardware is based on hybrid blade server technology. Blade server contains two Intel CPU and two Nvidia Tesla GPUs. All critical computing such as Fourier transform, spectra multiplication and addition, and phase cal extraction will be perfomed using GPU; other tasks (data stream synchronization and distribution) will be provided by CPU. By a preliminary estimate, the hardware will contain up to 20 blade servers.

VLBI Correlators in Kashima

Mamoru Sekido, Kazuhiro Takefuji

Abstract

Kashima Space Technology Center (KSTC) is making use of two kinds of software correlators, the multi-channel K5/VSSP software correlator and the fast wide-band correlator 'GICO3,' for geodetic and R&D VLBI experiments. Overview of the activity and future plans are described in this paper.

1. General Information

The Kashima Space Technology Center (KSTC) of the National Institute of Information and Communications Technology has developed two types of VLBI systems. The multi-channel VLBI system called 'K5/VSSP'[1, 2] and the wide band data acquisition system 'K5/VSI' [3, 4] were developed for applications of geodesy and astronomy, respectively. Software correlators for each of the systems have been developed and used for geodetic observing and R&D VLBI experiments.

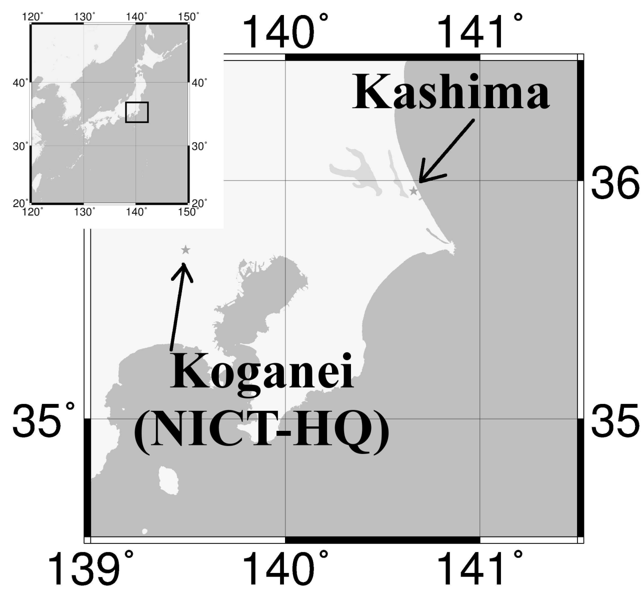

Figure 1. Locations of NICT Headquarters and KSTC.

The current main mission of our group is the development of transportable VLBI systems for frequency comparison over intercontinental distances. To gain better sensitivity with small diameter antennas, a wide-band observation system is employed in the system. Linear and dual polarization observing for the frequency range of 3-15 GHz almost meet the VLBI2010 specifications. The computation load of correlation is estimated to increase about two orders of magnitude over the conventional VLBI system; thus a new software correlator with a distributed computation design named KFC is planned.

2. Component Description

The KSTC correlator is mainly used for processing geodetic and R&D VLBI experiments organized by NICT. Two types of software correlators have been used.

2.1. K5/VSSP Software Correlator

Correlation Type: Both FX-type and XF-type software correlators are available in the K5/VSSP software suite [2]. The FFT algorithm used in the FX-type correlator has advantages in correlation with a large lag (delay) window, so it is mainly used for the clock parameter search in the beginning of routine processing. The XF-type correlator is relatively faster than FX-type in the processing of 1-bit quantization data with a small lag number. Because a small lag number is sufficient for geodetic applications, the XF-type correlator is mainly used in routine 1-bit quantization data processing for geodesy. Except for the case above, the XF-type software is used.

Processing unit: The K5/VSSP32 DAS is designed with one or four channel inputs per unit, so four channels is designed to be the maximum number of data streams to be fed to a single correlation task. This is a benefit for distributed processing with this software correlator, because correlation tasks are divided by the unit of channels and can be processed independently with multiple CPUs.

Processing speed: The single four-channel processing rate is three to six times slower than the data acquisition rate, when a single task is run on an Intel(R) Core2 Duo 3GHz processor, for example. The total processing rate is compensated by multiple run of the tasks on a cluster of computers in routine operation. This software correlator code is compiled with the GNU gcc compiler and can work on any CPU.

Other functions: The correlation product includes all the necessary information such as phase calibration information for further reduction of geodetic VLBI. In the next step, the correlator output files are synthesized by the bandwidth synthesis 'komb' software [5] to extract precise group delays from the data.

2.2. GICO3 Software Correlator

Correlation Type: FX-type correlator that uses an FFT algorithm. The optimum lag window is around 1024 lags, which is determined by the overhead of the function calls and the size of the fast access cache memory [6].

Processing unit: Processing with an arbitrary number of channels is made possible by the initial configuration.

Processing speed: The processing rate of 2 Gbps is a few times slower than the real-time data acquisition rate in the case of processing with an Intel(R) Xeon(R) CPU with a 2.33GHz clock, for example.

Other functions: Cross correlation and auto-correlation results are obtained at the same time, so that it is suitable for astronomical applications. The extraction of precise delay observables and the creation of Mark III databases is available through using Mk3Tools [7].

3. Staff

The names of the staff members who contribute to the correlator at NICT/Kashima and their tasks are listed below in alphabetical order.

- HASEGAWA Shingo (Kashima): in charge of maintenance and troubleshooting of K5 system computers, tasks of the data conversion from K5/VSSP format to Mark 5 format in IVS sessions.

- HOBIGER Thomas (Koganei, Tokyo): development of a new VLBI database system based on NetCDF, research on atmospheric delay calibration with the ray tracing technique, and development of the new software correlator KFC for the wide-band VLBI systems.
- KONDO Tetsuro (Bangkok, Thailand): maintenance of the software correlator package and documentation of the K5/VSSP32 system.
- KOYAMA Yasuhiro (Koganei, Tokyo): the Leader of the International Cooperation Office of NICT. Conductor of VLBI experiments for frequency comparison.
- SEKIDO Mamoru (Kashima): Coordination of VLBI experiments and development of the new VLBI system for frequency comparison.
- TAKEFUJI Kazuhiro (Kashima): Development of the new wide-band VLBI system with the small diameter antenna MARBLE and processing of experiment data with the GICO3 software correlator.
- TSUTSUMI Masanori (Kashima): maintenance of K5 system computers and the network.

4. Current Status and Activities

Table 1 shows a list of the experiments processed by the K5 software correlator. Because Time and Frequency comparison is the main project, some experiments for feasibility testing were made with the 11-m antennas. These data were processed with the K5/VSSP software correlator running on multi-core PCs (e.g., CPU Intel Core i7 920 2.67 GHz cache 8192 KB, Processor 4 (Hyper Threading Total Core8), Memory 12 GB).

Table 1. Correlation tasks processed with the K5/VSSP correlator in 2012.

Project	Exp code	Date	Stations	baseline x scans x days	Data rate (Mbps)
Freq. Comp.	K1203x	2-6 Feb.	K1,Kg	1 x 4723 (4 days)	512
Freq. Comp.	K12050	19-21 Feb.	K1,Kg	1 x 2295 (2 days)	512
Freq. Comp.	K12052	21-22 Feb.	K1,Kg	1 x 1349 (1 day)	512
Freq. Comp.	K122nx	28-31 Jul.	K1,Kg	1 x 4723 (3 days)	512
Freq. Comp.	K122wx	31 Jul.-4 Aug.	K1,Kg	1 x 3593 (3 days)	512
Sgr-A*	sg1218x	28 Jun.-8 Jul.	K1,Kg	1 x 35 x 10 days	512
Sgr-A*	sg1228x	11-15 Oct.	K1,Kg	1 x 35 x 6 days	512
Sgr-A*	sg12362	27 Dec.	K1,Kg	1 x 35 x 1 day	512

K1:Kashima-11m, Kg:Koganei-11m

Except for the frequency comparison, monitoring of Sgr-A* with S/X-band was organized with K5/VSSP32. Since it is predicted that a bunch of material will fall into the massive black-hole at the center of our galaxy by the summer in 2013, huge energy is expected to be emitted in the form of electromagnetic radiation in a wide frequency range. This monitoring observation will be continued in 2013 under collaboration with Keiou University, Ibaraki University, and the National Astronomy Observatory of Japan.

In addition to these experiments, fringe test and performance test experiments for a small diameter antenna with the K5/VSI (ADS3000+) data acquisition system were conducted. The GICO3 software correlator was used for this processing.

5. Future Plans

The project mission of the VLBI group in NICT is to establish a VLBI system for Time and Frequency comparison. For this purpose, we are developing the transportable wide-band VLBI system, which is semi-compliant with the VLBI2010 specifications. A new software correlator with distributed computation design is planned for this project [8].

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Shanghai VLBI Correlator

Fengchun Shu, Weimin Zheng, Zhong Chen

Abstract

This report summarizes the activities of the Shanghai VLBI Correlator during 2012.

1. Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory, Chinese Academy of Sciences. It is dedicated to the data processing of the Chinese domestic VLBI observing programs, inclusive of the CMONOC project for monitoring the Chinese regional crustal movement and the Chinese deep space exploration project for tracking spacecraft. As shown in Figure 1, the VLBI stations near Shanghai, Kunming, and Urumqi participate in some domestic geodetic sessions on an annual basis, while the Beijing station is mainly used for spacecraft data downlinks and VLBI tracking.

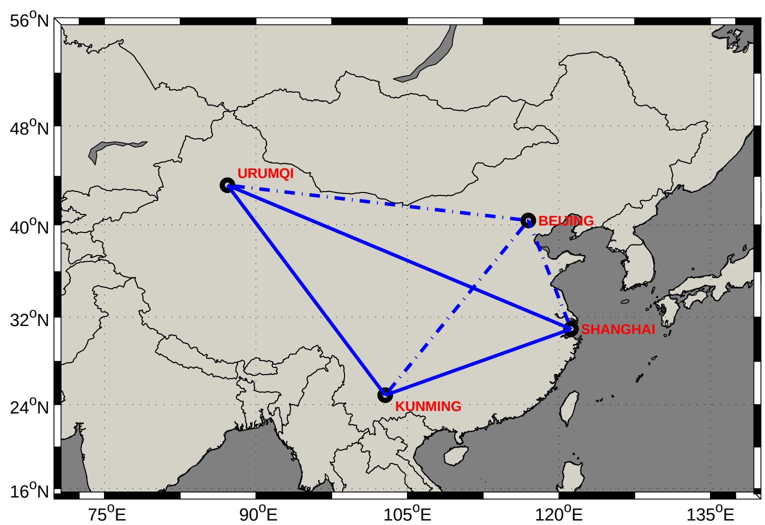

Figure 1. Distribution of the VLBI stations in China.

2. Component Description

Based on the FX type VLBA correlator, we began to design two correlators in 2003. One is the hardware correlator using the FPGA technology. The other one is the software correlator. The first version of our software correlator has been operational since 2006, and it was installed on an AMD Opteron 2200 CPU and later on an Intel X5400 CPU. The software correlator worked much better than the hardware correlator in the VLBI spacecraft tracking sessions. Because it was much easier to be modified, we adopted the second version of software correlator for geodetic applications. By using Message Passing Interface (MPI) and the POSIX thread APIs, the software correlator has been migrated to a computer cluster based on blade servers to get better performance since 2010 (see Figure 2). It has been formally accepted as an IVS correlator in March 2012.

Features of the software correlator cluster are listed below.

- IBM HS22 Blade Server, six computing nodes
- Each computing node: two socket Intel X5570 CPU (2.93 GHz), 12 GB Memory
- Two I/O nodes, with 48 TB raw storage capacity
- One management node with Rocks cluster software
- 10G Ethernet for blade internal network connection.

Figure 2. Shanghai VLBI Correlator.

A summary of the capabilities of the software correlator is presented in Table 1.

Table 1. Correlator capabilities.

Number available	five Mark 5B
Playback speed	1.8 Gbps
Input data formats	Mark 5B
Sampling	1 bit, 2 bits
IF channels	≤ 16
Bandwidth/channel	(2, 4, 6, 8, 32) MHz
Spectral points/channel	≤ 65536
Geometric model	supports plane wave front and curved wave front
online averaging time	0.1s∼4s
Phase cal extraction	yes
Output	CVN matrix format. NGS card file.

3. Staff

The people involved in the development and operation of the Shanghai Correlator are listed below.

- Weimin Zheng: group head, software correlator development
- Xiuzhong Zhang: CDAS and other technique development
- Fengchun Shu: scheduler, experiment oversight, CDAS evaluation
- Zhong Chen: e-VLBI, cluster administration
- Weihua Wang: lead correlator operator, automatic correlation process development
- Juan Zhang: correlator software development and maintenance
- Yun Yu: operator, experiment support
- Wu Jiang: operator, experiment support
- Wenbin Wang: media library, computer services
- Renjie Zhu: CDAS development
- Zhijun Xu: FPGA programming, hardware correlator development
- Yajun Wu: FPGA programming.

4. Summary of Activities

4.1. Correlator Software

The correlator model calculations for Quasars or spacecraft, driven by VEX file, have been implemented in the software in 2006. In order to improve the accuracy of differential VLBI observations to the level of better than 0.1 ns, we have incorporated more corrections such as tidal station motion and gravitational delay.

A great effort has been made to shorten the data latency for the navigation of spacecraft. After adjustment of the software structure in the whole chain of data processing, we aim to produce the final delay observables within one minute after data acquisition.

4.2. CDAS

The Chinese VLBI Data Acquisition System (CDAS) is a type of digital backend designed to replace the traditional analog BBCs. In order to solve the irregular integer bit jumps when CDAS is working at 1 Gbps or higher output data rate, we upgraded the VSI interface cards of CDAS which had been deployed at the four stations since 2010. A three-hour fringe test showed that the delay residuals had become stable on all baselines. In addition to the currently used DDC version, we also developed a PFB version of CDAS with much more compact design.

4.3. e-VLBI

The data link between the Shanghai VLBI center and Seshan25 has been upgraded to 10 Gbps. The data link to other stations is reduced to 20 Mbps data rate for now and can be up to 155 Mbps for domestic e-VLBI observations.

Supported by Chinese Next Generation Network Scientific Research Information Demonstration Project, we established an experimental IPv6-based network connection from the Shanghai VLBI center to Seshan25, Kunming, and Urumqi. e-VLBI application will be demonstrated as an example to push forward the extensive usage of the next generation network.

4.4. Experiments Correlated

In 2012, five domestic geodetic VLBI experiments were carried out at 256 Mbps data rate using 16 channels. The data correlations were done after the Mark 5 modules were shipped to the Shanghai VLBI center. The differential VLBI observations continued to support the navigation of the Chang'E-2 spacecraft from the probe orbiting around the Earth-Sun L2 Lagrangian point to flying by the asteroid Toutatis. Data processing were performed largely in e-tranfer mode.

5. Future Plans

We will continue to support the data correlation of Chinese domestic VLBI observations. As many efforts have been devoted to the development of the realtime correlation technique for differential VLBI observations of spacecraft, we plan to install a DiFX software correlator to meet the requirements of more astronomical VLBI experiments and VLBI2010 technique development in China.

Tsukuba VLBI Correlator

Shinobu Kurihara, Kentaro Nozawa

Abstract

The Tsukuba VLBI Correlator is invested by the Geospatial Information Authority of Japan (GSI). The K5/VSSP correlation software is regularly used, and the IVS-INT2, JADE, and other various sessions are correlated.

1. Introduction

The K5/VSSP software correlator (Figure 1), located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). It is fully dedicated to processing the geodetic VLBI sessions of the International VLBI Service for Geodesy and Astrometry. All of the weekend IVS Intensives (INT2) and the Japanese domestic VLBI observations organized by GSI were processed at the Tsukuba VLBI Correlator.

Figure 1. Tsukuba VLBI correlator.

2. Component Description

2.1. e-VLBI

Nowadays when the Internet is spread throughout the world, it seems that the physical transportation of the magnetic media on which the observed VLBI data is recorded is a bit outdated.

Most of the observed VLBI data processed at the Tsukuba VLBI Correlator is delivered via networks. The Tsukuba VLBI Correlator has a 10 Gbps dedicated link to the SINET4 operated by the National Institute of Informatics (NII), which is connected to some research networks such as Internet2 in the U.S., GÉANT2 in Europe, and TEIN4 at Singapore. It enabled us to transfer massive amounts of data between the Tsukuba VLBI Correlator and the IVS Components overseas. The ultra-rapid EOP experiment (see section 4.3) is also brought about by this network.

2.2. K5/VSSP Correlation Software

The K5/VSSP correlation 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 baselines (*fx_cor* or *cor*), and for monitoring the results of the correlation processing by performing a so-called "coarse search", following several utilities [1]. *Komb* is a bandwidth synthesis software that was developed on an HP-1000 series minicomputer using the FORTRAN program language when the K-3 VLBI system was being developed. It has now been ported to a Linux operating system using the C language. All these programs were developed and have been maintained by the National Institute of Information and Communications Technology (NICT), which are available not only for the K5 data processing but also for the Mark 5 data processing by using the data format conversion program (*m5tok5*).

The following are processes of the K5 correlation and programs used in each process.

1. Transferring data from network stations to correlator (*tsunami* and *tsunamid*).
2. Data format conversion from Mark 5 to K5 (*m5tok5* or *m5btok5*).
3. Preparation of a-priori parameter files (*apri_calc*).
4. Fringe search to find a clock offset at each station (*fx_cor* or *cor*).
5. Running correlation processing for all baseline (*fx_cor* or *cor*).
6. Coarse search for residual delay and delay rate and plotting a 3-D diagram to indicate the delay and fringe-rate axis (*sdelay*).
7. Bandwidth synthesis to derive a multi-band delay (*komb*) and generation of a Mark III database to be submitted to the IVS Data Center (*MK3TOOLS*).

We developed various management programs to run the above processes consecutively and ultra-rapidly. A program for the management of data transfer, *rapid_transfer*, accesses the hosts in observing stations, executes *tsunamid* there, and then at the correlator side, executes *tsunami* to transfer data automatically when an observation starts. The data is converted from Mark 5 to K5 format by a program *rapid_conv* as necessary. *Rapid_cor* is a program to search for fringes of each baseline according to the clock information of each station written in the FS log. Once the fringe is detected, the main correlation processing is run sequentially with the clock offset and rate found in the fringe search until the last observation. The solution, a triad of the Earth Orientation Parameter (EOP), is derived from a set of the bandwidth synthesis outputs generated by *rapid_komb* that executes *komb* one after another. The fully automated VLBI analysis software *c5++* developed by NICT estimates EOPs, clock parameters with respect to a reference station, and atmospheric delays for each station according to the configuration of parameterizations defined in advance [2]. The 3-D diagrams of the fringes of each baseline and the graphs of the time series of EOP are available on the GSI Web page and updated by the minute during an ultra-rapid experiment.

2.3. Correlator Hardware Capabilities

The hardware supporting the activities of the Tsukuba VLBI Correlator is summarized in Table 1. All these pieces of equipment are general-purpose and commercially available. It means that no dedicated hardware is required in the K5 correlation processing. In a correlator, mass data storage is required. Moreover, since some executed correlation processes access a file simultaneously, the capability of the correlator depends on the Read I/O of the data storage. The Lustre File System enables us to use numerous HDDs mounted on a lot of servers like one partition as if it were a large virtual disk. Thus, the I/O performance is dramatically improved compared with NFS.

In 2012, some aging servers crashed and were removed from the correlation system. It has had little impact on the overall capability of the correlator.

Table 1. Correlator Hardware Capabilities.

Number of servers	49 - 16 for correlation processing - 2 for controlling correlation processing - 31 for data storage
Operating System	CentOS version 5.4 or 5.5
CPU	Intel Pentium4 3.0 GHz / Intel Xeon 3.4 GHz dual CPU / Xeon 3.06 GHz dual CPU / Intel Xeon 3.07 GHz quad CPU
Total storage capacity	Lustre File System: 27.9 Tbytes individual RAIDs: 102 Tbytes in total
Network	10 Gbps dedicated line connected to SINET4 by NII

3. Staff

The technical staff members at the Tsukuba VLBI Correlator are

- **Shinobu Kurihara**: correlator/analysis chief, software design and development.
- **Kentaro Nozawa** (AES): correlator/analysis operator, software development.
- **Takashi Nishikawa** (AES): correlator/analysis operator.
- **Toshio Nakajima** (I-JUSE): system engineer.

Kensuke Kokado, who had been the correlator/analysis chief until the end of May 2012, moved to another division on April 1.

4. Correlator Operations

4.1. IVS-INT2 and IVS-INT3

In 2012, 107 IVS-INT2 sessions were correlated. 83 of them observed the Tsukuba-Wettzell baseline, and the other 24 observed the Kokee-Wettzell baseline. The observed data at Wettzell is transferred to the correlator in real-time with the VDIF/SUDP protocol and is recorded on data storage in the K5 format directly. Since the whole processes from correlation to analysis are implemented by the *rapid_* programs (see section 2.2), a dUT1 solution can be derived within two minutes after the end of the last scan of the session. In case of Kokee-Wettzell baseline, since the observed data at Kokee was transferred via the U.S. Naval Observatory (USNO), it took a few hours to derive a solution.

Besides, one IVS-INT3 observed on February 20 (k12051) was correlated instead of the Bonn correlator.

4.2. JADE and JAXA

JADE is the domestic geodetic VLBI series involving four GSI stations (Tsukuba, Aira, Chichijima, and Shintotsukawa), two 11-m stations at Koganei and Kashima owned by NICT, and two VERA stations of the National Astronomical Observatory of Japan (NAOJ) located in Mizusawa and Ishigakijima. Eight JADE sessions were correlated in 2012. A JAXA session involving Usuda 64-m to provide precise geodetic coordinates required in the tracking of the deep space probes was processed as well.

4.3. Ultra-Rapid EOP Experiment

This experiment is the joint project with Sweden, Australia, and South Africa, having been continued since 2007. The HartRAO 26-m and 15-m antennas newly joined in the experiments, and the automated ultra-rapid processing was implemented with a four-station/six-baseline network. For details refer to the report "Tsukuba VLBI Analysis Center", this volume.

5. Outlook

For more stable operation, we will make some improvements to *rapid_* programs.

References

[1] Kondo, T., et al.: Development of hte K5/VSSP System, *Journal of the Geodetic Society of Japan*, **54**(4), 233-248, 2008.

[2] Hobiger, T., et al.: Fully automated VLBI analysis with c5++ for ultra-rapid determination of UT1, *Earth Planets Space*, **62**, 933-937, 2010.

Washington Correlator

David M. Hall, David Boboltz

Abstract

This report summarizes the activities of the Washington Correlator for 2012. The Washington Correlator provides up to 80 hours of attended processing per week plus up to 40 hours of unattended operation, primarily supporting Earth Orientation and astrometric observations. In 2012, the major programs supported include the IVS-R4, IVS-INT, APSG, and CRF observing sessions.

1. Introduction

The Washington Correlator (WACO) is located at and staffed by the U.S. Naval Observatory (USNO) in Washington, DC, USA. The correlator is sponsored and funded by the National Earth Orientation Service (NEOS), which is a joint effort of the USNO and NASA. Dedicated to processing geodetic and astrometric VLBI observations, the facility spent 100 percent of its time on these sessions. The weekly IVS-R4 sessions, the IVS-INT01 Intensives, the Asian-Pacific space geodynamics (APSG), the Australian AuScope (AUST), and the Celestial Reference Frame (CRF) sessions were processed at WACO. The facility houses a Mark IV correlator and the new DiFX correlator.

2. Correlator Operations

- The Washington Correlator continues to operate 80 hours per week with an operator on duty. The correlator has continued to function well unattended, allowing another 40 hours per week, on average, of extra processing. This has also decreased the time it takes to process an R4 or other 24-hour session by one day, hence the latency in the data being fully processed and available by one day.
- The correlator staff continues the testing and repair of Mark 5 modules. Not only were failed disks replaced, but some modules were upgraded by the replacement of lower capacity disks with higher capacity disks.
- Intensive observations from Kokee Park and Wettzell were routinely transferred via high speed data networks (e-VLBI) during 2012. 24-hour sessions from both Hobart antennas, Katherine, Yarragadee, Warkworth, Ny-Ålesund, Fortaleza, Yebes, Noto, HartRAO, Tsukuba, Aira, Kashima, Chichijima, and Sintotu were also transferred by high-speed data networks.
- Table 1 lists the experiments processed during 2012.

3. Software Correlator

In September 2012, Phase I of the new DiFX software correlator was delivered by the National Radio Astronomy Observatory (NRAO) to the USNO. This Phase I implementation consists of 33 compute nodes with 16 processor cores per node for a total of 528 cores. The compute nodes are

Table 1. Experiments processed during 2012.

52	IVS-R4
16	CRF
3	APSG
3	AUST
230	Intensives

connected via 10 Gbps Ethernet over fiber. Cluster management is performed via two infrastruture servers that are connected to the diskless compute nodes. The new implementation runs the DiFX software package along with the USNO implementation of the graphical user interface (GUI).

Since delivery, USNO personnel have been involved in the configuration and testing of the new correlator. Successful processing of VLBI data from the VLBA and the IVS has been performed. Data have been streamed from the two connected Mark 5C units, as well as directly from the connected storage area network (SAN). Correlated data have been successfully passed through the entire geodetic reduction path from correlation to fringing via the Haystack Observatory Postprocessing System (HOPS) package to database generation and analysis via Calc/Solve.

4. Staff

The Washington Correlator is under the management and scientific direction of the Earth Orientation Department of the U.S. Naval Observatory. Due to a change in policy by the U.S. Navy, the NVI support contract was ended. At the beginning of 2012 the VLBI division had filled only three positions, Dr. Kerry Kingham, Mr. David Hall, and Ms. Roxanne Innis. Bruce Thornton was hired in February, and in May Mr. Daniel Veillette joined the VLBI division. Dr. Kerry Kingham retired at the beginning of June, and Ms. Maria Davis was hired later that month. Table 2 lists staff and their duties.

Table 2. Staff.

USNO Staff	**Duties**
Dr. Kerry Kingham	Chief VLBI Operations Division and Correlator Project Scientist
David Hall	VLBI Correlator Project Manager
Daniel Veillette	Astronomer
Bruce Thornton	Lead Physical Science Technician
Roxanne Inniss	Media Librarian
Maria Davis	Physical Science Technician

5. Outlook

During 2013, the processing load should be transferred from the present Mark IV hardware correlator to a DiFX software correlator.

Data Centers

BKG Data Center

Volkmar Thorandt, Reiner Wojdziak

Abstract

This report summarizes the activities and background information of the IVS Data Center for the year 2012. Included is information about functions, structure, technical equipment, and staff members of the BKG Data Center.

1. BKG Data Center Functions

The BKG (Federal Agency for Cartography and Geodesy) Data Center is one of the three IVS Primary Data Centers. It archives all VLBI related data of IVS components and provides public access for the community. The BKG Data Center is connected to the OPAR and GSFC CDDIS Data Centers by mirroring the OPAR and the CDDIS file stocks several times per day. The following sketch shows the principle of mirroring:

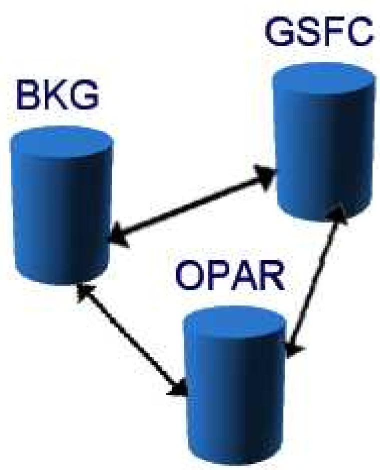

Figure 1. Principle of mirroring.

IVS components can choose one of these Data Centers through which to put their data into the IVS network by using its incoming area, which each of them has at its disposal. The BKG incoming area is protected, and users need to obtain the username and the password to get access.

An incoming script watches the incoming area and checks the syntax of the files sent by IVS components. If it is okay, the script moves the files into the Data Center directories. Otherwise the files will be sent to a badfile area. Furthermore, the incoming script informs the responsible staff at the Data Center by sending e-mails about its activities. The incoming script is part of the technological unit which is responsible for managing the IVS and the Operational Data Center and for carrying out the first analysis steps in an automatic manner. All activities are monitored to guarantee data consistency and to control all analysis steps from data arrival to delivery of analysis products to IVS.

Public access to the BKG Data Center is available through FTP and HTTP at the following Web sites:

```
FTP:            ftp://ivs.bkg.bund.de/pub/vlbi/

HTTP:           http://ivs.bkg.bund.de/vlbi/
```

Structure of the BKG IVS Data Center:

```
vlbi/            : root directory
ivs-special/     : special CRF investigations
ivscontrol/      : controlfiles for the data center
ivsdata/         : VLBI observation files
ivsdocuments/    : IVS documents
ivs-iers/        : old IERS solutions
ivsproducts/     : analysis products
    crf/         : celestial frames
    trf/         : terrestrial frames
    eops/        : earth orientation (24h sessions)
    eopi/        : earth orientation (Intensive sessions)
    daily_sinex/ : daily sinex files (24h sessions)
    int_sinex/   : daily sinex files (Intensive sessions)
    trop/        : troposphere
```

2. Technical Equipment

- DELL Server (SUSE Linux operating system)
- disk space: 500 GBytes (Raid system)
- backup: automatic tape library

3. Staff Members

1. Volkmar Thorandt (coordination, data analysis, data center; volkmar.thorandt@bkg.bund.de)
2. Reiner Wojdziak (data center, Web design; reiner.wojdziak@bkg.bund.de)
3. Dieter Ullrich (data analysis, data center; dieter.ullrich@bkg.bund.de)
4. Gerald Engelhardt (data analysis; gerald.engelhardt@bkg.bund.de)

CDDIS Data Center Summary for the IVS 2012 Annual Report

Carey Noll

Abstract

This report summarizes activities during 2012 and 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, staff supporting the system, archive contents, and future plans for the CDDIS within the IVS.

1. Introduction

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 providing users access to data and derived products to facilitate scientific investigation. The CDDIS archive of GNSS (GPS, GLONASS, etc.), laser ranging, VLBI, and DORIS data are stored on-line for remote access. Information about the system is available via the Web at the URL http://cddis.gsfc.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), the International DORIS Service (IDS), the International Earth Rotation and Reference Frame Service (IERS), and the Global Geodetic Observing System (GGOS) of the IAG. The current and future plans for the system's support of the IVS are discussed below.

2. System Description

The CDDIS archive of VLBI data and products is accessible to the public through anonymous ftp.

2.1. Computer Architecture

The CDDIS is operational on a dedicated server, cddis.gsfc.nasa.gov. The system has over 32 Tbytes of on-line disk storage; at this time, over 150 Gbytes are devoted to VLBI activities. The CDDIS is located at NASA GSFC and is accessible to users 24 hours per day, seven days per week.

In 2011, the CDDIS staff procured new server hardware to further enhance the capabilities of the system and ensure a robust archive environment. The new configuration is fully redundant with the primary and secondary/failover systems located in different buildings on the GSFC campus. Each system utilizes a distributed functionality (incoming, outgoing, processing, database, and map servers) and is configured with a local backup system as well as a full backup system located in a third building at GSFC. The archive is equipped with a 32 Tbyte RAID storage system and is scaled to accommodate future growth. Users and suppliers of data and product files did not need to update their software or procedures to access the new systems. The structure of the VLBI data and product archive remained unchanged in this new system configuration. The new server configuration became operational in May 2012.

2.2. Staffing

Currently, a staff consisting of one NASA civil service employee and four (one full-time, three part-time) contractor employees supports all CDDIS activities (see Table 1 below).

Table 1. CDDIS Staff.

Name	Position
Ms. Carey Noll	CDDIS Manager
Dr. Patrick Michael	System Engineer (part-time)
Dr. Maurice Dube	Senior programmer
Mr. Nathan Pollack	Programmer (part-time)
Ms. Lori Tyahla	Programmer (part-time)

3. Archive Content

The CDDIS has supported GSFC VLBI coordination and analysis activities for the past several years through an on-line archive of schedule files, experiment logs, and data bases in several formats. This archive has been expanded for the IVS archiving requirements.

The IVS Data Center content and structure is shown in Table 2. (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.) In brief, dedicated ftp-only accounts have been established on the CDDIS incoming computer, cddisin.gsfc.nasa.gov. Using specified file names, operation and analysis centers deposit data files and analyzed results to appropriate directories within their ftp-only accounts. Automated archiving routines, developed by GSFC VLBI staff, peruse the directories and move any new data to the appropriate public disk area. These routines migrate the data based on the file name to the appropriate directory as described in Table 2. Index files in the main sub-directories under ftp://cddis.gsfc.nasa.gov/pub/vlbi are updated to reflect data archived in the filesystem. Furthermore, mirroring software has been installed on the CDDIS host computer, as well as all other IVS data centers, to facilitate equalization of data and product holdings among these data centers. At this time, mirroring is performed between the IVS data centers located at the CDDIS, the Bundesamt für Kartographie und Geodäsie in Leipzig, and the Observatoire de Paris.

The public filesystem in Table 2 on the CDDIS computer, accessible via anonymous ftp, consists of a data area, which includes auxiliary files (e.g., experiment schedule information, session logs, etc.) and VLBI data (in both database and NGS card image formats). A products disk area has also been 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. Data Access

During 2012, over 1,300 distinct hosts accessed the CDDIS on a regular basis to retrieve VLBI related files. These users, which include other IVS data centers, successfully downloaded over 2.3

Table 2. 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/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/raw	Raw VLBI data
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/ivs-iers	IVS contributions to the IERS
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/dserver	Dserver software and incoming files

Tbytes of data and products (2.5M files) from the CDDIS VLBI archive last year.

5. 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.

Italy INAF Data Center Report

M. Negusini, P. Sarti

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 analysis activity and storage is concentrated in Bologna, where we store and analyze single databases, using CALC/SOLVE software.

The IRA started to store geodetic VLBI databases in 1989, but the databases archived in Bologna mostly contain data including European antennas from 1987 onward. In particular, most of the databases available here have VLBI data with at least three European stations. However we also store all the databases with the Ny-Ålesund antenna 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 observations performed from 1999 onwards. All the databases have been 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.

In some cases we have introduced GPS-derived wet delays into the European databases (1998 and 1999 EUROPE experiments, for the time being), as if they were produced by a WVR. These databases are available and stored with a different code from the original databases. In order to produce these databases, we have modified DBCAL, and this new version is available to external users.

2. Computer Availability and Routing Access

To date, the main computer is a Linux workstation, on which Mark 5 Calc/Solve version 10 was installed and to which all VLBI data analysis was migrated. The Internet address of this computer is sarip.ira.inaf.it. Since 2011 a new server with a storage capacity of 5 TB has been available, and, therefore, all experiments performed in the previous years were downloaded and archived, thus completing the catalog. The older experiments will be analyzed in order to perform global long term analysis. At present, the databases are stored in the following directories:

1 = /data2/dbase2
2 = /geo1/dbase1
3 = /geo1/dbase
4 = /geo1/dbase3

The superfiles are stored in:

/data1/super1

The list of superfiles is stored in the file /data2/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.

Data Center at NICT

Ryuichi Ichikawa, Mamoru Sekido

Abstract

The Data Center at the National Institute of Information and Communications Technology (NICT) archives and releases the databases and analysis results processed at the Correlator and the Analysis Center at NICT. Regular VLBI sessions of the Key Stone Project VLBI Network were the primary objective of the Data Center. These regular sessions continued until the end of November 2001. In addition to the Key Stone Project VLBI sessions, NICT has been conducting geodetic VLBI sessions for various purposes, and these data are also archived and released by the Data Center.

1. Introduction

The IVS Data Center at National Institute of Information and Communications Technology (NICT) archives and releases the databases and analysis results processed by the Correlator and the Analysis Center at NICT. Major parts of the data are from the Key Stone Project (KSP) VLBI sessions [1], but other regional and international VLBI sessions conducted by NICT are also archived and released. Because routine observations of the KSP network terminated at the end of November 2001, there have been no additional data from the KSP regular sessions since 2002.

On March 11, 2011, the devastating megaquake (M_w 9.0) hit our antennas. The azimuth track and one azimuth wheel of the Kashima 34-m were damaged as a consequence of the megaquake. Since the antenna is still under repair, there are no VLBI databases containing baselines with the 34-m antenna in 2012. On the other hand, the 11-m antennas at Kashima and Koganei were not damaged by the earthquake. We have carried out 39 VLBI experiments using the 11-m antennas including time and frequency transfer experiments, international and domestic geodetic experiments, and astrophysical experiments.

The analysis results in SINEX (Solution INdependent EXchange) format, as well as in other formats, are available on the WWW server. Database files of non-KSP sessions, i.e. other domestic and international geodetic VLBI sessions, are also available on the WWW server. Table 1 lists the WWW server locations maintained by the NICT Data Center. In the past, an FTP server was used to provide data files, but it was decided to terminate the FTP service because of the security risks of maintaining an anonymous FTP server. Instead, the www3.nict.go.jp WWW server was prepared to provide large size data files.

Table 1. URL of the WWW server systems.

Service	URL
KSP WWW pages	`http://ksp.nict.go.jp/`
IVS WWW mirroring	`http://ivs.nict.go.jp/mirror/`
Database files	`http://www3.nict.go.jp/aeri/sts/stmg/database/`
e-VLBI Sessions	`http://www2.nict.go.jp/aeri/sts/stmg/research/e-VLBI/UT1/`
Hayabusa Sessions	`http://www2.nict.go.jp/aeri/sts/stmg/research/Navi/HAYABUSA/`

The responsibility for the maintenance of these server machines was moved from the VLBI research group in 2001 to a common division which handles all institutional network service for the laboratory in order to improve the network security of these systems.

2. Data Products

2.1. KSP VLBI Sessions

The KSP VLBI sessions were performed with four KSP IVS Network Stations at Kashima, Koganei, Miura, and Tateyama on a daily or bi-daily basis until May 1999. The high-speed ATM (Asynchronous Transfer Mode) network line to the Miura station became unavailable in May 1999, and real-time VLBI observations with the Miura station became impossible. Thereafter, the real-time VLBI sessions were performed with the three other stations. Once every six days (every third session), the observed data were recorded to the K4 data recorders at three stations, and the Miura station participated in the sessions with the tape-based VLBI technique. In this case, the observed data at the three stations other than the Miura station were processed in real-time, and the analysis results were released promptly after the observations completed. A day later, the observed tapes were transported from the Kashima, Miura, and Tateyama stations to the Koganei station for tape-based correlation processing with all six baselines. After the tape-based correlation processing was completed, the data set produced with the real-time VLBI data processing was replaced by the new data set.

In July 2000, unusual site motion of the Tateyama station was detected from the KSP VLBI data series, and the frequency of the sessions was increased from bi-daily to daily on July 22, 2000. The daily sessions were continued until November 11, 2000, and the site motions of the Tateyama and Miura stations were monitored in detail. During the period, it was found that Tateyama station moved about 5 cm in the northeast direction. The Miura station also moved about 3 cm to the north. The unusual site motions of these two stations gradually settled, and the current site velocities seem to be almost the same as the site velocities before June 2000. By investigating the time series of the site positions, the unusual site motion started sometime between the end of June 2000 and the beginning of July 2000. At the same time, volcanic and seismic activities near the Miyakejima and Kozushima Islands began. These activities are believed to have caused the regional crustal deformation in the area, explaining the unusual site motions at Tateyama and Miura.

2.2. Other VLBI Sessions

In recent years, we have carried out time and frequency transfer experiments using VLBI. In addition, domestic and international geodetic and astronomical VLBI sessions were conducted by NICT in cooperation with the Geospatial Information Authority of Japan (GSI), the National Astronomical Observatory of Japan (NAO), and other organizations. These sessions are listed in Table 2. The recently observed data from these sessions were mainly processed by the K5 software correlator at NICT either at Koganei or at Kashima or by using a real-time hardware correlator developed by NAO.

In 2012, we have no data using the 34-m antenna since the antenna has been under repair to recover from the damages due to the earthquake. The repair will be finished at the end of March 2013.

Table 2. VLBI sessions conducted by NICT (since 2005). *In 2012, all experiments were observed using the 11-m antennas at Kashima and Koganei because the 34-m antenna was under repair to recover from the earthquake damage.

Year	exp. names	sessions
2005	Geodetic	c0505 (CONT05, partial participation),
	Hayabusa	GEX13, 14 sessions
2006	Geodetic	GEX14, viepr2, CARAVAN (3 sessions)
	Spacecraft	Geotail : 1 session
	Pulsar	1 session
2007	Ultra Rapid e-VLBI	15 times, 29 sessions
	Time Transfer	4 sessions, 12 days in total
	Cs-Gas-Cell	1 session
	Spacecraft	Hayabusa : 1 session
2008	Ultra Rapid e-VLBI	8 times, 33 sessions
	Time Transfer	26 sessions
	Variable Star e-VLBI	31 sessions
2009	e-VLBI	15 sessions, 90.5 hours in total
	IVS	12 sessions, 332 hours in total
	Time Transfer	9 sessions, 72 hours in total
	VERA	16 sessions, 149 hours in total
	Survey	26 sessions, 276 hours in total
2010	IVS	38 sessions, 442 hours in total
	Radio astronomy	34 sessions, 324 hours in total
	Spacecraft (IKAROS, UNITEC-1, QZSS)	33 sessions, 259 hours in total
	Domestic geodetic	13 sessions, 94 hours in total
	Time Transfer	9 sessions, 86 hours in total
	e-VLBI	9 sessions, 27 hours in total
2011	IVS	two sessions, 48 hours in total
	Radio astronomy	100 hours in total
	earthquake damage investigation	216 hours in total
2012*	IVS	9 sessions, 216 hours in total
	Radio astronomy (Sgr-A*)	13 sessions, 28 hours in total
	Domestic geodetic	3 sessions, 72 hours in total
	International fringe test (New Zealand and Korea)	2 sessions, 16 hours in total
	International geodetic (New Zealand)	1 session, 24 hours in total
	Time transfer	11 sessions, 264 hours in total

3. Staff Members

The Data Center at NICT is operated and maintained by the Space-Time Standards Group at the Kashima Space Research Center, NICT. The staff members are listed in Table 3.

Table 3. Staff members of the Space-Time Measurements Group, NICT. †Ichikawa moved to the Koganei division of the NICT on May 1, 2012.

Name	Main Responsibilities
ICHIKAWA Ryuichi†	Frequency and Time Transfer using compact VLBI system
SEKIDO Mamoru	Responsible for e-VLBI sessions
HASEGAWA Shingo	System Engineer

4. Future Plans

The IVS Data Center at NICT will continue its service and will archive and release the analysis results accumulated by the Correlator and the Analysis Center at NICT. In addition, a number of VLBI sessions will be conducted for the purposes of various technology developments.

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Paris Observatory (OPAR) Data Center

Christophe Barache, Sebastien Lambert

Abstract

This report summarizes the OPAR Data Center activities in 2012. Included is information about functions, architecture, status, future plans, and staff members of OPAR Data Center.

1. OPAR Data Center Functions

The Paris Observatory (OPAR) has provided a Data Center for the International VLBI Service for Geodesy and Astrometry (IVS) since 1999. The OPAR, as well as 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, and documents),
- mirrors the other ones every three hours, and
- gives free FTP access to the files.

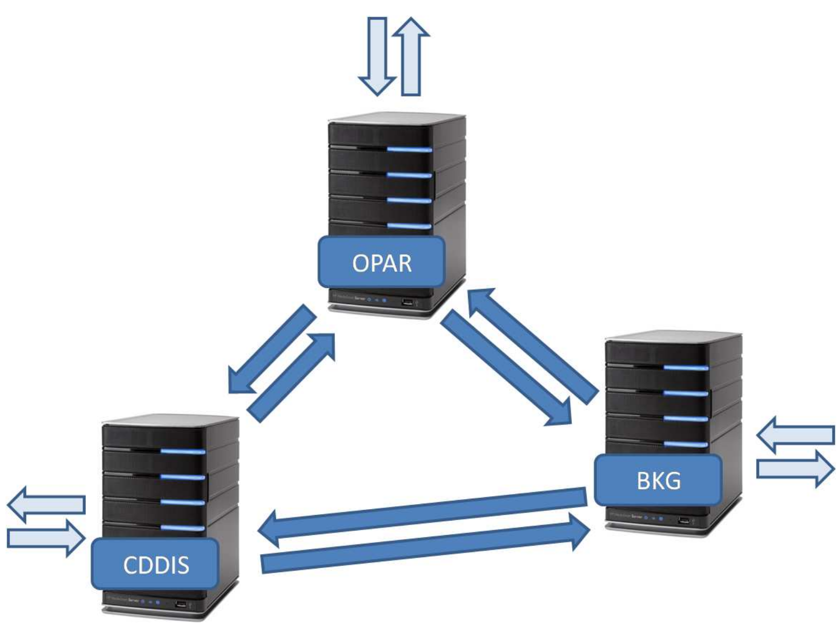


Figure 1. Mirroring among the primary IVS Data Centers.

This protocol gives the IVS community transparent access to a Data Center through the same directory and permanent access to files in case of a Data Center breakdown.

2. Architecture

To be able to put a file in a Data Center, Operational 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 in the right directory. The script undergoes permanent improvement and takes into account the IVS components' requests.

The structure of IVS Data Centers is:

```
RECENT/            : used for the new mirror method
ivscontrol/        : provides the control files needed by the data center
                     (session code, station code, solution code...)
ivsdocuments/      : provides documents and descriptions about IVS products
ivsdata/           : provides files related to the observations:
   aux/            :   auxiliary files (schedule, log...)
   db/             :   observation files in database CALC format
   ngs/            :   observation files in NGS format
   sinex/          :   observation files in SINEX format
ivsproducts/       : provides results from Analysis Center:
  eopi/            :   Earth Orientation Parameters, Intensive sessions
  eops/            :   Earth Orientation Parameters, sessions of 24h
  crf/             :   Celestial Reference Frame
  trf/             :   Terrestrial Reference Frame
  daily_sinex/     :   Time series solutions in SINEX format of Earth
                       orientation and site positions
  int_sinex/       :   Daily Intensive solution in SINEX format, mainly
                       designed for combination
  trop/            :   Tropospheric time series (starting July 2003)
```

3. Current Status

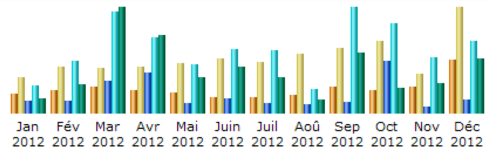
The OPAR Data Center is operated actually on a PC Server (PowerEdge 2800 - Xeron 3.0 GHz) located at Paris Observatory and running the Fedora Linux operating system.

To make all IVS products available on-line, the disk storage capacity was significantly increased, and the server is equipped now with a RAID 3 TB disk extensible up to 4.7 TB.

The OPAR server is accessible 24 hours per day, seven days per week through Internet connections with 2 Mbit/s rate. Users can get the IVS products by using the FTP protocol. Access to this server is free for users.

Historique mensuel

WEB OPAR



Mois	Visiteurs différents	Visites	Pages	Hits	Bande passante
Jan 2012	130	238	870	1901	89.26 Mo
Fév 2012	153	306	818	3612	174.89 Mo
Mar 2012	173	301	2270	7028	645.05 Mo
Avr 2012	152	306	2800	5274	479.42 Mo
Mai 2012	137	333	706	3397	218.90 Mo
Juin 2012	106	365	991	4408	279.96 Mo
Juil 2012	108	342	657	4363	220.68 Mo
Aoû 2012	120	394	607	1641	83.25 Mo
Sep 2012	176	435	791	7316	371.76 Mo
Oct 2012	154	479	3653	6191	152.14 Mo
Nov 2012	178	259	486	3852	183.62 Mo
Déc 2012	358	702	969	5028	334.31 Mo
Total	1945	4460	15618	54011	3.16 Go

Figure 2. Monthly access of the OPAR Data Center during 2012. For each month listed in column 1, columns 2 through 6 show the number of different visitors, the total number of visits, the number of pages viewed, the number of hits, and the downloaded bandwidth in Megabytes (Mo) or Gigabytes (Go).

FTP access:

ivsopar.obspm.fr
username: anonymous
password: your e-mail
cd vlbi (IVS directory)

This year, from July to September, the OPAR was disconnected from the CDDIS Data Center because of the new mirror method installation using lftp.

4. Future Plans

The OPAR staff will continue to work with the IVS community and in close collaboration with the two other Primary Data Centers in order to provide public access to all VLBI related data.

To obtain information about the OPAR Data Center please contact: ivs.opa@obspm.fr

Analysis Centers

Analysis Center of Saint Petersburg University

Dmitriy Trofimov, Veniamin Vityazev

Abstract

This report briefly summarizes the activities of the Analysis Center of Saint Petersburg University during 2012. The current status, as well as our future plans, are described.

1. Introduction

The Analysis Center of Saint Petersburg University (SPU AC) was established in 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 results of 24-hour session processing.

2. 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 was performed by Professor Veniamin Vityazev.

3. Activities in 2012

- In 2012, the routine estimation of the five Earth Orientation Parameters was performed. The OCCAM software package (version 6_2) was used for 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 25 years of observations (from January 2, 1989 until the end of 2012). The total number of experiments processed at the SPU AC is about 1870, of which about 100 VLBI sessions were processed in 2012. We also complemented our series for 2011 by 118 sessions not processed before. Our experience and the equipment of the Analysis Center was used for giving lectures and practical work on the basics of radio interferometry for university students. We use our original manual on the training in modern astrometry, in particular, VLBI [2].

  In 2012, the work of the SPU AC was performed within the projects “Acquisition and analysis of time-series in astronomy and study of astronomical catalogs” and “GLONASS, GPS and VLBI observations as the basis of astronomical, gravimetric, and geodynamic studies” (the SPU grants for fundamental research).

- All parameters were adjusted using the Kalman filter technique. For all stations (except the reference station), the wet delay, clock offsets, clock rates, and troposphere gradients were estimated. Troposphere wet delay 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 are summarized below:
  - Data span: 1989.01–2012.12
  - CRF: fixed to ICRF-Ext.2
  - TRF: VTRF2005 was used as an a priori TRF
  - Estimated parameters:
    1. EOP: $x, y, UT1 - UTC, d\psi, d\varepsilon$;
    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
  - mapping function: VMF1
  - technique: Kalman filter
  - software: OCCAM v.6_2

4. Future Plans

In 2013, we are going to continue our regular processing of the VLBI sessions as well as giving lectures and practical training for students in a special course on radio astrometry. This course is a part of the systematic curriculum of astronomical education at SPb University.

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Geoscience Australia Analysis Center

Oleg Titov, Laura Stanford

Abstract

This report gives an overview of the activities of the Geoscience Australia IVS Analysis Center during 2012.

1. General Information

The Geoscience Australia (GA) IVS Analysis Center is located in Canberra. The National Geospatial Reference System Section operates as a part of the Mineral and Natural Hazard Division (MNHD).

2. Component Description

Currently, the GA IVS Analysis Center contributes estimates of nutation offsets, EOP, and EOP rates on a regular basis for the IVS-R1 and IVS-R4 networks and their predecessors (IRIS-A and NEOS-A). The EOP time series are available from 1983 to 2012. The CRF catalogs, using a global set of VLBI data since 1979, are regularly submitted to the IVS database.

3. Staff

- Dr. Oleg Titov - senior scientist
- Dr. Laura Stanford - VLBI scientist

4. Current Status and Activities

Several CRF solutions have been prepared using the OCCAM 6.2 software. The latest solution was uploaded in September 2012. VLBI data comprising 4,109 daily sessions from 25 November 1979 to 31 May 2012 have been used to compute several global solutions with different sets of reference radio sources. This includes 5,537,065 observational delays from 2,895 radio sources having four or more observations.

Station coordinates were also estimated using No-Net-Rotation and No-Net-Tranlation 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 modeled using an exponential function typical of post-seismic deformation [1]. The tectonic motion of Tigoconc (2010) and Tsukub32 (2011) VLBI sites after the strong earthquakes is currently under study.

The adjustment was made by least squares collocation [2], 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 [3].

Our first CRF solution, aus2012a.crf, did not impose the NNR constraints. The second CRF solution, aus2012b.crf, imposed NNR constraints. This second solution is consistent with the CRF solutions submitted by other Analysis Centers.

A progress report on the secular aberration drift was presented at the IAU General Assembly in Beijing on August 28, 2012. This work was done in collaboration with colleagues from the IVS Analysis Center of Paris Observatory. The new estimate of the dipole systematic effect, 5.3 ± 1.5 μas/yr, was found using the individual proper motion of the 643 reference radio sources with the CALC/SOLVE software. New coordinates of the acceleration vector are $\alpha = 268 \pm 12$ degrees and $\delta = -30 \pm 13$ degrees [4].

5. Geodetic Activity of the Australian Radio Telescopes

In 2012, all three new AuScope 12-meter radio telescopes moved to full operational mode. Two other Australian radio telescopes – Hobart26, operated by the University of Tasmania (UTAS), and Parkes, operated by the Australia Telescope National Facility (ATNF) – participated in the geodetic VLBI programs occasionally.

The Parkes 64-meter telescope participated in six geodetic VLBI sessions in 2012 for improvement of the ITRF and the ICRF in the Southern Hemisphere. This program was undertaken in cooperation with ATNF and UTAS.

6. Optical Spectroscopic Observations of the Reference Radio Sources

A program for optical identification and spectroscopy of the reference radio sources is continued in collaboration with the Australian Telescope National Facility, University of Sydney and Nordic Optical Telescope. A new paper that includes redshifts of 126 reference radio sources was submitted [5].

Acknowledgements

This report has been published with the permission of the CEO, Geoscience Australia.

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Report for 2012 from the Bordeaux IVS Analysis Center

Patrick Charlot, Antoine Bellanger, Romuald Bouffet, Géraldine Bourda, Arnaud Collioud, Alain Baudry

Abstract

This report summarizes the activities of the Bordeaux IVS Analysis Center during the year 2012. The work focused on (i) regular analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package; (ii) systematic VLBI imaging of the RDV sessions and calculation of the corresponding source structure index and compactness values; (iii) investigation of the correlation between astrometric position instabilities and source structure variations; and (iv) continuation of our VLBI observational program to identify optically-bright radio sources suitable for the link with the future Gaia frame. Also of importance is the 11th European VLBI Network Symposium, which we organized last October in Bordeaux and which drew much attention from the European and International VLBI communities.

1. General Information

The "Laboratoire d'Astrophysique de Bordeaux" (LAB), formerly Bordeaux Observatory, is located in Floirac, near Bordeaux, in the southwest of France. It is funded by the University of Bordeaux and the CNRS ("Centre National de la Recherche Scientifique"). VLBI activities are primarily developed within the M2A team ("Métrologie de l'espace, Astrodynamique, Astrophysique").

The contribution of the Bordeaux group to the IVS has been mostly concerned with the maintenance, extension, and improvement of 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 reference frame.

In addition, the group is in charge of the VLBI component in the multi-technique GINS software package [1] as part of a collaborative effort within the French "Groupe de Recherches de Géodésie Spatiale" (GRGS) to combine VLBI and space geodetic data (SLR, GPS, and DORIS) at the observation level. This effort also involves space geodesy groups in Toulouse, Grasse, and Paris.

2. Description of the Analysis Center

The Bordeaux IVS group routinely analyzes the weekly IVS-R1 and IVS-R4 sessions with the GINS software package. During the past year, weekly normal equations for all such sessions in 2012 (with six-hour EOP resolution) have been produced and integrated into the multi-technique solutions derived by the GRGS within the framework of the "Combination at the Observation Level" (COL) Working Group. The CONT08 and CONT11 sessions were also analyzed in the same way.

The group is also focused on imaging the ICRF sources on a regular basis by systematic analysis of the data from the RDV sessions, which are conducted six times a year. This analysis is carried out with the AIPS and DIFMAP software packages. The aim of such regular imaging is to characterize the astrometric suitability of the sources based on the so-called "structure index", and to compare source structural evolution and positional instabilities. Such studies are essential for identifying sources of high astrometric quality, which is required, for example, for the future Gaia link.

3. Scientific Staff

During the past year, the group was strengthened by the arrival of a Ph. D. student, Romuald Bouffet. In all, six individuals contributed to IVS analysis and research activities during 2012. A description of what each person worked on, along with the time spent on it, is given below.

- Patrick Charlot (20%): overall responsibility for Analysis Center work and data processing. His research interests include the ICRF densification, extension, and link to the Gaia frame, studies of source structure effects in astrometric VLBI data, and astrophysical interpretation.
- Antoine Bellanger (80%): engineer with background in statistics and computer science. His tasks are to process VLBI data with GINS and to develop procedures and analysis tools to automate such processing. He is also the Web master for the M2A group.
- Romuald Bouffet (30%): Ph. D. student from University of Bordeaux whose thesis is focused on the study of the relationship between radio source structure and position instabilities. To this end, he uses astrometric data and VLBI images produced from IVS sessions.
- Géraldine Bourda (50%): astronomer in charge of developing the VLBI part of GINS and responsible for the analysis results derived from GINS. She also leads a VLBI observational program for linking the ICRF and the future Gaia frame.
- Arnaud Collioud (100%): engineer with background in astronomy and interferometry. His tasks are to image the sources in the RDV sessions using AIPS and DIFMAP, to develop the Bordeaux VLBI Image Database and the *IVS Live* tool, and to conduct VLBI2010 simulations.
- Alain Baudry (10%): radioastronomy expert with specific interest in radio source imaging and astrometric VLBI. Professor Emeritus and under a part-time ESO contract.

4. Analysis and Research Activities during 2012

As noted above, a major activity of the Bordeaux group consists of imaging the sources observed during the RDV sessions on a systematic basis. During 2012, two such sessions were processed (RDV86 and RDV88), resulting in 333 VLBI images at either X or S band for 159 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]. At present, the BVID comprises a total of 3517 VLBI images for 1110 different sources (with links to an additional 7851 VLBI images from the Radio Reference Frame Image Database of USNO at either S, X, K, or Q band) along with 11,368 structure correction maps and as many visibility maps.

In the past year, a collaboration was established with the Paris Observatory Analysis Center in order to look for correlation between astrometric instabilities and source structural variations. The study is focused on a sample of 68 sources with VLBI images available at 20 epochs or more over the

[1]The BVID may be accessed at http://www.obs.u-bordeaux1.fr/BVID

period 1994–2003. The astrometric data consists of all IVS sessions conducted over the same period, analyzed in a way that provides source positions on a monthly basis. A comparison of the time series of source positions with the relative motion of the brightness centroid (as derived from the available VLBI images) indicates similar trends in the evolution of the astrometric and brightness centroid positions. Based on this initial comparison, and awaiting quantitative assessment, an explanation of VLBI source position instabilities in terms of structural variations is thus favored [4].

Additionally, the work to identify and characterize appropriate radio sources to align the ICRF and the future Gaia optical frame was pursued. On the observational side, a total of 119 optically-bright radio sources with high astrometric quality was observed with the combined Very Long Baseline Array (VLBA) and European VLBI Network (EVN) during a dedicated 72-hour astrometric VLBI session conducted in May 2012. These sources were selected from an initial sample of 395 optically-bright weak radio sources, further reduced to 119 sources after assessing their VLBI detectability and astrometric suitability (see [5] for details of the project). Data from this session are being correlated. In parallel to this observational work, all ICRF2 sources (excluding those observed only as part of the VLBA Calibrator Survey) were assessed in terms of optical magnitude and astrometric suitability. This led to the identification of an additional 195 transfer sources, making altogether a total of 314 such sources available for the Gaia link. As a further step, a proposal was submitted to IVS to monitor the position stability and structure of the 195 ICRF2 transfer sources, some of which also require improvement in position accuracy.

5. Dissemination and Outreach

The highlight from the past year was the organization of the 11th EVN symposium by the Bordeaux VLBI group. The purpose of the symposium was to share and publicize the latest scientific results and technical developments from VLBI, space VLBI, and e-VLBI. The symposium took place in Bordeaux from the 9^{th} to the 12^{th} of October and was attended by a total of 122 participants from 47 institutes in 19 countries worldwide. The program of the meeting consisted of 71 oral presentations and 43 posters. Of particular interest to the IVS community was the session entitled "Astrometry and planetary science". The program also comprised an EVN Users Meeting to foster interaction between the EVN users and the EVN organization. Further details may be found at the symposium Web page available at http://evn2012.obs.u-bordeaux1.fr/.

The *IVS Live* Web site [6], dedicated to monitoring IVS sessions and viewing VLBI images of the observed sources, was updated on a regular basis during 2012. It now includes 5302 IVS sessions and more than 1600 sources. The Web site was also enhanced with a few features, including the addition of a "webcams" page. Monitoring of the connections indicates that there were more than 800 visits from around the world (47 countries) during 2012, 70% of which originate from different individuals. On the other hand, the Bordeaux VLBI Image Database was accessed from 39 countries, with more than 900 connections, half of which are from different individuals.

6. Outlook

Our plans for the coming year are focused on moving towards operational analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package. Imaging of the RDV sessions and evaluation of the astrometric suitability of the sources will continue along the same lines. On the observational side, the immediate plan will be to analyze the astrometric data that we acquired about the 119 Gaia transfer sources identified from our program (see Section 4), after correlation. Following our proposal, we also expect the IVS to strengthen observations for the 195 ICRF2 transfer sources identified so far, especially after the launch of the Gaia satellite in Fall 2013. To complete such identification, we would like to characterize the optical magnitude and astrometric suitability of the VLBA Calibrator Survey sources as well. Finally, we expect to contribute to the work towards the next realization of the ICRF because two of us were appointed to the Working Group in charge of this task at the last IAU General Assembly in August 2012.

Acknowledgements

We would like to thank the "Observatoire Aquitain des Sciences de l'Univers" (OASU) for supporting IVS activities in Bordeaux.

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BKG/DGFI Combination Center Annual Report 2012

Sabine Bachmann, Michael Lösler, Robert Heinkelmann, Michael Gerstl

Abstract

This report summarizes the activities of the BKG/DGFI Combination Center in 2012 and outlines the planned activities for the year 2013. The main focus was the stabilization of outlier detection and the update of the Web presentation of the combined products.

1. General Information

The BKG/DGFI 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, DGFI). The participating institutions, as well as the tasks and the structure of the IVS Combination Center, have been described in [5]. The tasks comprise quality control and a timely combination of the session-based intermediate results of the IVS Analysis Centers into a final combination product (e.g., Earth Orientation Parameters (EOP)). In coordination 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 activities. These tasks are performed on an operational basis.

2. Component Description

The BKG/DGFI Combination Center performs a combination of session-based results of the IVS Analysis Centers on an operational basis. The strategy for the combination is based on the combination of normal equations and has been adopted from the combination process developed and performed by the IVS Analysis Coordinator (cf. [3], [4]).

At BKG the following tasks are performed:

- Ensuring quality control of the Analysis Center results: checking the format of the results and their suitability for combination, performing identification and reduction of outliers, comparing the Analysis Centers' results with each other, and comparing the results w.r.t. external time series, e.g. from IERS or IGS.
- Providing feedback to the Analysis Centers: quality control results are available at the BKG IVS Combination Center Web page [7].
- Creating high quality combination products and performing timely archiving and distribution: combination products will be created by using the combination part DOGS-CS of DGFI's software package DOGS [6].
- Submitting 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., EOP rapid products and the EOP series IERS C04). Additionally, IVS product series are provided for ITRF computation (see next item). This work is also supported by the staff of the IERS Central Bureau hosted by BKG.

- Generating official IVS input to the ITRF: the time series of the combined session products (from 1984 to present) is submitted for ITRF computation in the form of normal equations in SINEX format.
- Archiving Results: Final results are archived in the BKG Data Center and mirrored to the IVS Data Centers at OPAR and CDDIS. This work is assisted by the staff of the BKG Data Center in Leipzig.

DGFI is in charge of the following Combination Center functions:

- DGFI is developing state-of-the-art combination procedures. This work, as well as the following item, is also related to the ITRS Combination Center at DGFI and DGFI's efforts within the IERS WG on the Combination on 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.
- DGFI generates the operational IVS troposphere combination products, analyzes the individual AC contributions and gives feedback to the IVS AC, and publishes the results on the Web page http://www.dgfi.badw.de/index.php?id=395. DGFI provides rapid as well as long-term series of combined tropospheric products.

3. Staff

The list of the staff members of the BKG/DGFI Combination Center in 2012 is given in Table 1.

Table 1. Staff members of the BKG/DGFI Combination Center.

Name	Affiliation	Function	E-Mail
Michael Gerstl	DGFI	Software maintenance	gerstl@dgfi.badw.de
Robert Heinkelmann*	DGFI	Combination strategies	heinkelmann@dgfi.badw.de
Sabine Bachmann	BKG	Combination	sabine.bachmann@bkg.bund.de
Michael Lösler	BKG	Hardware/Web site maintenance	michael.loesler@bkg.bund.de

* Robert Heinkelmann left DGFI at the end of October 2012 and moved to GFZ Potsdam, Germany.

4. Current Status and Activities

The combination of the IVS Rapid EOP series (R1 and R4 sessions), which started in 2009 at BKG, has been continued routinely in 2012. In 2012, six IVS Analysis Centers (BKG, DGFI, GSFC, IAA, OPA, and USNO) contributed to the IVS combined product (see [4]). Potential new

ACs are AUS, CGS, NMA, and TUW (see also Section 5). The rapid solutions contain only R1 and R4 sessions, and new data points are added twice a week as soon as the SINEX files of at least four IVS Analysis Centers are available. Long-term series are generated quarterly and include every 24-hour session since 1984. The quarterly series include long-term EOP series, station positions, and velocities. Furthermore, a VLBI TRF is generated and published. The preprocessing to read and write source positions has been implemented, and the software has been extended to process source parameters. The results of the combination process are archived by the BKG Data Center in Leipzig. The combined rapid EOP series, as well as the results of the quality control of the Analysis Center results, are also available directly at the BKG/DGFI Combination Center Web page [7] or via the IVS Analysis Coordinator Web site. The inclusion of new Analysis Centers has continued, a newly designed Web page has been brought on line and the Web-based analysis tools have been enhanced.

5. Plans for 2013

In 2013 the work of the BKG/DGFI Combination Center will focus on the following:

- Including new Analysis Center solutions: one based on the GEOSAT software and provided by Halfdan Pascal Kierulf from the Geodetic Institute, Norwegian Mapping Authority (NMA), Hønefoss, Norway; another one based on the OCCAM software and provided by Oleg Titov from Geoscience Australia (AUS), Canberra, Australia; and a third one based on VieVS (Vienna VLBI Software) provided by the Vienna VLBI Group from the Vienna University of Technology, Austria (TUW).
- Investigation into combination of source coordinates and set up of extended analysis and combination routines (e.g., the generation of the necessary datum conditions).
- Extending the Web-based data analysis feature on the IVS Combination Center Web pages ([7]).
- Providing more products and information resulting from the combination process.

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DOGS_CS software manual (German version only).

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BKG Combination Center Web page.

Matera CGS VLBI Analysis Center

Roberto Lanotte

Abstract

This paper reports the VLBI data analysis activities at the Space Geodesy Center (CGS), Matera, from January 2012 through December 2012, and the contributions that the CGS intends to provide for the future as an IVS Analysis Center.

1. General Information

The Matera VLBI station became operational at the Space Geodesy Center (CGS) of the Italian Space Agency (ASI) in May 1990. Since then, it has been active in the framework of the most important international programs. The CGS, operated by e-geos (a Telespazio/ASI company) on behalf of ASI, provides full scientific and operational support using the main space geodetic techniques: VLBI, SLR, and GPS.

2. 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.

3. Current Status and Activities

3.1. Global VLBI Solution cgs2010a

The main VLBI data analysis activities at the CGS in the year 2012 were directed towards the realization of a global VLBI solution, named cgs2010a, using the CALC/SOLVE software developed at GSFC. The solution activities started at the end of 2011, and they ended in March 2012, when the solution sections (crf, trf, and eop) were published in the IVS archives. The final characteristics of this solution are:

- Data span:
  1980.04.11 - 2011.12.29 (3594 sessions).
- Estimated Parameters:
  - Celestial Frame:
    Right ascension and declination as global parameters for 845 sources.
  - Terrestrial Frame:
    Coordinates and velocities for 81 stations as global parameters.
  - Earth Orientation:
    Unconstrained X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dpsi, and deps.

3.2. IVS Tropospheric Products

Regular submission of tropospheric parameters (wet and total zenith path delays, and east and north horizontal gradients) for all VLBI stations observing in the IVS R1 and R4 sessions continued during 2012. Currently, 1161 sessions have been analyzed and submitted, covering the period from 2002 to 2012. The results are available at the IVS products ftp site.

3.3. IVS Product "Time Series of Baseline Lengths"

Regular submission of station coordinate estimates, in SINEX files, continued during 2012 for the IVS product "Time Series of Baseline Lengths". This is composed of 3833 sessions, from 1979 to 2012.

3.4. CGS Contribution to IERS EOP Operational Series

Since 2008, CGS has been delivering IERS R1 and R4 session EOP estimates as a regular contribution to the IERS EOP operational series. The whole cgs2007a solution, available when the contribution started, has been delivered to IERS as a reference series updated by periodic EOP solution submissions.

4. Future Plans

- Continue to improve the realization of our global VLBI solution, providing its regular update on time.
- Continue to participate in IVS analysis projects, providing datum-free normal equations.

DGFI Analysis Center Annual Report 2012

Robert Heinkelmann, Manuela Seitz, Julian Andres Mora-Diaz, Mathis Bloßfeld, Michael Gerstl, Ralf Schmid

Abstract

This report summarizes the activities of the DGFI Analysis Center in 2012 and outlines the planned activities for 2013.

1. General Information and Component Description

The German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, DGFI) is an independent research institute hosted at the Bavarian Academy of Sciences and Humanities (BAdW) in Munich, Germany. It is directly funded by the Free State of Bavaria. The research covers all fields of geodesy and includes participation in national and international projects and working groups, as well as functions in international bodies (http://dgfi.badw.de). The Institut für Astronomische und Physikalische Geodäsie (IAPG) and the Forschungseinrichtung Satellitengeodäsie (FESG)(including FESG personnel at the Geodetic Observatory Wettzell), the geodetic part of the Commission for Geodesy and Glaciology (KEG), and the DGFI of the German Geodetic Commission cooperate within the Center of Geodetic Earth System Research[1] (CGE). IAPG and FESG are a part of Technische Universität München (TUM). KEG is a commission of BAdW, and DGFI is located at BAdW. CGE's main goal is the research of global change through the measurement of changes in the solid Earth, oceans, cryosphere, and atmosphere, as well as the analysis of changes with regard to the triggering physical processes. DGFI has been active as an Analysis Center (AC) of IVS since its foundation in 1999. For several years DGFI has been a reliable operational AC.

2. Staff

The DGFI IVS AC[2] is run by Robert Heinkelmann and Manuela Seitz. Julian Andres Mora-Diaz is working in a project for the establishment of space geodetic analysis software in Chile sponsored by the International Bureau of the Federal Ministry of Education and Research. In 2012, Mathis Bloßfeld started a promising and very interesting scientific comparison of the quality of various IVS networks and Michael Gerstl worked on the software developments and numerical optimizations of our VLBI analysis software DOGS-RI, which is about to be finished soon. Ralf Schmid (Figure 1) joined our VLBI group in July 2012. With his thorough background in space geodesy and his experience in GNSS and VLBI analysis and software development, Ralf is a great gain for DGFI's VLBI group. We are happy to have him on board. Robert Heinkelmann left DGFI to become the head of the VLBI group at GFZ, Potsdam. Manuela Seitz has been appointed as a member of the new IAU Division A Working Group on the 'Third Realization of the International Celestial Reference Frame'.

[1] http://dgfi.badw.de/index.php?id=323&L=0
[2] http://dgfi.badw.de/index.php?id=126&L=0

Figure 1. Our new colleague: Dr. Ralf Schmid.

3. Current Status and Activities

- IVS Operational Analysis Center at DGFI

  During 2012, we analyzed 404 sessions. Among them 265 were Intensive (IN112, IN212, and IN312), and 139 were regular observing sessions (73 IVS-R1 sessions, 52 IVS-R4 sessions, 10 astrometric type sessions, e.g. IVS-CRF, IVS-CRDS, etc., and four geodetic type sessions, e.g. IVS-T2). Several new telescopes became operational in 2012, and needed to be included in the software and catalog files. We thank the IVS colleagues, who provided initial a priori coordinates. For the operational analysis and for the preparation of normal equations in SINEX format OCCAM and DOGS-CS are used. CS is the module of the DGFI Orbit and Geodetic Parameter Estimation Software (DOGS) [1] for the handling and solution of normal equation systems. The entire process runs on DGFI-owned hardware.

- Rearrangement of the VLBI software used at DGFI

  The VLBI analysis software used at DGFI is currently being revised and will be a part of DOGS, named DOGS-RI (Radio Interferometry). In 2012, the inclusion of IERS 2010 conventional models was completed. In contrast to OCCAM, the theoretical VLBI model of DOGS-RI will directly refer to the Geocentric Celestial Reference System (GCRS) without application of the pole coordinates.

- Consistent computation of ITRF and ICRF from homogeneously processed observation data

  The main goal is the investigation of the effect of the combination of station coordinates and EOP of the space geodetic techniques (VLBI, GNSS, SLR) on the Celestial Reference Frame (CRF) [2]. In particular the combination of the ERP (terrestrial pole and LOD) has an impact on the CRF. The sources affected most are the sources observed by VLBA Calibrator Survey (VCS) sessions only. A systematic effect was found in right ascension for some of the VCS sources with declinations between -40° and $+30^\circ$ (see Figure 2). This work will be related to the new IAU Division A Working Group on the 'Third Realization of the International Celestial Reference Frame,' but it is on the IUGG agenda (Resolution 3 adopted in 2011) as well.

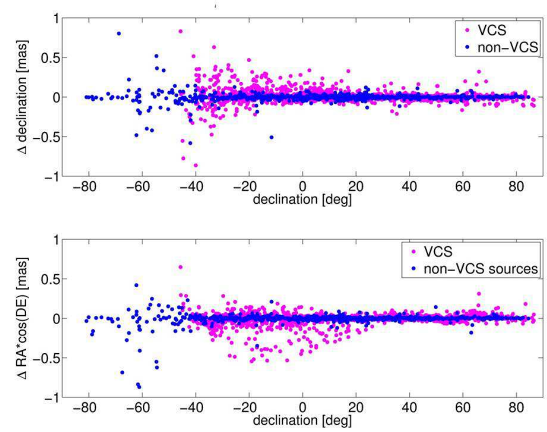

Figure 2. Position differences of radio sources of a TRF-CRF solution w.r.t. a VLBI-only CRF: (top) declination (DE), (bottom) right ascension (RA).

- The role of VLBI in the weekly inter-technique combination

  In the case of the standard ITRF computation, VLBI and SLR observations are used for the realization of the scale, and VLBI is the only technique which provides the full set of transformation parameters (terrestrial pole, UT1-UTC, celestial pole) necessary for transformations between the ITRS and the GCRS. Current terrestrial reference frames approximate the station coordinates by a position and a constant velocity after the well-known geophysical effects, e.g. tidal variations, have been reduced directly at the observation level. Other non-linear motions such as deformations caused by oceanic, atmospheric, and hydrologic mass loading deformations are still not sufficiently modeled and are thus not reduced at the observation level. This leads to larger observation residuals and introduces systematics, mainly seasonal signals, into the estimated parameters of the reference frame, e.g. if observations do not cover a complete season or are not evenly distributed within the seasonal cycle. In particular, this is the case for stations with short observation time spans. Besides the station coordinates, the neglected motions affect epoch-wise parameters as well, e.g. the EOP. To overcome this problem, reference frames can be based on much shorter time spans, e.g. by computing weekly reference frames. This approach is called epoch reference frame. In this case, non-linear station motions are approximated very well and, consequently, the EOP are not affected. An additional advantage of epoch reference frames is the significantly better timeliness after an episodic motion (earthquake or other seismic event, antenna repair, etc.), provided that the stations are still operating and a recent local tie measurement is available. Challenges within the epoch reference frame computation are the low average number of VLBI observations per week. The limited number of local tie measurements is a general problem for terrestrial reference frame determination; epoch reference frames are affected by the local ties even more. One week is practically the minimum supporting time base. Further studies will follow based on slightly longer time spans, e.g. two or four weeks. Based on those intervals we expect a significant increase in the stability of the solution but, of course, at the expense of a slightly worse approximation. The optimum interval length needs to be assessed. Probably it will comprise a trade-off between the stability and the quality of the approximation. Here, we investigate a sequence of epoch reference frames, all of which are determined by a combination of VLBI, GNSS, and SLR normal equations on a weekly basis [3]. For each VLBI session, the relative weighting of the techniques is achieved by estimating variance components (VC). Figure 3 shows the estimated VC for different types of IVS sessions between the beginning of 2000 and the end of 2006. The VC of the IVS-R1 sessions show a significant seasonal variation. The reasons for this seasonal variation are not completely understood.

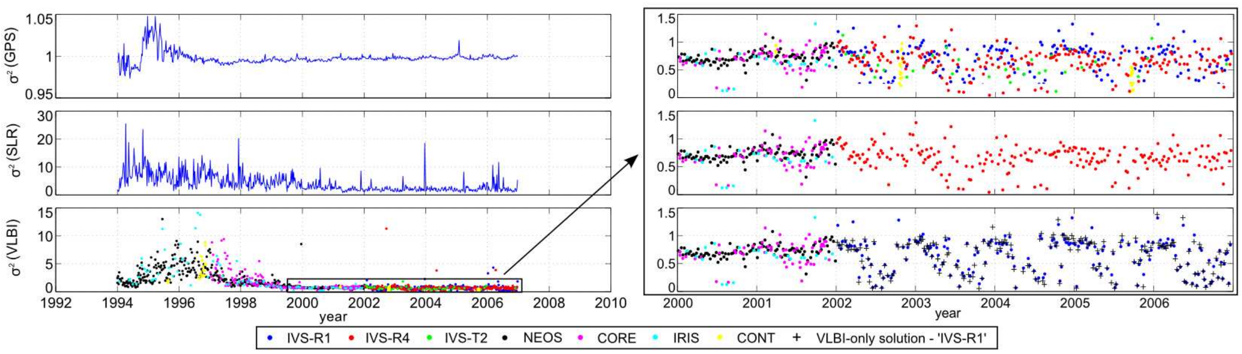

Figure 3. Left: posterior VCs of the techniques GPS (top), SLR (middle), and VLBI (bottom). In the case of VLBI, one VC per session is estimated. Right: zoom of the VLBI plot for 2000.0–2007.0. All VLBI sessions are shown for 2000 and 2001. Data shown for 2002.0–2007.0: all VLBI sessions (top), IVS-R4 sessions only (middle), and IVS-R1 sessions only (bottom). In addition, the lower right plot contains the posterior VCs of the VLBI-only solutions for the IVS-R1 sessions for comparison.

4. Future Plans

At the DGFI AC we will continue our operational contributions to IVS, but with our new VLBI analysis software DOGS-RI. After extensive comparisons we will switch to DOGS-RI, and the maintenance of OCCAM will cease. Investigations into the gain of CRF through an inter-technique combination and the quality of different types of IVS sessions will go on as well.

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GFZ Analysis Center

Robert Heinkelmann, Maria Karbon, Tobias Nilsson, Virginia Raposo, Harald Schuh

Abstract

This report briefly provides general information and a component description of the recently established IVS Analysis Center at GFZ and outlines the planned activities.

1. General Information and Component Description

Helmholtz Centre Potsdam, GFZ German Research Center for Geosciences, is the national research center for Earth Sciences in Germany. The main tasks of GFZ according to its Web site (www.gfz-potsdam.de) are:

> *We investigate System Earth at locations all over the world with all the geological, physical, chemical and biological processes which occur at its surface and in its interior. The goal of our interdisciplinary research is to understand these processes on all scales of time and space, whether they occur at the level of atoms and molecules or galaxies, and independently of whether they take place faster than [...] nanoseconds or if they happen infinitely slowly over billions of years. We not only investigate the processes within the planet itself, but also study the multitude of interactions between solid earth, the atmosphere, the hydrosphere and the inhabited world. We also analyse how man, living at the Earth's surface, affects our planet. In sum, our research deals with the entire 'Earth System' including the influence of mankind.*

At this research facility within Department 1 'Geodesy and remote sensing' and its Section 1.1 'GPS/GALILEO Earth observation' a new VLBI group was established in November 2012.

2. Staff

At the GFZ IVS AC the operational work is done by Robert Heinkelmann and Tobias Nilsson. In addition, Maria Karbon works in a project about the application of Kalman filter to VLBI analysis, and Virginia Raposo works on the ICRF and related systematic effects. Harald Schuh is managing our group, and, as long as his schedule allows, he is still very active for the IVS. A photo of our group is shown in Figure 1.

3. Future Plans

- IVS Associate Analysis Center at GFZ

  At GFZ we will use VieVS for VLBI data analysis starting at DB version 4 or a higher level. We will develop VieVS together with the IVS Analysis Center at the Department of Geodesy and Geoinformation, Vienna University of Technology.

- Space applications

  Our scientific work will focus on VLBI applications in space, on space navigation by differential VLBI, and on co-location in space of the various space geodetic techniques (VLBI, GNSS, SLR, and DORIS).

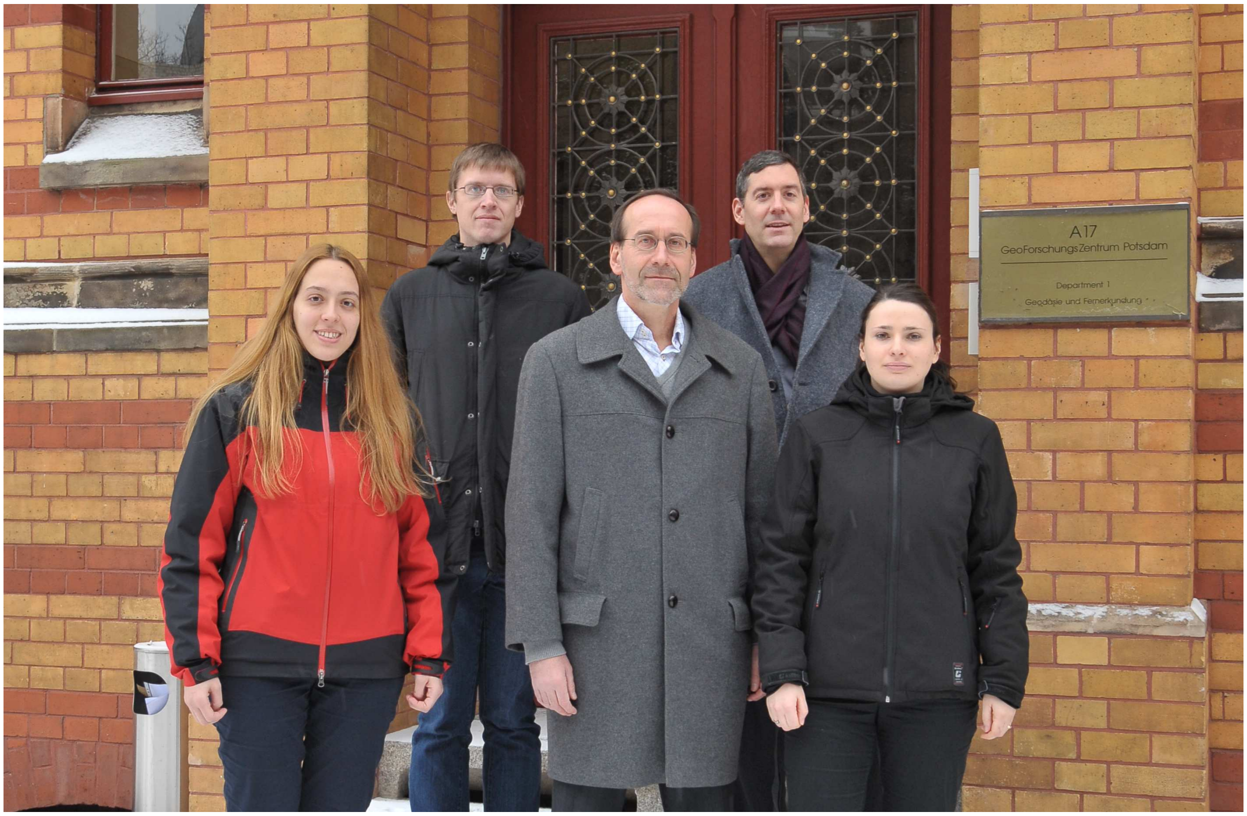

Figure 1. The GFZ VLBI group in January 2013.

- Kalman filtering for VLBI analysis with VieVS

  We will implement a Kalman filter solution in VieVS. It will be optimized in order to be able to analyze VLBI data in near real-time, and it will also allow for inclusion of data from other sensors, such as water vapor radiometers.

- Rapid troposphere combined product

  It is planned to take over the rapid troposphere combination from DGFI (Deutsches Geodätisches Forschungsinstitut) at GFZ.

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The BKG/IGGB VLBI Analysis Center

Volkmar Thorandt, Axel Nothnagel, Gerald Engelhardt, Dieter Ullrich, Thomas Artz, Judith Leek

Abstract

In 2012, the activities of the BKG/IGGB VLBI Analysis Center, as in previous years, consisted of routine computations of Earth orientation parameter (EOP) time series and of a number of research topics in geodetic VLBI. 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. Quarterly updated solutions have been computed to produce terrestrial reference frame (TRF) and celestial reference frame (CRF) realizations. Routine computations of the UT1–UTC Intensive observations include all sessions of the Kokee–Wettzell and Tsukuba–Wettzell baselines and the networks Kokee–Svetloe–Wettzell and Ny-Ålesund–Tsukuba–Wettzell. The VLBI group at BKG developed a procedure to get the most probable station positions of Tsukuba after the earthquake on March 11, 2011 for the epochs of the Intensive sessions. The analysis of the Intensive sessions with station Tsukuba could be resumed in February 2012. At IGGB, the emphasis has been placed on individual research topics.

1. General Information

The BKG/IGGB VLBI Analysis Center has been established jointly by the analysis groups of the Federal Agency for Cartography and Geodesy (BKG), Leipzig, and the Institute of Geodesy and Geoinformation of the University of Bonn (IGGB). Both institutions cooperate intensely in the field of geodetic VLBI. The responsibilities include both data analysis for generating IVS products and special investigations with the goal of increasing accuracy and reliability. BKG 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 group is also responsible for writing schedules for the Tsukuba-Wettzell Int2 UT1-UTC observing sessions. IGGB continues to host the office of the IVS Analysis Coordinator and carries out special investigations within the technique of geodetic and astrometric VLBI. Details of the research topics of IGGB are listed in Section 3.

2. Data Analysis at BKG

At BKG, the Mark 5 VLBI data analysis software system Calc/Solve, release 2010.05.21 [1], has been used for VLBI data processing. It is running on a Linux operating system. As in the previous releases, the Vienna Mapping Function (VMF1) has been implemented in a separate Solve version. This modified version was used for all data analysis. The VMF1 data were downloaded daily from the server of the Vienna University of Technology. Additionally, the technological software environment for Calc/Solve has been refined to link the Data Center management with the pre- and post-interactive parts of the EOP series production and to monitor all Analysis and Data Center activities.

- **Processing of correlator output**
  The BKG group continued the generation of calibrated databases for the sessions correlated at

the MPIfR/BKG Astro/Geo Correlator at Bonn (e.g., EURO, OHIG, and T2) and submitted them to the IVS Data Centers.

- **Scheduling**
  BKG continued scheduling the Int2 Intensive sessions, which are observed on the TSUKUBA-WETTZELL baseline. Altogether 86 schedule files for this baseline were created in 2012. Furthermore 30 schedule files for baseline KOKEE-WETTZELL (Int1 Intensive sessions on weekends) were made available in the first half of the year 2012.

- **BKG EOP time series**
  The BKG EOP time series bkg00013 was continued. The main features of this solution were not changed. But three new VLBI stations (HART15M in South Africa, KOGANEI, and UCHINOUR in Japan) could be included successfully in data processing.

  Each time after the preprocessing of any new VLBI session (correlator output database version 1), a new global solution with 24-hour sessions since 1984 was computed, and the EOP time series bkg00013 was extracted. Altogether 4391 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 VTRF2008a and a no-net-rotation condition for 295 defining sources with respect to ICRF2. The station coordinates of the telescopes AIRA (Japan), CHICHI10 (Japan), CTVASTJ (Canada), DSS13 (USA), HOBART12 (Australia), KASHIM34 (Japan), KATH12M (Australia), PT_REYES (USA), SEST (Chile), SINTOTU3 (Japan), TIGO-CONC (Chile), TSUKUB32 (Japan), WIDE85_3 (USA), VERAISGK (Japan), VERAMZSW (Japan), WARK12M (New Zealand), YARRA12M (Australia), and YEBES40M (Spain) were estimated as local parameters in each session. The three new VLBI stations HART15M (South Africa), KOGANEI (Japan), and UCHINOUR (Japan) were modeled in the same way.

- **BKG UT1 Intensive time series**
  Regular analysis of the UT1-UTC Intensive time series bkgint09 was continued. The series bkgint09 was generated with fixed TRF (VTRF2008a) and fixed ICRF2. The a priori EOP were taken from finals USNO series [2]. The estimated parameter types were only UT1-TAI, station clock, and zenith troposphere.

  A semi-automatic process for handling the Intensive sessions (Int2/3) with station TSUKUBA after the Japan earthquake has been developed. Using the latest global solution with 24-hour sessions, including all available sessions with the station TSUKUBA, a particular a priori coordinate file for each TSUKUBA Intensive session is created by interpolating the values of the 24-hours TSUKUBA sessions. These files are used as input for the session by session TSUKUBA Intensive cycle run. Finally, an IVS formatted EOP list is created and mixed with the non-TSUKUBA IVS EOP list. These algorithms are included in the BKG post_solve procedure for establishing the IVS EOP solutions.

  A total of 4048 UT1 Intensive sessions were analyzed for the period from 1999.01.01 to 2012.12.31.

- **Quarterly updated solutions for submission to IVS**
  In 2012, one quarterly updated solution was computed for the IVS products TRF and CRF.

There are no differences in the solution strategy compared to the continuously computed EOP time series bkg00013. The results of the radio source positions were submitted to IVS in IERS format. The TRF solution is available in SINEX format, version 2.1, and includes station coordinates, station velocities, and radio source coordinates together with the covariance matrix, information about constraints, and the decomposed normal matrix and vector.

- **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. The tropospheric parameters were extracted from the standard global solution bkg00013 and transformed into SINEX format.
- **Daily SINEX files**
  The VLBI group of BKG also continued regular submissions of daily SINEX files for all available 24-hour sessions for the IVS combined products and for the IVS time series of baseline lengths. In addition to the global solutions, independent session solutions were computed for the station coordinates, radio source coordinates, and EOP parameters including the X,Y-nutation parameters. The a priori datum for TRF was defined by VTRF2008a, and ICRF2 was used for the a priori CRF information.
- **SINEX files for Intensive sessions**
  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.

3. Research Topics at IGGB

- **Measurements of paraboloid deformations of the Effelsberg 100-m telescope with a laser scanner**
  Variations in the focal length of a radio telescope have a direct effect on the delay observables and on the position estimates. To study this, the paraboloid of the Effelsberg 100-m telescope was scanned with a Leica HDS 6100 terrestrial Laser scanner. The scanner was mounted head-down on an empty prime focus receiver box. Putting the receiver box in place gave the scanner an almost unobstructed view of the main paraboloid. Scans were repeated in various telescope elevation angles down to 7.5° with each data set consisting of 370 million points with three polar components each. This is equivalent to one data point every 64 mm^2. Proprietary software of the instrument's manufacturer was not able to handle this large amount of data; thus, a dedicated C++ program running on a computer cluster was developed. As a first result, the estimated focal length variations agree very well with the empirical model for the sub-reflector displacement corrections. Since the accuracy of the individual distance measurements of the scanner is only a few millimeters at a distance of 50-m, the ultimate insight into the deformations cannot be achieved from individual data points but from a surface fitting procedure to the residuals. Figure 1 shows the smoothed surface of the solid part of the paraboloid at 30° elevation after a best fit paraboloid has been subtracted. In the second and third quadrant, two reflector panels can be identified which had been displaced on purpose by plus and minus 3 mm for a holography survey some time ago, validating the

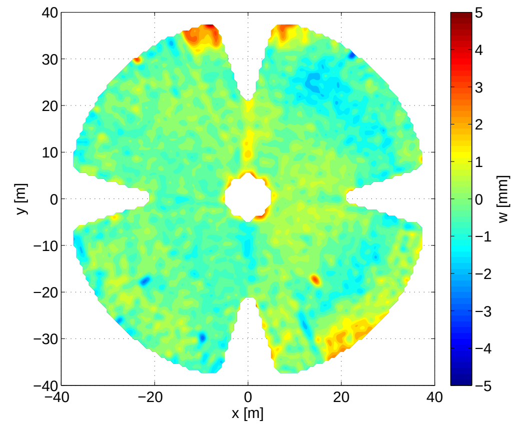

Figure 1. Smoothed surface of the solid part of the paraboloid at 30° elevation after a best fit paraboloid has been subtracted.

correctness of the whole procedure. The second blue spot at the third quadrant persists at other elevation angles as well and must, thus, be a real local deformation.

- **Automatic scheduling based on Singular Value Decomposition**
  The automatic scheduling method which selected the observations successively by means of their impact factors has been developed to create schedules for VLBI Intensive sessions replacing the participating single telescopes by twin telescopes successfully. For assessment reasons, observations related to the created schedules have been simulated. The simulation has been adapted for the special features of twin telescopes. However, the simulation has to be improved some more to reach a well-founded evaluation of twin telescope observations in Intensive sessions.

4. Personnel

Table 1. Personnel at BKG/IGGB Analysis Center.

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GSFC VLBI Analysis Center

David Gordon, Chopo Ma, Dan MacMillan, John Gipson, Sergei Bolotin, Karine Le Bail, Karen Baver

Abstract

This report presents the activities of the GSFC VLBI Analysis Center during 2012. 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 Network Station. The Analysis Center participates in all phases of geodetic and astrometric VLBI analysis, software development, and research. We maintain a Web site at http://lupus.gsfc.nasa.gov. We also provide a pressure loading service to the geodetic community at http://gemini.gsfc.nasa.gov/results/aplo. We now provide additional services described below for hydrology loading, nontidal ocean loading, and meteorological data. These time series can be found by following the links on the GSFC VLBI group Web site: http://lupus.gsfc.nasa.gov/dataresults_main.htm.

2. Activities

2.1. Analysis Activities

The GSFC VLBI Analysis Center analyzes all IVS sessions, using the *Calc/Solve* system, and it performs the fringe fitting and *Calc/Solve* analysis of the VLBA-correlated RDV sessions. The group submits the analyzed databases to IVS for all R1, RDV, R&D, APSG, AUST, CONT11, INT01, and INT03 sessions. During 2012, GSFC analyzed 189 24-hour (54 R1, 55 R4, 15 CONT11, 11 RDV, 9 R&D, 3 AUST, 1 APSG, 5 EURO, 4 T2, 5 OHIG, 7 CRF, 9 CRDS, and 11 JADE) sessions, and 371 one-hour UT1 (244 INT01, 83 INT02, and 44 INT03) sessions, and we submitted updated EOP and daily Sinex files to IVS immediately following analysis. One update was made in 2012 of our 24-hr and Intensive EOP series. Also, as part of the RDV program, we observed 17 requested sources for the astronomical community.

2.2. Research Activities

- Meteorological Data Analysis: Because of the inhomogeneity of the pressures and temperatures in the Mark III databases, we derived a set of meteorological data time series, named G-ECM, from the ERA-Interim reanalysis model of the ECMWF for all VLBI stations. These series are available online (http://lacerta.gsfc.nasa.gov/met) and are updated when new data becomes available from ECMWF. When applied as a replacement for met data in VLBI databases, VLBI solutions are improved. For the R1 and R4 sessions from 2002 to 2011, use of the G-ECM pressures a) reduces baseline length weighted RMS for 55% of the baselines, with an average reduction of 0.06 mm, and b) reduces position weighted RMS for nine out of 19 stations by an average of 0.22 mm, with no conclusive improvement or degradation for eight stations. Using the G-ECM temperatures, a) 47% of the baseline lengths have a reduced weighted RMS and an average reduction of 0.01 mm, b) ten out of 19 stations show reduced weighted RMS position scatter of up to 0.08 mm, with five stations showing no conclusive improvement or degradation, and c) the amplitudes of the annual signal are significantly reduced, by up to 0.27 mm.

- Analysis of LOD Time Series with SSA: In [1], we studied an LOD time series obtained from VLBI measurements and extracted its principal components using Singular Spectrum Analysis (SSA). After removing the long-term trend, which explains 73.8% of the signal, three remaining components explain a further 22.0% of the signal: an annual and a semi-annual signal as well as a second trend. Using the complex demodulation method, we obtained the variations in the amplitudes of the annual and semiannual components. We compared the Multivariate ENSO Index (MEI) with these series and with the second trend obtained by the SSA. The correlations are significant: 0.58 for the annual component, -0.48 for the semi-annual component, and 0.46 for the second trend.
- Nutation Analysis: We focus on the two nutation parameters. We developed nutkal2012.f, a FORTRAN routine that uses the Kalman filter to regularize these irregular time series into a daily time series. The model is defined by a linear trend and specified harmonics, and we included an indicator of the quality of the estimate (goodness of fit). After investigating the various characteristics of the initial time series (Free Core Nutation component, periodic components, level and type of noise), we set up the parameters of the Kalman filter to fit the nutation data [2].
- Source Monitoring: Together with USNO we continued monitoring all ICRF2 defining sources. Our goal is to schedule and observe each geodetic source in at least 12 sessions over the preceding 12 months. In April 2012 the observing target for non-geodetic sources was increased from three to five sessions per year. The R1, R4, and RDV sessions participate in the source monitoring program.
- Intensive Scheduling: We continued to study the Uniform Sky Strategy (USS), the alternative INT01 scheduling strategy proposed and tested in 2009 and 2010 and in use for the INT01s operationally on alternating days since mid-2010. We compared the 2011 USS sessions to the non-USS 2011 sessions, and we found that the USS provided better overall protection against source loss and noise than the original strategy did. The USS also improved the UT1 formal errors at a time of the year (early October) that typically has bad sky coverage and high UT1 formal errors. But during some periods of the year, the USS produced a larger average UT1 formal error than the original strategy, generated higher UT1 formal errors, and provided worse protection against noise. We investigated the effect of schedule characteristics (e.g., the temporal distribution of the observations) on results, as a first step towards refining the USS.
- Astronomical Source Catalog and Source Time Series: A new astronomical source catalog, gsf2012a_astro, was generated. This catalog contains positions of 3708 sources, of which 3589 are X/S sources, 103 are X/GPS-ionosphere sources, and 16 are X-only sources. A new source time series, gsf2012a_ts, was also generated. It contains single session positions of 1563 sources in the ICRF2 time series format. Both files will be updated regularly and are available at http://lupus.gsfc.nasa.gov/dataresults_main.htm.

- VLBA Correlator Support: D. Gordon spent three weeks at NRAO in Socorro, N.M. as a 'resident shared risk observer' (RSRO). While there, he set up a script for automated conversion of DiFX correlator output into Mark IV format, and he modified an existing script to archive the Mark IV files. VLBA observers can now request Mark IV output for further processing with *fourfit* in addition to the normal fits.idi output.
- Non-tidal ocean loading: We computed non-tidal ocean loading series at VLBI sites using ocean bottom pressures from the ECCO model maintained at JPL. At coastal VLBI sites, typical peak-to-peak vertical loading variations are 3-6 mm, and vertical annual amplitudes are 1 mm. When these loading series are applied in VLBI analysis, the baseline length scatter, the site position scatter, and the annual vertical amplitude are reduced at these sites.
- Loading services: We set up hydrology loading (http://lacerta.gsfc.nasa.gov/hydlo/) and non-tidal ocean loading (http://lacerta.gsfc.nasa.gov/oclo/) services at GSFC. Monthly hydrology loading series based on the NASA/GSFC GLDAS hydrology model are available with a latency of about 1.5 months for 170 VLBI stations as well as for a 1x1 degree gridded map with loading series for each lattice point. Non-tidal ocean loading series derived from the JPL ECCO ocean model are available with a latency of about two months for 170 VLBI stations with 12-hour resolution.
- Tsukuba postseismic motion: To compute an a priori position for TSUKUB32 in analysis, we set up a Tsukuba position service that provides a post-earthquake nonlinear correction series based on GPS position data generated by JPL. The series is updated every day with the latest GPS data with a latency of 8-14 days depending on the day of the week and when GPS final orbits were available for the JPL solution. The service location is ftp://gemini.gsfc.nasa.gov/pub/misc/dsm/tsukuba/.

2.3. Software Development

The GSFC VLBI Analysis Center develops and maintains the *Calc/Solve* analysis system, a package of approximately 120 programs and 1.2 million lines of code. Work began on Calc 11 for compliance with the IERS 2010 Conventions and will be finished in 2013.

We continued developing and refining the new "openDB" data format to store VLBI data. We modified *Solve* to use the openDB format instead of superfiles, and we reproduced our 2011a (and other) solutions in the new format. Large solutions using most of the VLBI data take about the same amount of time using the openDB format or superfiles. In timing tests with larger data sets, such as the CONT11s, *Solve* runs about twice as fast using the openDB format. In addition, we wrote several utilities which produce, use, and modify the openDB format. We also began work on *openDBmake*, a partial replacement for *dbedit*, to make "version 1" openDB sessions from *fourfit* fringe files. We also began work on *openDB96*, a plug-compatible replacement library for the *dbase96* library. The goal is to allow programs which use the Mark III database handler to use openDB files with no or minimal changes to the code.

Developing the new VLBI data analysis software νSolve has reached its final stage. After thorough comparisons of SOLVE and νSolve, we started using νSolve in our routine data processing of Intensive and IVS-R4 sessions. Currently we are focused on the implementation of openDB in all parts of CALC/SOLVE. νSolve can now import and analyze a VLBI session in openDB format.

3. Staff

During 2012, the Analysis Center staff consisted of one GSFC civil servant, Dr. Chopo Ma, six NVI, Inc. employees who work under contract to GSFC, and four half-year student interns from Chalmers University of Technology (Sweden). Dr. Ma oversees the GSFC VLBI project for GSFC, and he is also the IVS co-representative to the IERS and the current chair of the IERS Directing Board. Dr. John Gipson is the GSFC VLBI Project Manager and also the chair of IVS Working Group 4 on VLBI Data Structures. Table 1 lists the staff members and their main areas of activity.

Table 1. Staff members and their main areas of activity.

Ms. Karen Baver	Intensive analysis, monitoring, and improvement; software development; Web site development; quarterly nuvel updates.
Dr. Sergei Bolotin	Database analysis, ν*Solve* development.
Dr. John Gipson	Source monitoring, high frequency EOP, parameter estimation, new data structure, station dependent noise.
Dr. David Gordon	Database analysis, RDV analysis, ICRF2 and astronomical catalogs, K/Q reference frame, *Calc* development, quarterly ITRF updates.
Dr. Karine Le Bail	Time series statistical analysis (EOP, nutation, source positions), database meteorological data analysis.
Dr. Chopo Ma	ICRF2, CRF/TRF/EOP, K/Q reference frame.
Dr. Daniel MacMillan	CRF/TRF/EOP, mass loading, antenna deformation, VLBI2010 and SGP simulations, VLBI/SLR/GPS combinations.
Mr. David Eriksson	Mass loading, troposphere raytracing (through June).
Ms. Johanna Juhl	Meteorological data analysis, troposphere ray tracing (through June).
Ms. Julia Ringsby	openDB development (starting in June).
Mr. Ronny Videkull	openDB development (starting in June).

4. Future Plans

Plans for the next year include ICRF2 maintenance, astronomical catalog expansion in preparation for ICRF3, participation in VLBI2010 development, continued development of ν*Solve* and the new “openDB” data format, upgrade of program *Calc* for the IERS 2010 Conventions, and further research aimed at improving the VLBI technique.

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Haystack Analysis Center

Arthur Niell, Roger Cappallo, Brian Corey, Mike Titus

Abstract

Analysis activities at Haystack Observatory are directed towards improving the accuracy of geodetic measurements, whether these are from VLBI, GNSS, SLR, or any other technique. Those analysis activities that are related to technology development are reported elsewhere in this volume. In this report, a preliminary analysis of the first geodetic sessions with the new broadband geodetic VLBI system is reported.

1. Introduction

The broadband instrumentation for the next generation geodetic VLBI system, previously called VLBI2010 but now referred to as VGOS (for VLBI2010 Geodetic Observing System), has been implemented on a new 12-m antenna at the Goddard Space Flight Center near Washington, D.C., and on the Westford 18-m antenna at Haystack Observatory near Boston, Massachusetts, USA. In October 2012, the first two serious geodetic observing sessions were conducted using the broadband system.

The new features for the VGOS system are:

- four bands of 512 MHz each, rather than the two (S and X) for the Mark IV systems
- dual linear polarization in all bands
- more than 30 scans per hour due to the short scans and relatively high slew rates of the smaller antennas proposed for VGOS systems
- multitone phase cal delay for every channel in both polarizations
- group delay estimation from the full spanned bandwidth (~2.2 GHz to potentially 14 GHz)
- simultaneous estimation of the group delay and the ionosphere TEC difference between sites, using the phases across all four bands

The features indicated in the last three bullets have required changes in analysis of the geodetic delays, and these have been implemented in the post-correlation fringe-detection software *fourfit*.

2. Observations

For these two sessions the frequency range spanned by the four bands was limited by the hardware capability at the time of the observations. The lower band edges for the lowest and highest bands were chosen to be 3200 MHz and 9344 MHz. A simulation by Bill Petrachenko found that the best frequencies for the other two bands were 5248 MHz and 6272 MHz.

While the goal for the VLBI2010 systems is to reduce the scan length to the minimum in order to obtain the greatest temporal density of scans, for these sessions the minimum scan length was chosen to be 30 seconds to ensure high SNR. This was necessary because of uncertainty in the measured sensitivity of the antennas and in the scaling factors used for the SEFDs in *sked*. These considerations resulted in an observation rate of approximately 33 scans per hour, about double the usual IVS R1 schedule.

A problem that was not anticipated until observations were first made with the MV3 proof-of-concept system at GGAO is the strong impact of the SLR aircraft avoidance radar on the VLBI system. The radar signal, at about 9.3 GHz, is strong enough to damage the VLBI front end. It is now known that the VLBI antenna must avoid pointing too close to the radar when the SLR system is tracking. This means that a cone of the sky with an opening angle of about 40 degrees must be excluded.

The two six-hour sessions were scheduled for October 4 and 5, 2012. On the first day the SLR systems at GGAO did not observe, so the radar was off and a mask on the sky available to the VLBI observations was not required. On the second day the SLR system was observing, the radar was on, and the VLBI schedule avoided the danger zone. The same number of observations was obtained on the two days, but there is a decrease in geometric strength on the second day along the direction to the SLR system (azimuth 195°) because of the loss of scheduled observations in that direction.

Each of the four bands was sampled and formatted in an RDBE-H digital backend running FPGA code version 1.4 which produced eight 32 MHz channels in each polarization. The output from each RDBE was recorded on a Mark 5C.

Phase calibration pulses were injected between the feed and the low noise amplifier to produce tones every 5 MHz in the spectrum.

3. Correlation and Observable Extraction (Fourfit)

The data were correlated on the DiFX software correlator at Haystack Observatory. A separate correlation pass was required for each band, although both the polarization parallel-hands and cross-hands of a scan were correlated at the same time. For each scan fourfit was used to obtain a coherent fit to all phase and amplitude observables for all one-second accumulation periods in the scan.

The instrumental delay from the pulse cal injection point to the digitization point was corrected within *fourfit* for each channel using all of the phase cal phases in that channel.

The estimation of the coherent amplitude, delay, and TEC difference was achieved using recent improvements in the program *fourfit*. The new processing requires several steps.

The steps are:

a) *fourfit* the H and V polarizations separately for each band to obtain amplitude, delay, phase, and delay rate (eight values of each); b) merge the data from the four bands and two polarizations into one file; c) input an *a priori* station delay from the point of phase cal pulse insertion on the antenna to the digitization point in the control room based on the length of the cable; d) input an *a priori* difference in TECs between the sites; for this session the estimation appears to be insensitive to the value used; more work is needed on how to generate the *a priori* value; e) *fourfit* the merged data for each polarization for one or more strong sources to verify (or adjust) the station delays and to determine the phase and delay offsets among the bands; f) *fourfit* the merged data for all bands and polarizations for a combined amplitude, the coherent delay (called pseudo-I delay because it is analogous to the I Stokes parameter), phase, delay rate, and ΔTEC.

The extracted observables were exported to GSFC, where a database was generated by David Gordon; this required modification of the *dbedit* software in order to bring in the delay with ionosphere (charged particle dispersion) already estimated.

4. Analysis

The geodetic analysis was done using *nuSolve*, a new GUI-based program for editing and parameter estimation that is being developed by Sergei Bolotin of NVI, Inc. *nuSolve* was used because of the potential to model the clocks and atmospheres as stochastic processes. However, for the period covered by this report the temporal modeling of all parameters was piecewise linear (PWL). The estimated parameters for the results reported below are the position of GGAO12M, and atmosphere zenith delays and gradients and clock values for both sites. Various time intervals from two hours down to ten minutes were tested for all of the atmosphere and clock parameters. This process was applied to H, V, and I for both sessions. However, the H and V delays did not include estimation of the ionosphere.

A series of trials with varying intervals for atmospheres, atmosphere gradients, and clocks indicated that consistent results and minimum RMS delay scatter could be obtained using 20-minute intervals for the atmosphere zenith delays and clocks and 40 minutes for the atmosphere gradients. The default constraints included in the nuSolve setup were not adjusted. Outliers were excluded in an iterative process of estimation, outlier rejection, and re-estimation, leaving approximately 140 of the original 178 points in the solution. These observations should be examined carefully to determine if the cause for being an outlier can be ascertained.

The delay uncertainties for all observations have a median value of less than one picosecond. After arriving at a set of estimated parameters and retained observations, the additional quadratically-added delay required to obtain chi-square per degree of freedom of 1.0 was calculated within nuSolve (a process known as re-weighting). The additive delay value for both sessions is about 12 psec. This is not unexpected due at least in part to the PWL parameterization of the atmosphere and clock values.

5. Results

The H and V polarization observables are statistically independent as far as system noise is concerned, and thus they provide two separate solutions. However, other sources of noise, such as the atmosphere delay, source structure and positions, and clock variations, are almost completely correlated. Therefore the agreement of the estimated parameters for H and V should be much better than the formal uncertainties. On the other hand, the I solution, for which the delay is a combination of all polarization products, may differ slightly because the TEC difference between the stations was estimated.

The topocentric offsets from the *a priori* position for GGAO12M, as well as the changes in baseline length, are shown in Figure 1. The agreement among the components and length for H and V is reasonable, but the differences for I among the components on the two days is larger than expected. One possible source of the additional scatter is the estimation of the ionosphere. The additional ionosphere delay parameter, which is a quadratic function of frequency, makes the estimated parameters susceptible to systematic phase errors among the different bands. Clearly, a closer look at the data is required.

Delays obtained from the multiple phasecal tones in each channel indicate that there is a large dependence on the direction the antenna is pointing for both Westford and GGAO12M. If the variations were in the signal path from the receiver to the digital back end, the multitone delays would correct them. However there is evidence that the variation occurs in the 5 MHz uplink cable,

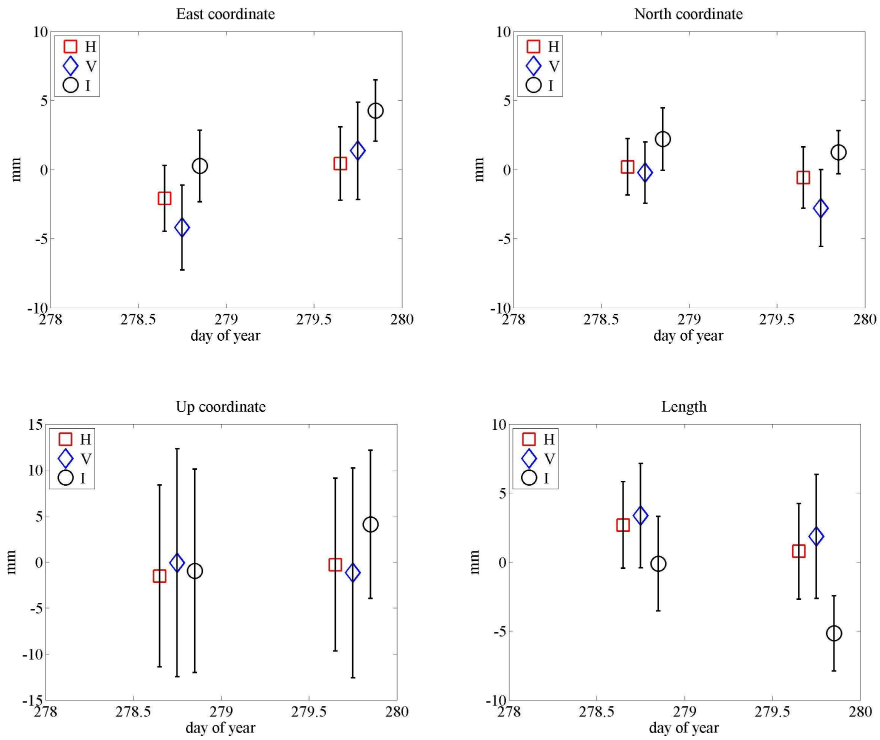

Figure 1. Adjustments to the topocentric position of the GGAO12M antenna and to the length of the baseline. Ionosphere was estimated for I but not for H and V.

in which case it is not corrected. Most of the variation is in azimuth for Westford. Discovery of this effect emphasizes the need for a cable calibration system for the broadband antennas.

6. Outlook

Regular broadband observations using the 12-m and Westford are scheduled to begin in mid-2013. Operational procedures for correlation and data analysis (correlator/fourfit/solve) for both stand-alone Broadband observations and Broadband-Mark IV observations need to be developed.

In order to facilitate development of these procedures we hope to install the new *openDB/calc/solve* data handling and parameter estimation packages at Haystack. This will allow us to experiment with, understand, and verify the entire data chain from scheduling through parameter estimation.

Acknowledgements

We thank the Broadband Development group for their efforts in constructing, implementing, and operating the systems at GGAO and at Westford and for assisting in the testing and observations; John Gipson for guidance in getting *sked* to work; David Gordon for getting the broadband output into databases; and Sergei Bolotin for developing *nuSolve* and for help getting it to work with the new broadband observable.

IAA VLBI Analysis Center Report 2012

Elena Skurikhina, Sergey Kurdubov, Vadim Gubanov

Abstract

This report presents an overview of IAA VLBI Analysis Center activities during 2012 and the plans for the coming year.

1. General Information

The IAA IVS Analysis Center (IAA AC) is located at the Institute of Applied Astronomy of the Russian Academy of Sciences in St. Petersburg, Russia. The IAA AC contributes to IVS products, such as daily SINEX files, TRF, CRF, rapid and long-term series of EOP, baseline lengths, and tropospheric parameters. EOP, UT1, and station positions were estimated from domestic observation programs Ru-E and Ru-U. The IAA AC generates NGS files.

2. Component Description

The IAA AC performs data processing of all kinds of VLBI observation sessions. For VLBI data analysis we use the QUASAR and the OCCAM/GROSS software packages. All reductions are performed in agreement with IERS Conventions (2010). Both packages use NGS files as input data.

The IAA AC submits to the IVS Data Center all kinds of products: daily SINEX files for EOP and EOP-rates and station position estimates, TRF, CRF, baseline length, and tropospheric parameters.

The QUASAR and the OCCAM/GROSS software packages are supported and developed.

IVS NGS files are generated in automatic mode on a regular basis.

3. Staff

– Vadim Gubanov, Prof.: development of the QUASAR software and development of the methods of stochastic parameter estimation.

– Sergey Kurdubov, Dr.: scientific researcher: development of the QUASAR software, global solutions, and DSNX file calculation.

– Elena Skurikhina, Dr.: team coordinator, VLBI data processing, and OCCAM/GROSS software development.

4. Current Status and Activities

- **Software Development for VLBI Processing**

  The QUASAR software is capable of calculating all types of IVS products. A new release of the QUASAR software was developed in 2012 by S. Kurdubov and has the ability to estimate a generous amount of new parameters (tidal waves, for example).

- **Routine Analysis**

  During 2012 the IAA AC continued to submit daily SINEX files for the IVS-R1 and IVS-R4 sessions as rapid solution (iaa2010a.snx) and SINEX files based on all 24-hour experiments for the quarterly solution.

  A new global solution was calculated.

  The routine data processing was performed with the OCCAM/GROSS software using a Kalman Filter. The IAA AC operationally processed the "24h" and Intensive VLBI sessions and submitted the results to the IERS and IVS on a regular basis. Processing of the Intensive sessions is fully automated. The EOP series iaa2007a.eops and iaa2005a.eopi, baseline lengths iaa2007a.bl (until November 2012), and troposphere parameters iaa2007a.trl were continued. Long-time series of station coordinates, baseline lengths, and tropospheric parameters (ZTD, gradients) were computed with the station position catalog ITRF2005.

- **EOP Parameter Calculation from Domestic QUASAR Network Observations**

  Regular determinations of Earth orientation parameters with the QUASAR VLBI Network Svetloe-Zelenchukskaya-Badary and single baseline one-hour observations for UT1 with e-VLBI transfer were performed weekly. On July 1st, daily Ru-U sessions began. Correlation is performed at the IAA correlator ARC. For 2012 the mean RMS EOP deviations from the IERS 08 C04 series in the Ru-E program were 0.72 mas for X-Pole position, 0.97 mas for Y-Pole position, 36 μs for UT1-UTC, and 0.29 mas for Celestial Pole position for 36 Ru-E sessions. The RMS deviation of the Universal Time values from the IERS C04 series for 187 sessions of the Ru-U program was 65 μs. We used station positions from the QUASAR global solution in our calculations.

5. Future Plans

We plan to:

- Continue to submit all types of IVS product contributions.
- Continue investigations of VLBI estimation of EOP, station coordinates, and troposphere parameters, and comparison with satellite techniques.
- Further improve algorithms and software for processing VLBI observations.
- Contribute to ICRF3 Working group study.

Italy INAF Analysis Center Report

M. Negusini, P. Sarti

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 Radioastronomy, which is part of the National Institute of Astrophysics. IRA runs the observatories of Medicina and Noto, where two 32-m VLBI AZ-EL telescopes are situated. This report contains the AC's VLBI data analysis activities and shortly outlines the investigations into the co-locations of space geodetic instruments.

1. Current Status and Activity

A thorough investigation into the local stability of the geodetic monuments at the Medicina site and the determination of local, intra-site motions was completed in 2012. The data sets used in the investigation were those acquired during the terrestrial surveys of the GPS-VLBI tie vector during the period 2001-2010. These precise terrestrial observations allowed us to determine the local stability of the local ground control network over a decade. The intra-site motions are remarkable, with rates of 1.7 mm/yr over baselines not exceeding a few tens of meters. The variation of the VLBI-GPS tie vector was also determined and is 0.4 ± 0.4 mm/yr. The results derived by the analysis of the terrestrial data were cross-checked against those obtained by the analysis of the GPS data acquired by the two permanent EUREF [1] stations MEDI and MSEL over the period 2004-2010. The GPS results show a non-negligible, statistically significant relative motion of the two permanent stations, especially in the horizontal component. GPS and terrestrial results are consistent over the common time span. A thorough description of the analysis and a discussion of the results can be found in [2], (http://gji.oxfordjournals.org/content/early/2013/01/07/gji.ggs092.full). In 2012 we published a paper ([3]) where VLBI was used in order to study the Etna volcano's activity by means of the crustal deformations between Noto and Matera (located on the African and the Eurasian Plates, respectively). By analyzing European VLBI experiments, we obtained the behavior of the baseline that crosses the Etnean area. VLBI data are very sparse even if the time series is quite long; therefore, to fill gaps in the information, we analyzed GPS continuous observations at the two sites, and we were able to highlight both extensions and compressions in detail. Comparisons between the trend of Noto-Matera baseline length variations, volcanic activity, and seismicity in the Mt. Etna area show the complexity of the development over time and space of these phenomena, which are caused deep in the earth by a catalyst that can be traced, in our opinion, to the interaction between the asthenospheric mantle, deep crust, and surface crust.

2. Data Analysis and Results

The IRA started to analyze VLBI geodetic databases in 1989, using a CALC/SOLVE package on the HP1000 at the Medicina station. In subsequent years, the same software was installed first on an HP360 workstation and later on an HP715/50 workstation. In more recent years, two HP785/B2600 workstations and an HP282 workstation were used. In 2007, a new Linux workstation was set up for the migration of all the VLBI data analysis, and Mark 5 Calc/Solve was installed. During 2012, we stored all the 1999-2012 databases available on the IVS data centers. All the databases were processed and saved with the best selection of parameters for the final arc solutions. The most recent IRA solution for crustal deformation comprises all the Europe sessions analyzed at IRA from 1987 to 2009, and the estimated horizontal and vertical velocities are presented in [4].

Our Analysis Center has participated in the IVS TROP Project on Tropospheric Parameters since the beginning of the activities. Tropospheric parameters (wet and total zenith delay and horizontal gradients) of all IVS-R1 and IVS-R4 24-hour VLBI sessions were regularly submitted. In 2012 we submitted our results to IVS.

3. Outlook

We will continue with the regular submission of INAF tropospheric parameters to the IVS data centers, also studying the impact of the Vienna Mapping Function on the geodetic results. We will submit a long time series of troposphere parameters using all VLBI sessions available in our catalog in order to estimate the variations over time of the content of water vapor in the atmosphere.

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JPL VLBI Analysis Center Report for 2012

Chris Jacobs

Abstract

This report describes the activities of the JPL VLBI Analysis Center for the year 2012. The highlight of the year was the successful MSL rover Mars landing, which was supported by VLBI-based navigation using our combined spacecraft, celestial reference frame, terrestrial reference frame, earth orientation, and planetary ephemeris VLBI systems. We also supported several other missions with VLBI navigation measurements. A combined NASA-ESA network was demonstrated with first Ka-band fringes to ESA's Malargüe, Argentina 35 m. We achieved first fringes with our new digital back end and Mark 5C recorders.

1. General Information

The Jet Propulsion Laboratory (JPL) Analysis Center is in Pasadena, California. Like the rest of JPL, the center is operated by the California Institute of Technology under contract to NASA. JPL has done VLBI analysis since about 1970. We focus on spacecraft navigation, including:

1. Celestial Reference Frame (CRF) and Terrestrial Reference Frame (TRF) are efforts which provide infrastructure to support spacecraft navigation and Earth orientation measurements.
2. Time and Earth Motion Precision Observations (TEMPO) measures Earth orientation parameters based on single baseline semi-monthly measurements. These VLBI measurements are then combined with daily GPS measurements as well as other sources of Earth orientation information. The combined product provides Earth orientation for spacecraft navigation.
3. Delta differenced one-way range (ΔDOR) is a differential VLBI technique which measures the angle between a spacecraft and an angularly nearby extragalactic radio source. This technique thus complements the radial information from spacecraft doppler and range measurements by providing plane-of-sky information for the spacecraft trajectory.

2. Technical Capabilities

The JPL Analysis Center acquires its own data and supplements it with data from other centers. The data we acquire are taken using NASA's Deep Space Network (DSN).

1. Antennas: Most of our work uses 34-m antennas located near Goldstone (California, USA), Madrid (Spain), and Tidbinbilla (Australia). These include the following Deep Space Stations (DSS): the "High Efficiency" subnet comprised of DSS 15, DSS 45, and DSS 65 which has been the most often used set of JPL antennas for VLBI. More recently, we have been using the DSN's beam waveguide (BWG) antennas: DSS 13, DSS 24, DSS 25, DSS 26, DSS 34, DSS 54, and DSS 55. Less frequent use is made of the DSN's 70-m network (DSS 14, DSS 43, and DSS 63). Typical X-band system temperatures are 35K on the HEF antennas. The

70-m and BWG temperatures are about 20K. Antenna efficiencies are typically well above 50% at X-band.

2. Data acquisition: We use the Mark IV DAT and Mark 5A VLBI recorders. In addition, we have JPL-unique systems called the VLBI Science Recorder (VSR) and the Wideband VSRs (WVSR) which have digital baseband converters and record directly to hard disk. The data are later transferred via network to JPL for processing with our software correlator. ROACH-based Digital Back Ends and Mark 5C recorders are now being tested for deployment in 2013.
3. Correlators: JPL VLBI Correlator has been exclusively based on the SOFTC software which handles the ΔDOR, TEMPO, and CRF correlations as well as tests of antenna arraying.
4. Solution types: We run several different types of solutions. For ΔDOR spacecraft tracking we make narrow field ($\approx 10^\circ$) differential solutions. The TEMPO solutions typically have a highly constrained terrestrial (TRF) and celestial frame (CRF) as a foundation for estimating Earth orientation parameters. These reference frames are produced from global solutions which then provide the framework needed for use by TEMPO and ΔDOR.

3. Staff

Our staff are listed below along with areas of concentration. Note that not all of the staff listed work on VLBI exclusively, as our group is involved in a number of projects in addition to VLBI.

- Durgadas Bagri: TEMPO and Ka-band phase calibrators.
- James Border: ΔDOR spacecraft tracking.
- Cristina García-Miró: Madrid data acquisition, NASA-ESA southern declination collaboration, educational outreach.
- Shinji Horiuchi: Canberra data acquisition, NASA-ESA southern declination collaboration.
- Chris Jacobs: NASA-ESA southern declination collaboration, X/Ka CRF, TRF, S/X CRF.
- Christina King: source stability studies.
- Peter Kroger: ΔDOR spacecraft tracking.
- Gabor Lanyi: MODEST, fringe fitting and correlation support, ΔDOR, and TRF.
- Steve Lowe: Software correlator, fringe fitting software, ΔDOR.
- Walid Majid: pulsars, ΔDOR, VLBA phase referencing.
- Chuck Naudet: NASA-ESA southern declination collaboration, source stability studies.
- Andres Romero-Wolf: ΔDOR, CRF and TRF, MODEST scripts, source stability studies.
- Lawrence Snedeker: Goldstone data acquisition, NASA-ESA southern declination collaboration.
- Ioana Sotuela: Madrid antenna calibration, NASA-ESA southern declination collaboration.
- Ojars Sovers: S/X and X/Ka CRFs and TRF. Maintains MODEST analysis code.
- Alan Steppe: TEMPO and TRF.

4. Current Status and Activities

TEMPO EOP and S/X CRF work continues. X/Ka-band (8.4/32 GHz) CRF took a major step forward with the integration of ESA's Malargüe, Argentina antenna into our network thus adding much needed southern coverage.

VLBI spacecraft tracking continues to provide measurements of angular position in support of mission navigation and planetary ephemeris development. The New Horizons trajectory toward Pluto was verified in May-June. MSL was targeted to a near perfect aim point at the top of the Martian atmosphere in August. The Juno Deep Space Maneuver in August-September was supported to target the Earth flyby in October 2013. Dawn is being supported during its low thrust cruise from Vesta to Ceres. Monthly measurements of MRO and Mars Odyssey continue to improve the ephemeris of Mars.

5. Future Plans

In 2013, we hope to improve our VLBI system by increasing data rates to 2048 Mbps. Operational Ka-band phase calibrators have been built and are planned for deployment in 2013. Work on the Digital Back End (DBE) continues. Our next generation fringe fitting program is also expected to come online. We expect the combined NASA-ESA deep space network to start producing Ka-band CRF results. On the spacecraft front, we plan to continue supporting a number of operational missions while further improving techniques for using VLBI for spacecraft tracking.

Acknowledgements

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KASI Combination Center Report

Younghee Kwak, Jungho Cho

Abstract

This report presents the activities of the Korea Astronomy and Space Science Institute (KASI) as an IVS Combination Center during 2012, and it sketches the intended tasks for 2013.

1. General Information

As a goverment-funded research institute, KASI is in charge of operating an IVS Combination Center. It has a wide range of research areas observing the Earth, the Sun, stars, and galaxies based on various instruments. Concerning the Earth observations, KASI operates GNSS, VLBI, and SLR. Space geodesy is one of the important research fields of KASI.

2. Component Description

KASI has prepared for regular combination analysis after it was designated as an IVS Combination Center. KASI has rich experience for GPS data processing and analysis using the Bernese GNSS Software (Bernese). Bernese, especially the subprogram ADDNEQ2, supports stacking of the normal equations and estimation of parameters [1]. We adopted Bernese to combine the sessionwise VLBI products of the IVS Analysis Centers (ACs) at the normal equation level. We altered the software, which was developed for GPS data processing and analysis, to handle IVS products appropriately. The inputs to the Bernese are the normal equation matrices and vectors from the daily SINEX files of the individual ACs (see Table 2). The outputs are daily SINEX files including combined station coordinates and Earth orientation parameters (EOPs). The missions of the KASI Combination Center are to create high quality combination products, to verify the combination solution of the BKG/DGFI Combination Center through cross-checking, to control the quality of the ACs' results, to provide feedback to the Analysis Centers, and to adhere to the IERS Conventions.

3. Staff

The staff members of the KASI Combination Center are listed below.

Table 1. Personnel of the KASI Combination Center.

Jungho Cho	+82-42-865-3234	jojh@kasi.re.kr
Younghee Kwak	+82-42-865-2031	bgirl02@kasi.re.kr

Table 2. Products of individual ACs for the combination.

AC	BKG	DGFI	GSFC	IAA	OPA	USNO
Solution	bkg2010a	dgf2009a	gsf2010a	iaa2010a	opa2010c	usn2007b

4. Current Status and Activities

(1) Removing systematic variations of X and Y pole rates

In the IVS 2011 Annual Report [2], we reported that there were systematic variations of polar rates between individual and combined solutions. They looked like sine curves, so we expected that they might be caused by one of the EOPs. Most of the IVS ACs (BKG, DGFI, IAA, GSFC, and OPA) provide the SINEX format which has celestial pole offsets dX and dY as nutation parameters. The Bernese 5.0 version, however, handles nutation angles in obliquity and longitude, and thus the nutation part of the normal equations were not combined properly. Therefore, we fixed the nutation parameters of five ACs (BKG, DGFI, IAA, GSFC, and OPA) and pre-reduced the nutation parameters of USN to keep the nutation information. Finally, we could remove the systmatic variation in X-pole and Y-pole rate as shown in Figure 1.

(2) Automation using BPE

KASI uses Bernese for combining individual ACs. Bernese provides an automation tool, the Bernese Processing Engine (BPE), which is able to do routine processing. The routine processes include converting the SINEX format to the NQ0 Bernese input format, transforming the normal equations to refer to identical a priori values (reference frame and EOPs) and parameter epochs, and combining sessionwise products of ACs. Due to naming conventions of input and output files in Bernese, complete automation is restricted. Using additional scripts made BPE extensively support long-term processing, e.g. 10 years. Figure 2 shows the functions of the scripts for VLBI combination.

5. Future Plans for 2013

In 2013, we will focus on the following tasks:

- Rejecting outliers
- Weighting the individual solutions
- Combining whole period IVS products (1984-present)
- Comparing with BKG/DGFI Combination Center [3], IERS 08C04 [4], and IGS solutions [5]
- Providing IVS EOP format solutions [3] (Rapid and Quarterly)

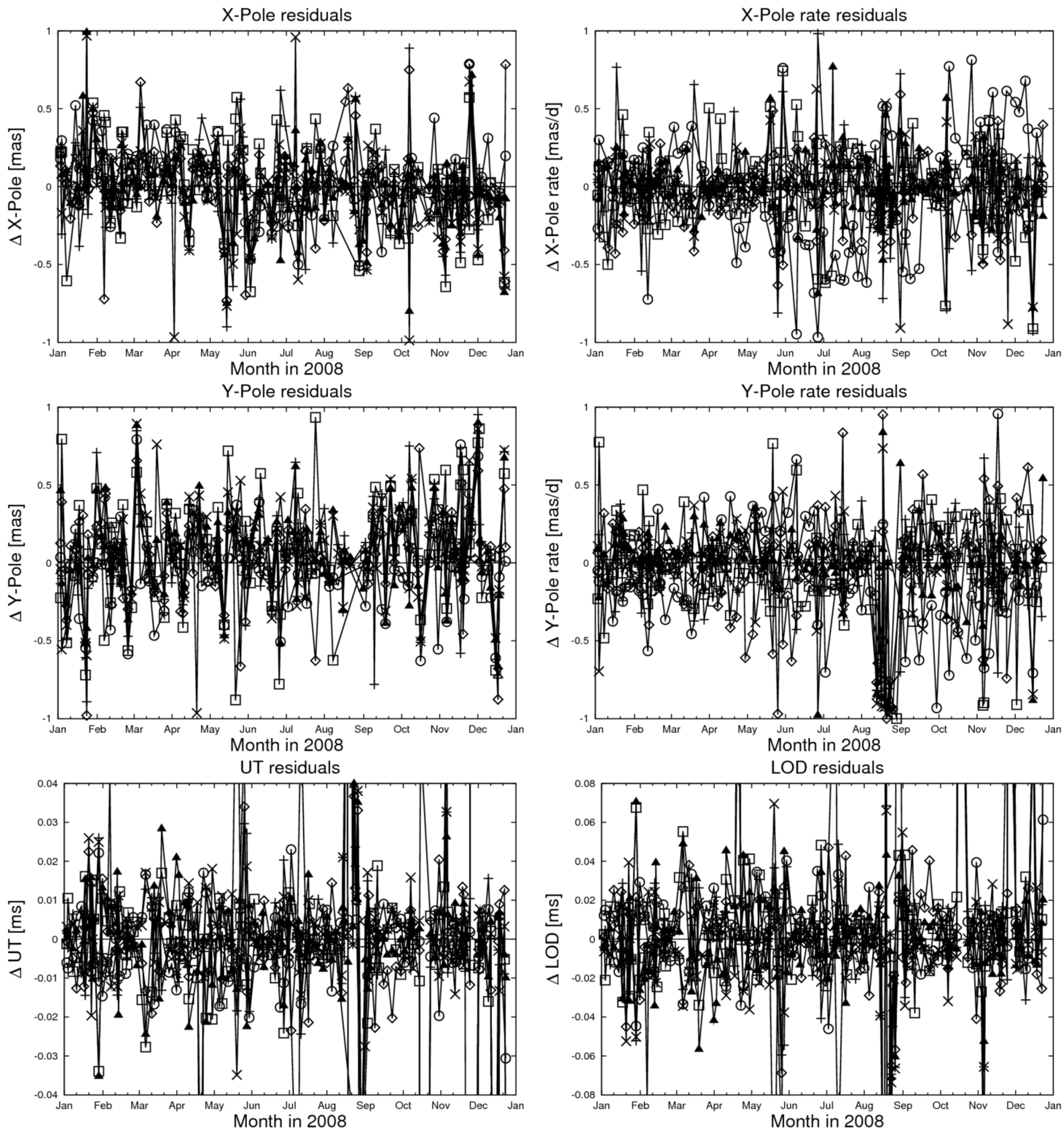

Figure 1. Internal comparison between individual solutions and the KASI combination solution (Individual solutions - Combined solution). + : BKG, ◊ : DGFI, × : GSFC, □ : IAA, ▲ : OPA, ∘ : USNO.

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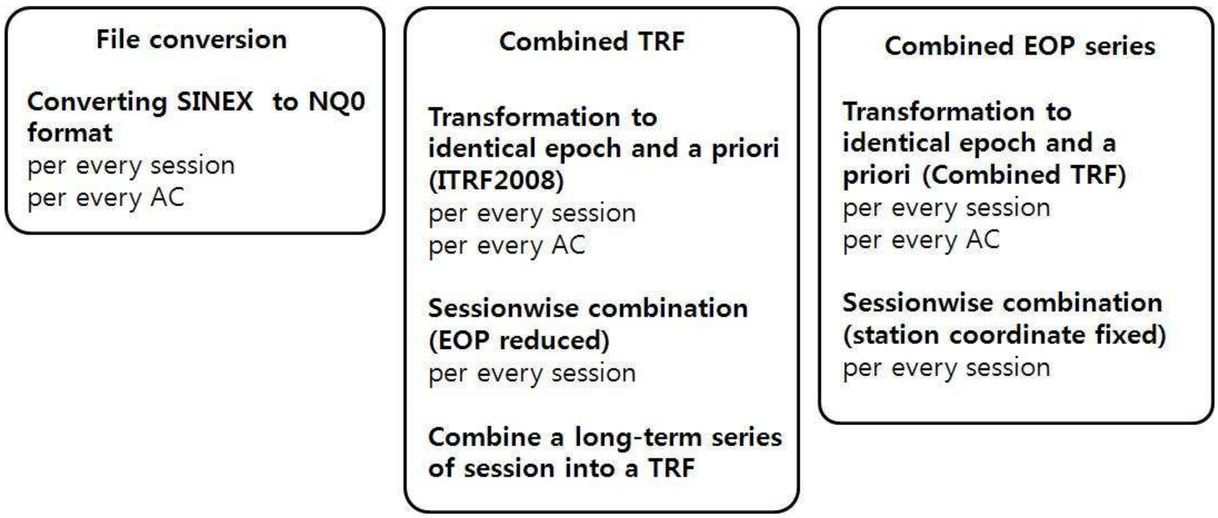

Figure 2. The scripts for KASI combination analysis.

[3] http://ccivs.bkg.bund.de
BKG/DGFI Combination Center Web page.

[4] http://hpiers.obspm.fr/eop-pc
IERS Earth Orientation Center Web page.

[5] http://igscb.jpl.nasa.gov/components/prods.html
IGS Products Table.

KTU-GEOD IVS Analysis Center Annual Report 2012

Emine Tanır Kayıkçı, Kamil Teke

Abstract

This report summarizes the activities of the KTU-GEOD IVS Analysis Center (AC) in 2012 and outlines planned activities for 2013. The analysis of the EUROPE sessions is one of our specific interests, and the combination of different AC solutions for continuous VLBI campaigns, e.g. CONT11, will be investigated.

1. General Information

The KTU-GEOD IVS Analysis Center (AC) is located at the Department of Geomatics Engineering, Karadeniz Technical University, Trabzon, Turkey.

Figure 1. KTU-GEOD staff at Vienna State Opera.

2. Staff at KTU-GEOD

The staff who are contributing to the research at the KTU-GEOD IVS Analysis Center (AC) in 2012 are listed in Table 1 with their main focus of research and working location.

3. Current Status and Activities

In 2012, we investigated sub-daily (three-hour) antenna TRF coordinates estimated from the VLBI observations of the continuous 24h sessions of the CONT11 campaign [8]. We analyzed VLBI observations using the Vienna VLBI Software (VieVS) which is developed at the Department of Geodesy and Geoinformation at the Vienna University of Technology [2]. Troposphere zenith wet delays (ZWD) and total gradients (east and north) were estimated as piecewise linear offsets at one hour and six hours, respectively. Clock errors were estimated as hourly piecewise linear offsets, in addition to as quadratic polynomials. Source coordinates were fixed to ICRF2 [3]. The IERS

Table 1. Staff members of KTU-GEOD ordered alphabetically.

Name	Working location	Main focus of res.	Contact
Emine Tanır Kayıkçı	Karadeniz Technical University, Dept. of Geomatics Engineering, Trabzon, Turkey	Responsibility for the Analysis Center and data processing	etanir@ktu.edu.tr
Kamil Teke	Hacettepe University, Dept. of Geomatics Engineering, Ankara, Turkey	Data processing	kteke@hacettepe.edu.tr

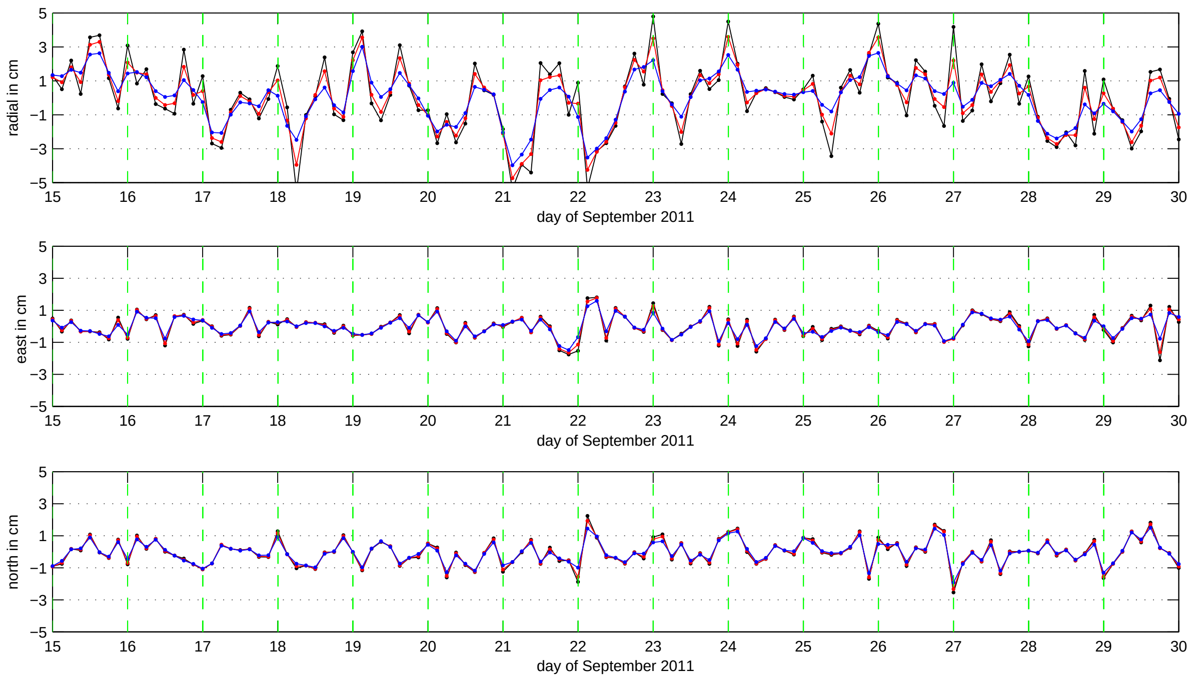

Figure 2. Kokee VLBI antenna piecewise (pw) coordinate offsets at three-hour intervals. Weighted means of pw coordinate offsets were calculated at the overlapping 24h session boundaries. The black, red, and blue dotted lines denote the pw coordinate estimates when loose relative constraints of 5 cm, 2 cm, and 1 cm after three hours were imposed [8].

C04 08 series [1] was taken as a priori values of Earth Orientation Parameters, and high frequency ocean tidal corrections were modeled as recommended by the IERS Conventions 2010 [5]. Earth orientation parameter residuals were estimated as one offset per 24-hour VLBI session. An a priori TRF was estimated from a global solution of CONT11 where antenna velocities were fixed to those of VTRF2008. In the global solution, TRF datum condition equations were introduced on the accumulated datum-free normal equation system in such a way that the estimated TRF had no-net-translation (NNT) and no-net-rotation (NNR) with respect to VTRF2008. Atmospheric loading [6] and tidal ocean loading corrections (FES2004, [4]) to the antenna coordinates were introduced for each observation before the adjustment. All the antenna coordinates were fixed to the TRF (from global solution) except for one antenna whose coordinates were estimated as piecewise linear offsets at three-hour intervals. Different loose relative constraints on the coordinate estimates of this one antenna were imposed for each analysis of the CONT11 campaign as: 5 cm, 2 cm, and 1 cm after three hours (see Figure 2). Readers are referred to [7] and [10] for more information on the analysis of VLBI observations.

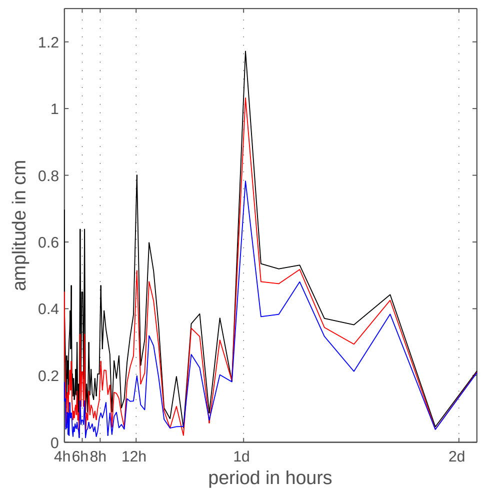

Figure 3. Fourier spectra of piecewise (pw) coordinate offsets on radial direction at three-hour intervals at Kokee. The black, red, and blue dotted lines denote the pw coordinate estimates when loose relative constraints as 5 cm, 2 cm, and 1 cm after three hours were imposed [8].

The reasons for large unrealistic leaps of three-hour antenna coordinates, especially for radial components, are investigated (e.g., shown for Kokee in Figure 2). One of the possible reasons might be the large correlation between certain parameters (e.g., clock errors, troposphere delays, source coordinates, and Earth rotation parameters) and antenna coordinates at sub-daily intervals. Another possible reason might be the unreduced tidal effects on the antenna coordinates. In this case, one might ask whether the radial amplitudes of the tidal variations can reach up to 1 cm (see black and red lines at one-day period in Figure 3) even though antenna coordinates are corrected at each observation epoch using state-of-the-art geodynamic models. The correct answer to this question needs further investigation. In Figure 3, the significant amplitude of 8 mm at 12 hours (black line) vanishes when 1 cm after 3h relative constraint (blue line) was imposed in the analysis. Thus, selecting really loose constraints is essential in order to not hide the dependencies (shared variances) between parameters in the observation equations. Further investigations are discussed in [8].

4. Future Plans

We will continue to analyze VLBI sessions with different parameterizations, focusing on the EUROPE sessions by using VieVS. In 2013, we will study intra-technique combination of different AC solutions of the continuous VLBI campaigns, i.e. CONT02, CONT05, CONT08, and CONT11.

Besides, we will do statistical comparisons between certain geodetic parameters, e.g. troposphere [9].

Acknowledgements

We are thankful to all components of the IVS. We are grateful to Karadeniz Technical University for their financial support of KTU-GEOD IVS AC research activities. One of the authors, Kamil Teke, acknowledges the Scientific and Technological Research Council of Turkey (Tübitak) for the financial support of his postdoctoral research in Vienna.

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IVS Analysis Center at Main Astronomical Observatory of National Academy of Sciences of Ukraine

Yaroslav Yatskiv

Abstract

This report summarizes the activities of the VLBI Analysis Center at the Main Astronomical Observatory of the National Academy of Sciences of Ukraine in 2012.

1. Introduction

The VLBI Analysis Center was established in 1994 by the Main Astronomical Observatory (MAO) of the National Academy of Sciences of Ukraine (NASU) as a working group of the Department of Space Geodynamics of the MAO. In 1998, the group started its IVS membership as an IVS Analysis Center. The MAO AC is located at the office building of the observatory in Kiev.

2. Technical Description

VLBI data analysis is performed on two computers: an Intel Core 2 Duo 3.1 GHz box with 4 GB RAM and a 1 TB HDD, and a Pentium-4 3.4 GHz box with 1 GB RAM and two 200 GB HDDs. Both computers are running under the Linux/GNU Operating System.

For data analysis, we use the SteelBreeze software which was developed at the MAO NASU. The SteelBreeze software is written in the C++ programming language and uses the Qt 2.x widget library. SteelBreeze makes Least Squares estimation of different geodynamical parameters with the Square Root Information Filter (SRIF) algorithm (see [1]).

The software analyzes VLBI data (time delays) of a single session or a set of multiple sessions. The time delay is modeled according to the IERS Conventions (2003) [2], as well as by using additional models (tectonic plate motion, nutation models, wet and hydrostatic zenith delays, mapping functions, etc.). The following parameters are estimated: Earth orientation parameters, coordinates and velocities of a selected set of stations, coordinates of a selected set of radio sources, clock function, and wet zenith delay. This year we started the refactoring of the software to implement the newest IERS Conventions [3] and to use the newest version of the Qt library.

3. Staff

The VLBI Analysis Center at Main Astronomical Observatory consists of the following members:

Yaroslav Yatskiv: Head of the Department of Space Geodynamics; general coordination and support of activity of the Center.

Vasyl Choliy: Head of EOP determination laboratory.

Sergei Bolotin: Scientific consultant.

4. Current Status and Activities in 2012

In 2012, we performed regular VLBI data analysis to determine Earth orientation parameters. "Operational" solutions were produced and submitted to the IVS on a weekly basis. The IERS Conventions (2003) [2] models were applied in the analysis. In the solutions, station coordinates and Earth orientation parameters were estimated.

Also this year, we continued to participate in the IVS Tropospheric Parameters project. Estimated wet and total zenith delays for each station were submitted to IVS. The analysis procedure was similar to the one used for the operational solutions.

5. Plans for 2013

The MAO Analysis Center will continue to participate in operational EOP determination, as well as in updating the TRF and CRF solutions from VLBI analysis of the full data set of observations.

Acknowledgements

The work of our Analysis Center would be impossible without the activities of other components of IVS. We are grateful to all contributors from the Service.

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Analysis Center at National Institute of Information and Communications Technology

Thomas Hobiger, Mamoru Sekido, Ryuichi Ichikawa

Abstract

This report summarizes the activities of the Analysis Center at National Institute of Information and Communications Technology (NICT) for the year 2012.

1. General Information

The NICT Analysis Center is operated by the space-time standards group of NICT and is located in Kashima, Ibaraki, Japan as well as at the headquarters in Koganei, Tokyo. The Analysis Center focuses on the processing of VLBI experiments which are related to NICT's research goals. Effort is spent on developing new VLBI technology for time and frequency transfer, the development of a modern multi-technique analysis software package, prototyping of a compact VLBI system, real-time EOP determination, and atmospheric path delay studies.

2. Staff

Members who are contributing to the Analysis Center at NICT are listed below (in alphabetical order, with working locations in parentheses):

- HOBIGER Thomas (Koganei, Tokyo): analysis software development, time and frequency transfer, and software correlator development
- ICHIKAWA Ryuichi (Kashima): compact VLBI system and atmospheric modeling
- KONDO Tetsuro (Bangkok/Thailand and Kashima): software correlator development
- KOYAMA Yasuhiro (Koganei, Tokyo): time and frequency transfer experiments
- SEKIDO Mamoru (Kashima): development of VLBI systems and coordination of activities

3. Current Status and Activities

3.1. Development of a Multi-technique Space-Geodetic Analysis Software Package

In a cooperation between several Japanese institutes the multi-technique space geodetic analysis software "c5++" [3] has been developed over recent years. The software provides consistent geodetic and geophysical models which can be accessed by single technique space-geodetic applications or can be used to combine several techniques on the observation level (Figure 1). Satellite Laser Ranging (SLR) and Very Long Baseline Interferometry (VLBI) stand-alone applications have been realized in the last two years. With the introduction of an option to utilize local tie information as well as the possibility of estimating common parameters (clock, troposphere, orbits) the software enables rigorous combination of space geodetic techniques on the observation level. Moreover, the inclusion of GNSS as a third space geodetic technique since 2012 has increased the choice of analysis strategies tremendously. However, rigorous combination of space geodetic data on the observation level depends on proper handling of inter-technique biases and other offsets in order to make this approach work well. Moreover, the large number of unknown parameters requires sophisticated algorithms, as well as a large enough PC memory in which huge matrices can be stored temporarily.

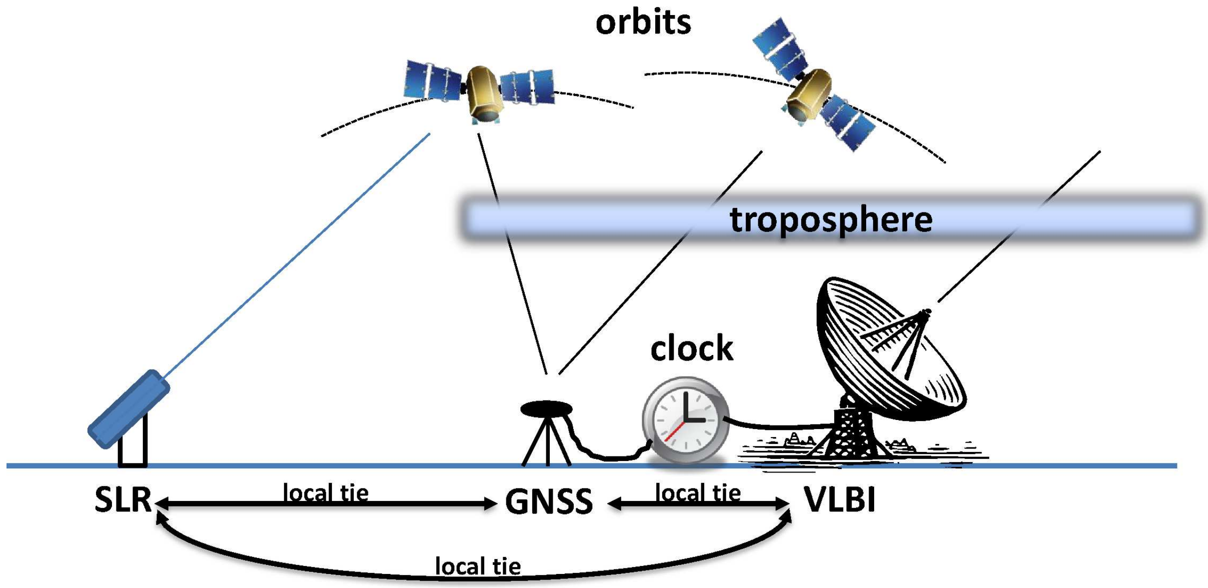

Figure 1. Combination of space geodetic data on the observation level requires the knowledge of precise local tie information. Co-located VLBI and GNSS technology often shares the same frequency standard, which allows estimation of a single clock model for both techniques. In addition troposphere delays are thought to be identical except for a constant bias (so-called "troposphere tie").

3.2. Frequency Transfer by Means of VLBI

Space geodetic techniques such as GNSS have been proven to be a useful tool for time and frequency transfer purposes. Besides SLR, which is currently tested under the name T2L2, VLBI could be another space geodetic technique that can be utilized for frequency transfer. Unlike GNSS, VLBI does not require any orbital information as it directly refers to an inertial reference frame defined by the location of the quasi stellar objects. As summarized by [4], current VLBI systems can provide a frequency link stability of about 2 x 10-15 @ 1d (ADEV), but due to the fact that geodetic VLBI networks do not observe for more than 24 hours continuously, no statement about long-term stability can be made. Moreover, as VLBI only provides one observation per epoch, troposphere and station clocks need to be de-correlated in space geodetic analysis by estimating these parameters from a batch of several scans. Thus, VLBI can only contribute to frequency transfer with clock estimates made every 30 minutes or longer. In order to overcome these drawbacks, NICT's Space-Time Standards Laboratory has started to work on the realization of a frequency transfer system based on the principles of VLBI, whereas developments from the upcoming geodetic VLBI2010 system are expected to help in reaching these goals. VLBI2010 is designed to provide observables with a few picoseconds of uncertainty, and once a global station network is deployed, it is expected to operate 24h/7d which would allow access to long-term frequency stability on intercontinental links. The VLBI2010 short-term frequency transfer limitation is thought to be improved when VLBI is combined with GNSS (or TWSTFT) in the analysis processing (see prior section). Our software c5++ has been prepared to combine VLBI and GNSS data on the observation level. Thereby, the concept of a reference clock within the VLBI station network needs to be dismissed when VLBI data is combined with GNSS information, which is processed in precise point positioning (PPP) mode. Thus, when combining both techniques, GNSS data are expected to provide the absolute clock information at each site and contribute to the short-term frequency stability. On the other side VLBI will provide good long-term stability and compares station clocks over long baselines.

3.3. Ultra-rapid EOP Experiments

Geospatial Information Authority of Japan (GSI), Onsala Space Observatory, University of Tasmania, and the Hartebeesthoek Radio Astronomy Observatory carried out several ultra-rapid EOP experiments which were automatically analyzed with c5++. The analysis process had to be adopted to handle automated ambiguity resolution of a multi-baseline session and to allow for a robust estimation of the three EOP components. First results demonstrated that all three EOPs can be estimated from such a dedicated ultra-rapid observation network. However, small software updates and bug fixes are still necessary in order to make the automated multi-baseline ambiguity resolution algorithm work with low SNR data or outliers. In addition to the dedicated ultra-rapid experiments, GSI regularly submits UT1 results from INT2 sessions that have been automatically processed by c5++ on an operational basis (see [3] for details on the processing strategy).

3.4. Ray-traced Troposphere Slant Delay Correction for Space Geodesy

A software package, called Kashima Ray-tracing Tools (KARAT), has been developed. It is capable of transforming numerical weather model data sets to geodetic reference frames, computing fast and accurate ray-traced slant delays, and correcting geodetic data on the observation level. KARAT has been extended to support frequency dependency of the refractivity following the Liebe model [1] with the goal of finding out whether modern space-geodetic microwave techniques (including VLBI2010 and higher dual-frequency VLBI configurations) should be corrected for dispersive troposphere delays. By the use of this model it is possible to compute the complex refractivity based on atmosphere quantities such as pressure, temperature, and relative humidity. Although the frequency dependent delay contribution appears to be of small order, one has to consider that signals are propagating through few kilometers of troposphere at high elevations to hundreds of kilometers at low elevations. Thus, it has been investigated whether such an effect has a magnitude above the noise floor of current space geodetic instruments or if it can be safely neglected. It could be shown [2] that dispersive troposphere delays grow inversely proportional to the cosine of the zenith distance (like any other troposphere delay) and will be absorbed into the estimated zenith delays during post-processing. Thus frequency dependent troposphere delays should not affect the geodetic results on a significant level. However, for X/Ka-VLBI the question remains of the level to which troposphere products are comparable to other estimates from other space geodetic techniques when a frequency dependent troposphere contribution is neglected.

4. Future Plans

For the year 2013 the plans of the Analysis Center at NICT include:

- Time and frequency transfer experiments by VLBI and combination with other techniques such as GNSS or TWSTFT
- Combination of multi-technique space-geodetic data on the observation level with c5++
- Implementation of an interface for c5++, which allows reading and creation of OpenDB data
- Experiments and analysis of multi-baseline networks which allows the determination of all three EOPs in real-time
- Usage of multi-processors/multi-core processing platforms for the acceleration of space geodetic applications

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NMA Analysis Center

Halfdan Pascal Kierulf, Per Helge Andersen

Abstract

The Norwegian Mapping Authority (NMA) has during the last few years had a close cooperation with Norwegian Defence Research Establishment (FFI) in the analysis of space geodetic data using the GEOSAT software. In 2012 NMA has taken over the full responsibility for the GEOSAT software. This implies that FFI stopped being an IVS Associate Analysis Center in 2012. NMA has been an IVS Associate Analysis Center since 28 October 2010. NMA's contributions to the IVS as an Analysis Centers focus primarily on routine production of session-by-session unconstrained and consistent normal equations by GEOSAT as input to the IVS combined solution. After the recent improvements, we expect that VLBI results produced with GEOSAT will be consistent with results from the other VLBI Analysis Centers to a satisfactory level.

1. Introduction

A number of co-located geodetic stations with more than one observation technique have been established. In principle, all instruments at a given co-located station move with the same velocity, and it should be possible to determine one set of coordinates and velocities for each co-located station. In addition, a constant eccentricity vector from the reference point of the co-located station to each of the individual phase centers of the co-located instruments is estimated using constraints in accordance with a priori information given by the ground surveys. One set of Earth orientation parameters (EOP) and geocenter coordinates can be estimated from all involved data types. The present dominating error source of VLBI is the water content of the atmosphere, which must be estimated. The introduction of GPS data with a common VLBI and GPS parameterization of the zenith wet delay and atmospheric gradients will strengthen the solution for the atmospheric parameters. The inclusion of SLR data, which is nearly independent of water vapor, gives new information which will help in the de-correlation of atmospheric and other solve-for parameters and will lead to more accurate parameter estimates. These, and many more advantages with the combination of independent and complementary space geodetic data at the observation level, are fully provided by the GEOSAT software developed by FFI [1, 2]. GEOSAT is also useful for single technique analysis. The VLBI module of GEOSAT is now further developed by the NMA [5]. The goals are both to act as an IVS Analysis Center delivering session-by-session unconstrained and consistent normal equations to the IVS Combination Center and to provide quality control for the different modules used in GEOSAT.

2. The GEOSAT Software and Analysis Activities in 2012

The NMA has during 2012 continued the work of making the VLBI module of the GEOSAT software compatible with other VLBI analysis software that delivers results to IVS. In addition, there is a lot of activity going on at NMA to further develop the multi-technique software GEOSAT (see the FFI TDC 2011 annual report).

One of the first challenges that had to be solved was how to extract an unconstrained SINEX solution from the Upper-Diagonal UD Kalman filter solution produced by GEOSAT. A first test solution was sent to the IVS Combination Center in autumn 2009. During 2010 several solutions covering all VLBI sessions with at least four stations from the start of 1994 to the end of 2009 were submitted to the IVS Combination Center. The first solution was presented at the 6th IVS General Meeting, in Hobart, Australia [5]. The overall agreement between the NMA-GEOSAT solution and the solutions from the other ACs was satisfactory for this first comparison. However, some discrepancies were found. There were some systematic differences in the nutation parameters, which in our latest comparisons seem to have vanished. A misinterpretation of the NGS-format led to systematic differences in UT1-UTC. Systematic differences in station heights have also disappeared in the latest comparison mostly due to the use of the VMF1 [4] model instead of 3D ray tracing. We also noticed more noise in the GEOSAT-derived EOP compared to results from the other software packages. The largest "EOP-outliers" disappeared after some manual editing of the observations. Some other "EOP-outliers" were removed after a manual introduction of clock breaks in the analysis.

3. Plans for 2013

Our plan is to go through the VLBI data from the start of 1994 to the present and to perform a detailed manual editing of outliers. We expect that this will contribute to a reduction of the EOP "noise level". When the editing is completed, a new set of normal equations will be submitted to IVS for a test combination. We hope (and expect) that the results then will be at the level of the other IVS ACs. As soon as the GEOSAT solution is in satisfactory agreement with the other solutions, NMA will start to deliver unconstrained normal equations in the SINEX format to the IVS Combination Center on a routine basis.

Unlike most of the other VLBI analysis software GEOSAT is based on a UD-Kalmanfilter. This allows the stochastic behavior of the system to be changed. NMA will test different stochastic parameters especially for the troposphere. Station and epoch dependent stochastic parameters based on input from numerical weather models and IGS tropospheric products will be tested and evaluated. Tests of different models are also planned — for instance, a comparison of results using VMF1 and 3D ray tracing.

Producing VLBI solutions for IVS [3] is the first part of a larger strategic plan from NMA. The next step is to include other geometric geodetic techniques (GNSS, SLR, and DORIS) in a common solution where the different techniques are combined at the observation level. The long-term goal of this large effort is to also include data from the gravity satellites GRACE and GOCE and from altimeter satellites.

4. Staff

- Dr. Halfdan Pascal Kierulf - Research geodesist of Norwegian Mapping Authority (NMA).
- Dr. Per Helge Andersen - Research Professor of Forsvarets forskningsinstitutt (FFI and NMA).
- Ann-Silje Kirkvik - Master of Science.
- Lena Pedersen and Ingrid Fausk - Research geodesist of the Norwegian Mapping Authority (NMA).
- Dr. Oddgeir Kristiansen - Section Manager at the Norwegian Mapping Authority (NMA).

- Reidun Kittelsrud - Section Manager at the Norwegian Mapping Authority (NMA).

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Paris Observatory Analysis Center (OPAR): Report on Activities, January - December 2012

Sébastien Lambert, Christophe Barache

Abstract

We report on activities of the Paris Observatory VLBI Analysis Center (OPAR) for calendar year 2012 concerning the development of operational tasks, the development of our Web site, and various other activities: monitoring of the Earth's free core nutation, measuring of the post-seismic displacements of some stations, and the analysis of the recent IVS R&D sessions, including observations of quasars close to the Sun.

1. Operational Solutions for Diurnal and Intensive Sessions

A reanalysis of the complete diurnal session database was done (identified as opa2012a), and resulting EOP series and radio source catalogs were sent to the IVS. This solution estimated EOP and rates as session parameters, station coordinates and velocities as global parameters, and most of the sources' coordinates as global parameters. Troposphere and clock parameters were estimated every 20 minutes and 60 minutes, respectively, and gradients were estimated every six hours (at all sites). Axis offsets were estimated as global parameters for a list of 80 stations. We used up-to-date geophysical and astronomical modeling to compute the theoretical delay and partials, including the IAU 2006 nutation and precession, the Vienna mapping functions 1, the FES 2004 ocean loading model, and the antenna thermal deformations as provided by A. Nothnagel (2009, J. Geod., 83, 787). Since the solution was released after the March 11, 2011 earthquake that occured in Japan, the displacement of the 32-m antenna at Tsukuba was modeled by splines, as was done earlier for Fairbanks and the TIGO antenna at Concepción. Constraints were applied to the 295 ICRF2 defining sources (no-net rotation) and to 24 stations (no-net rotation and no-net translation of positions and velocities). We used the latest version of the Calc/Solve geodetic VLBI analysis software package. More details can be found at

http://ivsopar.obspm.fr/earth/glo

Diurnal sessions were analyzed routinely within 24 hours after their version 4 databases were submitted to the IVS. The operational solution was aligned to the opa2012a global solution. Unconstrained normal equations relevant to EOP, rates, and station and source coordinates were sent to the IVS in SINEX format for combination in the framework of the IVS analysis coordinator's task.

An operational solution analyzing Intensive sessions after 2006, started in 2011, was also continued (opa2011i) together with corresponding SINEX files. The solution opa2011i processed Intensive sessions in order to produce UT1 consistent with VTRF 2008A, ICRF2, and the IERS EOP 08 C 04 Earth orientation data.

All the above products, except SINEX files, were also published on the OPAR Web site. The SINEX files were only sent to the data centers.

2. Other Products and Improvements of the Web Site

Station and radio source coordinate time series were also updated. For each source, a page displays the time series and provides links to source information at various external databases (e.g., the French Virtual Observatory software package Aladin that provides the optical counterpart of the VLBI quasars, or the Bordeaux VLBI Image Database that gives the VLBI structure). In late 2012, we used Google's application programming interface (API) to insert Google Earth and Google Sky views in our Web pages to display telescopes and radio sources on Earth and sky maps. These features are available in the sections 'Radio Sources' and 'Stations' of the OPAR Web site.

We used also the *dygraphs* JavaScript visualization library to plot recent EOP data and TIGO and Tsukuba coordinates. This interface offers interactive, zoomable charts of the time series, so that the user can easily manipulate, explore, and interpret them.

3. Follow-up of Various Phenomena

3.1. Assessment of R&D Sessions Including Observations Close to the Sun

In late 2011, the IVS decided to re-observe quasars at low angular distances to the Sun, typically lower than 15° (whereas this lower limit has been imposed on all schedules since 2002). These observations were scheduled during R&D experiments, at a rate of about 5 to 10 sources out of a total of a hundred sources observed in the session, in order to check that they do not degrade the other VLBI products.

In dedicated pages on the OPAR Web site, the R&D experiments are analyzed with a standard parameterization as used for the operational analysis. The Calc/Solve analysis software package is used in independent mode. All Earth orientation parameters (EOP) and rates are estimated as session parameters together with station and source coordinates. To avoid degeneracy of the solution of the system of equations, no-net rotation and no-net translation conditions are applied to the station coordinates (with respect to VTRF 2008A), excluding TIGO at Concepción and the Japanese stations within the Tokyo area because of the strong 2010 and 2011 earthquakes. For similar reasons, a loose no-net rotation condition ($\sigma = 2$ mas) is applied to the source coordinates with respect to ICRF2, excluding the 39 sources which needed special handling in the ICRF2 work. Troposphere parameters are estimated every 20 minutes and gradients every six hours. Clock parameters are estimated every 30 minutes. The post-Newtonian parameter γ is fixed to unity. The results of the analysis of nine R&D sessions (November 2011 to September 2012) can be seen at

http://ivsopar.obspm.fr/rd

This analysis work will be continued for all upcoming R&D sessions that observe sources close to the Sun.

3.2. Free Core Nutation

The free core nutation (FCN) is a free oscillation of the Earth's figure axis in space due to the presence of a liquid core rotation inside the viscoelastic mantle. Its period is close to 430 days and is retrograde. Understanding the excitation of the FCN and its amplitude and phase variations is still an open question, although the community generally believes that the key resides in improved

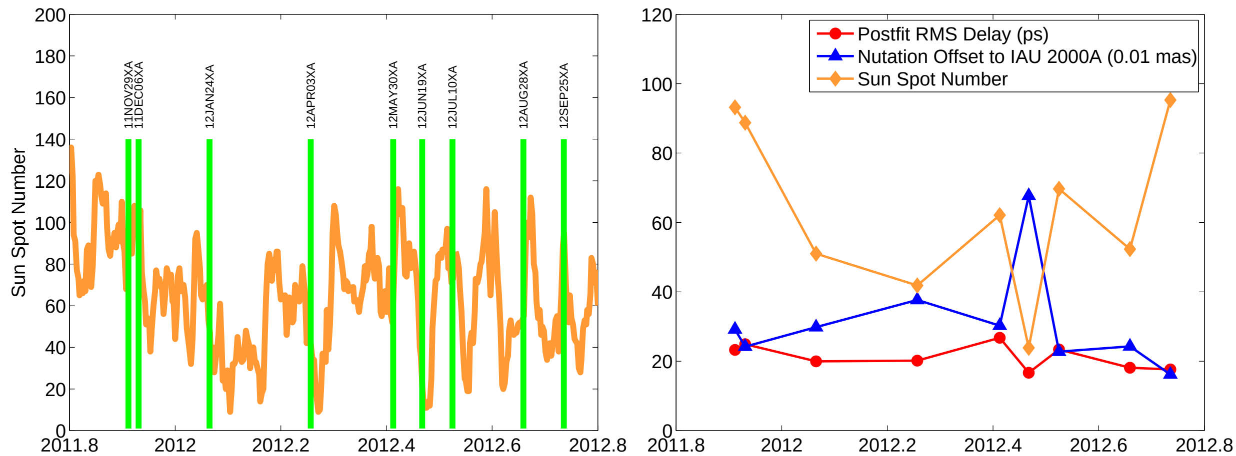

Figure 1. Left: the Sun Spot Number as given by the Solar Influence Data Center (SIDC) at Royal Observatory of Belgium, and the IVS R&D experiments. Right: the postfit RMS delay and nutation offsets to IAU 2000A estimated from the R&D sessions, along with the Sun Spot Number.

atmospheric and oceanic circulation modeling at diurnal and subdiurnal frequencies. At OPAR, we maintain a FCN model directly fitted to routinely estimated nutation offsets (Figure 2).

In addition to the FCN, amplitudes and phases of a set of 42 prograde and retrograde tidal waves are also fitted to the data. These tidal terms are interpreted as small deficiencies of the IAU 2000A nutation model. More explanations and material can be found at

http://ivsopar.obspm.fr/nutation

3.3. Huge Post-seismic Displacements

Still using the routinely analyzed diurnal sessions, we monitored the displacements of the station of TIGO at Concepción after the 27 February 2010 earthquake and of the radio telescope at Tsukuba after the 11 March 2011 earthquake. Figure 3 displays the East coordinates of the two sites with respect to the mean position as given in the VTRF 2008A. The monitoring is continued at

http://ivsopar.obspm.fr/eq

4. Staff Members

Staff members who contributed to the OPAR analysis and data centers in 2012 are listed below:

- Sébastien Lambert, Analysis Center manager, responsible for data analysis, development of GLORIA analysis software,
- Christophe Barache, Data Center manager, data analysis,
- Daniel Gambis, responsible for the IERS Earth Orientation Center, interface with IERS activities.

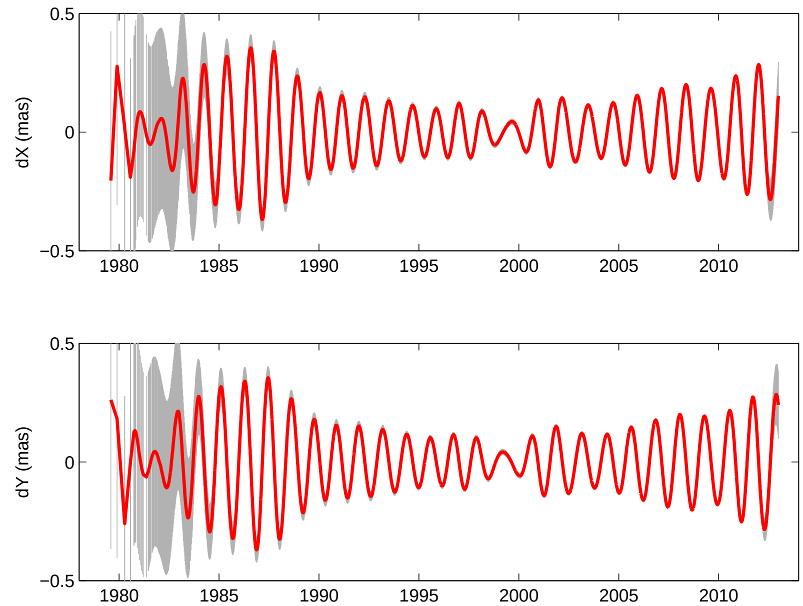

Figure 2. The free core nutation fitted to opa2012a nutation offset time series with respect to the IAU 2000A nutation and IAU 2006 precession models.

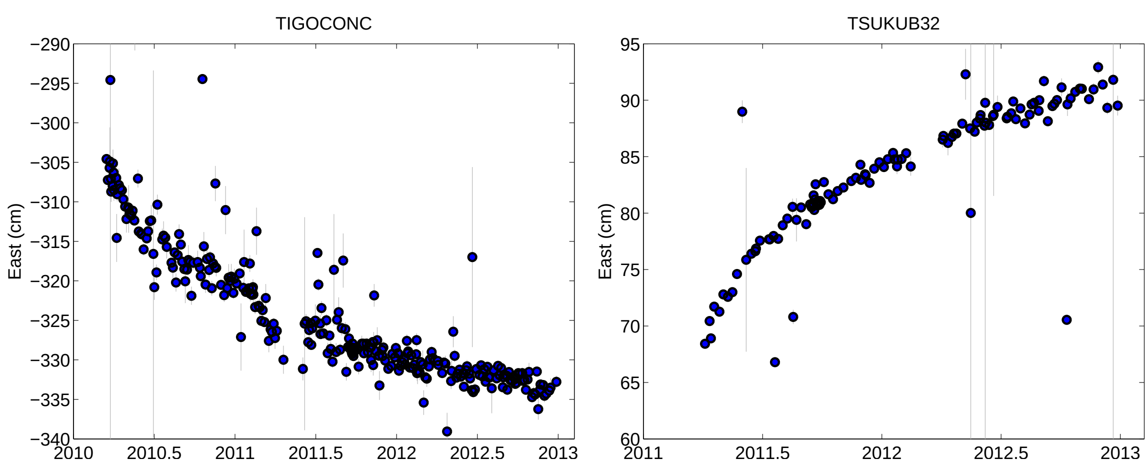

Figure 3. The East coordinates of the TIGOCONC and TSUKUB32 antennas with respect to the VTRF 2008A solution.

Onsala Space Observatory – IVS Analysis Center

Rüdiger Haas, Hans-Georg Scherneck, Gunnar Elgered, Tong Ning, Johan Löfgren

Abstract

This report briefly summarizes the activities of the IVS Analysis Center at the Onsala Space Observatory during 2012 and gives examples of results of ongoing work.

1. Introduction

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 complementary techniques.

2. VLBI and GPS Frequency Link Stabilities

We analyzed the two continuous campaigns CONT08 and CONT11 to study the frequency link stabilities that can be achieved today with VLBI and GPS [1], [2]. Our analysis shows that VLBI and GPS perform today equally well for frequency comparisons. We achieved overlapping Allan Deviations for 1 day on the order of $1.2 \cdot 10^{-15}$ and better, and the VLBI and GPS derived frequency estimates agree in most cases with common clocks at a level of $5 \cdot 10^{-16}$. As an example, Figure 1 depicts the overlapping Allan Deviations for CONT11. The residual phase differences in a root-mean-square sense were on the order of 100 ps. The result is that VLBI is an interesting alternative for frequency transfer since it is completely independent of the usual techniques applied. The upcoming VLBI2010 system could thus be of interest for continuous time and frequency transfer.

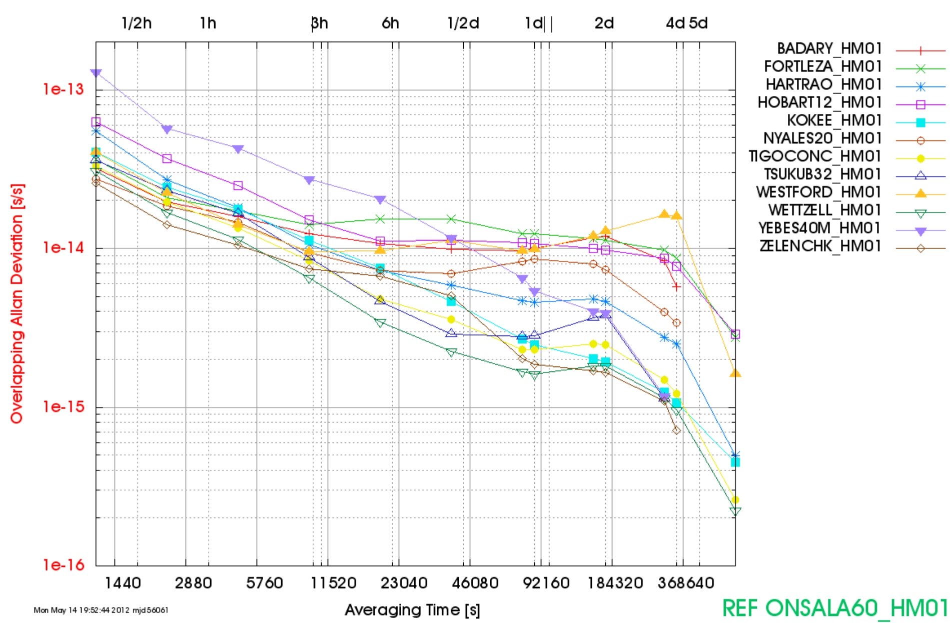

Figure 1. Frequency link instability for CONT11. The reference clock is the H-maser at Onsala.

3. Atmospheric Water Vapor from CONT Campaigns

We analyzed the four continuous campaigns CONT02, CONT05, CONT08, and CONT11 and compared the atmospheric water vapor results derived from the co-located equipment available at the participating stations [3]. All VLBI stations contributing to the CONT campaigns are co-located with GPS stations, and several of the stations also operated water vapor radiometers (WVR) during the CONT campaigns, see Table 1.

Table 1. Co-located instrumentation (V - VLBI, G - GPS, W - water vapor radiometer), operated at the stations contributing to the four continuous campaigns CONT02, CONT05, CONT08, and CONT11.

Station	continuous campaign											
	CONT02			CONT05			CONT08			CONT11		
Hartebeesthoek (South Africa)	V	G		V	G	W	V	G		V	G	
Kokee Park (Hawaii, USA)	V	G	W	V	G	W	V	G		V	G	
Ny-Ålesund (Svalbard, Norway)	V	G		V	G		V	G		V	G	
Onsala (Sweden)	V	G	W	V	G	W	V	G	W	V	G	W
Westford (Massachusetts, USA)	V	G		V	G		V	G		V	G	
Wettzell (Germany)	V	G	W	V	G	W	V	G		V	G	
Algonquin Park (Canada)	V	G		V	G	W						
Gilcreek (Alaska, USA)	V	G		V	G							
Svetloe (Russia)				V	G		V	G				
Tigo Concepción (Chile)				V	G		V	G		V	G	
Tsukuba (Japan)				V	G	W	V	G	W	V	G	W
Medicina (Italy)							V	G				
Zelenchukskaya (Russia)							V	G		V	G	
Fortaleza (Brazil)										V	G	
Hobart (Tasmania, Australia)										V	G	
Yebes (Spain)										V	G	

In general, we found good agreement between the zenith wet delay (ZWD) results derived from VLBI and GPS for all stations in all four CONT campaigns. The biases are on the order of ±5 mm, and the standard deviations are on the order of $5-10$ mm. The biases are however not constant for a given station, but vary from campaign to campaign. The comparison between VLBI and WVR is heavily dependent on the WVR instrument operated. The Onsala Space Observatory is the only station that had three co-located techniques for all four CONT sessions. The comparison between VLBI and WVR at Onsala showed biases on the order of $1-5$ mm and standard deviations on the order of $5-15$ mm. As an example, Figure 2 shows times series of zenith wet delay (ZWD) values derived from the co-located techniques at Onsala for all four CONT campaigns.

4. Ocean Tide Loading

The Automatic Ocean Tide Loading service has been moved to a new machine and can now be found at `http://holt.oso.chalmers.se/loading`. There have only been slight improvements during 2012, such as to the graphics display.

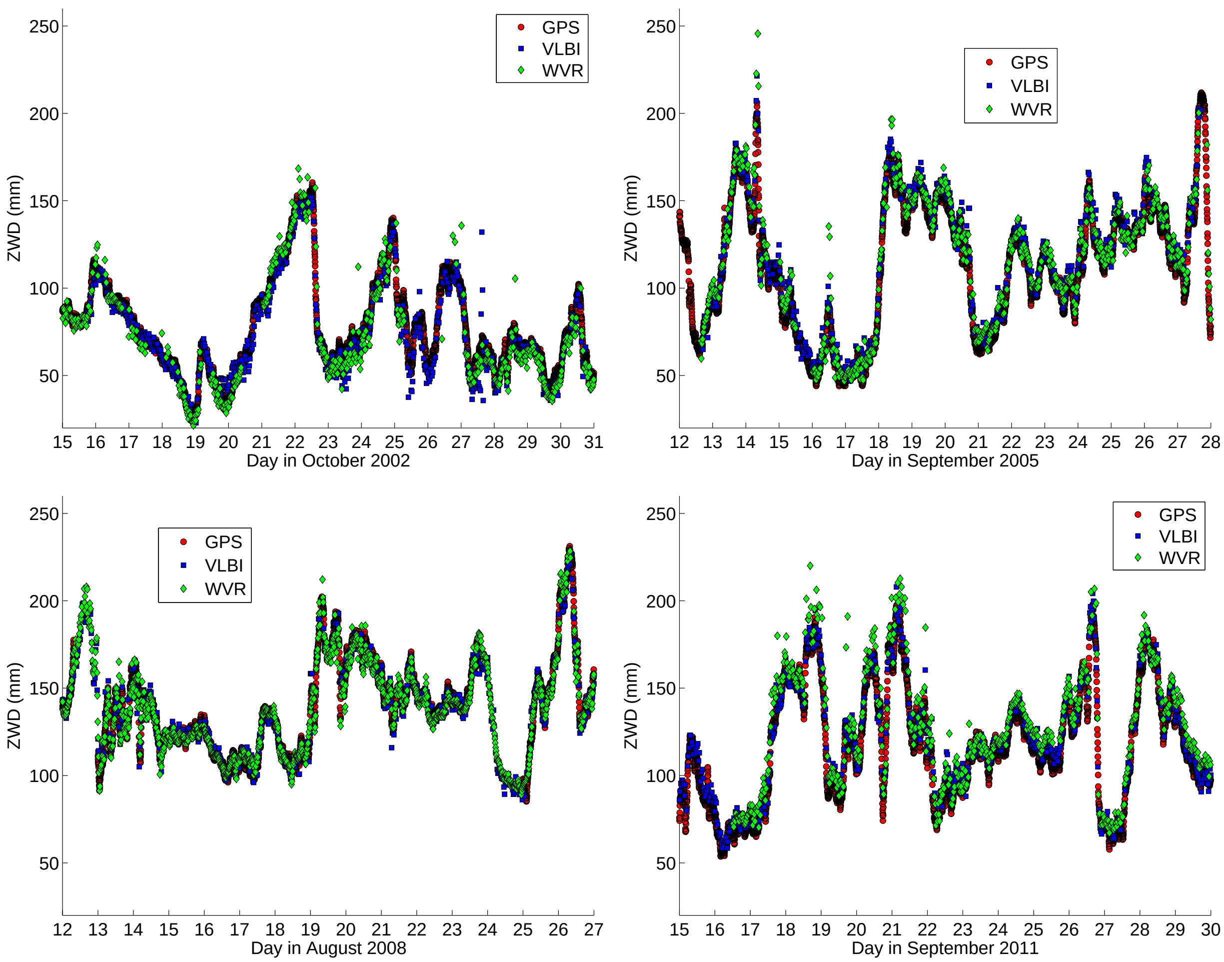

Figure 2. Zenith Wet Delay (ZWD) values derived from the co-located techniques GPS (red dots), VLBI (blue squares), and WVR (green diamonds) at Onsala for the continuous campaigns CONT02, CONT05, CONT08, and CONT11.

5. Gravimetric Laboratory

The Superconducting Gravimeter GWR 054 has been running without interruption during 2012. Since December 2012, one-second data has been available through a monitoring Web interface with a maximum latency of two minutes. The address is `http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html`, see Figure 3.

From June 6 to September 11 a calibration project with Leibniz University Hannover, Germany, was carried out. A portable ZLS Burris gravimeter was operated continuously in parallel with the GWR 054. The portable meter was calibrated before and after the project on the calibration line in Hannover. The result was somewhat disappointing because the GWR 054 calibration factor was achieved at a similar precision level as previous calibration attempts by short, parallel recordings with an absolute FG5 gravimeter.

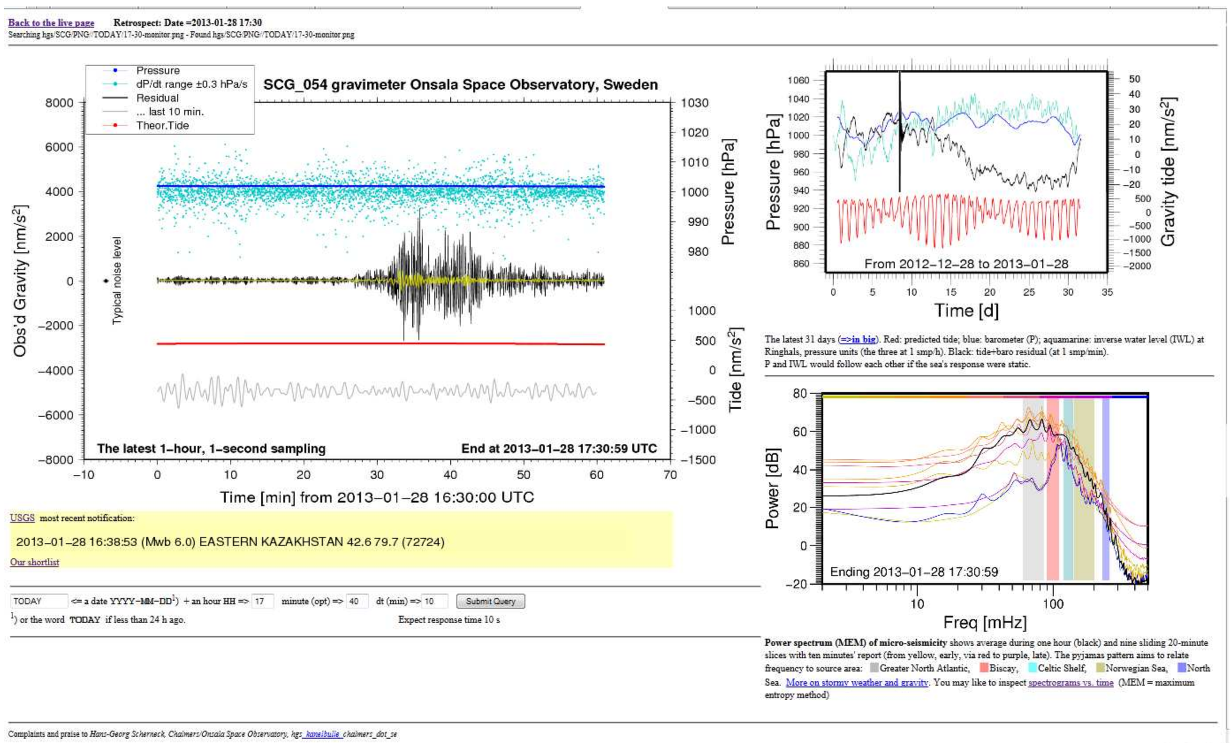

Figure 3. http://holt.oso.chalmers.se/hgs/SCG/monitor-plot.html, the monitoring site for the Superconducting Gravimeter at Onsala with links to power spectrograms, earthquake information, and numerical data. Earlier segments of the data can be visualized interactively.

6. Outlook

The IVS Analysis Center at the Onsala Space Observatory will continue its efforts to work on specific topics relevant to space geodesy and geosciences. For the future we plan to intensify our activities, in particular concerning horizontal gradients in the atmosphere using VLBI, GNSS, and radiometers.

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PMD IVS Analysis Center

Vincenza Tornatore

Abstract

The main activities carried out at the PMD (Politecnico di Milano DIIAR) IVS Analysis Center during 2012 are briefly higlighted, and future plans for 2013 are sketched out.

We principally continued to process European VLBI sessions using different approaches to evaluate possible differences due to various processing choices. Then VLBI solutions were also compared to the GPS ones as well as the ones calculated at co-located sites.

Concerning the observational aspect, several tests were performed to identify the most suitable method to achieve the highest possible accuracy in the determination of GNSS (GLOBAL NAVIGATION SATELLITE SYSTEM) satellite positions using the VLBI technique.

1. General Information

The Department DIIAR (Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture viarie e Rilevamento) belongs to the Technical University of Milan (Politecnico di Milano). The 'Rilevamento' research unit deals with various areas of research that concern, e.g., classical topography and photogrammetry surveying, numeric cartography, GIS (Geographic Information Systems) data processing, remote sensing, GNSS static and real time positioning, and mathematical and physical geodesy (space geodesy included). In this framework, the PMD IVS AC and the IAG (International Association of Geodesy) Service: IGES (International Geoid Service) are hosted and operated.

DIIAR continues to support all office supplies, hardware, and personnel necessary to manage the PMD IVS AC since its establishment in October 2010 [1]. Part of the work here described was developed also with the support of MIUR (Ministry of Education, University, and Research) under the framework of a project with considerable national interest.

2. Current Status and Activities

All the European sessions available since 1990 through the end of 2011 have been processed under the same modeling conditions and analogous parameterizations. To calculate solutions, we used the VieVS (Vienna VLBI Software) software [2] developed by the members of the VLBI group of the Institute of Geodesy and Geophysics (IGG) at the Vienna University of Technology (TU Wien).

Among the different approaches used to process European sessions, we report on the investigations made on seven VLBI stations that had longer historical data series and were co-located with GPS stations. The period used in this preliminary study starts in 1993 and ends in 2007. European site coordinates and baseline lengths (with respective variance-covariance matrices), have been estimated to study their temporal evolution. The adjustments were performed using the single session approach. The baseline lengths, used to infer European crustal deformations, were calculated with respect to the Wettzell station due to its stable position in the European network and its barycentric location with respect to the other six stations selected for the study (Onsala, Ny-Ålesund, Madrid, Medicina, Matera, and Noto).

The results were compared with those calculated in another previously performed study [3].

The principal crustal motions identified in that work were post-glacial rebound in Northern Europe (baseline Wettzell-Ny-Ålesund) and compression motion in southern Europe (baselines of Wettzell with the Italian stations). These motions were also confirmed by our investigations.

Another analysis of GPS and VLBI time series was performed on the velocities estimated by a least squares adjustment for each of the seven selected VLBI European stations using a linear trend as a deterministic model. Once the estimated trend was removed, the method of Empirical Covariance [4] was applied to the residuals, to look for the presence of a possible residual signal; it was found only for the Matera, Medicina, Noto, and Wettzell GPS stations, but not for the co-located VLBI ones. This difference in behavior between the VLBI and the GPS time series was reported also in other studies, e.g. [5], that made the comparisons using the SLR series also, and residual correlation was not found in the SLR time series either. According to these studies, it is possible to confirm that the presence of residual correlation in the GPS series does not indicate possible geophysical reasons but could instead be related to intrinsic GPS data processing.

During 2012, a strong activity to realize observational tests of GLONASS satellites with VLBI techniques took place. In contrast to previous years, when only two VLBI stations (Medicina and Onsala) were used during the tests (see for example [6] and [7]), another VLBI antenna, Noto, was added to increase data redundancy and to make it possible to cross-check among different baselines. Data are still undergoing processing, but one of the main problems that was found is related to a strong emitted satellite signal that entered through the secondary lobes during the observation of a nearby calibrator (a natural radio source). Usually natural calibrators have a flux lower than that of the GNSS satellites by about six orders of magnitude. Therefore the contamination due to the caught satellite signal made the data from the calibrator, which had been observed with the aim of correcting main systematic effects that were corrupting satellite observations, useless also.

3. Future Plans

Completion of the study described for European time series of baselines and site coordinates for data analysis is foreseen. A comparison with results of other ACs also involved in the studies of Europe campaigns would be worthwhile. The upgrade to the new VieVS version 2.0 is devised, and comparisons with results obtained with the previous VieVS version are also foreseen.

Concerning the problem of the observation of GNSS satellites through the VLBI technique, one objective is to use the same experience gained for GLONASS satellite observations to observe also the GPS constellation. The installation under the FS (Field System) of software dedicated to satellite tracking is of very high priority.

Simulations to evaluate the best procedure to be followed to observe GNSS satellites and nearby natural calibrators are also under development to gain the possibility of using the precious information coming from calibrator observations to correct systematic effects common to the satellites and the calibrators in L-band.

Acknowledgements

The work described was in part performed under the national Project PRIN 2008 'Il nuovo di sistema di riferimento geodetico italiano: monitoraggio continuo e applicazioni alla gestione e al controllo del territorio'.

The author wishes to thank the International VLBI Service for Geodesy and Astrometry (IVS) for coordinating the EUROPE campaigns and providing the data.

The VLBI satellite observations are based from Medicina and Noto radio telescopes, operated by INAF, Istituto di Radioastronomia, Italy, and the Onsala85 radio telescope, operated by the Swedish National Facility for Radio Astronomy, Sweden. The author thanks the personnel at the VLBI stations of Medicina, Noto, and Onsala25, and the processing center at the Joint Institute for VLBI in Europe (JIVE) for supporting the experiments.

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Pulkovo IVS Analysis Center (PUL) 2012 Annual Report

Zinovy Malkin, Julia Sokolova

Abstract

This report briefly presents the PUL IVS Analysis Center activities during 2012 and plans for the coming year. The main topics of the investigations of PUL staff in that period were ICRF related studies, computation and analysis of EOP series, celestial pole offset (CPO) modeling, and VLBI2010 related issues.

1. General Information

The PUL IVS Analysis Center (AC) was organized in September 2006 and 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).
- Computation and analysis of the Earth orientation parameters (EOP) from Intensives and 24-hour IVS sessions.
- Modeling of the celestial pole offset (CPO) and free core nutation (FCN).
- Comparison of VLBI products, primarily as Earth orientation parameters (EOP), with results of other space geodesy techniques.
- Computation and analysis of observation statistics.

The PUL AC's Web page [2] is supported. It contains the following sections:

- *General Information on the PUL AC.* Includes brief history, activity overview, and a scientific staff list.
- *VLBI data analysis.* Includes results of VLBI data analysis, such as UT1 Intensive series, CPO/FCN series, and mean Pole coordinates. These data are updated daily.
- *OCARS catalog.* Includes the latest version of the catalog of optical characteristics of astrometric radio sources (OCARS) [3]. The catalog is continually updated as new information becomes available.
- *Approaches and occultations.* Includes tables for forthcoming mutual events of planets and astrometric radio sources, such as close angular approaches and occultations for the period until 2050 [4].
- *PUL members' publications and presentations.*
- *VLBI technology overview.*
- *Links to the VLBI World.* Includes links to (primarily geodetic and astrometric) VLBI coordinating bodies, stations, analysis centers, software, etc.
- *Contact information.*

2. Scientific Staff

In 2012 the following persons contributed to the PUL activity:

1. Zinovy Malkin (70%) — PUL coordinator, EOP and CRF analysis;
2. Natalia Miller (5%) — EOP analysis;
3. Julia Sokolova (100%, since August 2012) — CRF analysis.

3. Activities and Results

The main activities and results of the PUL IVS Analysis Center during 2012 included:

- Operational processing of the IVS Intensive sessions in automated mode and submission of results to IVS was continued.
- ICRF related research was continued. The main directions of this activity were comparison and combination of radio source catalogs and investigation of their stochastic and systematic errors. In 2012, the following results were obtained.
  - A new Pulkovo combined catalog was computed [5]. Using CRF realizations from seven IVS ACs (bkg, cgs, gsf, igg, opa, sha, and usn) we computed two combined catalogs PUL(2012)C01 and PUL(2012)C02. Besides using more data, several developments were realized as compared with the previous version of Pulkovo combined catalog of 2007 [6]. The PUL(2012)C01 catalog is constructed in the ICRF2 system and is aimed at improvement of the ICRF2 random errors, and the PUL(2012)C02 catalog is constructed in an independent system and thus provides both stochastic and systematic improvement of the ICRF2.
  - Several related studies were conducted [7, 8].
- CPO and FCN related researches. The main activities and results in 2012 were the following.
  - Two CPO and two FCN series were updated daily and made available at the PERSAC Web site. One CPO and one FCN series were started at the end of 2012.
  - Comparison of several CPO series were made from the eight individual ones computed at IVS ACs (aus, bkg, cgs, gsf, iaa, opa, sopu, and usn) and combined solutions of IVS and IERS (C04 and NEOS) [9]. It has been shown that significant random and systematic errors beween these series do exist and in turn lead to differences and inconsistencies between results of users' applications. This situation requires clear IVS and IERS recommendations on using different CPO series.
  - Joint analysis of the Polar Motion and CPO time series was made along with time series of two geomagnetic indices, Kp and Dst [10]. Two groups of common principal components (PCs) were found: trends, and quasi-harmonic terms with near-Chandlerian frequencies for PM, Kp, and Dst series, and near-FCN frequency for CPO series (both periods are near 430 days). Comparison of the spectra of the investigated series and their amplitude and phase variations showed some interesting common features. However, the obtained results are still not sufficient to quantify the effects of interconnections of the Chandler Wobble (CW), FCN, and the geomagnetic field.

- Investigations of the impact of the Galactic aberration on the ICRS realization and EOP were continued in cooperation with Paris Observatory and Nanjing University [11, 12]. It was shown that the effect of the Galactic aberration strongly depends on the distribution of the sources that are used to realize the ICRS. According to different distributions of sources the amplitude of the apparent rotation of the ICRS is between about 0.2 and 1 μas/yr. This rotation has no component around the axis pointing to the Galactic center and has zero amplitude in the case of uniform distribution of sources. The effect on the coordinates of the Celestial intermediate pole (CIP) is between about 1 to 100 μas/cy, and the effects on the Earth rotation angle (ERA) are from four to several tens of μas/cy.
- Studies have been conducted in the framework of the IAG SC 1.4 activity on investigation of the mutual impact of celestial and terrestrial reference frame and related issues such as systematic errors of the ICRF, impact of astronomical and geophysical modeling on the CRF and TRF results, and future prospects of improvement of the ICRF systematic accuracy [13, 14, 15].
- The work on the OCARS catalog [3] was continued. The current basic statistics of the catalog are the following.

	OCARS	ICRF2	ICRF2 def.
Sources	7174	3414	295
Sources with known redshift	3927 (54.7%)	2199 (64.4%)	257 (87.1%)
Sources with known magnitude	4861 (67.8%)	2589 (75.8%)	284 (96.3%)

- A catalog of approaches of planets to radio sources and occultations of astrometric radio sources by planets through the year 2050 was updated [4].
- The PUL archive of VLBI data and products is supported. At present, all available databases and corresponding NGS cards for 1979-2012 have been stored (about 9.4 million observations) along with the main IVS and IERS products. These archives are continually updated as new databases becomes available.
- Development of algorithms and software for data processing and analysis continued.
- PUL staff members participated in activities of several IERS, IAG, and IVS projects, committees, and working groups.

4. Outlook

Plans for the coming year include:

- Continue VLBI related studies.
- Continue UT1 Intensive processing.
- Continue OCARS catalog support.
- Continue development of algorithms and software for data processing.
- Continue support of the PUL archives of data and products.

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SAI VLBI Analysis Center Report 2012

Vladimir Zharov

Abstract

This report presents an overview of the SAI VLBI Analysis Center activities during 2012 and the plans for 2013. The SAI 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 VLBI Analysis Center is located at Sternberg State Astronomical Institute of Lomonosov Moscow State University in Moscow, 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 Radioastron mission.

2. Component Description

SAI AC performs data processing of all kinds of VLBI observation sessions. For VLBI data analysis we use the ARIADNA software package developed at SAI. Version 4 was finished and tested in 2012. All reductions are performed in agreement with the IERS Conventions (2010).

The package uses files in the NGS format as input data.

The ARIADNA package (v. 4) is the basis of software named ORBITA installed on the correlator of the AstroSpace Center of Lebedev Physical Institute. It is used for correlation of the ground-space interferometer data during the Radioastron mission.

3. Staff

- Vladimir Zharov, Professor: development of the ARIADNA software, development of the methods of parameter estimation;
- Dmitry Duev, post-graduate student: VLBI data processing, troposphere modeling;
- Nikolay Voronkov, scientific researcher: global solution;
- Svetlana Nosova, engineer: VLBI data processing;
- Natalya Shmeleva, engineer: VLBI data processing.

4. Current Status and Activities

- **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. Version 4 was developed in 2012. The main features of this version are the performance of all reductions in agreement with the IERS Conventions (2010), the generation of the SINEX files, and the combination of some of the SINEX files to stabilize solutions.

A new model for delay was developed for the ground-space interferometer. It was realized as software ORBITA, which is used for correlation and routine analysis of the Radioastron observations.

- **Routine Analysis**

  During 2012 the routine data processing was performed with the ARIADNA software using the least-squares method with rigid constraints, and non-rigid constraints were used for generation of SINEX files.

  SAI AC operationally processed the 24-hour and Intensive VLBI sessions. Creation of databases of the VLBI sessions and processing of all sessions is fully automated. The EOP series sai2012a.eops and sai2012a.eopi were calculated. These series were computed with the catalog VTRF2008 of station positions and velocities. Experimental series sai2012b.eops was calculated with the experimental catalog of radio sources with non-zero velocities. New EOP series will be used in 2013 for generation of new nutation series.

- **Global Solution**

  An experimental catalog of the radio source positions and velocities was obtained by N.Voronkov.

- **Troposphere Modeling**

  At the stations with the meteorological data missing, we used surface data files (temporal coverage: four times daily, spatial coverage: 2.5 degrees latitude x 2.5 degrees longitude global grid) from NCEP/NCAR Reanalyzes (http://www.cdc.noaa.gov/data/gridded/data.ncep.reanalysis.surface.html) for calculating air temperature, pressure, and relative humidity. For that purpose a program was written to interpolate these data to the given coordinates of the station at the time of observations.

  This method was used for generation of air temperature, pressure and relative humidity for the ground stations that participate in observations with the space radio telescope.

SHAO Analysis Center 2012 Annual Report

Guangli Wang, Jinling Li, Minghui Xu, Li Guo, Li Liu, Fengchun Shu, Zhihan Qian, Liang Li

Abstract

The Shanghai Astronomical Observatory (SHAO) Analysis Center in 2012 continued routine VLBI data analysis and produced earth orientation parameter (EOP), terrestrial reference frame (TRF), and celestial reference frame (CRF) information, which was submitted to the IVS quarterly. The activities of SHAO also consisted of data reduction of the Chinese VLBI Network (CVN), spacecraft navigation using the VLBI technique, and some research activities.

1. General Information

SHAO is responsible for the data processing and analysis of the CVN sessions which aim to monitor the crustal movement of the Chinese Mainland. This work includes the computation of the group delay and the analysis of these observations. Quarterly solutions of the IVS 24hr sessions were conducted to generate the time series of EOP and to realize the TRF and CRF. The software used for VLBI data analysis is Calc/Solve, released on 21 May 2010 [1]. We tried to model the movement of TIGOCONC after the big earthquake in Chile, and added the modeling into the Calc/Solve software. As in 2010 and 2011, SHAO continued to conduct the real-time navigation of the ChangE-2 (CE-2) satellite using the VLBI technique [2]. Research topics are outlined in Section 3. The members involved in these activities are Guangli Wang, Jinling Li, Minghui Xu, Li Guo, Li Liu, Liang Li, Fengchun Shu, and Zhihan Qian.

2. Activities and Data Analysis at SHAO

SHAO is in charge of the CVN and is an Analysis Center of the IVS. Routine VLBI activities at SHAO included:

-Data processing and analysis of the CVN geodetic experiments

The related work contains the calculation of the delay and delay rate of the CVN observations at every band, resolving group delay ambiguities, and computation of ionosphere calibrations. In addition, SHAO is responsible for the generation of the VLBI group delay in the NGS format and for the analysis of all CVN sessions by the software *shops*, which has been developed based on the software $OCCAM6.1E(Linux)$ with modifications mainly to VLBI data processing models.

-Regular data analysis of the IVS 24h sessions and product submission

We continued to routinely analyze all IVS 24h sessions using the Calc/Solve software, and during this year we regularly submitted our analysis products (EOP, TRF, and CRF) to the IVS Data Centers. For the movements of stations after earthquakes, especially for core stations such as TIGOCONC, modeling of the movements was built and added into the software.

-Analysis of EOP Determination via the Chinese VLBI Network

The EOPs are determined from the IVS observations in which Sheshan station in Shanghai and Nanshan station in Urumqi were involved. The precision is comparable to that of the IERS

EOP series. The current precision of UT1 determined from single baseline observations of the two stations is in the middle level of the international precision. The determination of precisions of UT1 either from the IVS Intensive sessions in 2011 with Sheshan included or from international EOP observations with the two stations included, meets the requirements of the 100-m positioning precision of the satellite of Mars to UT1 [3].

3. Research Topics at SHAO

3.1. Determination of the Solar Acceleration

Due to the acceleration of the known Solar system barycenter (SSB), the velocity vector of the origin of the International Celestial Reference System (ICRS) [4] is no longer constant but varies with time, which consequently causes a systematic variation in the direction of the observed object. This phenomenon is referred to as the secular aberration drift [5]. Based on the relationship between this effect and the acceleration of the SSB, the acceleration can be determined directly from VLBI measurements without any available kinematic or dynamic models of the Milky Way.

We developed two approaches to estimate the acceleration vector. One is to treat the Solar acceleration vector as a global parameter, which we call the global solution. The second method is to estimate the time series of the velocity variations through the solution and fit the acceleration from the time series. Although the latter method lacks the ability to effectively separate the velocity from other error sources, such as the influences of the position errors of the radio sources, the time series solution can clearly show the details and trends of the velocity variations of the SSB, and it can be taken as a validation for the first method. In total, 4,632 sessions, 3,492 radio sources, and approximately 7,100,000 group delay observables were analyzed.

We obtained the acceleration vector in the three components in the Galactic coordinate system (7.47±0.46, 0.17±0.57, 3.95±0.47) $mm{\cdot}s^{-1}{\cdot}yr^{-1}$ [6,7]. Figure 1 shows the velocity variation time series and the acceleration. The result from the two methods are consistent with each other. Traditionally it was generally believed that the acceleration component in the direction normal to the Galactic plane was too small to be detected and thus the acceleration vector should nearly point to the Galactic center [8], but our results show that the vertical acceleration is notable. And the vertical component is likely to be explained by three potential possibilities. Please refer to our paper [7] for details.

3.2. The Epoch ICRF

Due to the acceleration of the solar system, the radio source positions in the ICRF2 catalog measured by a fictitious observer located at the origin of the ICRS vary with time. It is technically incorrect, then, to state that the ICRF has no dependence on time. We propose the epoch ICRF as a new concept to consider the effect of apparent proper motion of the positions of radio sources. This apparent proper motion has a magnitude of approximately 5.8 microarcseconds (μas) per year, and for the 30-year Very Long Baseline Interferometry (VLBI) observational history these position variations will exceed 100 μas. We show that the dipole structure of the apparent proper motions leads to global rotation in the ICRF2, and the main term, the shift of the direction of the origin of right ascension, reaches 25 μas per century. The epoch ICRF is constructed using epoch positions at J2000.0 and apparent proper motions of radio sources [9]. Figure 2 shows the apparent proper motion field for 295 ICRF2 [10] defining sources.

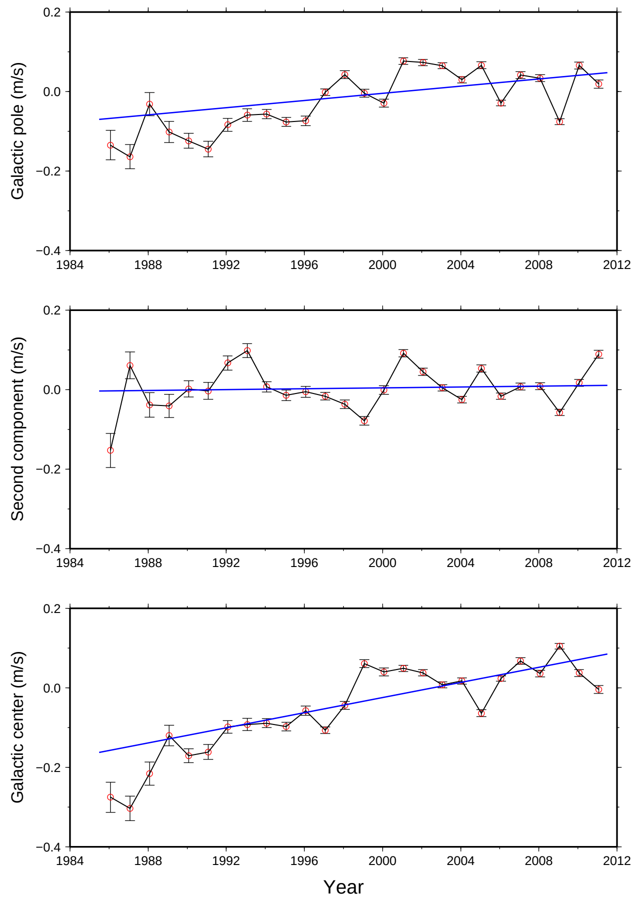

Figure 1. The velocity time series and its linear trend obtained from the time series solution [7].

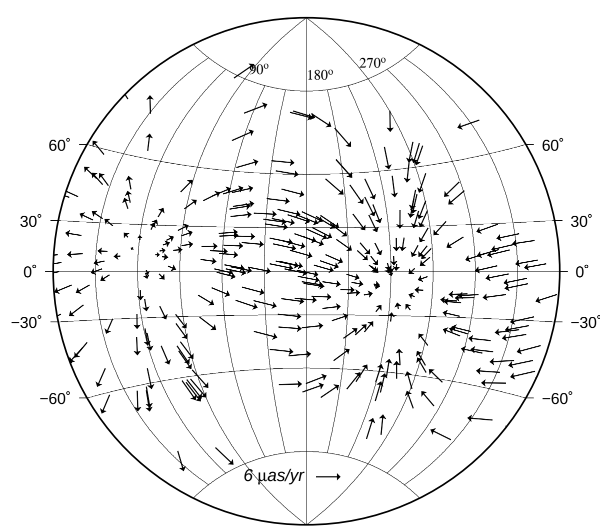

Figure 2. Apparent proper motion field for 295 ICRF2 defining sources based on the model of secular aberration drift [9]. It is plotted in right ascension and declination coordinates.

4. Plans for 2013

We will continue to submit our analysis products to the IVS Data Centers regularly and to develop software to transfer the data format of CVN observations, NGS, to netcdf. The research activities will focus on the effect of the Solar acceleration on the ICRF and the ICRS and on the study of the high frequency variations of EOP using VLBI observations. The processing strategy and treatment of irregularly moving stations, such as TSUKUB32 and KASHIM11 after a big earthquake, will also be considered in the near future.

5. References

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Tsukuba VLBI Analysis Center

Shinobu Kurihara, Kentaro Nozawa

Abstract

The Tsukuba Analysis Center is funded by the Geospatial Information Authority of Japan (GSI). The *c5++* analysis software is regularly used for the IVS-INT2 analysis and the ultra-rapid EOP experiments.

1. Introduction

The Tsukuba Analysis Center located in Tsukuba, Japan, is operated by the Geospatial Information Authority of Japan (GSI). One of our major roles is to analyze the weekend IVS Intensives (INT2) using the fully automated VLBI analysis software *c5++* developed by the National Institute of Information and Communications Technology (NICT) regularly. It should be noted that the dUT1 solution becomes available within a few minutes after the end of the last scan of the session. A 10 Gbps dedicated link to the SINET4 operated by the National Institute of Informatics (NII) and various process management programs enable the rapid dUT1 derivation. In addition, the ultra-rapid EOP experiments consisting of 23 regular IVS 24-hour sessions and three dedicated experiments were implemented.

2. Component Description

2.1. Fully Automated VLBI Analysis Software C5++

c5++, which is a space-geodetic analysis software that handles SLR, GNSS, and VLBI, has been undergoing several modifications and updates by NICT, and it was installed on some hosts at the Tsukuba Analysis Center in the summer of 2012 [1]. Since before then, the program *c5UT1* that has partial functionality of *c5++* has been used and has provided dUT1 solutions for the regular INT2 sessions. The newly installed *c5++* enables flexible parameterization (X-pole, Y-pole, dUT1, nutation, station clocks, and troposphere) and SINEX input/output with the covariance matrix. Currently only two data formats (NGS and KOMB) are supported for analysis, but the import and export of the new IVS Open DB format will be available in the near future, as well as estimation of station and source coordinates and troposphere gradients. Now the *c5++* solutions have been evaluated, and consistency with the current *c5UT1* solutions has been confirmed. *c5++* will start to be used operationally in place of *c5UT1* at the start of 2013.

2.2. Calc/Solve

Calc/Solve has been in continuous use since the early days of VLBI work at GSI. It is used for the analysis of JADE in its interactive mode and for global analysis in its batch mode, which is reserved for our internal use and is not used to generate IVS Analysis Center products.

2.3. Potential to Use VieVS

VieVS, which has been developed by the Institute of Geodesy and Geophysics (IGG) of the

Vienna University of Technology, has already been installed at the Tsukuba Analysis Center, but it has not been made operational yet [2]. *VieVS* is quite interesting VLBI analysis software, having some unique features that are not seen in other software. We would like to start utilizing the features in 2013.

2.4. Analysis Center Hardware Capabilities

Both *c5++* and *Calc/Solve* are installed on some general purpose and commercially-produced Linux computers (Table 1). MATLAB as a platform for VieVS is also available on a host. Individual RAIDs are mounted on each host for storing a lot of VLBI data files, e.g. Mark III databases.

Table 1. Analysis Center hardware capabilities.

Number of servers	four for VLBI analysis (*c5+*, *Calc/Solve*, and *VieVS*)
Operating System	CentOS version 5.2, 5.4, or 5.5
CPU	Intel Xeon 3.80 GHz quad CPU / Intel Xeon 3.00 GHz quad CPU / Intel Xeon 2.83 GHz quad CPU
Total storage capacity	individual RAIDs: 1.22 Tbytes in total

3. Staff

The technical staff members in the Tsukuba Analysis Center are:

- **Shinobu Kurihara**: correlator/analysis chief, software design and development.
- **Kentaro Nozawa** (AES): correlator/analysis operator, software development.
- **Takashi Nishikawa** (AES): correlator/analysis operator.

Kensuke Kokado, who was correlator/analysis chief until the end of May 2012, moved to another division.

4. Analysis Operations

4.1. IVS-INT2

In 2012, 107 IVS-INT2 sessions were correlated at the Tsukuba VLBI Correlator that is also operated by GSI. 83 of them observed the Tsukuba-Wettzell baseline. The observed data at Wettzell is transferred to the correlator in real-time with the VDIF/SUDP protocol. The correlated data is rapidly analyzed by *c5++* as soon as all of the correlator output becomes available, and then a dUT1 solution is derived. Figure 1 shows in how many sessions their analyses are completed within a short latency. Due to some sort of trouble on the station's side, nine sessions are excluded from the total number of sessions. 90% of the total sessions derived dUT1 solutions within four minutes after the end of the last scan, and 50% were within two minutes. The ending time of the IVS-INT2 sessions is 8:30 UT on every Saturday and Sunday. Thus, the dUT1 solution becomes available at 8:40 UT at the latest. This is really an advantage of the Tsukuba Analysis Center.

The eopi file that is a product of the Intensives from the Analysis Center is submitted immediately after the analysis and becomes accessible as an IVS product. The U.S. Naval Observatory (USNO) operates as 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 EOP information sooner than that available in the final EOP series.

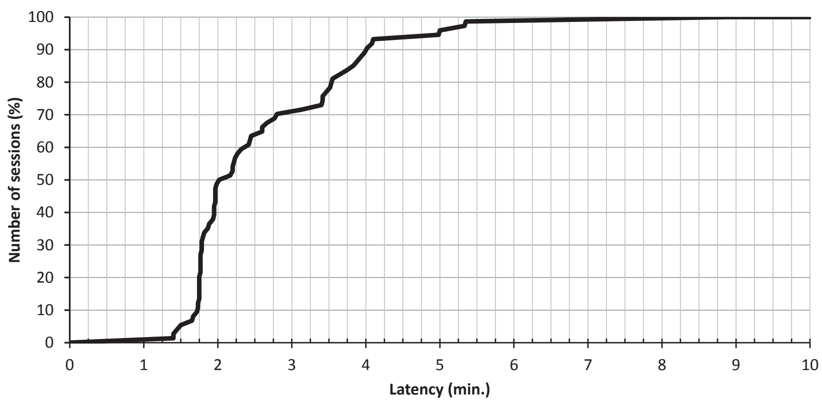

Figure 1. Latency vs. percentage of sessions (out of 74 sessions, excluding nine sessions with some sort of trouble during these sessions).

4.2. Ultra-rapid EOP Sessions

This session type started in 2007 as a joint project of Japan (Tsukuba and Kashima) and Fennoscandia (Onsala and Metsähovi). It aims to derive consecutive time series of EOP as soon as possible taking advantage of the strategy which is that the observed data is sent in real-time via the international optical fiber backbone to Tsukuba, where the data is correlated and analyzed in near real-time. *c5++* is used in the whole analysis (see section 2.1).

Nowadays four countries — Japan, Sweden, Australia, and South Africa — are involved in association with Hobart and HartRAO, which recently joined in 2012. 23 regular IVS 24-hour sessions that involved at least two stations from Hobart, HartRAO, Onsala, and Tsukuba were operated with the ultra-rapid strategy. Eight which were originally scheduled with HartRAO, Onsala, and Tsukuba added Hobart as the fourth station by using the tag-along function of SKED and performed with a four-station/six-baseline network in order to derive not only dUT1 but also two polar motion parameters more accurately with a very low latency by better network geometry.

However, since the regular IVS 24-hour session schedule is optimized for networks consisting of the originally involved stations, the network geometry throughout the whole duration of the experiment does not improve obviously even if Hobart is added. Therefore we planned three dedicated experiments and carried out them from November to December (Table 2).

In particular, the ultra-rapid processing in UR1203, which had a duration of 35 hours, worked very well for most of the time except the periods when some sort of trouble on the station's side happened. Figure 2 presents time series of EOP derived from this experiment. You can see some points with a large error bar and gaps, which might be caused by failure in the analyses in this period.

Table 2. The ultra-rapid EOP experiments with dedicated schedules that are optimized for all involved stations in 2012.

Experiment	Date	Time	Duration	Stations	#obs. (skd)	#obs. (cor)
UR1201	NOV29	18:00	24	HbHtTs	822	382
UR1202	DEC06	18:00	24	HbHtTs	482	363
UR1203	DEC17	07:30	35	HbHtOnTs	1033	846

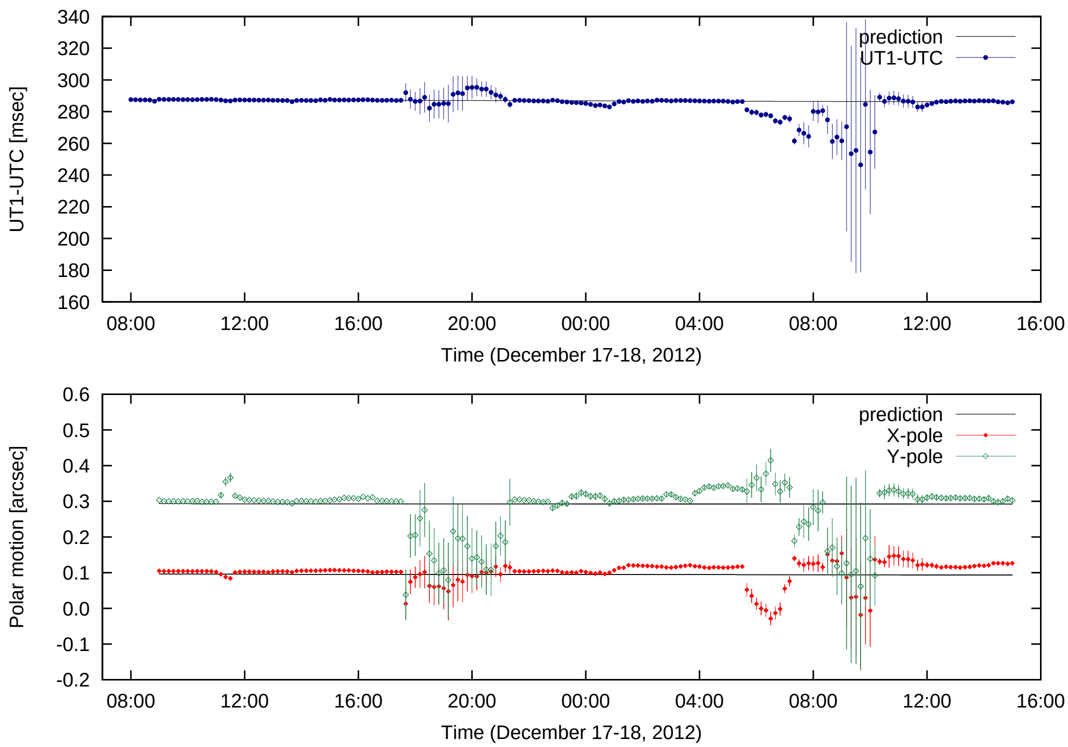

Figure 2. The time series of EOP estimation derived from the UR1203 experiment with the prediction (Rapid Service/Prediction of Earth Orientation, finals2000A.daily).

5. Outlook

Analyses of all INT2 sessions are being performed as in 2011, and dUT1 solutions will be produced with a low latency. In addition, the ultra-rapid EOP experiments will be continued.

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[2] Böhm, J., et al.: The New Vienna VLBI Software VieVS, In Proceedings of IAG Scientific Assembly 2009, *International Association of Geodesy Symposia Series*, **136**, edited by S. Kenyon, M. C. Pacino, and U. Marti, doi: 10.1007/978-3-642-20338-1_126, 1007-1011, 2012.

U.S. Naval Observatory VLBI Analysis Center

David A. Boboltz, Alan L. Fey, Nicole Geiger, Chris Dieck, David M. Hall

Abstract

This report summarizes the activities of the VLBI Analysis Center at the United States Naval Observatory for the 2012 calendar year. Over the course of the year, Analysis Center personnel continued analysis and timely submission of IVS-R4 databases for distribution to the IVS. During the 2012 calendar year, the USNO VLBI Analysis Center produced two VLBI global solutions designated as usn2012a and usn2012b. Earth orientation parameters (EOP) based on this solution and updated by the latest diurnal (IVS-R1 and IVS-R4) experiments were routinely submitted to the IVS. Sinex files based upon the bi-weekly 24-hour experiments were also submitted to the IVS.

During the 2012 calendar year, 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-hour duration Intensive observations were initiated 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. A total of 270 VLBA Intensive experiments were observed and electronically transferred to and processed at USNO in 2012.

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 experiments and 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, the electronic transfer of VLBI data, and software correlation.

2. Current Analysis Center Activities

2.1. IVS Experiment Analysis and Database Submission

During the 2012 calendar year, personnel at the USNO VLBI Analysis Center continued to be responsible for the timely analysis of the IVS-R4 experiments, with the resulting databases submitted within 24 hours of correlation for dissemination by the IVS. Analysis Center personnel continue to be responsible for the analysis and database submission for the periodic IVS-CRF experiments. In 2012, USNO scheduled and analyzed 16 CRF related experiments including IVS-CRF67 through IVS-CRF72, IVS-CRDS56 through IVS-CRDS62, and IVS-CRMS09 through IVS-CRMS11. The analyzed databases were submitted to the IVS. Analysis Center personnel also continued analyzing IVS Intensive experiments for use in the USN-EOPI time series, and they initiated a new series of Intensive sessions using the VLBA antennas at Pie Town, NM and Mauna Kea, HI.

2.2. Global VLBI Solutions, EOP, and Sinex Submission

USNO VLBI Analysis Center personnel continued to produce periodic global TRF/CRF/EOP solutions over the course of the 2012 calendar year. Two solutions (usn2012a and usn2012b) were produced and submitted to the IVS. 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 experiments. The updated EOPS series is submitted to the IVS twice weekly within 24 hours of experiment 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 experiments.

2.3. Software Correlator

Over the course of the 2012 calendar year, Analysis Center personnel continued the implementation, testing, and evaluation of the DiFX software correlator. In March 2012, a contract was awarded to the National Radio Astronomy Observatory (NRAO) for the procurement of a full-up software correlator based on the DiFX software correlator package. In September 2012, Phase I of the software correlator was delivered to USNO. This correlator has two management nodes and 33 compute nodes (with each node having a 2.9 GHz dual-core processor with eight cores per processor for a total of 528 processing cores), and it is capable of simultaneous processing of data from 15 VLBI antennas at a recorded data rate of 2 Gbps at each antenna. Phase II of the software correlator contract is expected to be delivered in 2013 and will double the processing power of the Phase I correlator. Post-correlation calibration and analysis of software correlated data is now routinely performed using the standard geodetic data reduction path including the use of the Haystack Observatory Post-processing System (HOPS) for data calibration and the GSFC CALC/SOLVE package for data analysis.

Analysis Center personnel continue to interface with colleagues from various institutions within the DiFX consortium and attended the DiFX workshop at the ATNF in Sydney, Australia in September 2012. Work continued on a graphical user interface (GUI) to the software correlator. A beta version was released to the user community in June 2012.

2.4. VLBA Intensive Experiments

During the 2012 calendar year, 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 Intensive sessions of one-hour duration were initiated 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.

These VLBA Intensive sessions use the newly available digital backends with sixteen 32 MHz wide channels at a data rate of 2 Gbps. VLBA Intensive sessions run for 40 minutes with approximately 12 seconds per scan on source resulting in roughly 30-35 scans per session. The 12-second scan length allows the data size to be ~100 GB per station per session, which makes for more manageable e-transfers. The VLBA Intensive sessions are correlated on the new USNO DiFX software correlator. Mark IV style output is generated using the difx2mark4 software and the data are fringe-fitted using FOURFIT/HOPS. Geodetic style databases are generated with DBEDIT and analyzed within CALC/SOLVE. A total of 270 VLBA Intensive experiments were observed and electronically transferred to and processed at USNO in 2012. Once fully operational, these VLBA Intensive sessions will be scheduled as IVS-INT4, and data will be released to the IVS for community-wide distribution.

Figure 1 shows the differences between the VLBA MK-PT baseline UT1–UTC results and IERS C04 from October 15, 2011 through January 31, 2012. Differences between IERS C04 and the USN-EOPI and USN-EOPS series are also shown for comparison.

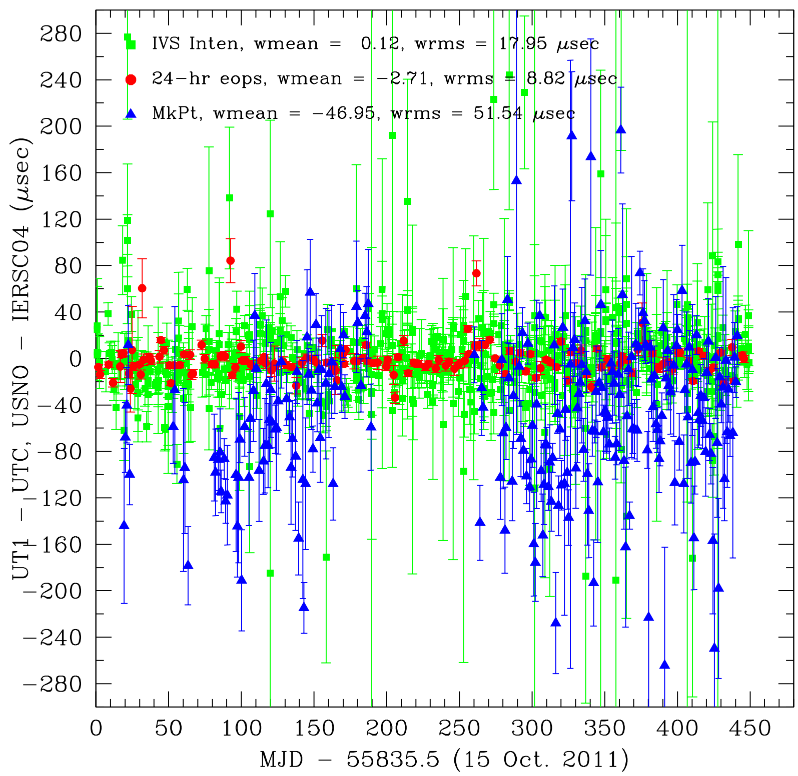

Figure 1. Differences in UT1-UTC between data from the VLBA Intensive test sessions using the MK-PT baseline and IERS C04. Also shown are differences between IERS C04 and both the USN-EOPI and USN-EOPS standard series for comparison. Error bars are 1σ formal uncertainties.

3. Staff

The staff of the VLBI Analysis Center is drawn from individuals in both the Astrometry and Earth Orientation departments at the U.S. Naval Observatory. The staff and their responsibilities are as follows:

Name	Responsibilities
David Boboltz	VLBA Intensive program; software correlator implementation; VLBI data analysis.
Alan Fey	Periodic global CRF/TRF/EOP solutions and comparisons; CRF densification research; software correlator implementation; VLBI data analysis.
Nicole Geiger	software correlator implementation; VLBI data analysis; EOP, database, and Sinex submission.
Chris Dieck	software correlator implementation; VLBI data analysis; EOP, database, and Sinex submission.
David Hall	Hardware correlator interface; software correlator implementation; VLBI data analysis.

4. Future Activities

The following activities for 2013 are planned:

- Continue analysis and submission of IVS-R4 experiments 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 experiments.
- Continue submission of Sinex format files based on the 24-hour experiments and begin production of a Sinex series based upon the Intensive experiments.
- Continue the analysis of IVS Intensive experiments and the submission of EOP-I estimates to the IVS.
- Continue the scheduling, analysis, and database submission for IVS-CRF, IVS-CRMS, and IVS-CRDS experiments.
- Continue testing and evaluation of the USNO implementation of the DiFX software correlator. Streamline pre- and post-correlation processing.
- Continue routine electronic transfer, correlation, post-processing, and analysis of VLBI Intensive data from the MK and PT VLBA stations.
- Continue graphical user interface (GUI) development for the USNO implementation of the DiFX software correlator.

USNO Analysis Center for Source Structure Report

Alan L. Fey, David A. Boboltz, Ralph A. Gaume

Abstract

This report summarizes the activities of the United States Naval Observatory Analysis Center for Source Structure for the 2012 calendar year and the activities planned for the year 2013.

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 Web server for the Analysis Center is hosted by the USNO and can be accessed by pointing your browser to

`http://rorf.usno.navy.mil/ivs_saac/`

The primary service of the Analysis Center is the Radio Reference Frame Image Database (RRFID), a Web accessible database of radio frequency images of ICRF sources. The RRFID contains 7,279 Very Long Baseline Array (VLBA) images of 782 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 1,867 images of 285 sources at frequencies of 24 GHz and 43 GHz. The RRFID can be accessed from the Analysis Center Web page or directly at

`http://rorf.usno.navy.mil/rrfid.shtml`

The RRFID also contains 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://www.obs.u-bordeaux1.fr/m2a/BVID/`

2. Current Activities

VLBA high frequency sessions BL166A (2011JAN14) and BL166B (2011FEB05) were calibrated and imaged, adding 161 images at 24 GHz to the RRFID including three sources not previously imaged.

We maintained the Radio Reference Frame Image Database as a Web accessible database of radio frequency images of ICRF sources.

3. Staff

The staff of the Analysis Center is drawn from individuals who work at the USNO. The staff are Alan L. Fey, David A. Boboltz, and Ralph A. Gaume.

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 2013 are planned:

- Continue imaging and analysis of VLBA 2.3/8.4/24/43 GHz experiments.
- Maintain the Radio Reference Frame Image Database (RRFID) as a Web accessible database of radio frequency images of ICRF sources.

5. Relevant Publications

Publications of relevance to Analysis Center activities were:

- "Relativistic Jets in the Radio Reference Frame Image Database. II. Blazar Jet Accelerations from the First 10 Years of Data (1994-2003)," Piner, B. G., Pushkarev, A. B., Kovalev, Y. Y., Marvin, C. J., Arenson, J. G., Charlot, P., Fey, A. L., Collioud, A., & Voitsik, P. A. 2012, ApJ, 758, 84.
- "Characterization of long baseline calibrators at 2.3 GHz," Hungwe, F., Ojha, R., Booth, R. S., Bietenholz, M. F., Collioud, A., Charlot, P., Boboltz, D., & Fey, A. L. 2011, MNRAS, 418, 2113.
- "The Position/Structure Stability of Four ICRF2 Sources," Fomalont, Ed, Johnston, Kenneth, Fey, Alan, Boboltz, Dave, Oyama, Tamoaki, & Honma, Mareki 2011, AJ, 141, 91.

Vienna Special Analysis Center Annual Report 2012

Johannes Böhm, Sigrid Böhm, Hana Krásná, Matthias Madzak, Tobias Nilsson, Lucia Plank, Virginia Raposo, Harald Schuh, Benedikt Soja, Jing Sun, Kamil Teke, Claudia Tierno Ros

Abstract

The main activities of the VLBI group at the Department of Geodesy and Geoinformation of the Vienna University of Technology were related to the development of the Vienna VLBI Software VieVS (http://vievs.hg.tuwien.ac.at/) and its application for various studies. For example, we dealt with scheduling, satellite tracking, and the estimation of geodynamical and astronomical parameters from VLBI observations. One highlight was the release of VieVS 2.0 just before the third VieVS User Workshop in September 2012.

1. General Information

Since October 2012, we have been part of the Department of Geodesy and Geoinformation (GEO) in the Faculty of Mathematics and Geoinformation of the Vienna University of Technology. GEO is divided into seven research units, one of them focusing on advanced geodesy (mathematical and physical geodesy, space geodesy). Within this research unit, one group (out of three) is dealing with geodetic VLBI.

Figure 1. Excursion to Wettzell in June 2012 with staff members and students of the master course.

2. Staff

Personnel at GEO associated with the IVS Special Analysis Center in Vienna and their main research fields and activities are summarized in Table 1.

Table 1. Staff members ordered alphabetically.

Johannes Böhm	VLBI2010, atmospheric effects
Sigrid Böhm	Earth orientation, global solution
Hana Krásná	global solution, solid Earth tides, sources
Matthias Madzak	GUIs and special files in VieVS
Tobias Nilsson	VLBI2010, troposphere
Lucia Plank	satellite tracking with VLBI
Virginia Raposo	celestial reference frame
Harald Schuh (moved to GFZ in November 2012)	IVS activities (Acting Chair)
Benedikt Soja	Sun corona studies with VLBI
Jing Sun	scheduling and simulation
Kamil Teke (from July 2012)	least-squares, tropospheric parameters
Claudia Tierno Ros	European VLBI sessions, simulations

3. Current Status and Activities

- **Vienna VLBI Software VieVS Development**
  A new graphical user interface (GUI) has been developed which contains all components in one window, from scheduling to the global solution. The GUI also includes a plotting tool where users can visualize analysis statistics and estimated parameters, and in a beta-version we provide the possibility of plotting station networks, covariance matrices, baseline length repeatabilities, or scheduling information. All *static* information for the stations is now stored in one *superstation* file, which makes the reading of many different files from different directories obsolete. In the future, we will work on a similar file for sources containing static information for radio sources. Additionally, a *scan-wise update mode* has been added to the least-squares tool in VieVS, which allows the analysis of huge observation files. More information about the Vienna VLBI Software and the most recent release 2.0 (VieVS, Böhm et al., 2012 [1]) can be found at http://vievs.hg.tuwien.ac.at.

- **Global solutions with VieVS**
  The parameter setup and the global solution of VieVS were modified in order to estimate coefficients of tidal variations in the Earth rotation parameters. The altered version of the global solution enables the determination of 76 diurnal and semi-diurnal terms in polar motion and UT1 and of 63 zonal terms with periods from five days to 18.6 years in UT1. Due to certain restrictions concerning the calculation of the a priori UT1 values, the zonal tidal variations were derived only up to the monthly period from a global solution using selected sessions from 1984 to 2011.
  Additionally, we determined solid Earth tide parameters, Love and Shida numbers, from VLBI global solutions with VieVS. We estimated complex frequency-dependent Love and Shida numbers of degree two from 27 years of geodetic VLBI observations. The estimates of the Love and Shida numbers are notably improved in terms of precision and accuracy (Krásná et al., 2013 [2]). Another area of research was a comprehensive study on free core nutation (FCN). We computed the period of the FCN in a rigorous least-squares adjustment

of VLBI data simultaneously from two phenomena: from the resonance effect in solid Earth tides and from the nutation motion of the Earth rotation axis (Krásná, 2013b [3]).

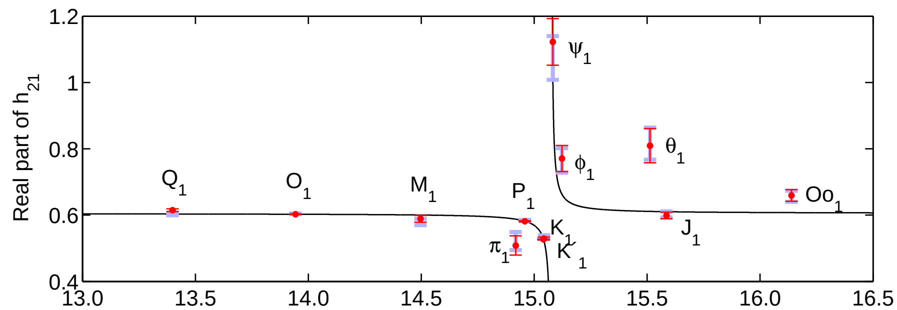

Figure 2. Real part of the Love numbers versus frequency in degrees/hour for twelve diurnal tides estimated from two solutions with different a priori ocean tidal loading models (FES2004 in red, AG06a in light blue).

- **Combining VLBI and Ring Laser Data**
We have continued investigating the possibilities for combining data from VLBI and ring laser gyroscopes for the estimation of Earth rotation parameters (Nilsson et al., 2012a [4] and Nilsson et al., 2012b [5]). For the CONT11 campaign we combined VLBI with observations from the *G* ring laser in Wettzell. The combination did work; however, since only one ring laser was used, there was only a minor improvement in the results compared to what is achieved by VLBI only. One ring laser only senses one component of the Earth rotation vector; thus at least three ring lasers are needed in order to sense the full Earth rotation vector. We made simulations testing the impact of having more than one ring laser. If every VLBI station in CONT11 was equipped with a ring laser similar to that in Wettzell, an improvement of about 25% could be expected.

- **VLBI Satellite Tracking**
The employment of the VLBI technique to near Earth satellites is a research topic in Vienna. Therefore, various parts of VieVS were extended to be applicable for moving sources at finite distance. In particular, this includes the scheduling of satellite targets, the processing of an alternative observation file, the delay modeling, and the estimation part. In combination with the VieVS simulator, observations to satellites can now be simulated, and investigations concerning observation interval, tracking network, and expected accuracies have been started.

- **Scheduling with VieVS**
The module *vie_sched* is designed to fully exploit the possibilities of the future VLBI2010 system. In 2012, *vie_sched* was validated by scheduling real IVS sessions. We generated seven sessions (RD1204 to RD1210) for a solar corona study on the basis of the RD session setup. All these sessions have been observed successfully, and the data files are already available in the IVS Data Centers after being correlated at Haystack and analyzed by Goddard. Studies on the optimum scheduling strategies are still ongoing, e.g., we assess the application of source-based schedules compared to station-based schedules.

- **European VLBI Sessions**
As a Special Analysis Center for Specific Observing Sessions (SAC-SOS), we have analyzed

the European VLBI sessions, and we have used them for the investigation of crustal motion in Europe.

- **Comparison of tropospheric parameters**
  We compared zenith total delays and troposphere gradients as determined from VLBI, GNSS, and DORIS observations at co-located sites in the CONT campaigns in October 2002, September 2005, August 2008, and September 2011. We did not find an improved standard deviation between the series from the various techniques over time, nor did we find a seasonal dependence. On the other hand, the agreement and thus the accuracy of the troposphere parameters clearly depend on the latitude and the amount of humidity in the atmosphere.

4. Future Plans

In 2013 we will continue the development of VieVS, with special focus on satellite tracking, scheduling, and the estimation of terrestrial and celestial reference frames. Additionally, we will contribute to the ongoing activities within VLBI2010.

Acknowledgements

We are very grateful to the Austrian Science Fund (FWF) for supporting our work by projects P21049 ('SCHED2010'), P23143 ('Integrated VLBI'), and P24813 ('SPOT'). We also acknowledge the German Research Foundation (DFG) for funding projects SPEED2 (SCHU 1103/3-2) and D-VLBI (SCHU 1103/4-1).

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Technology Development Centers

Canadian VLBI Technology Development Center

Bill Petrachenko

Abstract

The Canadian VLBI Technology Development Center (TDC) is involved in activities related to the realization of the VLBI2010 Global Observing System (VGOS).

1. Introduction

The Canadian TDC is a collaborative effort of the National partners interested in the advancement of VLBI technology, namely the Geodetic Survey Division of Natural Resources Canada (GSD/NRCan) and the Dominion Radio Astrophysical Observatory (DRAO) of the National Research Council of Canada (DRAO/NRC).

2. VGOS

The Canadian TDC is primarily focused on encouraging the realization of VGOS. This is done by Bill Petrachenko of NRCan, who is the IVS Technology Development Coordinator, chairman of the VLBI2010 Committee (V2C), and a member of the VLBI2010 Project Executive Group (V2PEG). In collaboration with others, this year's activity focused on the following areas:

- Development of FPGA code for VGOS digital back ends.
- Compilation of a comparison of VGOS digital back ends.
- Compilation of a comparison of VGOS feeds.
- Execution of studies into the mitigation of intra-site RFI from DORIS and SLR aircraft avoidance radar.
- Analysis of V2PEG RFI survey responses.

3. NRC Activities in Support of the Square Kilometer Array (SKA)

Under the leadership of Brent Carlson, NRC is lead of SKA central signal processing encompassing the SKA correlator, beam former, and pulsar processing.

Under the leadership of Gordon Lacy, a light, stiff, and cost effective 15-m off-axis Gregorian top-fed composite antenna is being fabricated.

Under the leadership of Gary Hovey, development progresses in the areas of focal plane arrays and a general purpose high-capacity multi-FPGA signal processing platform.

GSFC Technology Development Center Report

Ed Himwich, John Gipson

Abstract

This report summarizes the activities of the GSFC Technology Development Center (TDC) for 2012 and forecasts planned activities for 2013. The GSFC TDC develops station software including the Field System (FS), 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. Technology Center Activities

The GSFC IVS 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, and Rich Strand, all employed by NVI, Inc. The remainder of this report covers the status of the main areas supported by the TDC.

2. Field System

The GSFC TDC is responsible for 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). 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 the IVS Network Stations (more than 35) and also at many stations that do VLBI only for astronomical observations. The only major VLBI facilities not using it are the VLBA and VERA.

There were no new releases of the FS during this period. However, several development projects were underway:

- Patriot 12-m Interface. Development of the interface for Patriot Antenna Control Unit (ACU) continued. Several improvements were made including wind-stow automatic recovery and systematic error reporting with classification of errors and documentation on how to respond to them.
- DBBC Support. FS support for the DDC personality of the DBBC was developed and tested. It will be released in early 2013. This will support DBBC use for recording with Mark 5B recorders and is compatible with "legacy" VLBI observing.
- Miscellaneous. Many small improvements and bug fixes were made for the new release expected in early 2013. These included a new, faster version of *gnplt* for antenna gain calibration and a work-around for the "day 49" kernel "feature"/bug.

2.1. Plans for Next Year

Several other improvements are expected in future releases, including:

- Support for RDBE racks
- Support for DBBC PFB personality
- Support for Mark 5C and Mark 6 recorders
- Use of *idl2rpc* for remote operation
- A complete update to the documentation and conversion to a more modern format that will be easier to use and maintain
- Conversion of the FORTRAN source to use the *gfortran* compiler, which will enable use of the source level debugger, *gdb*, for development and field debugging
- *Chekr* support for Mark 5A and Mark 5B systems
- FS Linux 9 (based on Debian *wheezy*, skipping *squeeze*) distribution
- Support for periodic firing of the noise diode during observations.

3. 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 geodetic schedules, first SKED is run at the Operation Centers to generate the .skd file that contains the full network observing schedule. Then stations use the .skd file as input to DRUDG for making the control files and procedures for their station. Catalogs are used to define the equipment, stations, sources, and observing modes which are selected when writing a schedule with SKED.

Changes to SKED and DRUDG are driven by changes in equipment and by feedback from the users. The following summarizes some of the important changes to these programs in 2012.

3.1. SKED Changes

- Release of completely re-written SKED documentation in May 2012. The documentation includes examples of all commands. The last time the documentation was updated was in 1996.
- Added “source cull” command to remove sources that are only observed a few times in a session.
- Added support for Mark 5B in VEX files.
- Added list of catalogs used to the schedule file. This will help in debugging.

3.2. DRUDG Changes

- Better support of Mark 5B.

- Limited support of DBBCs
- Treatment of VEX as a default file type. Users no longer have to include '.vex' in the filename.

3.3. Plans for Next Year

Plans for next year include:

- In 2012 we began work on making VEX the native format for SKED. We plan to finish this project in 2013.
- We also plan to expand support for RDBEs and DBBCs. This will involve changes to SKED, DRUDG, and the catalogs.
- If time permits we will convert SKED to compile using a freely available compiler such as *gfortran*.

Haystack Observatory Technology Development Center

Chris Beaudoin, Brian Corey, Arthur Niell, Roger Cappallo, Alan Whitney

Abstract

Technology development at MIT Haystack Observatory were focused on four areas in 2012:

- VGOS developments at GGAO
- Digital backend developments and workshop
- RFI compatibility at VLBI stations
- Mark 6 VLBI data system development

1. VGOS Developments at GGAO

1.1. New Receiver Installation

A proof-of-concept (PoC) VLBI2010 receiver incorporating the Quadruple-ridged flared horn (QRFH) designed by Caltech was installed in spring 2011. The sensitivity of this PoC receiver met theoretical expectations in the 3-12 GHz spectrum [1], and it enabled processing of the first geodetic broadband VLBI observables. However, this system still did not meet the receiver requirements set forth for VLBI2010[1]. Firstly, the PoC receiver required a post-LNA 3.1 GHz filter to reject strong RFI that would otherwise saturate the receiver stages following the low-noise amplifier (LNA); this placed a 3 GHz lower limit on observing frequencies. The PSI-1601 fiber optic links incorporated in the PoC receiver were not specified for operation above 12 GHz and thus place a maximum observing sky frequency of 12 GHz. Furthermore, it was unknown at the time that these fiber optic links exhibited a noise figure that varied significantly (as much as 15 dB) across the operational frequency range. This introduces a significant loss of dynamic range in the PoC receiver and complicates the requirement to maintain a uniform 2500 Jy system-equivalent flux density (SEFD) uniformly across the 2-12 GHz spectrum. Lastly, the PoC frontend was not easy to service and maintain. In order to truly meet the VLBI2010 specified receiver requirements and to realize a system that can be easily serviced and maintained, Haystack Observatory initiated a receiver upgrade project that was focused on addressing these shortcomings. The following outline presents the high-level requirements of the receiver upgrade:

Upgrade Requirements:

- S-band coaxial downlink
- Electronic control of feed position
  - feed positioning uncertainty < 1mm
- Remote servicing of cryogenics
  - control vacuum pumps and valve
- Monitor
  - Cryogenic refrigerator temperature

[1] 12-m radio telescope capable of 2-14 GHz observations with SEFD < 2500 Jy [2].

  - Supply/return helium pressure
  - Air pressure in vacuum vessel
  - Crosshead motor electrical drive power
- Ease of receiver removal for servicing outside antenna
- In-situ access to the following components:
  - LNA power supply and cryo temperature sensor connectors
  - Bias box adjustments/test points
  - SMA connectors accessible to 5/16” wrench
  - Coupler outputs for RF sampling
  - Fiber optic connectors

The receiver upgrade was installed in mid-November 2012, and the sensitivity of the receiver will be characterized in early 2013.

2. Digital Backend Developments and Intercomparison Workshop

The MIT Haystack Observatory digital engineering staff have also developed new FPGA bitcode personalities for both the geodesy and astronomy applications. The latest versions are enhancements to the RDBE v1.4, which is a Polyphase Filter Bank (PFB) design producing real-valued samples in Mark 5B format that is detailed in [1]. The following new RDBE personalities were developed in 2012:

2.1. RDBE v1.5

This personality quantizes to two bits the full 512 MHz bandwith of each of the two IF input signals. Each IF input signal is formatted as Mark 5B and output as a TCP/IP transmission over a single network interface card (NIC) at a data rate of 2 Gbps. Since the data processed for each IF are transmitted over independent NICs, the aggregate output data rate of this personality is 4 Gbps.

2.2. RDBE v2.0

This personality processes four 512 MHz bandwidth IF input signals. The signal processor routes all thirty-two 32-MHz channels derived from a pair of IF input signals into a VDIF packet stream as complex-valued time samples at 4 Gbps. Each 4 Gbps VDIF stream is transmitted over an independent NIC using TCP/IP network communications, so the aggregate output data rate is 8 Gbps.

2.3. RDBE v2.5

This is a derivative of the RDBE v2.0 that processes only two 512 MHz IF inputs, so the aggregate output data rate is 4 Gbps. Two IF inputs were deleted from the v2.0 personality to accommodate the limited resources on the ROACH board so that diagnostics critical to geodetic VLBI operations could be incorporated into this personality. The diagnostics include:

- Pulse calibration detection from raw 1024 MHz ADC samples
- Synchronous raw capture of the raw ADC samples relative to the RDBE 1 PPS epoch
- MASER-RDBE 1PPS and GNSS-RDBE 1PPS time delay monitoring

2.4. DBE Intercomparison Workshop

The second DBE intercomparison workshop was held at Haystack Observatory on 25-26 October 2012. This workshop provided a forum to explicitly address validation and interoperability issues among independent global developers of DBE equipment The first such workshop was held at Haystack Observatory in May 2009. The 2012 workshop took advantage of the completion of a new Instrumentation Lab at Haystack Observatory that provided the space and signal connections needed to efficiently support the comparison exercise. The results of this workshop can be found at the following link:

http://www.haystack.mit.edu/workshop/ivtw/2012.12.17_DBE_testing_memo_final.pdf

3. RFI Compatilibitity at VLBI Stations

The IVS appointed a task force comprised of IVS members Bill Petrachenko, Brian Corey, and Christopher Beaudoin to evaluate Radio Frequency Interference (RFI) power levels at current and prospective VLBI stations in order to assess the feasibility of broadband geodetic VLBI observations at these stations. In 2012, stations were requested by the IVS to provide RFI data, and the task force has conducted preliminary analyses of the data provided by the nine responding stations. A formal report is expected to be released in 2013.

4. Mark 6 VLBI Data System Development

4.1. First Demonstration of the 16 Gigabit Mark 6 Data Recorder

The availability of inexpensive, commercial-off-the-shelf high performance computing (HPC) hardware and the parallel development of broadband RF equipment for VLBI has enabled dramatically improved sensitivity for both astronomical and geodetic VLBI. The recognition of these technological developments provided the motivation for Haystack to develop the Mark 6 16 Gbps data recorder. In June 2012, a VLBI experiment utilizing a single Mark 6 recorder at each end of the Westford/GGAO baseline demonstrated 16 Gbps VLBI capability. The correlation amplitudes and signal-to-noise ratios for the 2 GHz bandwidth, dual polarization observations were within the expected range [3].

4.2. Current Capabilities

During this report period, operational Mark 6 software was developed, based upon the principles refined in the prototype software, but with an entirely new code base. The Mark 6 software is currently at revision 2; it splits the workload into modules that are called the control and data planes. The control plane software, which implements control and monitor functions, is written in python for ease of maintenance.

The data plane software performs the time-critical tasks of receiving the high-speed packetized data-streams, organizing them, and writing to disk files, and it is thus coded in C.

Two file-writing modes are supported: a single-file RAID mode and a multiple (1-32) disk scattered mode. The scattered mode allows disks to record data at whatever rate they are able, with the intent that it will be more robust in the face of slow or non-functioning disks. There is currently a stand-alone program, called *gather*, to recombine the separate files into a seamless single file for the correlator. It is expected that this functionality will eventually be built into the file-reading portion of the DiFX correlator, and perhaps into a general-purpose FUSE/Mark 6 file interface.

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IAA Technology Development Center Report 2012

Dmitry Marshalov, Evgeny Nosov, Leonid Fedotov

1. Development of the Broadband Russian Acquisition System (BRAS)

The new data acquisition system BRAS is being developed for radio telescopes with 13-m diameter antennas [1]. Researches on the creation of such a system were spent in IAA RAS since 2010 [2]. BRAS is the digital backend terminal, which consists of eight Digital Signal Processing Units (DSP Units), one Clock Unit, and a Power supply (see Figure 1).

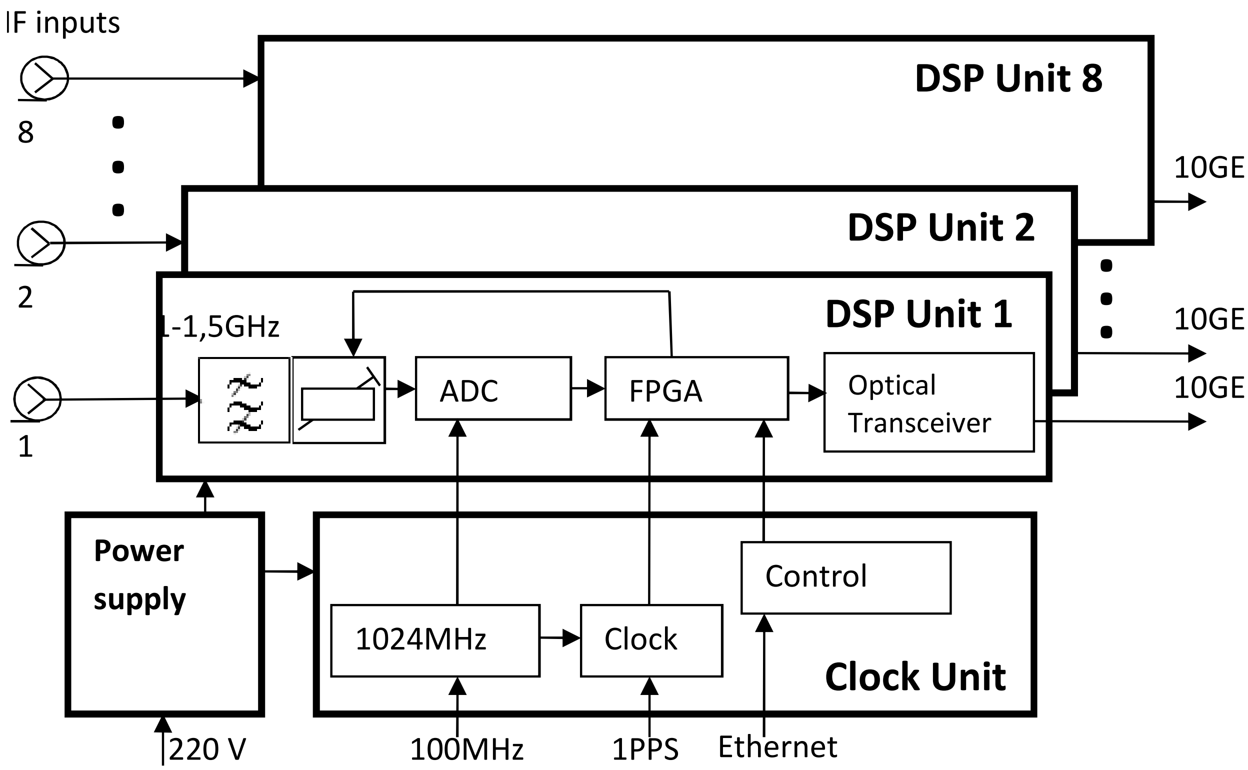

Figure 1. Simplified structure of BRAS.

BRAS inputs are connected to IF outputs of receivers. In every DSP unit the signal of 1-1.5 GHz frequency range is transformed to a VDIF data stream. After that it is translated to a special data buffering device by means of 10 G Ethernet for transmission to the correlator. The Clock unit is intended for formation and distribution of clock signals between all DSP units. Phases of these signals are synchronized with 100 MHz signal from H-maser and 1PPS from the time scale of a radio telescope. The distributed control system of BRAS is realized via controllers in the FPGA of the DSP units and the Clock Unit. The interface for communication with a computer is located in the Clock Unit. BRAS provides an expansion of channel bandwidth up to 512 MHz and an increase of the total rate of a data stream up to 16 Gbps (Table 1).

Table 1. R1002M DAS specification.

Input frequency range	1 to 1.5 GHz
Number of IF-inputs	8
Number of channels (BBCs)	8
Bandwidth	512 MHz
Output data format	VDIF
Output data rate	16 Gbps
Output interface	10 G Ethernet
Control interface	Ethernet
Total dimension	376 x 233 x 200 mm

The modular design of BRAS provides convenience of operation. The special case with electromagnetic protection allows placement of this system directly on the antenna near to outputs of receivers. Two one-channel prototypes of BRAS have been made (see Figure 2). They have been placed in VLBI Network "Quasar" observatories and connected to IF outputs of usual receivers.

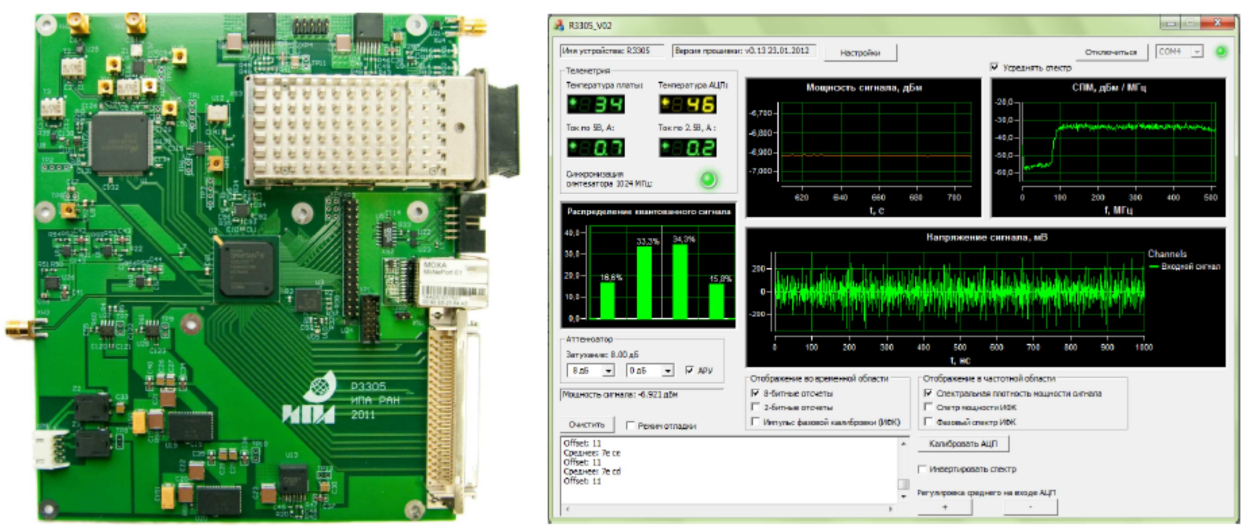

Figure 2. The single channel prototype of BRAS (left) and the interface of control software (right).

It has allowed observation of an experimental VLBI observing session on the Svetloe-Zelenchukskaya baseline with the recording of signals in 512 MHz frequency bandwidth by means of a Mark 5C recording system. On eight observed sources with flux densities from 0.1 Jy up to 2 Jy good fringe responses have been obtained with SNRs from 42 up to 1737 (see Figure 3). Experimental research has validated the technical and program decisions, which are incorporated into BRAS. The end of development and the commissioning of BRAS samples is planned for 2015.

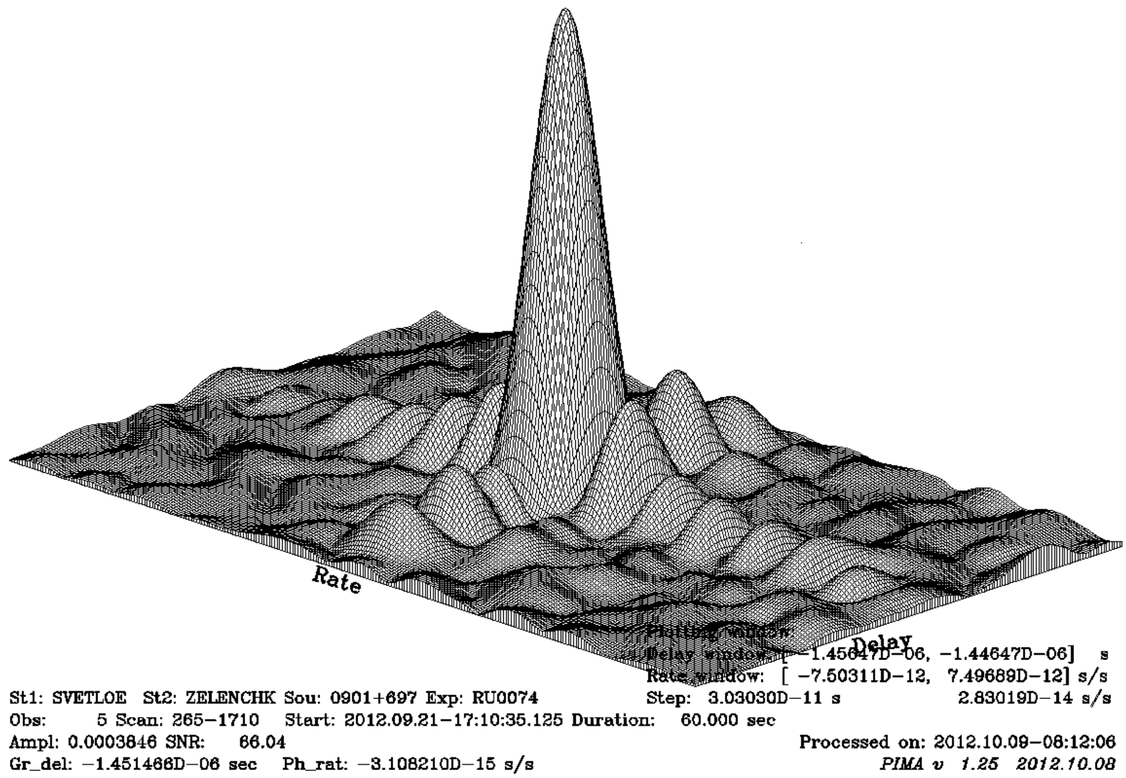

Figure 3. Amplitude of the search function on the group-delay and fringe-frequency plane, obtained from the VLBI observation of 0901+697 source at frequency range 8.6-9.1 GHz with 512 MHz bandwidth.

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Technology Development Center at NICT

Kazuhiro Takefuji, Hideki Ujihara

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 National Institute of Information and Communications Technology (NICT) publishes the newsletter "IVS NICT-TDC News (former IVS CRL-TDC News)" at least once a year in order to inform readers about the development of VLBI related technology as an IVS Technology Development Center. The newsletter is available at the URL **http://www2.nict.go.jp/w/w114/stmg/ivstdc/news-index.html**. Table 1 lists the staff members at NICT who are contributing to the Technology Development Center.

Table 1. Staff Members of NICT TDC as of January 2013 (listed alphabetically).

HASEGAWA, Shingo	HOBIGER, Thomas	ICHIKAWA, Ryuichi	KAWAI, Eiji
KONDO, Tetsuro	KOYAMA, Yasuhiro	MIYAUCHI, Yuka	SEKIDO, Mamoru
TAKEFUJI, Kazuhiro	TSUTSUMI, Masanori	UJIHARA, Hideki	———

2. Current Status and Activities

We report about the progress of VLBI technology development hereafter.

2.1. Development of Gala-V: Brand New VLBI System

In order to conduct time and frequency transfer with a compact and portable VLBI system, NICT has been developing a system with a 1.5 meter antenna. As expected, the SEFDs of such a small antenna are quite large due to the size of the antenna and the ambient temperature of the receiver. Thus, we are developing a broadband VLBI system, which meets the requirements of VLBI2010, in order to improve the signal-to-noise ratio of the compact VLBI system. Because fringes will only be detected with the compact antenna if the second antenna on the baseline is large enough, our 34-meter antenna will also be upgraded with a broadband system. Before we started with the development, we measured the RFI conditions, in particular at Kashima, Ibaraki and Koganei, Tokyo. Figures 1 to 3 show the results of the RFI measurements in a range from 2 GHz to 18 GHz. It can be seen that RFI is very strong on the roof of our headquarters in Tokyo, but there are still some quiet frequency bands.

We designed the system so that it utilizes only bands in the RFI quiet zones and still provides a narrow delay function. We fixed the four bands with the zero redundancy array technique [Moffet(1968)] to be set with frequency differences in a 1:3:2 proportion at 3.2-4.8 GHz, 4.8-6.4

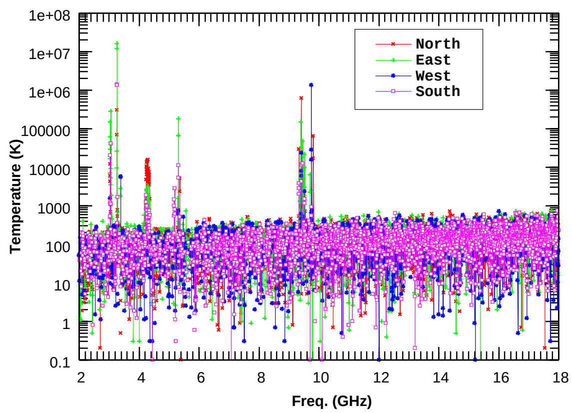

Figure 1. RFI survey in Kashima.

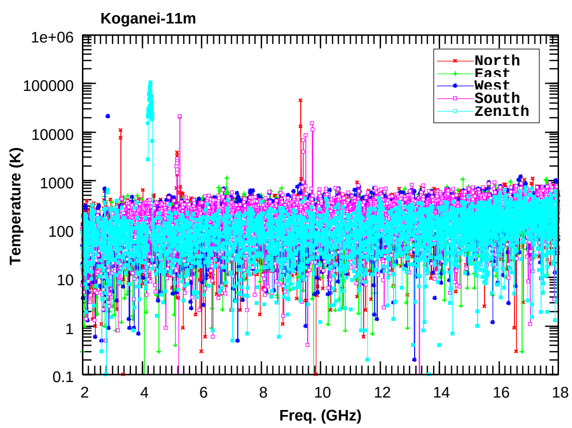

Figure 2. RFI survey near the 11-meter antenna in Koganei, Tokyo.

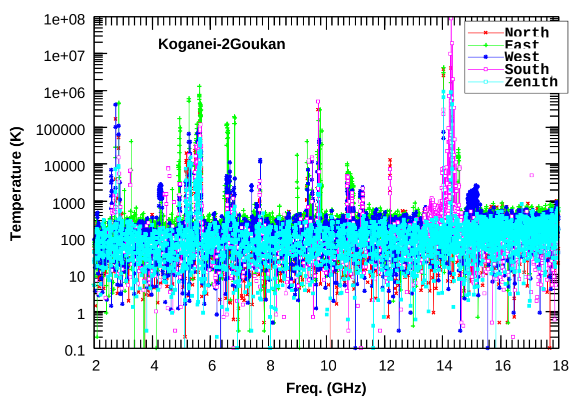

Figure 3. RFI survey on the headquarters roof in Koganei, Tokyo.

GHz, 9.6-11.2 GHz, and 12.8-14.4 GHz, in accordance with frequency ranges of VLBI2010. The proportion of 1:3:2 shows the differences between the starting values of the four bands, so, (4.8-3.2 GHz):(9.6-4.8 GHz):(12.8-9.6 GHz) = 1.6 GHz:4.8 GHz:3.2 GHz = 1:3:2. Then we started to develop the broadband system based on these fixed bands. We named the whole broadband VLBI system the Gala-V (Galapagos VLBI, which we hope will be a unique evolution in VLBI.) The effective frequency of the Gala-V bands becomes 4.4 GHz. Also the Gala-V bands have a great advantage for sampling. In the case of 12.8 GHz, they can be covered with high order sampling without any analog frequency conversion. Thus, we are developing a new digital A/D sampler with a sampling speed of 16 GHz. The sampler has two input channels, in order to sample four bands (1-1.6 GHz wide) at two polarizations.

2.2. Development of Wideband Feeds

Wideband feeds have been developed at NICT, NAOJ (National Astronomical Observatory of Japan), and universities in Japan for VLBI2010 and SKA. SKA is an international project in radio astronomy to construct a Square Kilometer Array. In this fiscal year, a novel wideband feed is being developed for the Kashima 34-m antenna, which will be used for our time and frequency transfer project and also for radio astronomy.

The feed, named the IGUANA feed, has unique specifications and structure. Operational frequency bands of the feed are carefully selected to avoid RFI and to satisfy the Gala-V bands and also the feasibility conditions of a nested feed (Figure 4). The beam size of the feed is nearly proportional to the operational frequency. Thus the frequencies for each of the nested feeds must be separated, and the inner feed must be small to prevent it from decreasing the beam patterns in the outer feed. To receive the four fixed bands and to achieve a sharp beam pattern for the installation at the Kashima 34-m antenna, a nested feed is the only candidate feed. The lower two channels are received with the outer IGUANA feed, which is a corrugated horn. Currently we will use the original C band of the Kashima 34-m to check the effectivness of the nested structure. The higher two channels are received with the inner IGUANA feed, which is a multi-mode horn and was derived from designs of multi-mode horns for the ASTRO/VSOP-2 and VERA projects. The feed is currently being manufactured, after a half year of development with numerical simulations (Figure 5) and it will hear the first radio noise from the universe in spring 2013.

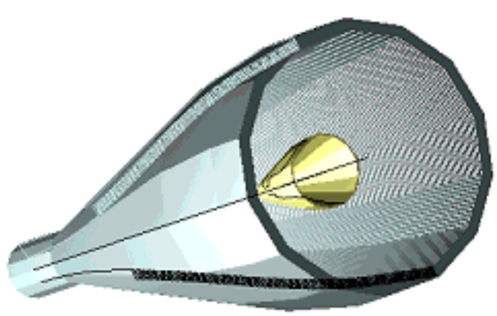

Figure 4. Conceptual model of the IGUANA feed.

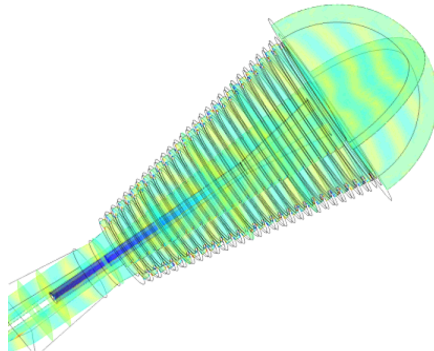

Figure 5. Experimental results of the Ey field in the Mom feed at 4.8 GHz with COMSOL.

2.3. Kashima Flexible Correlator (KFC)

In order to process the growing amount of data that comes along with the implementation of the VLBI2010 technology, NICT has started to develop the “Kashima Flexible Correlator (KFC)”. This software correlator is expected to operate in a similar way as other existing correlators by making use of the Message Passing Interface (MPI) for distribution of the workload across several computing nodes. KFC will consist of three components (see Figure 6), i.e. one master control, several data streamers, and a certain number of correlators. The master control oversees the correlation process and manages all other components. Data streamers extract PCAL signals, decode the sampling data depending on bit resolution and the number of channels, and send the data to the packetized correlators where auto- and cross-correlation are computed. The initial development will only rely on CPU nodes, but the flexible software design will support heterogeneous CPU-GPU (or other multi-processor) platforms in the future as well.

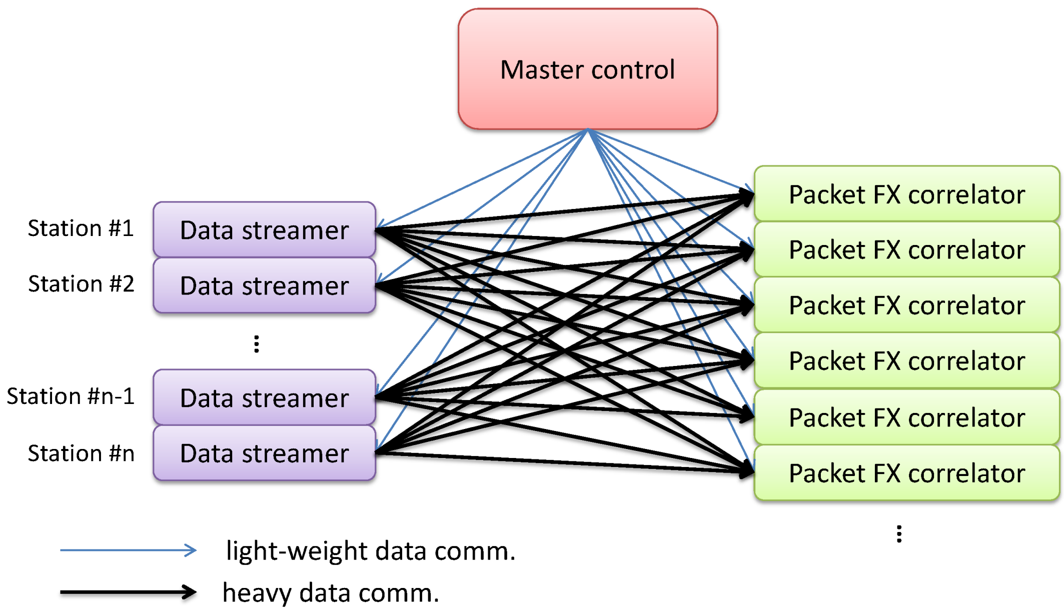

Figure 6. Basic concept of KFC.

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Onsala Space Observatory – IVS Technology Development Center

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Abstract

We report 2012 activities and plans for 2013.

1. Improved Eleven Feed for VLBI2010

We completed the mechanical implementation and prototype fabrication of a new circular Eleven feed designed by the Antenna Group at Chalmers. Figure 1 shows a photo of the first prototype. The circular Eleven feed is constructed of curved folded dipoles on a flat printed circuit board (PCB), with the aim of making this antenna structure more rotationally symmetrical at a low manufacturing cost. The measurements showed an efficiency of better than −1 dB over a decade bandwidth of 1.3 – 14 GHz [1].

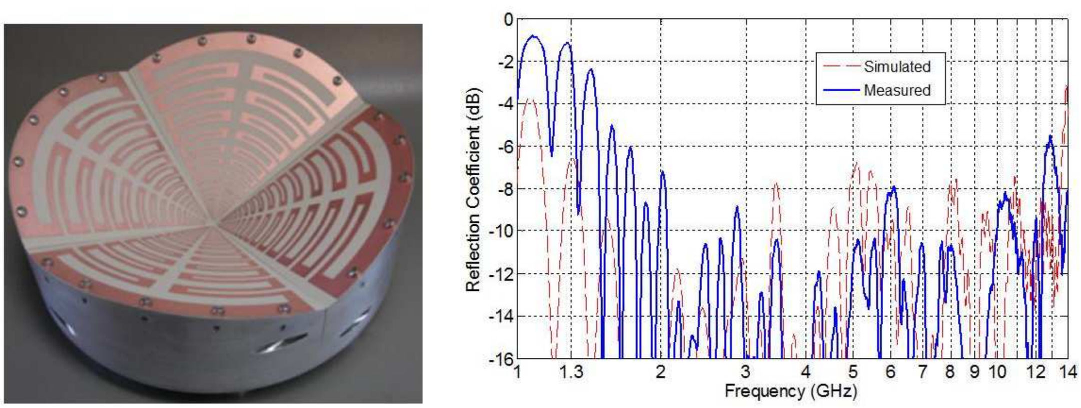

Figure 1. Left: The circular Eleven feed. Right: Simulated and measured reflection coefficient.

2. Broadband Feed Comparison

Following up on the decision of the IVS Technical Workshop in Wettzell in March 2012, we did extensive work to compare the performance of two broadband feeds considered for VLBI2010, the Eleven feed and the QRFH feed. Figure 2 depicts a comparison of the two feeds in a real VLBI2010 system, a 12-m shaped reflector system manufactured by Intertronics Solutions. The efficiency plot for the QRFH is calculated via physical optics software at JPL using measured feed beam patterns as input. The efficiency plot for the Eleven feed is calculated using GRASP software, also using measured feed patterns as input.

The performance of the feeds is comparable: the Eleven feed has slightly higher efficiency than the QRFH over the 3 – 5 GHz band, while the QRFH has slightly higher efficiency over the

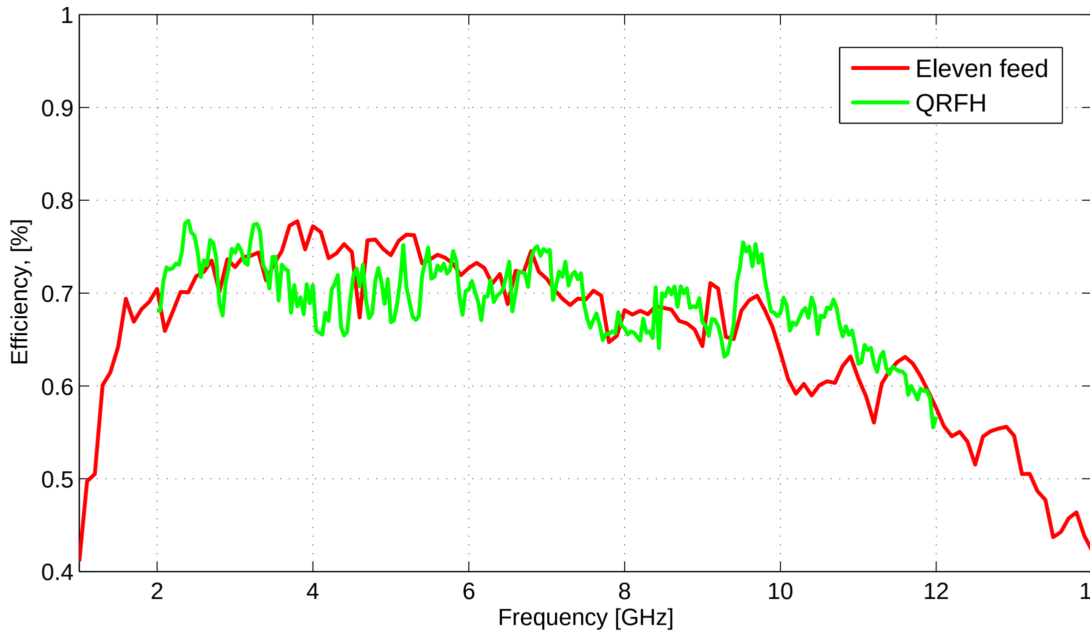

Figure 2. Comparison of the aperture efficiencies of the Eleven feed and the QRFH in a 12-m Cassegrain shaped reflector antenna system. The red curve shows the results for the Eleven feed, calculated with the GRASP software using simulated far field patterns. The green curve shows the calculated aperture efficiency for the QRFH calculated with physical optics software using measured beam patterns.

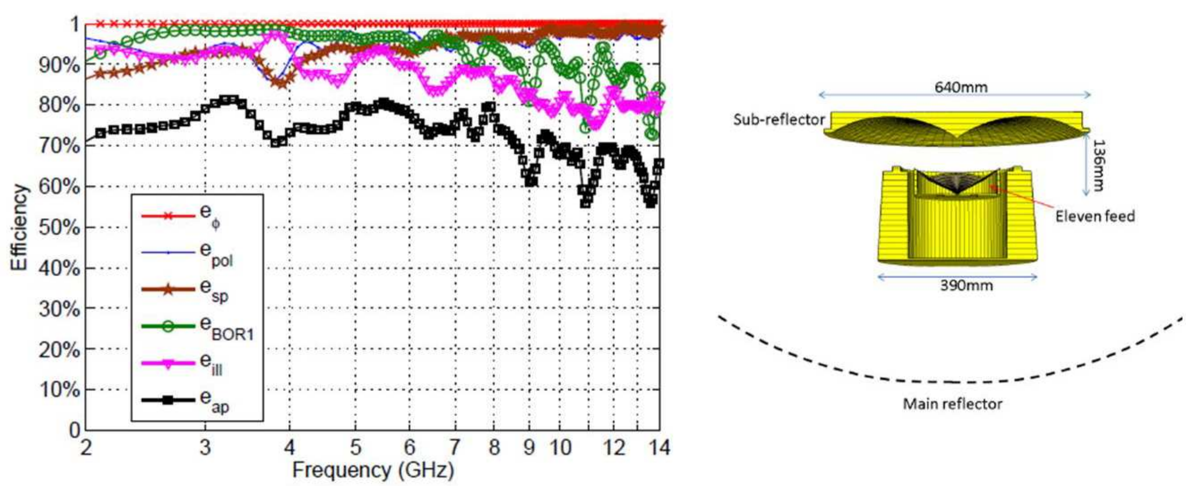

Figure 3. Left: calculated aperture efficiency and its sub-efficiencies based on a simulated radiation function when the circular feed illuminates a dual-reflector antenna (including a sub-reflector) with a subtended angle of $2 \times 80°$ for the main reflector. Right: geometry of the main and the sub-reflector.

$9-11$ GHz band. Data for the QRFH for the $12-14$ GHz were unfortunately not made available for us for this study.

We have also studied the performance of the Eleven feed in a dual-reflector antenna with subtended angles of $2 \times 67°$ and $2 \times 80°$ for the sub-reflector and the main reflector, respectively. The reflection coefficient of the feed is almost not affected by the sub-reflector, and the aperture efficiency of the whole antenna is calculated, as shown in Figure 3, which indicates a good performance. As reported in [2], Eleven feeds provide an optimal performance when the subtended angle is from $2 \times 55°$ to $2 \times 70°$ for the primary reflector systems. By using a dual-reflector arrangement, the Eleven feed can be used in an optimal performance for different subtended angles.

3. Characterization of the RFI Environment at Onsala

In order to characterize the RFI environment and its potential impact on the future broadband observations for VLBI2010, we have carried out a survey over the frequency band from $0.85-26.5$ GHz. The setup used for the test (see Figure 4) was borrowed from Yebes Observatory. The measurements were performed on the location of the new twin-telescope (see Figure 4).

The measurement setup and the calibration are described in detail in [3]. Each spectrum has been taken with the analyzer in MAX-HOLD mode (which keeps the maximum measured value) during one complete turn in azimuth of the antenna. The measurements were performed at 0° elevation angle and used vertical polarization. For this antenna location the nearby trees obscure about $15° - 20°$ of the sky above the horizon for more than 180° in azimuth, but probably the attenuation and scattering effects are negligible. The full spectrum is presented in Figure 5 to give an overall impression of the situation. There are interferences from GSM/UMTS links, flight radars (around 1.1 GHz), GPS signals, WLAN (2.6 GHz), navy radars and military applications ($2.9-3.1$ GHz), radio links and navy radars ($9.25-9.5$ GHz), and radio links (22.5 GHz).

Figure 4. Left: setup for RFI-measurements. Right: map showing the location of the setup.

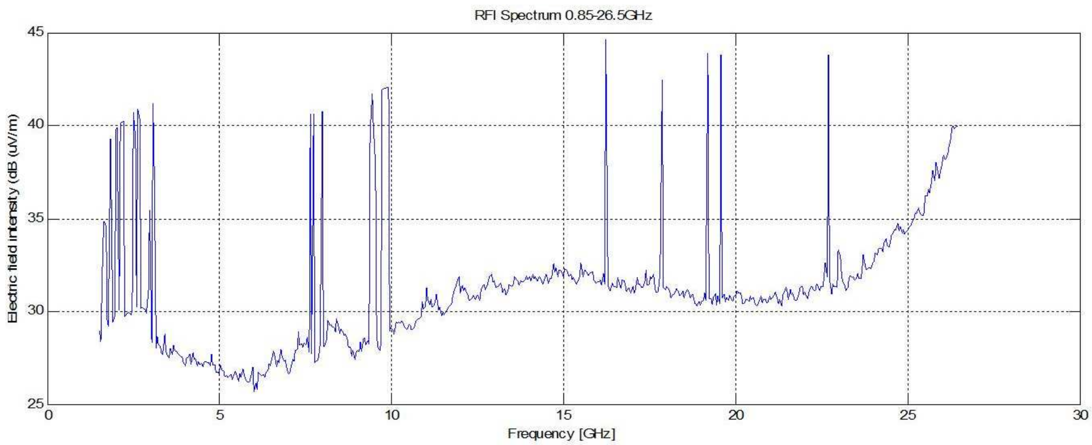

Figure 5. Measured spectrum over the $0.85 - 26.5$ GHz band. See text for an explanation of the observed RFI signals.

4. Improvement of the IF-distribution for S/X-band

As part of the transition to a fully digital system using the DBBC and Mark 5B+ we had to improve the IF-distribution for S/X-band. An interdigital filter was designed for S-band following [4], using the software CST Microwave Studio and tuning for the proper frequency range. The results from the simulation matched well to the actually produced filter. An amplification and attenuation system was installed for X-band to counteract the slope of the bandpass. After several tests with parallel observations and recording with both the analog system (Mark IV rack and Mark 5A recorder) and the new digital system (DBBC and Mark 5B+ recorder), fringes could be found successfully.

5. Outlook and Future Plans

We will continue to work on the development of an Eleven feed for VLBI2010. Starting in 2013, we will extensively work with the establishment of the Onsala Twin Telescope. We also aim at keeping the 20-m telescope interoperable for geodetic observations with the twin telescope.

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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), and
- 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, and
- 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, and
- 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), and
- 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, and
- 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, and
- 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, and
- 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, and
- 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, and
- maintain and support operational equipment.

2.7. 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, and
- provide the Secretariat of the Directing Board.

2.8. 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, and
- 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, and
- 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
- 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: 16

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 I – Fundamental Astronomy
- President of IAU Commission 8 – Astrometry
- President of IAU Commission 19 – Rotation of the Earth
- President of IAU Commission 31 – Time
- President of IAU Commission 40 – Radio Astronomy
- President of URSI Commission 52 – Relativity in Fundamental Astronomy
- President of URSI Commission J – Radio Astronomy

Individuals are accepted as IVS Corresponding Members upon request to the Coordinating Center.

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University of Tasmania	Australia
Vienna University of Technology	Austria
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Dominion Radio Astrophysical Observatory	Canada
Geodetic Survey Division, Natural Resources Canada	Canada
Instituto Geográfico Militar	Chile
Universidad de Concepción	Chile
Chinese Academy of Sciences	China
Finnish Geodetic Institute, Aalto University	Finland
Laboratoire d'Astrophysique de Bordeaux	France
Observatoire de Paris	France
Bundesamt für Kartographie und Geodäsie	Germany
Deutsches Geodätisches Forschungsinstitut	Germany
Forschungseinrichtung Satellitengeodäsie, TU Munich	Germany
Institut für Geodäsie und Geoinformation der Universität Bonn	Germany
Max-Planck-Institut für Radioastronomie	Germany
GeoForschungsZentrum Potsdam	Germany
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Istituto di Radioastronomia INAF	Italy
Politecnico di Milano DIIAR	Italy
Geospatial Information Authority of Japan	Japan
National Astronomical Observatory of Japan	Japan
National Institute of Information and Communications Technology	Japan
National Institute of Polar Research	Japan
Auckland University of Technology	New Zealand
Norwegian Mapping Authority	Norway
Astronomical Institute of St.-Petersburg University	Russia
Institute of Applied Astronomy	Russia
Pulkovo Observatory	Russia
Sternberg State Astronomical Institute, Lomonosov Moscow State University	Russia
Hartebeesthoek Radio Astronomy Observatory	South Africa
Korea Astronomy and Space Science Institute	South Korea
National Geographic Information Institute	South Korea
Instituto Geográfico Nacional	Spain
Chalmers University of Technology	Sweden

Organization	Country
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Laboratory of Radioastronomy of Crimean Astrophysical Observatory	Ukraine
Main Astronomical Observatory, National Academy of Sciences, Kiev	Ukraine
Jet Propulsion Laboratory	USA
NASA Goddard Space Flight Center	USA
U. S. Naval Observatory	USA

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IVS Permanent Components

(listed by types, within types alphabetical by component name)

Network Stations

Component Name	Sponsoring Organization	Country
Radioastronomical Observatory Badary	Institute of Applied Astronomy RAS	Russia
Fortaleza, Radio Observatório Espacial do Nordeste (ROEN)	Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Goddard Geophysical and Astronomical Observatory	NASA Goddard Space Flight Center	USA
Hartebeesthoek Radio Astronomy Observatory	Foundation for Research and Development	South Africa
Hobart 12-m and 26-m, Katherine and Yarragadee	University of Tasmania	Australia
Kashima 34-m	National Institute of Information and Communications Technology (NICT)	Japan
Key Stone Project Kashima 11-m	National Institute of Information and Communications Technology (NICT)	Japan
Key Stone Project Koganei	National Institute of Information and Communications Technology (NICT)	Japan
Kokee Park Geophysical Observatory	National Earth Orientation Service (NEOS)	USA
Matera	Agenzia Spaziale Italiana (ASI)	Italy
Medicina	Istituto di Radioastronomia	Italy
Metsähovi Radio Observatory	Aalto University, Finnish Geodetic Institute	Finland
Mizusawa 10-m	National Astronomical Observatory of Japan (NAOJ)	Japan
Noto (Sicily)	Istituto di Radioastronomia	Italy
Ny-Ålesund Geodetic Observatory	Norwegian Mapping Authority	Norway
ERS/VLBI Station O'Higgins	Bundesamt für Kartographie und Geodäsie (BKG)	Germany
Onsala Space Observatory	Chalmers University of Technology	Sweden
Parkes Observatory	CSIRO Astronomy and Space Science	Australia
Sejong Station	National Geographic Information Institute (NGII)	South Korea
Seshan	Joint Laboratory for Radio Astronomy (JLRA), CAS and Shanghai Observatory, CAS	China

Simeiz	Laboratory of Radioastronomy of Crimean Astrophysical Observatory	Ukraine
Svetloe Radio Astronomy Observatory	Institute of Applied Astronomy RAS	Russia
JARE Syowa Station	National Institute of Polar Research	Japan
Transportable Integrated Geodetic Observatory (TIGO)	Universidad de Concepción (UdeC), Instituto Geográfico Militar (IGM), Bundesamt für Kartographie und Geodäsie (BKG)	Germany, Chile
Tsukuba VLBI Station	Geospatial Information Authority of Japan (GSI)	Japan
Nanshan VLBI Station	Chinese Academy of Sciences	China
Warkworth Observatory	Auckland University of Technology	New Zealand
Westford Antenna, Haystack Observatory	NASA Goddard Space Flight Center	USA
Geodätisches Observatorium Wettzell	Bundesamt für Kartographie und Geodäsie (BKG) and Forschungseinrichtung Satellitengeodäsie der Technischen Universität München (FESG)	Germany
Observatório Astronómico Nacional - Yebes	Instituto Geográfico Nacional	Spain
Radioastronomical Observatory Zelenchukskaya	Institute of Applied Astronomy RAS	Russia

Operation Centers

Component Name	**Sponsoring Organization**	**Country**
Institut für Geodäsie und Geoinformation (IGGB)	Universität Bonn	Germany
CORE Operation Center	NASA Goddard Space Flight Center	USA
NEOS Operation Center	National Earth Orientation Service (NEOS)	USA

Correlators

Component Name	**Sponsoring Organization**	**Country**
Astro/Geo Correlator at MPI	Bundesamt für Kartographie und Geodäsie, Institut für Geodäsie und Geoinformation der Universität Bonn, Max-Planck-Institut für Radioastronomie	Germany
MIT Haystack Correlator	NASA Goddard Space Flight Center	USA

Institute of Applied Astronomy Correlator	Institute of Applied Astronomy RAS	Russia
National Institute of Information and Communications Technology (NICT)	National Institute of Information and Communications Technology (NICT)	Japan
Shanghai Correlator	Shanghai Astronomical Observatory	China
Tsukuba VLBI Center	Geospatial Information Authority of Japan (GSI)	Japan
Washington Correlator	National Earth Orientation Service (NEOS)	USA

Data Centers

Component Name	**Sponsoring Organization**	**Country**
BKG, Leipzig	Bundesamt für Kartographie und Geodäsie	Germany
Crustal Dynamics Data Information System (CDDIS)	NASA Goddard Space Flight Center	USA
GeoDAF	Agenzia Spaziale Italiana (ASI)	Italy
Italy INAF	Istituto di Radioastronomia INAF	Italy
National Institute of Information and Communications Technology	National Institute of Information and Communications Technology	Japan
Observatoire de Paris	Observatoire de Paris	France

Analysis Centers

Component Name	**Sponsoring Organization**	**Country**
Astronomical Institute of St.-Petersburg University	Astronomical Institute of St.-Petersburg University	Russia
Geoscience Australia	Geoscience Australia	Australia
BKG/DGFI Combination Center	Bundesamt für Kartographie und Geodäsie and Deutsches Geodätisches Forschungsinstitut	Germany
Laboratoire d'Astrophysique de Bordeaux	Laboratoire d'Astrophysique de Bordeaux	France
Centro di Geodesia Spaziale (CGS)	Agenzia Spaziale Italiana	Italy
DGFI	Deutsches Geodätisches Forschungsinstitut	Germany
GFZ Potsdam	GFZ German Research Center for Geosciences	Germany
IGGB-BKG Analysis Center	Institut für Geodäsie und Geoinformation der Universität Bonn and Bundesamt für Kartographie und Geodäsie	Germany

Goddard Space Flight Center	NASA Goddard Space Flight Center	USA
Haystack Observatory	MIT Haystack Observatory and NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Analysis Center	Institute of Applied Astronomy RAS	Russia
Italy INAF	Istituto di Radioastronomia INAF	Italy
Jet Propulsion Laboratory	Jet Propulsion Laboratory	USA
Karadeniz Technical University (KTU)	Karadeniz Technical University	Turkey
Korea Astronomy and Space Science Institute	Korea Astronomy and Space Science Institute	South Korea
Main Astronomical Observatory	Main Astronomical Observatory, National Academy of Sciences, Kiev	Ukraine
National Astronomical Observatory of Japan	National Astronomical Observatory of Japan	Japan
National Institute of Information and Communications Technology	National Institute of Information and Communications Technology	Japan
Norwegian Mapping Authority (NMA)	Norwegian Mapping Authority (NMA)	Norway
Observatoire de Paris	Observatoire de Paris	France
Onsala Space Observatory	Chalmers University of Technology	Sweden
Politecnico di Milano DIIAR	Politecnico di Milano DIIAR (PMD)	Italy
Pulkovo Observatory	Pulkovo Observatory	Russia
Sternberg State Astronomical Institute	Lomonosov Moscow State University	Russia
Shanghai Observatory	Shanghai Observatory, Chinese Academy of Sciences	China
Tsukuba VLBI Analysis Center	Geospatial Information Authority of Japan (GSI)	Japan
U. S. Naval Observatory Analysis Center	U. S. Naval Observatory	USA
U. S. Naval Observatory Analysis Center for Source Structure	U. S. Naval Observatory	USA
VIE Analysis Center	Department of Geodesy and Geoinformation/Vienna University of Technology	Austria

Technology Development Centers

Component Name	**Sponsoring Organization**	**Country**
Canadian VLBI Technology Development Center	NRCan, DRAO	Canada

Goddard Space Flight Center	NASA Goddard Space Flight Center	USA
Haystack Observatory	MIT Haystack Observatory and NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Technology Development Center	Institute of Applied Astronomy RAS	Russia
National Institute of Information and Communications Technology	National Institute of Information and Communications Technology	Japan
Onsala Space Observatory	Chalmers University of Technology	Sweden

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List of Acronyms

AAM	Atmosphere Angular Momentum
AARNet	Australia Academic and Research Network
AAS	American Astronomical Society
AC	(IVS) Analysis Center
ACF	AutoCorrelation Function
ACU	Antenna Control Unit
AD	Analog to Digital
ADB	Analog to Digital Board
ADC	Analog to Digital Converter
ADEV	Allan DEViation
AEB	Agência Espacial Brasileira (Brazilian Space Agency) (Brazil)
AER	Atmospheric and Environmental Research, Inc. (USA)
AES	Advanced Engineering Services Co., Ltd (Japan)
AGILE	Astro-rivelatore Gamma ad Immagini LEggero satellite (Italy)
AGN	Active Galactic Nuclei
AGOS	Australian Geophysical Observing System (Australia)
AGU	American Geophysical Union
AIPS	Astronomical Image Processing System
AIUB	Astronomical Institute, University of Bern (Switzerland)
ALMA	Atacama Large Millimeter Array
AMRFP	Access to Major Research Facilities Program
ANU	Australian National University (Australia)
AO	Astronomical Object
AOA	Allen Osborne Associates
AOC	Array Operation Center (Japan)
AOG	Auxilliary Output Generator
APEX	Atacama Pathfinder EXperiment (Chile)
API	Application Programming Interface
APPS	Advanced Precise Positioning System
APSG	Asia-Pacific Space Geodynamics program
APT	Asia Pacific Telescope
APTF	Asian Pacific Time and Frequency
ARC	Astrometric Radiointerferometric Correlator
ARIES	Astronomical Radio Interferometric Earth Surveying program
ARO	Algonquin Radio Observatory (Canada)
ASC	Astro Space Center (Russia)
ASD	Allan Standard Deviation
ASI	Agenzia Spaziale Italiana (Italy)
ASKAP	Australian Square Kilometre Array Pathfinder (Australia)
ATA	Advanced Technology Attachment
ATA	Allen Telescope Array (USA)
ATCA	Australia Telescope Compact Array (Australia)

ATM	Asynchronous Transfer Mode
ATNF	Australia Telescope National Facility (Australia)
AUSLIG	AUstralian Surveying and Land Information Group (now Geoscience Australia (GA)) (Australia)
AUT	Auckland University of Technology (New Zealand)
AWI	Alfred Wegener Institute for polar and marine research (Germany)
A-WVR	Advanced Water Vapor Radiometer
BAAS	Bulletin of the American Astronomical Society
BAdW	Bayerische Akademie der Wissenschaften (Bavarian Academy of Sciences and Humanities) (Germany)
BBC	Base Band Converter
BdRAO	Badary Radio Astronomical Observatory (Russia)
BEK	Bayerische Kommission für die internationale Erdmessung (Germany)
BIPM	Bureau Internacional de Poids et Mesures (France)
BKG	Bundesamt für Kartographie und Geodäsie (Germany)
BMC	Basic Module of Correlator
BOR1	Body Of Revolution type 1
BOSSNET	BOSton South NETwork
BPE	Bernese Processing Engine
BPF	Band Pass Filter
BRAS	Broadband Russian Acquisition System
BVID	Bordeaux VLBI Image Database
BW	BandWidth
BWG	Beam WaveGuide
CACS	Canadian Active Control System
CAGS	Council of Astronomical and Geophysical data analysis Services
CARAVAN	Compact Antenna of Radio Astronomy for VLBI Adapted Network (Japan)
CAS	Chinese Academy of Sciences (China)
CASPER	Center for Astronomy Signal Processing and Electronics Research (USA)
CAY	Centro Astronómico de Yebes (Spain)
CC	(IVS) Combination Center
CC	(IVS) Coordinating Center
CDAS	Chinese vlbi Data Acquisition System
CDDIS	Crustal Dynamics Data Information System (USA)
CDP	Crustal Dynamics Project
CDT	Centro de Desarrollo Tecnológico at Yebes Observatory (Spain)
CE	Conformité Europée ne
CE-1	Chang'E-1 (China)
CfA	Harvard-Smithsonian Center for Astrophysics (USA)
CGE	Centrum für Geodätische Erdsystemforschung (Germany)
CGLBI	Canadian Geodetic Long Baseline Interferometry
CGPS	Continuous GPS
CGS	Centro di Geodesia Spaziale (Italy)
CHAMP	Challenging Mini-Satellite Payload
CIB	Correlator Interface Board

CIP	Celestial Intermediate Pole
CLARA	Cooperación Latino Americana de Redes Avanzadas
CLIWA-NET	Cloud LIquid WAter NETwork
CMB	Core-Mantle Boundary
CMNOC	Crustal Monitoring Network Of the Chinese mainland geological environment (China)
CMONC	Crustal Movement Observation Network of China (China)
CMONOC	Crustal Movement Observation Network Of China (China)
CMVA	Coordinated Millimeter VLBI Array
CNES	Centre National d'Etudes Spatiales (France)
CNIG	Centro Nacional de Información Geográfica (Spain)
CNR	Consiglio Nazionale delle Ricerche (Italy)
CNRS	Centre National de la Recherche Scientifique (France)
CNS	Communication, Navigation and Surveillance systems, Inc. (USA)
CODA	Correlator Output Data Analyzer
COL	Combination at the Observation Level
CONGO	COoperative Network for GIOVE Observation
CORE	Continuous Observations of the Rotation of the Earth
CORS	Continuously Operating Reference Stations
COTS	Commercial-Off-The-Shelf
CP	Circularly Polarized
CPO	Celestial Pole Offset
CPOS	POSition accuracy on the Centimetre level
CPP	IERS Combination Pilot Project
CRAAE	Centro de Rádio Astronomia e Aplicações Espaciais (Brazil)
CRAAM	Centro de Rádio Astronomia e Astrofísica Mackenzie (Brazil)
CrAO	Crimean Astrophysical Observatory (Ukraine)
CRDS	Celestial Reference frame Deep South
CRESTech	Centre for Research in Earth and Space Technology (Canada)
CRF	Celestial Reference Frame
CRL	Communications Research Laboratory (now NICT) (Japan)
CRS	Celestial Reference System
CSA	Canadian Space Agency (Canada)
C-SART	Constrained Simultaneous Algebraic Reconstruction Technique
CSCU	Cryogenic System Control Unit
CSIR	Council for Scientific and Industrial Research (South Africa)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CSRIFS	Combined Square Root Information Filter and Smoother
CSRS	Canadian Spatial Reference System
CSTnet	China Science and Technology Network (China)
CTVA	Canadian Transportable VLBI Antenna
CUTE	CRL and University Telescopes Experiment (Japan)
CVN	Chinese VLBI Network
CW	Chandler Wobble
CW	Continuous Wave

CWDM	Coarse Wavelength Division Multiplexer
CYLAR	CDT Yebes Laser Ranging
DAO	GSFC Data Assimilation Office (USA)
DAQ	Data AcQuisition
DAR	Data Acquisition Rack
DAS	Data Acquisition System
DASOS	DAS Operating System
DAT	Digital Audio Tape
DB	Data Base
DBBC	Digital Base Band Converter
DBE	Digital BackEnd
DDC	Digital DownConverter
DDOR	Delta Differenced One-way Range
DeltaDOR	Delta Differenced One-way Range
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation) (Germany)
DFT	Discrete Fourier Transform
DGFI	Deutsches Geodätisches ForschungsInstitut (Germany)
DGK	Deutsche Geodätische Kommission (Germany)
dGPS	differential GPS
DHC	De Havilland Canada Company
DIIAR	Dipartimento di Ingegneria Idraulica, Ambientale, Infrastrutture viarie, Rilevamento (Italy)
DIISR	Department of Innovation, Industry, Science and Research (Australia)
DIM	Data Input Module
DISTART	Dipartimento di Ingegneria delle Strutture, dei Trasporti, delle Acque, del Rilevamento del Territorio (Italy)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DNSC	Danish National Space Center (Denmark)
DOGS	Dgfi Orbit and Geodetic parameter estimation Software
DOGS-RI	Dgfi Orbit and Geodetic parameter estimation Software (Radio Interferometry)
DOM	Data Output Module
DOMES	Directory Of MERIT Sites
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DPFU	Degrees Per Flux Unit
DPN	Dual Pseudo-random Noise
DR	Dichroic Reflector
DRAGON	Dynamic Resource Allocation through GMPLS over Optical Networks
DRAO	Dominion Radio Astrophysical Observatory (Canada)
DREN	Defense Research and Engineering Network (USA)
DSAMS	Direct Sampling Applied for Mixed Signals
DSCB	Data Stream Combining Board
DSCIG	Direcção de Serviços de Cartografia e Informação Geográfica (Portugal)
DSIF	Deep Space Instrumentation Facility
DSN	Deep Space Network
DSNA	Deep Space Network Array (USA)

DSP	Digital Signal Processor
DSS	Deep Space Station
DTU	Danmarks Tekniske Universitet (Denmark)
D-VLBI	Differential VLBI
EAN	Eastern Asia VLBI Network
EAS	European Astronomical Society
ECCO	Estimating the Circulation and Climate of the Ocean
ECMWF	European Centre for Medium-Range Weather Forecasts
EDM	Electronic Distance Measurement
EFTF	European Frequency and Time Forum
EGAE	Experiment Guided Adaptive Endpoint
EGS	European Geophysical Society
EGU	European Geosciences Union
EIA	Environmental Impact Assessment
ELSA	European Leadership in Space Astrometry
ENC GNSS	European Navigation Conference on Global Navigation Satellite Systems
ENSG	L'École Nationale des Sciences Géographiques
ENSO	El-Niño/Southern Oscillation
ENVISAT	ENVIronmental SATellite
EOP	Earth Orientation Parameter
EOP-PC	Earth Orientation Parameter Product Center (France)
EOS	Earth Observing System
EOT	Empirical Ocean Tide
EOT8A	Empirical Ocean Tide 2008 model from multi-mission satellite Altimetry
ERA	Earth Rotation Angle
ERP	Earth Rotation Parameter
ERS	European Remote Sensing Satellites
ESA	European Space Agency
ESO	European Southern Observatory
ESTEC	European Space research and TEchnology Centre
ETS-8	Engineering Test Satellite 8
ETSIT	Escuela Técnica Superior de Ingenieros de Telecomunicación
ETS-Lindgren	EMC Test Systems-Lindgren (USA)
ETS-VIII	Engineering Test Satellite 8
EU	European Union
EuCAP	European Conference on Antennas and Propagation
EUREF	EUropean REFerence Frame
EVGA	European Vlbi group for Geodesy and Astrometry
EVLA	Expanded Very Large Array
e-VLBI	Electronic VLBI
EVN	European VLBI Network
EXPReS	Express Production Real-time e-VLBI Service
FACH	Fuerza Aérea de Chile (Air Force of Chile) (Chile)
FAGS	Federation of Astronomical and Geophysical data analysis Services
FCN	Free Core Nutation

FEM	Finite Element Method
FES	Finite Element Solution
FESG	Forschungseinrichtung Satellitengeodäsie/Technical University of Munich (Germany)
FFI	Forsvarets ForskningsInstitutt (Norwegian Defence Research Establishment) (Norway)
FFT	Fast Fourier Transform
FFTS	Fast Fourier Transform Spectrometer
FGI	Finnish Geodetic Institute (Finland)
FGS	ForschungsGruppe Satellitengeodäsie (Germany)
FICN	Free Inner Core Nutation
FILA	FIrst LAst
FINEP	Financiadora de Estudos e Projetos (Brazilian Innovation Agency) (Brazil)
FIR	Finite Impulse Response
FITS	Flexible Image Transport System
FOV	Field Of View
FP7	Seventh Framework Programme (Europe)
FPDP	Front Panel Data Port
FPGA	Field-programmable Gate Array
FS	Field System
FSS	Frequency Selective Sub-reflector
FTP	File Transfer Protocol
FWF	Fonds zur Förderung der wissenschaftlichen Forschung (Austrian Science Fund)
GA	Geoscience Australia (Australia)
GALAXY	Giga-bit Astronomical Large Array with cross connect
GAPE	Great Alaska and Pacific Experiment
GARNET	GSI Advanced Radiotelescope NETwork (Japan)
GARR	Gruppo per l'Armonizzazione delle Reti della Ricerca (Italian Academic and Research Network) (Italy)
GARS	German Antarctic Receiving Station (Germany)
GASP	GLAST-AGILE Support Program
GBT	Green Bank Telescope (USA)
GCGO	Gilmore Creek Geophysical Observatory (USA)
GCRS	Geocentric Celestial Reference System
GD SATCOM	General Dynamics SATCOM technologies
GDR	altimeter Geophysical Data Record
GEMD	Geospatial and Earth Monitoring Division (Australia)
GeoDAF	Geodetic Data Archiving Facility (Italy)
GEX	Giga-bit series VLBI EXperiment
GFZ	GeoForschungsZentrum (Germany)
GGAO	Goddard Geophysical and Astronomical Observatory (USA)
GGFC	Global Geophysical Fluids Center
GGN	Global GPS Network
GGOS	Global Geodetic Observing System
GGP	Global Geodynamics Project

GICO	GIga-bit COrrelator
GINS	Géodésie par Intégrations Numériques Simultanées
GIOVE	Galileo In-Orbit Validation Element
GIS	Geographic Information System
GISTM	GPS Ionospheric Scintillation and TEC Monitor
GIUB	Geodetic Institute of the University of Bonn (now IGGB) (Germany)
GLAST	Gamma ray Large Area Space Telescope (USA)
GLDAS	Global Land Data Assimilation System
GLONASS	GLObal NAvigation Satellite System (Russia)
GLORIA	GLObal Radio Interferometry Analysis
GMF	Global Mapping Function
GMPLS	Generalized MultiProtocol Label Switching
GMST	Greenwich Mean Sideral Time
GNS Science	Geological and Nuclear Sciences Research Institute (New Zealand)
GNSS	Global Navigation Satellite Systems
GOCE	Gravity field and steady-state Ocean Circulation Explorer
GOES	Geostationary Operational Environmental Satellite (USA)
GOT	Goddard/Grenoble Ocean Tide
GOW	Geodetic Observatory Wettzell
GP-B	Gravity Probe B
GPS	Global Positioning System
GPT	Global Pressure and Temperature
GPU	Graphics Processing Unit
GR	General Relativity
GRACE	Gravity Recovery and Climate Experiment (USA)
GREAT-ESF	Gaia Research for European Astronomy Training — European Science Foundation
GREF	German GPS REFerence network
GRGS	Groupe de Recherches de Géodésie Spatiale (France)
GSD/NRCan	Geodetic Survey Division of Natural Resources Canada (Canada)
GSFC	Goddard Space Flight Center (USA)
GSI	GeoSpatial Information authority of japan (Japan)
GSK	Generalized Spectral Kurtosis
GSM	Global System for Mobile communication
GSOS	GPS Surface Observing System
GSS	Generator of Synchronization Signals
GST	Greenwich Sideral Time
HAMTIDE	Hamburg direct data Assimilation Methods for TIDEs
HartRAO	Hartebeesthoek Radio Astronomy Observatory (South Africa)
HAT-Lab	High Advanced Technology-Lab (Italy)
HEMT	High Electron Mobility Transistor
HF	High Frequency
HIA	Herzberg Institute for Astrophysics (Canada)
HIC	Hawaii Intranet Consortium (USA)
HIRLAM	High Resolution Limited Area Model

Honeywell TSI	Honeywell Technology Solutions Inc. (USA)
HOPS	Haystack Observatory Postprocessing System
HPBW	Half Power BeamWidth
HPC	High Performance Compute
HSI	High Speed Input bus
HSIR	High Speed Input Replicated bus
HTS	High Temperature Superconductor
HTSI	Honeywell Technology Solutions Incorporated (USA)
HVAC	Heating, Ventilation, and Air Conditioning
IAA	Institute of Applied Astronomy (Russia)
IAG	International Association of Geodesy
IAPG	Institut für Astronomische und Physikalische Geodäsie (Institute for Astronomical and Physical Geodesy) (Germany)
IAR	Instituto Argentino de Radioastronomía (Argentina)
IAU	International Astronomical Union
IBGE	Instituto Brasileiro de Geografia e Estatistica (Brazil)
IBM	International Business Machines Corporation (USA)
iBOB	Interconnect Break Out Board
ICRAR	International Centre for Radio Astronomy Research (Australia)
ICRF	International Celestial Reference Frame
ICRF2	2nd realization of the International Celestial Reference Frame
ICRF3	3rd realization of the International Celestial Reference Frame
ICRS	International Celestial Reference System
IDS	International DORIS Service
IDV	IntraDay Variability
IERS	International Earth Rotation and Reference Systems Service
IETF	Internet Engineering Task Force
IF	Intermediate Frequency
IGeS	International Geoid Service
IGFN	Italian Space Agency GPS Fiducial Network (Italy)
IGFS2	second International Symposium of the Gravity Field of the earth
IGG	Institute of Geodesy and Geophysics (Austria)
IGG	Institut für Geodäsie und Geoinformation der universität bonn (Germany)
IGGB	Institut für Geodäsie und Geoinformation der Universität Bonn (Germany)
IGGOS	Integrated Global Geodetic Observing System (now GGOS)
IGM	Instituto Geográfico Militar (Chile)
IGM	Istituto Geografico Militare (Italy)
IGN	Institut Geographique National (France)
IGN	Instituto Geográfico Nacional (Spain)
IGS	International GNSS Service
IISGEO	International Institute for Space Geodesy and Earth Observation
I-JUSE	Institute of Japanese Union of Scientists and Engineers (Japan)
IKAROS	Interplanetary Kite-craft Accelerated by Radiation of the Sun (Japan)
ILRS	International Laser Ranging Service
IMC	Interface Module of Correlator

IMF	Isobaric Mapping Function
INACH	Institute for Antarctic Research Chile
INAF	Istituto Nazionale di Astrofisica (Italy)
INGV	Institute of Geophysics and Volcanology (Italy)
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
InSAR	Interferometric Synthetic Aperture Radar
INTA	Instituto Nacional de Técnica Aeroespacial (Spain)
IP	Internet Protocol
IPEV	Institut polaire français Paul Emile Victor (France)
IPWV	Integrated Precipitable Water Vapor
IRA	Istituto di RadioAstronomia (Italy)
IRAM	Institut de RAdioastronomie Millimétrique (France)
IRAS	InfraRed Astronomy Satellite
IRASR	Institute for Radio Astronomy and Space Research (New Zealand)
IRIS	International Radio Interferometric Surveying
IRP	Invariant Reference Point
IRSR	Institute for Radiophysics and Space Research (New Zealand)
ISACCO	Ionospheric Scintillations Arctic Campaign Coordinated Observation
ISAS	Institute of Space and Astronautical Science (Japan)
ISBN	International Standard Book Number
ISI	Information Sciences Institute (USA)
ISV	Instantaneous State Vector
ITIS	Istituto di Tecnologia Informatica Spaziale (Italy)
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
ITSS	(Raytheon) Information Technology and Science Services (USA)
IUGG	International Union of Geodesy and Geophysics
IVOA	International Virtual Observatory Alliance
IVP	Invariant Point
IVS	International VLBI Service for Geodesy and Astrometry
IWV	Integrated Water Vapor
IYA	International Year of Astronomy
JADE	JApanese Dynamic Earth observation by VLBI
JARE	Japanese Antarctic Research Expedition (Japan)
JAXA	Japan Aerospace Exploration Agency (Japan)
JENAM	Joint European and National Astronomy Meeting
JGN	Japan Gigabit Network (Japan)
JGR	Journal of Geophysical Research
JHB	JoHannesBurg
JIVE	Joint Institute for VLBI in Europe
JLRA	Joint Laboratory for Radio Astronomy (China)
JMA	Japan Meteorological Agency (Japan)
JPL	Jet Propulsion Laboratory (USA)
JSPS	Japanese Society for the Promotion of Science (Japan)
JST	Japan Standard Time

KARAT	KAshima RAy-tracing Tools (Japan)
KARATS	KAshima RAy-Tracing Service (Japan)
KAREN	Kiwi Advanced Research and Education Network (New Zealand)
KASI	Korea Astronomy and Space Science Institute (Korea)
KAT	Karoo Array Telescope (South Africa)
KBR	K-Band Ranging
KEG	Kommission für Erdmessung und Glaziologie (Commission for Geodesy and Glaciology) (Germany)
KFC	Kashima Flexible Correlator
KPGO	Kokee Park Geophysical Observatory (USA)
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
KSP	KeyStone Project (Japan)
KSRC	Kashima Space Research Center (Japan)
KSTC	Kashima Space Technology Center
KTU	Karadeniz Technical University (Turkey)
KTU-GEOD	Karadeniz Technical University (KTU), Department of Geomatics Engineering (Turkey)
KVG	Korea VLBI system for Geodesy (Korea)
KVM	Keyboard, Video, and Mouse
KVN	Korean VLBI Network
LAB	Laboratoire d'Astrophysique de Bordeaux (France)
LAGEOS	LAser GEOdynamic Satellite
LAMOST	Large Sky Area Multi-object Fiber Spectroscopic Telescope (China)
LAREG	Laboratoire de Recherches en Géodésie (France)
LBA	Long Baseline Array (Australia)
LCP	Left Circular Polarization
LCS	Long baseline array Calibrator Survey
LD	Laser Diode
LEA	Lab of Ephemeris Astronomy (Russia)
LED	Light-Emitting Diode
LEIF	Large Equipment and Infrastructure Funding
LEO	Low Earth Orbit
LHC	Left Hand Circular
LIEF	Large Infrastructure and Equipment Funding
LINZ	Land Information New Zealand (New Zealand)
LLR	Lunar Laser Ranging
LNA	Low Noise Amplifier
LNMAG	Lab of New Methods in Astrometry and Geodynamics (Russia)
LO	Local Oscillator
LOC	Local Organizing Committee
LOD	Length Of Day
LPF	Low Pass Filter
LPI	Lebedev Physical Institute (Russia)
LRS	Laser Ranging System
LSB	Lower Side Band

LSC	Least Squares Collocation
LSF	Large Scale Facility
LSGER	Lab of Space Geodesy and Earth Rotation (Russia)
LSM	Least Squares Method
LSQM	Least Squares Method
MAO	Main Astronomical Observatory (Ukraine)
MARBLE	Multiple Antenna Radio-interferometry for Baseline Length Evaluation
MBH	Mathews/Buffett/Herring Nutation Model
MCB	Monitor and Control Bus
MCI	Monitor and Control Infrastructure
MDION	Multi-Dimensional IONosphere modeling
MDSCC	Madrid Deep Space Communications Complex (Spain)
MEI	Multivariate ENSO Index
MERIT	Monitoring of Earth Rotation and Intercomparison of the Techniques of Observation and Analysis
METLAB	Microwave Energy Transmission LABoratory (Japan)
MEX	Mars Express
MIT	Massachusetts Institute of Technology (USA)
MITEQ	Microwave Information Transmission EQuipment (USA)
MIUR	Ministero dell'Istruzione, dell' Università e della Ricerca (Ministry of Education, University and Research) (Italy)
MJD	Modified Julian Date
MLRO	Matera Laser Ranging Observatory (Italy)
MNHD	Mineral and Natural Hazard Division (Australia)
MNRAS	Monthly Notices of the Royal Astronomical Society
MOBLAS	MOBile LASer
MODEST	MODel and ESTimate
MOU	Memorandum of Understanding
MPI	Max-Planck-Institute (Germany)
MPI	Message Passing Interface
MPIfR	Max-Planck-Institute for Radioastronomy (Germany)
MPM	Millimeter-wave Propagation Model
MRO	Mars Reconnaissance Orbiter
MRO	Metsähovi Radio Observatory (Finland)
MSL	Mars Science Laboratory
MTLRS	Modular Transportable Laser Ranging System
NAO	National Astronomical Observatories (China)
NAO	National Astronomical Observatory (Japan)
NAOC	National Astronomical Observatories of China (China)
NAOJ	National Astronomical Observatory of Japan (Japan)
NAR	Noise-Adding Radiometer
NAS	Network Attached Storage
NASA	National Aeronautics and Space Administration (USA)
NASU	National Academy of Sciences of Ukraine (Ukraine)
NCAR	National Center for Atmospheric Research (USA)

NCEP	National Centers for Environmental Prediction (USA)
NCRIS	National Collaborative Research Infrastructure Strategy (Australia)
NDBC	National Data Buoy Center
NDRE	Norwegian Defence Research Establishment (Norway)
NEA	Near-Earth Asteroid
NENS	Near Earth Network Services
NEOS	National Earth Orientation Service (USA)
NEQ	Normal Equation System
NESDIS	National Environmental Satellite, Data, and Information Service (USA)
NetCDF	Network Common Data Form
NEXPReS	Novel EXploration Pushing Robust e-VLBI Services
NGII	National Geographic Information Institute (Korea)
NGS	National Geodetic Survey (USA)
NGSLR	Next Generation Satellite Laser Ranging
NIC	Network Interface Card
NICT	National Institute of Information and Communications Technology (Japan)
NII	National Institute of Informatics (Japan)
NIPR	National Institute of Polar Research (Japan)
NMA	Norwegian Mapping Authority (Norway)
NMF	Niell Mapping Function
NNR	No-Net-Rotation
NNT	No-Net-Translation
NOAA	National Oceanic and Atmospheric Administration (USA)
NOFS	U.S. Naval Observatory, Flagstaff Station (USA)
NORAD	North American Aerospace Defense Command
NOT	Nordic Optical Telescope
NRAO	National Radio Astronomy Observatory (USA)
NRC	National Research Council of canada (Canada)
NRCan	Natural Resources Canada (Canada)
NRF	National Research Foundation (South Africa)
NSF	National Science Foundation (USA)
NTP	Network Time Protocol
NTT	New Technology Telescope (Chile)
NTT	Nippon Telegraph and Telephone Corporation (Japan)
NVI	NVI, Inc. (USA)
NWP	Numerical Weather Prediction
NySMAC	Ny-Ålesund Science Managers Committee
OAM	Observatorio Astronómico de Madrid (Spain)
OAN	Observatorio Astronómico Nacional (Spain)
OASU	Observatoire Aquitain des Sciences de l'Univers (France)
OCA	Observatoire de la Côte d'Azur (France)
OCARS	Optical Characteristics of Astrometric Radio Sources
OPAR	Observatoire de Paris (France)
OPC	(IVS) Observing Program Committee
ORCA	Optical ReCeiver/splitter/Amplifier

Orion KL	Orion Kleinmann-Low
OS	Operating System
OSI	Operator Software Impact
OSO	Onsala Space Observatory (Sweden)
OTL	Ocean Tidal Loading
PARNASSUS	Processing Application in Reference to NICT's Advanced Set of Softwares Usable for Synchronization
PASJ	Publications of the Astronomical Society of Japan
PASP	Publications of the Astronomical Society of the Pacific
PATA	Parallel Advanced Technology Attachment
PC	Principal Component
PCAL	Phase CALibration
PCB	Printed Circuit Board
PCU	Power Control Unit
PEACESAT	Pan-Pacific Education and Communication Experiments by Satellite
PERSAC	Pulkovo EOP and Reference Systems Analysis Center (Russia)
PF	Processing Factor
PFB	Polyphase Filter Bank
PIVEX	Platform Independent VLBI EXchange format
PLC	Programmable Logic Controller
PLO	Phase Locked Oscillator
PM	Polar Motion
PMD	Politecnico di Milano DIIAR (Italy)
PMRF	Pacific Missile Range Facility (USA)
PNR	Peak to Noise Ratio
POLARIS	POLar motion Analysis by Radio Interferometric Surveying
POP	Point of Presence
PPN	Parameterized Post-Newtonian
PPP	Precise Point Positioning
PRAO	Pushchino Radio Astronomy Observatory (Russia)
PRARE	Precise RAnge and Range-rate Equipment
PSD	Power Spectrum Density
PSS	Point Source Sensitivity
PTCB	Precise Temperature Control Box
PWL	PieceWise Linear
QDOR	Quadruply Differenced One-way Ranging
QRFH	Quad-Ridged Flared Horn
QRHA	Quad-Ridge Horn Antenna
QZSS	Quasi Zenith Satellite System (Japan)
RAEGE	Red Atlántica de Estaciones Geodinámicas y Espaciales
RAID	Redundant Array of Independent Disks
RAS	Russian Academy of Sciences (Russia)
RCP	Right Circular Polarization
RCU	Receiver Control Unit
RDBE	Roach Digital Back End

RDBE-H	RDBE Hardware version
RDBE-S	RDBE Software version
RDV	Research and Development sessions using the VLBA
RedCLARA	CLARA (Cooperación Latino Americana de Redes Avanzadas) network
REFAG	Reference Frames for Applications in Geosciences
REGINA	REseau GNSS pour l'IGS et la NAvigation (GNSS Receiver Network for IGS and Navigation) (France)
REPA	REsidual Plotting and Ambiguity resolution
REUNA	Red Universitaria Nacional (Chile)
RF	Radio Frequency
RFCN	Retrograde Free Core Nutation
RFI	Radio Frequency Interference
RHC	Right Hand Circular
ROACH	Reconfigurable Open Architecture Computing Hardware
ROEN	Rádio-Observatório Espacial do Nordeste (Brazil)
ROM	Real Observatorio de Madrid (Spain)
RRFID	Radio Reference Frame Image Database
RS-232C	Recommended Standard-232C
RT	Radio Telescope
RTCM	Radio Technical Commission for Maritime services
RTIS	Real-Time Ionospheric Scintillation
RTK	Real-Time Kinematic
RTNF	Radio Telescope National Facility (New Zealand)
RTP	Real-Time Protocol
RTW	Radio Telescope in Wettzell
SAC	Satellite Application Centre
SAC-SOS	Special Analysis Center for Specific Observing Sessions
SAGE	Small Advanced Geodetic e-VLBI System
SAI	Sternberg State Astronomical Institute (Russia)
SAN	Storage Area Network
SANSA	South African National Space Agency (South Africa)
SANSA EO	South African National Space Agency Earth Observation
SAR	Synthetic Aperture Radar
SAS	Scandinavian AirlineS
SATA	Serial Advanced Technology Attachment
SBIR	Small Business Innovation Research
SC	Sub-Commission
SCG	SuperConducting Gravimeter
SCNS	Space Communications Network Services
SCR	Silicon Controlled Rectifier
SDK	Software Development Kit
SDM	Signal Distribution Modules
SDSS	Signal Distribution and Synchronization System
SEAC	Sociedad Española de Aplicaciones Cibernéticas (Spain)
SEFD	System Equivalent Flux Density

SETI	Search for Extraterrestrial Intelligence
SG	Superconducting Gravimeter
SGL	Space Geodynamics Laboratory (Canada)
SGP	Space Geodesy Project
SGT	Stinger Ghaffarian Technologies (USA)
SHAO	SHanghai Astronomical Observatory (China)
SI	Special Issue
SI	Structure Index
SIDC	Solar Influence Data Center (Belgium)
SIMD	Single Instruction Multiple Data
SINEX	Solution INdependent EXchange
SISMA	Seismic Information System for Monitoring and Alert
SK	Spectral Kurtosis
SKA	Square Kilometre Array
SLR	Satellite Laser Ranging
SMA	SubMillimeter Array (USA)
SMA	SubMiniature type-A
SMART	Small Missions for Advanced Research and Technology
SMHI	Swedish Meteorological and Hydrological Institute (Sweden)
SMTO	SubMillimeter Telescope Observatory (USA)
SNAP	Standard Notation for Astronomical Procedures
SNR	Signal to Noise Ratio
SNSN	Swedish National Seismic Network (Sweden)
SOD	Site Occupation Designator
SOSW	Satellite Observing System Wettzell (Germany)
SPb	Saint-Petersburg (Russia)
SPbU	Saint-Petersburg University (Russia)
SPEED	Short Period and Episodic Earth rotation Determination
SPU	Saint-Petersburg University (Russia)
SPV	Signal Path Variation
SRIF	Square Root Information Filter
SRT	Sardinia Radio Telescope (Italy)
SRTM	Shuttle Radar Topography Mission
SSA	Singular Spectrum Analysis
SSAI	Science Systems and Applications, Inc. (USA)
SSB	Solar System Barycenter
STDN	Satellite Tracking Data Network (NASA)
STEREO	Solar TErrestrial RElations Observatory
SU	Station Unit
SUDP	Simple User Datagram Protocol
SVD	Singular Value Decomposition
SvRAO	Svetloe Radio Astronomical Observatory (Russia)
SWT	SW Technology (USA)
SYRTE	SYstème de Références Temps-Espace
TAC	Totally Accurate Clock

TAI	Temps Atomique International (International Atomic Time)
TAL	Terrestrial Air Link
TANAMI	Tracking Active galactic Nuclei with Austral Milliarcsecond Interferometry (Australia)
TanDEM-X	TerraSAR-X add-on for Digital Elevation Measurement (Germany)
TAO	Telecommunications Advanced Organization (Japan)
TCE	Time Comparison Equipment
TDC	(IVS) Technology Development Center
TEC	Total Electron Content
TECU	Total Electron Content Units
TEIN	Trans-Eurasia Information Network
Telecom NZ	Telecom New Zealand
TEM	Transverse ElectroMagnetic
TEMPO	Time and Earth Motion Precision Observations
TENET	Tertiary Education and Research Network of South Africa (South Africa)
TERENA	Trans-European Research and Education Networking Association
TerraSAR	Terra Synthetic Aperture Radars (Germany)
TerraSAR-X	Terra Synthetic Aperture Radars X-band (Germany)
TID	Traveling Ionospheric Disturbance
TIGA–PP	GPS TIde GAuge Benchmark Monitoring Pilot Project
TIGO	Transportable Integrated Geodetic Observatory (Germany, Chile)
TLE	Two Line Elements
TLRS	Transportable Laser Ranging System
TMR	Training and Mobility of Researchers program of the European Community
ToR	IVS Terms of Reference
TOW	Technical Operations Workshop
TRF	Terrestrial Reference Frame
TSPM	Test Synchronization Pulsar gating Module
TTC	Tracking, Telemetry, and Command
TTL	Transistor-Transistor Logic
TTW	Twin Telescope Wettzell (Germany)
TU	Technische Universität
TUM	Technische Universität München (Technical University of Munich) (Germany)
TWA	Travel Wave Antennas
TWSTFT	Two-Way Satellite Time and Frequency Transfer
UAO	Urumqi Astronomical Observatory (China)
UBB	Universidad del Bío Bío (Chile)
UC Berkeley	University of California, Berkeley (USA)
UCP	Unified Control Point
UD	Upper Diagonal
UDC	Up-Down Converter
UDMA	Ultra Direct Memory Access
UEN	Up East North
UMTS	Universal Mobile Telecommunications System
UNAVCO	University NAVSTAR Consortium

UNICAMP	Universidade Estadual de Campinas (Brazil)
UNISEC	UNIversity Space Engineering Consortium (Japan)
UNITEC-1	UNIsec Technological Experiment Carrier-1 (Japan)
UR	Ultra Rapid
UREO	Ultra-Rapid Earth Orientation
URSI	Union Radio-Scientifique Internationale
USB	Unified S-Band
USB	Upper Side Band
USNO	United States Naval Observatory (USA)
USP	Universidade de São Paulo (Brazil)
USS	Uniform Sky Strategy
UT	Universal Time
UT1	Universal Time
UTAS	University of TASmania (Australia)
UTC	Coordinated Universal Time
u-VLBI	Ultra High Sensitivity VLBI
UWB	Ultra WideBand
V2PEG	VLBI2010 Project Executive Group
VC	Variance Components
VC	Video Converter
VCS	VLBA Calibrator Survey
VDBE	VLBA Digital BackEnd
VDIF	VLBI Data Interchange Format
VEGA	Venus-Halley project (Russia)
VERA	VLBI Exploration of Radio Astrometry
VEX	Venus EXpress
VEX	VLBI EXchange format
VHDL	Very High-level Design Language
VieVS	Vienna VLBI Software
VGOS	Vlbi2010 Global Observing System
VLA	Very Large Array (USA)
VLBA	Very Long Baseline Array (USA)
VLBI	Very Long Baseline Interferometry
VMF	Vienna Mapping Function
VMware	Virtual Machine software
VO	Virtual Observatory
VSI	VLBI Standard Interface
VSI-C	Metsähovi VSI-H Converter board
VSI-H	VLBI Standard Interface Hardware
VSI-S	VLBI Standard Interface Software
VSN	Volume Serial Number
VSOP	VLBI Space Observatory Program
VSR	VLBI Science Recorder
VSSP	Versatile Scientific Sampling Processor
VTEC	Vertical Total Electron Content

VTM	Vienna TEC (Total Electron Content) Model
VTP	VLBI Transport Protocol
VTRF	VLBI Terrestrial Reference Frame
WACO	WAshington COrrelator (USA)
WEBT	Whole Earth Blazar Telescope
WEGENER	Working Group of European Geoscientists for the Establishment of Networks for Earth-science Research
WG	Working Group
WGS84	World Geodetic System 1984
WIDAR	Wideband Interferometric Digital ARchitecture
WLAN	Wireless Local Area Network
WLRS	Wettzell Laser Ranging System (Germany)
WMAP	Wilkinson Microwave Anisotropy Probe
WVR	Water Vapor Radiometer
WVSR	Wideband VLBI Science Recorder
WWW	World Wide Web
XDM	eXperimental Development Model
ZcRAO	Zelenchukskaya Radio Astronomical Observatory (Russia)
ZTD	Zenith Total Delay
ZWD	Zenith Wet Delay