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INTERNATIONAL VLBI SERVICE FOR GEODESY AND ASTROMETRY

# 2005 Annual Report



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Edited by  
D. Behrend and K.D. Baver

IVS Coordinating Center  
April 2006



## Preface

This volume of reports is the 2005 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 2005 Annual Report documents the work of the IVS components for the calendar year 2005, our seventh 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 (described below), the contents of this Annual Report also appear on the IVS web site at

<http://ivscc.gsfc.nasa.gov/publications/ar2005>

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 contains the final report of the IVS Working Group on VLBI2010.
- 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 newly added bibliography section contains a compilation of publications in the field of geodetic and astrometric VLBI during 2005.
- 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.



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# About IVS

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# 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

- 30 Network Stations, acquiring high performance VLBI data,
- 3 Operation Centers, coordinating the activities of a network of Network Stations,
- 6 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,
- 21 Analysis Centers, analyzing the data and producing the results and products,
- 7 Technology Development Centers, developing new VLBI technology,
- 1 Coordinating Center, coordinating daily and long term activities.

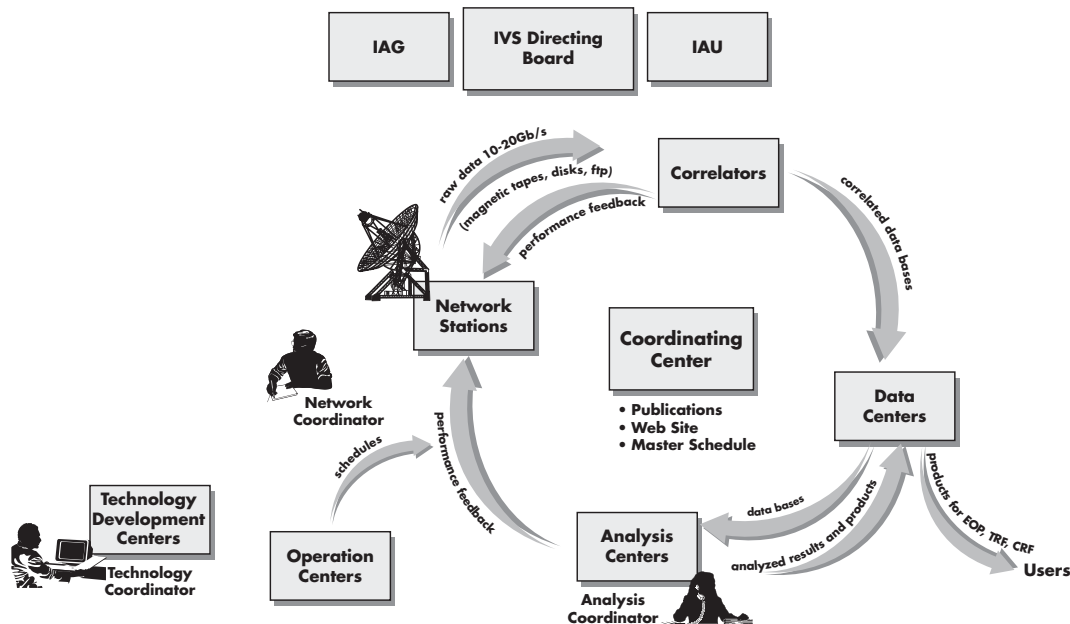
### Altogether

- 74 Permanent Components, representing 37 institutions in 17 countries,
- ~250 Associate Members.

### In addition the IVS has:

- Directing Board, determining policies, standards and goals; the board is composed of 16 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 University of Tasmania	Australia Australia
Vienna University of Technology	Austria
Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Space Geodynamics Laboratory	Canada
Geodetic Survey Division, Natural Resources Canada	Canada
Dominion Radio Astrophysical Observatory	Canada
Canadian Space Agency	Canada
Universidad de Concepción	Chile
Universidad del Bío Bío	Chile
Universidad Católica de la Santísima Concepción	Chile
Instituto Geográfico Militar of Chile	Chile
Chinese Academy of Sciences	China
Observatoire de Paris	France
Observatoire de Bordeaux	France
Deutsches Geodätisches Forschungsinstitut	Germany
Bundesamt für Kartographie und Geodäsie	Germany
Geodetic Institute of the University of Bonn	Germany
Forschungseinrichtung Satellitengeodäsie, TU-Munich	Germany
Istituto di Radioastronomia CNR	Italy
Agenzia Spaziale Italiana	Italy
Geographical Survey Institute	Japan
National Institute of Information and Communications Technology	Japan
National Astronomical Observatory of Japan	Japan
National Institute of Polar Research	Japan
Norwegian Defence Research Establishment	Norway
Norwegian Mapping Authority	Norway
Astronomical Institute of St.-Petersburg University	Russia
Institute of Applied Astronomy	Russia
Hartebeesthoek Radio Astronomy Observatory	South Africa
Instituto Geografico Nacional	Spain
Chalmers University of Technology	Sweden

Organization	Country
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
Max-Planck-Institut für Radioastronomie	Germany
FÖMI Satellite Geodetic Observatory	Hungary
Korea Astronomy Observatory	Korea
Joint Institute for VLBI in Europe (JIVE)	Netherlands
Westerbork Observatory	Netherlands
Auckland University of Technology	New Zealand
Central (Pulkovo) Astronomical Observatory	Russia
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)

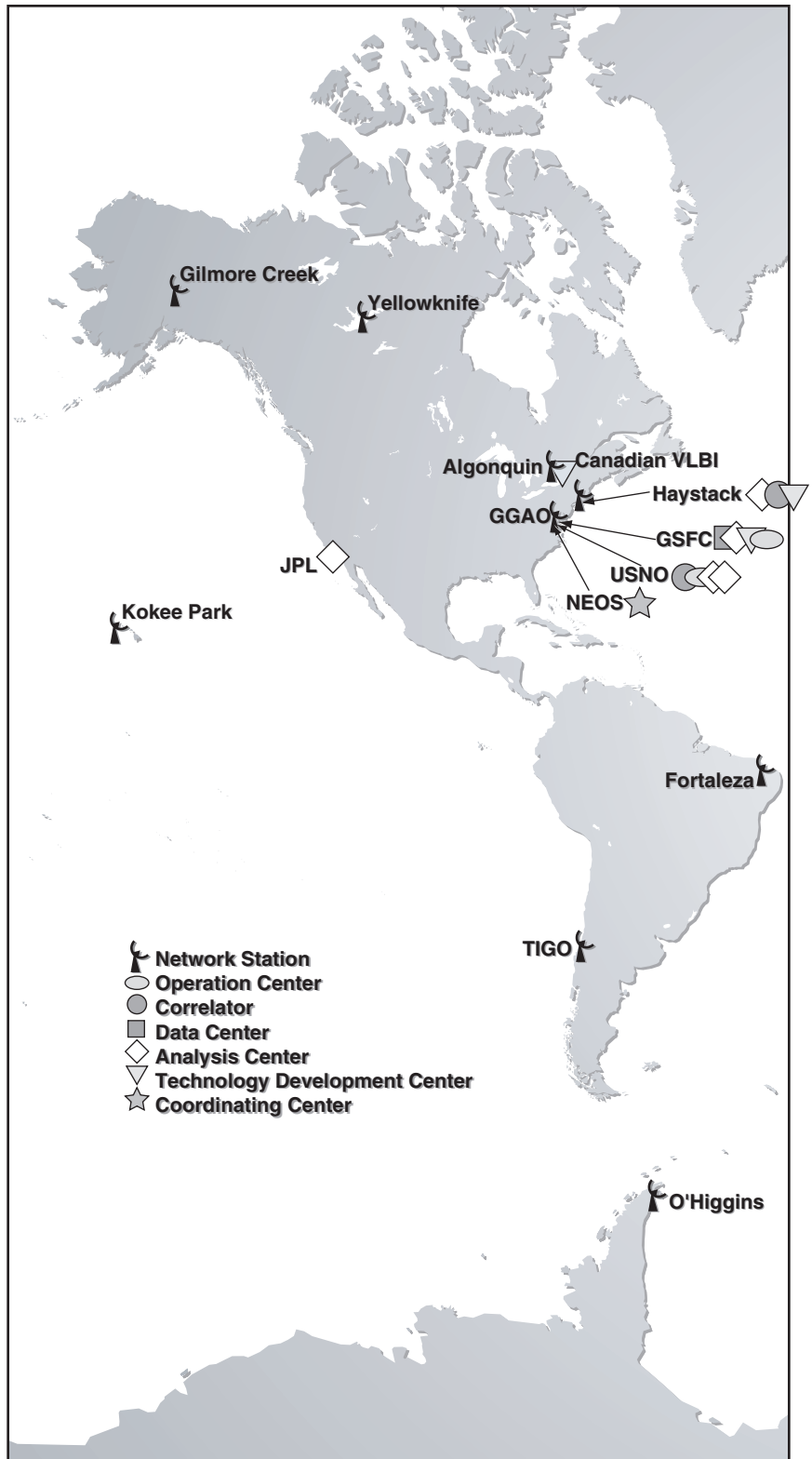
All VLBI data and results in appropriate formats are archived in data centers and publicly available for research in related areas of geodesy, geophysics and astrometry.

# IVS Component Map

## IVS COMPONENTS BY COUNTRY

Australia	2
Austria	1
Brazil	1
Canada	3
Chile	1
China	3
France	3
Germany	8
Italy	7
Japan	12
Norway	3
Russia	6
South Africa	1
Spain	1
Sweden	3
Ukraine	2
USA	17
<b>Total</b>	<b>74</b>

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

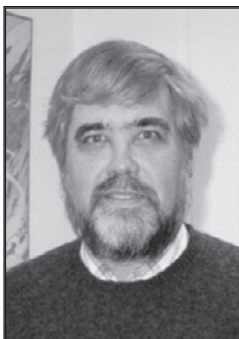




# IVS Directing Board



NAME: Wolfgang Schlüter  
AFFILIATION: Bundesamt für Kartographie und Geodäsie, Germany  
POSITION: Chair and Networks Representative  
TERM: Feb 2003 to Feb 2007



NAME: Kerry Kingham  
AFFILIATION: U.S. Naval Observatory, USA  
POSITION: Correlators and Operation Centers Representative  
TERM: Feb 2003 to Feb 2007



NAME: Dirk Behrend  
AFFILIATION: NVI, Inc./Goddard Space Flight Center, USA  
POSITION: Coordinating Center Director  
TERM: ex officio



NAME: Yasuhiro Koyama  
AFFILIATION: National Institute of Information and Communications Technology, Japan  
POSITION: At Large Member  
TERM: Feb 2005 to Feb 2007



NAME: Roy Booth  
AFFILIATION: Hartebeesthoek Radio Astronomy Observatory, South Africa, and part-time Onsala Space Observatory, Sweden  
POSITION: FAGS Representative  
TERM: ex officio



NAME: Chopo Ma  
AFFILIATION: NASA Goddard Space Flight Center, USA  
POSITION: IERS Representative  
TERM: ex officio



NAME: Ed Himwich  
AFFILIATION: NVI, Inc./Goddard Space Flight Center, USA  
POSITION: Network Coordinator  
TERM: permanent



NAME: Zinovy Malkin  
AFFILIATION: Institute of Applied Astronomy, Russia  
POSITION: At Large Member  
TERM: Sept 2005 to Feb 2007



NAME: Franco Mantovani  
 AFFILIATION: CNR Bologna, Italy  
 POSITION: At Large Member  
 TERM: Sept 2005 to Feb 2007



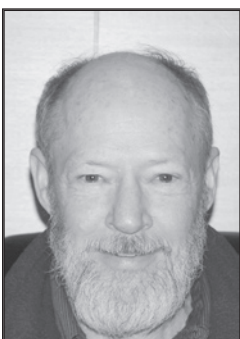
NAME: William Petrachenko  
 AFFILIATION: National Resources Canada, Canada  
 POSITION: Technology Development Centers Representative  
 TERM: Feb 2005 to Feb 2009



NAME: Shigeru Matsuzaka  
 AFFILIATION: Geographical Survey Institute, Japan  
 POSITION: Networks Representative  
 TERM: Feb 2003 to Feb 2007



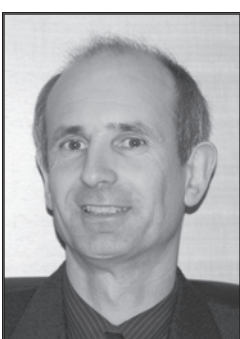
NAME: Harald Schuh  
 AFFILIATION: Vienna University of Technology, Austria  
 POSITION: IAG Representative  
 TERM: ex officio



NAME: Arthur Niell  
 AFFILIATION: Haystack Observatory, USA  
 POSITION: Analysis and Data Centers Representative  
 TERM: Feb 2005 to Feb 2009



NAME: Patrick Wallace  
 AFFILIATION: Rutherford Appleton Laboratory, UK  
 POSITION: IAU Representative  
 TERM: ex officio



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

Wolfgang Schlüter,  
Bundesamt für Kartographie und Geodäsie, Germany

Another year passed by during which the International VLBI Service for Geodesy and Astrometry (IVS) successfully supported geodetic, geophysical and astrometric research as well as operational activities. With the 2005 Annual Report the IVS components report about their progress and activities which were conducted during the service's seventh year of existence. I would like to thank the 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 2005 IVS service activities could be maintained at a level comparable to the previous year, a fact that in view of the reduced resources can be attributed to optimized coordination by the Coordinating Center and strong support from all components. I would like to express my sincere gratitude to the staff of the Coordinating Center who bear much responsibility and carry a heavy burden for the entire service activities.

## Main Activities 2005

Day-to-day work is carried out continuously by the Network Stations, the Correlators, the Data Centers, and the Analysis Centers and is the basis for the regular provision of precise IVS products. Now I would like to emphasize those activities performed in 2005 that go beyond the normal work load.

The Working Group 3 (WG3), led by the chairs Arthur Niell and Alan Whitney, prepared the very important report "VLBI2010: Current and Future Requirements for Geodetic VLBI Systems". This report is a strategic paper and a road map for IVS to motivate new developments and to encourage investments towards the next generation VLBI system. Internally it supports the coordination of the activities to be done by the IVS supporting agencies; externally it documents the continued need for VLBI in the future and provides arguments to request financial support. It also demonstrates that IVS takes seriously its responsibility for preparing the service towards future requirements. Such requirements will arise with the program "Global Geodetic Observing System (GGOS)" of

the International Association of Geodesy. GGOS aims at realizing a precise reference frame consistent for decades and consistent with respect to geometric and physical parameters. IVS, as the service which uniquely provides the CRF and the complete set of EOP and which contributes strongly to the TRF, will play a key role in GGOS. I would like to express my appreciation to the chairs and to the co-authors Bill Petrachenko, Nancy Vandenberg, Hayo Hase, Yasuhiro Koyama, Chopo Ma, Harald Schuh, and Gino Tuccari for generating the important WG3 report.

As a consequence of the VLBI2010 report the IVS Directing Board established the VLBI2010 Committee, which is tasked with promoting the ambitious goals set by the VLBI2010 report. Bill Petrachenko was elected as chair of the committee. He contributed strongly to the VLBI2010 paper. Members of the committee are the highly respected experts Dirk Behrend, Johannes Böhm, Brian Corey, Rüdiger Haas, Yasuhiro Koyama, Dan MacMillan, Zinovy Malkin, Arthur Niell, and Gino Tuccari. I would like to thank them all for taking over the responsible leading role in the realization of the VLBI2010 visions.

A very important observing session in 2005 was CONT05, which provided the most ambitious data set VLBI generated so far. During the period September 12–27, 2005 eleven IVS network stations—Algonquin Park, Gilmore Creek, Hartebeesthoek, Kokee Park, Ny Ålesund, Onsala, Svetloe, TIGO/Concepcion, Tsukuba, Westford, and Wettzell—carried out the observations. Prior to the campaign the stations had to perform technical tests in order to ensure their best performance. I thank the stations' staff for the reliable support. The campaign was masterfully organized and executed. I express my gratitude to Dirk Behrend and Cynthia Thomas of the Coordinating Center. IGS, ILRS, and IDS enhanced their activities during CONT05 which is of importance for obtaining the best results through the combination of the techniques. I would like to thank the IGS, ILRS, and IDS for joining the campaign and for their support and cooperation.

## Meeting Events in 2005

In April 2005, both the 6th IVS Analysis Workshop and the 17th Working Meeting on European VLBI for Geodesy and Astrometry were held at the Noto Observatory in Sicily, Italy. Both meetings were successful events. At the end of the conference the European VLBI Group for Geodesy and Astrometry (EVGA) was established. I would like to congratulate Axel Nothnagel and Rüdiger Haas—elected



chair and secretary, respectively, of EVGA—and to express my best wishes for the success of this group. The organization of the meetings was performed with the close collaboration of the Analysis Coordinator Axel Nothnagel and the local organizing committee led by Gino Tuccari. The Directing Board held its 13th board meeting before the two meetings. I take this opportunity to thank Gino Tuccari for making the stay very pleasant and the meetings successful.

The 3rd IVS Technical Operations Workshop (TOW) was held at the Haystack Observatory in May 2005. TOW is an important meeting for exchanging experience in operation and for providing information about new developments. “Hands on” training and teaching in classes is the key for the success of TOW. It was a very useful meeting also with respect to preparing the stations for the CONT05 campaign. I would like to thank Ed Himwich and the local organizers at Haystack for their commitment to the TOW.

The IVS Directing Board held its 14th Meeting at the U.S. Naval Observatory, Washington, DC in September. The venue made it possible to invite Nancy Vandenberg to celebrate her retirement as Coordinating Center Director. For that, greeting pages were prepared by almost all IVS components and I was able to hand over a very personal booklet with greetings and best wishes from the entire VLBI community. It was highly appreciated by Nancy.

Summary information about all IVS events and activities is available in the Newsletters 11, 12, and 13. 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 did again an excellent job, which is highly appreciated.

## Changes in the Directing Board in 2005

The elections of the representatives of the Analysis and Data Centers as well as of the Technology Development Centers (term 2005 to 2009) were held in January 2005 and were carried out by the Election Committee consisting of Kerry Kingham (chair), Nancy Vandenberg, and Shigeru Matzusaka. 46% of the Associate Members voted and elected Bill Petrachenko as the Representative of the Technology Development Centers and Arthur Niell as the Representative of the Analysis and Data Centers. For the at large positions (term 2005 to 2007) Yasuhiro Koyama, Zinovy Malkin, and Franco Mantovani were elected by the

Directing Board. The elections did not change the names of the people on the board, but resulted in a reshuffling of some of the positions. The stability in personnel can be regarded as a confirmation of the good work done by the representatives. I express my thanks to the Associate Members for voting, to the Election Committee for conducting the elections, and to the “old/new” board members for their willingness to continue to serve on the board.

At a FAGS (Federation of Astronomical and Geophysical Data Analysis Services) meeting in Paris, we were informed—as IVS is a member service of FAGS—that a Representative of FAGS had to have a position on the Directing Board. FAGS had already nominated Roy Booth from Onsala (now mainly with HartRAO). As a consequence, at the Board Meeting at USNO in September, the Terms of Reference were slightly modified to include a FAGS Representative. I would like to welcome Roy Booth as an additional VLBI expert on the IVS Directing Board.

In the 2004 Annual Report I already noted that Nancy Vandenberg reduced her activities in our community and that Dirk Behrend would take over Nancy’s part after a transition period. Nancy’s contributions and experience were of extreme importance for IVS. The notion that Nancy would retire was, at the beginning, not easy to accept. Nancy strongly supported VLBI from the very beginning. The IVS was formed with significant contributions from her side. Nevertheless, with the official letter from NEOS (NASA/GSFC and USNO) and the acknowledgement by the board, she officially withdrew from the board in September 2005. I am very grateful that I had the good fortune to work with her. On behalf of the IVS I express my gratitude for all that she has done for VLBI/IVS and I wish her all the best for the future. Dirk Behrend completely took over the responsibilities as the Director of the Coordinating Center and as chair of the Observing Program Committee. Dirk has already shown that he is a worthy successor to Nancy, e.g. through organizing the CONT05 campaign. I wish him continued success and thank him for his commitment to IVS.



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# Special Reports

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# VLBI2010: Current and Future Requirements for Geodetic VLBI Systems

*Arthur Niell, Alan Whitney, Bill Petrachenko, Wolfgang Schlüter, Nancy Vandenberg, Hayo Hase, Yasuhiro Koyama, Chopo Ma, Harald Schuh, Gino Tuccari*

## Abstract

Geodetic VLBI stands at the brink of a new era. Such societally relevant issues as climate change and natural hazards are placing ever increasing demands on performance. This comes at a time when problems with aging antennas, a deteriorating RFI environment, obsolete electronics, and high operating costs are making current levels of accuracy, reliability, and timeliness difficult to sustain. Attaining modern requirements for significantly greater accuracy, continuous data flow, and shortened times to product delivery challenge the continuing progress made by geodetic VLBI over the past 30 years. Fortunately, recent advances in antenna manufacture, digital electronics, and data transmission technology are enabling modes of operation unimaginable only a few years ago. Furthermore, the capital investment and reduced operating costs associated with the new technology make complete renewal of present infrastructure appear cost effective. A new instrument that will meet requirements for decades to come can now be envisioned.

IVS Working Group 3 (WG3) was asked to examine current and future requirements for geodetic VLBI, including all components from antennas to analysis, and to create recommendations for a new generation of VLBI systems. To constrain these recommendations, a new set of criteria by which to measure the next generation geodetic VLBI system was established based on the recommendations for future IVS products detailed in the IVS Working Group 2 Report [23], on the requirements of the Global Geodetic Observing System project of the International Association of Geodesy [7], and on the science driven geodetic goals outlined in the NASA Solid Earth Science Working Group Report [19]. These criteria are:

- 1 mm measurement accuracy on global baselines
- continuous measurements for time series of station positions and Earth orientation parameters
- turnaround time to initial geodetic results of less than 24 hrs.

While the new requirements are significant challenges, it is vital to continue the measurements for which VLBI is the unique space geodetic technique:

- UT1 and nutation
- the celestial reference frame (CRF)

UT1 and the CRF are currently defined by VLBI, and there is no alternative for the foreseeable future.

It is recognized that achieving long term accuracy at the level of 1 mm or better is a daunting task. From the outset WG3 sought approaches for the design of the new system that would enable the following performance enhancing strategies:

- Reduce the random component of the delay-observable error, i.e., the per-observation measurement error, the stochastic properties of the clocks, and the unmodeled variation in the atmosphere
- Reduce systematic errors
- Increase the number of antennas and improve their geographic distribution
- Reduce susceptibility to external radio-frequency interference
- Increase observation density, i.e. the number of observations per unit time
- Develop new observing strategies

All of the above considerations, along with the need for low cost of construction and operation, required a complete examination of all aspects of geodetic VLBI, including equipment, processes, and observational strategies. The results of this examination have led WG3 to make the following recommendations:

- **Design a new observing system based on small antennas.** The new system will be automated and operate unattended and will be based on small (10–12 m diameter), fast-moving, mechanically reliable antennas that can be replicated economically. The observing should be done over a broad, continuous frequency range, perhaps 1–14 GHz, which includes both the current S-band and X-band frequencies for backwards compatibility, but allows much more agility to avoid RFI and more bandwidth to significantly improve delay measurement precision. At the same time, the best of the existing large antennas will be updated for compatibility with the new small-antenna system; this will allow them to co-observe with the small-antenna systems to preserve continuity with the historical record, as well as to improve the CRF measurements made primarily by the large antennas.
- **Transfer data with a combination of high-speed networks and high data-rate disk systems.** Data recording rates and transmission rates are rapidly increasing courtesy of vast investments by the computer and communications industries.
- **Examine the possibilities for new correlator systems** to handle the anticipated higher data rates, including correlation based on commodity PC platforms, possibly widely distributed.
- **Automate and streamline the complete data-analysis pipeline**, enabling rapid turnaround and consistent TRF, CRF, and EOP solutions.

Because the new systems should be fully backwards compatible with the existing systems, the transition from the old to the new systems can be gradual and deliberate, maintaining important continuity of geodetic results and measurements series while dramatically upgrading the quality, precision, and timeliness of new observations. Furthermore, with more of the new VLBI systems co-located with the suite of complementary space-geodetic techniques, the space-geodetic program as a whole will be greatly strengthened.

The above recommendations describe a system that can begin to become reality very soon. This report identifies specific steps that need to be taken next in order to develop, deploy, and bring the system into operation. The next steps include two broad categories of efforts:

- **System studies and simulations:** error budget development, decisions on observing frequencies, optimal distribution of new sites, number of antennas per site, new observing strategies, and a transition plan.
- **Development projects and prototyping:** small antenna system, feed and receiver, cost and schedule, higher data rate system, correlator development, backend development, and data management and analysis software.

Almost all of the recommended next steps can be done in parallel, and WG3 hopes that various IVS components will find the resources to support one or several of these studies and development projects. Results of these studies and projects should be well communicated within the community and coordinated by IVS so that common goals for the new vision are recognized and met.

It is important that IVS make a strong recommendation that some of the resources dedicated today to routine product generation and technology development be directed to address the studies and projects recommended in this report. These studies must move forward so that a detailed plan can be generated, including defensible costs and schedules. Building on the efforts of WG3, the results of these studies and projects will provide the final element required for IVS members to move forward with requests for augmented funding to implement the new vision. We believe that this vision will renew the interest of current funding resources and inspire new interest from universities, industry, and government, based on the exciting possibilities for a more accurate and data-rich geodetic VLBI system.

## 1. Introduction

The quest for increasing accuracy, continuity, and timeliness of geodetic data as a benefit to both science and society has been at the root of the development of space-geodetic techniques for more than 30 years. VLBI has played, and continues to play, an important role in providing high-precision geodetic data, having improved measurement accuracy and precision from meters

in the 1970s to millimeters at the turn of the century. However, the existing worldwide VLBI system, though being continually upgraded, has now nearly reached the limits of its capabilities and requires major renewal in order to provide the 1 mm accuracies demanded in the coming years. In this report, we will examine the role of VLBI in high-precision geodetic measurements, outline the challenges that are currently being faced, and propose a new system (and transition plan) based on small antennas that will achieve the goals set forth by the geodetic community.

### **1.1. The Importance of High Accuracy Geodesy to Science and Society**

High-precision geodesy is central to a broad variety of human activities, including private, commercial and governmental interests, as well as being of broad scientific interest. In everyday life the applications include monitoring of dam and bridge deformation; navigation for commercial airlines; and agriculture (fertilizing by tractor or crop duster). In not-so-every-day life high accuracy geodesy is fundamental to the evaluation of natural hazards with the goal of mitigating the suffering of individuals and reducing the cost to society. Among these applications are monitoring volcano inflation, measuring stress levels for earthquake hazard assessment, and refining our models of sea level change. For the advancement of science, precise geodetic measurements contribute to the fundamental understanding of many aspects of our Earth, including structure and deformations of the crust, mantle, and core, and the magnetic coupling between the inner and outer cores.

Modern geodesy relies on space-based observing systems. The three primary techniques are Very Long Baseline Interferometry (VLBI), the Global Navigation Satellite System (GNSS), and Satellite Laser Ranging (SLR). All three systems provide the basic measurement of the positions of the instruments on the surface of the Earth. These positions define the reference frame for the high-accuracy applications described above. In addition, each technique makes unique and complementary contributions to the overall framework. GNSS provides the high surface density and ready availability of reference positions needed for a practical system. SLR most accurately measures the center of mass of the Earth. VLBI provides the orientation of the Earth in inertial space and the celestial reference frame (CRF).

### **1.2. Contributions of VLBI**

VLBI can accurately measure the geodetic parameters associated with the shape of the Earth and orientation in inertial space. This includes the positions and velocities of the sites occupied by VLBI antennas, UT1-UTC, polar motion, and nutation. In addition, of the three space geodetic techniques, VLBI provides the only access to the inertial reference system through observations of the extragalactic sources that form the CRF. The orientation of the Earth in inertial space, as given by UT1-UTC and nutation, is necessary for accurate satellite orbit determination.

The scale of the Earth-fixed reference frame is accurately determined by VLBI measurements of the relative positions and velocities of the VLBI antennas on the surface of Earth. The changes in position are due to the motion of the tectonic plates, to deformation of the crust near faults, to post-glacial rebound, and even to volcanic activity. The inertial frame is defined by the quasars billions of light years away which form the CRF. A global network of VLBI antennas relates the two frames by measurements of the rotational position of the Earth (UT1-UTC) and measurement of changes in direction of the spin axis in the inertial frame.

A further significant contribution of the VLBI technique is accurate positioning of planetary spacecraft relative to the CRF for interplanetary navigation. A recent application has been the measurement of the change in position of the Huygens lander of the Cassini mission to determine the velocity of winds in the atmosphere of Saturn's moon Titan [18].

The historic series of VLBI measurements of the Earth's nutations and variation in rotation are unique for investigating the properties of the mantle and core and changes with time [13].

### 1.3. Challenges of the Current System

The current geodetic VLBI network of antennas has achieved extraordinary success. However, a number of factors are converging which challenge continued progress:

- Most VLBI equipment now in use around the world for geodetic VLBI programs was developed in the 1970s and 1980s. The equipment is being pushed to the limits of performance and is costly to maintain.
- Radio interference at S-band has increased dramatically in the past few years, reducing the sensitivity and increasing the errors in that band at many locations.
- Existing antennas at many sites move slowly, which makes it difficult to provide the rapid whole sky coverage needed for the highest accuracy.
- The location of many antennas is not ideal; a number of gaps in the worldwide distribution leaves the Terrestrial Reference Frame (TRF) incomplete and reduces the sensitivity for measurement of EOP.
- Operational costs remain high due to the fact that unmanned operations are generally not possible.
- Processing time to final results is long, due to shipping times and to the lack of automation of final solution software.

### 1.4. Recent Developments

Over the past few years there have been several technological developments that will enable significant improvement in the capability of a new geodetic VLBI network, and at a lower cost than would have been possible earlier.

- **lower cost antennas:** The development of large radio-frequency arrays for other projects, such as the Allen Telescope Array (ATA), the Square Kilometer Array (SKA), and the NASA Deep Space Network Array (DSNA), has led to the creation of antennas of a size that is useful for geodesy but at an order of magnitude lower cost.
- **cheaper, higher capability disk technology:** The decreasing cost and increasing rate and capacity of disk media have made it possible to develop and demonstrate inexpensive, high-data-rate recording, with much higher rates to be attainable in the future.
- **global optical-fiber network infrastructure:** The rapid increase in global availability and deployment of optical fiber provides the means of transferring data from antennas directly to the correlators.



- **high-speed digital signal-processing technology:** Advances in digital signal-processing technology will increase the absolute stability, repeatability, and predictability of the signal-processing chain. At the same time the technology can provide much higher data rates for recording and/or transmission, thus permitting the use of smaller antennas.

In addition, a major organizational development, the International VLBI Service for Geodesy and Astrometry (IVS), has enabled a more tightly focused and broadly coordinated global VLBI effort. IVS, organized in 1998 as one of the services of the International Association of Geodesy (IAG), is responsible for coordinating VLBI components operated and provided by its member organizations and for generation and distribution of accurate TRF, CRF, and EOP parameters in a timely manner.

### 1.5. Goals for the VLBI System

In the same time period that important advances have been achieved in the technology realm, the goals that influence the actions of the space geodetic services have become more focused. In 2001, a review of the existing products and observing programs was carried out by IVS Working Group 2 [23], which clearly defined the goals for IVS products and prescribed an IVS observing program optimized to make best use of the available resources to create these products. The major recommendations of Working Group 2 for IVS products are briefly summarized in Table 1.

The science drivers for geodesy in general have been advanced by the NASA Solid Earth Science Working Group [19]. Additionally, global goals for geodesy as a science are expressed in the scientific rationale of the GGOS project [7]. Combining these science goals with the operational goals laid out by the IVS WG2 report, the requirements for the next-generation VLBI system can be essentially distilled into the following three distinct goals:

- 1 mm position and 1 mm/year velocity for position (TRF)
- Continuous measurements for EOP
- Rapid generation and distribution of the IVS products

These goals, along with both the challenges presented by the current status of the global VLBI system and the opportunities presented by recent technological developments, provide the motivation for the recommendations made in this report.

### 1.6. Charge to WG3

The IVS Directing Board formed WG3 with the charge to examine current and future requirements for geodetic VLBI systems, including all components from antennas to analysis, and to create a vision and concrete recommendations for a new generation VLBI system that not only meets the goals stated above, but also satisfies the following criteria:

- low cost of construction
- low cost of operation
- prompt analysis and delivery of final results

Among the issues to be explored were:

- small, low-cost, fast-moving antennas

Table 1. Summary of primary goals of IVS Working Group 2.

Category	Products	Accuracy	Frequency of solutions	Resolution	Timeliness
TRF	x, y, z time series (one solution per session)	2–5 mm	7 d/w	1 day	1 day
	episodic events	2–5 mm	7 d/w	< 1 day	near real time
	annual solution coordinates velocities (multi session)	1–2 mm 0.1–0.3 mm/y	yearly	–	1 month
CRF	radio source coordinates	0.25 mas for as many sources as possible	yearly		1 month
	$\alpha$ , $\delta$ time series	0.5 mas	monthly	1 month	1 month
EOP	UT1-UTC	5 $\mu$ s	7 d/w continuous	10 min	near real time
	$d\varphi$ , $d\epsilon$	25–50 $\mu$ as	7 d/w	1 day	near real time
	$x_p$ , $y_p$	25–50 $\mu$ as	7 d/w	10 min	near real time
	$dx_p/dt$ , $dy_p/dt$	8–10 $\mu$ as/day	7 d/w	10 min	–
geodynamical parameters	solid Earth tides h, l	0.1%	1 y	1 y	1 month
	ocean loading A, $\varphi$	1%	1 y	1 y	1 month
	atmosphere loading	10%	1 y	1 y	1 month
physical parameters	tropospheric parameters zenith delay gradients	1–2 mm 0.3–0.5 mm	7 d/w 7 d/w	10 min 2h	near real time
	ionospheric mapping	0.5 TEC-units	7 d/w	1 h	near real time
	light deflection parameter	0.1%	1 y	all sessions used	1 month

- optimum and practical observing frequencies
- inclusion of existing antennas
- modernization of VLBI data-acquisition systems for higher stability and reliability, wider bandwidth, lower cost
- transmission of data via high-speed network (e-VLBI)
- new observing strategies
- automation of observations; remote monitoring
- possible correlator upgrades

- advances in models and strategies for data analysis
- automation of data processing

For this work, WG3 was asked to draw on the resources of both the astronomy and geodesy VLBI communities to obtain the best ideas and technological advances worldwide, and to examine other relevant developments, such as the SKA and ATA antenna system development. To facilitate the goals of WG3 and to draw the largest possible group of experts into the effort, seven sub-groups were formed, each with members from the broad international VLBI community.

The remainder of this report summarizes the strategies and recommendations that arose from the work of this broad array of expertise. Necessarily, many of the details presented in the sub-group studies are omitted here, though the reader is invited to review them [24].

## 2. Strategies to Achieve the Goal of 1 mm Accuracy

The existing VLBI network and observing procedures evolved largely from an astronomical background. For the next-generation instrument it is important to consider from the beginning the best strategies to achieve the geodetic objectives. The path to achieving the last two of the goals stated in Section refsec1.5, namely continuous measurements for EOP and rapid generation of products, involves reasonably straightforward technological approaches and will be addressed in Section 3. However, 1 mm position accuracy that is consistent over global distances and long time periods, e.g. decades or more, is unprecedented.

A number of actions can be considered in order to reach the 1 mm accuracy goal. These include reducing both the random and systematic components of the delay observable itself, increasing the number of observations per unit time, increasing the number of antennas and their geographic distribution, reducing susceptibility to external radio frequency interference (RFI), and developing improved observing strategies. We will briefly examine each of these in the sections below.

### 2.1. Reduce the Random Component of the Delay Observable

The primary contributors to random delay-like errors, which currently limit vertical accuracy to about three millimeters, are the per-observation delay measurement error, the stochastic behavior of the troposphere, and the stochastic behavior of the frequency standard and distribution system. It would be helpful to be able to place hard targets on each of these contributions. Unfortunately, this is more difficult than it might at first appear since the contributions are heavily correlated, and their effects are strongly influenced by other factors, such as the details of the observing schedule, array geometry, etc. Nevertheless, reducing each effect individually will have some beneficial effect.

#### 2.1.1. Reduce the Per-Observation Delay Measurement Error

To improve the instrumental noise limitation on short time scales, a per-observation delay precision of approximately four picoseconds is the target [25]. Three approaches can be considered to achieve this target: 1) increase SNR; 2) increase the frequency spanned within a band by moving to higher frequencies: for example, at Ka band ( $\sim 32$  GHz) the available bandwidth is several GHz, and the present X-band could be used as the second frequency for ionosphere correction; or 3) use an ATA-style feed [1] to sample more frequencies over the range from about 1 GHz to 14 GHz so that phase-delay ambiguities can be resolved. It has been shown in the Observing Strategies

report [25] that the last option can produce a delay measurement uncertainty of about 1.5 ps with a signal-to-noise ratio (SNR) of 24.

### 2.1.2. Improve the Frequency Reference Standard

The set of hydrogen maser frequency standards in use at existing antenna sites is satisfactory for the current level of accuracy of a few millimeters, but their performance does not appear to be good enough to support 1 mm accuracy, at least with the current observing densities. H-masers of 1970s vintage, many of which are still in use at the existing observing sites, typically have a stability of several parts in  $10^{15}$  over 1 to 24 hours, while modern laboratory masers are capable of closer to about a few parts in  $10^{16}$  over the same period [9]. Further investigation is needed to determine the tradeoffs between required frequency standard stability and increased observing density since there is a strong correlation. The frequency-standard issue is examined further in Section 3.

### 2.1.3. Improve Models and Procedures for Handling the Troposphere

The accuracy with which the troposphere model can be made to approximate the effect of the actual troposphere depends on the accuracy of the model itself and on the density in direction and time with which the troposphere is sampled. Recent developments indicate that sufficient accuracy in the troposphere model is likely to be obtainable by using a meteorological Numerical Weather Model (NWM) to provide either the parameters of an analytic mapping function ([14], [15], [3]) or a numerical relation among observations in different directions.

The troposphere remains one of the most challenging limitations for all space geodetic techniques. It is important to continue efforts to improve modeling and analysis strategies. In addition, information may be added by including a water vapor radiometer at the site, although the benefit has yet to be demonstrated. The impact of the atmosphere might also be reduced by including the desirability of a benign troposphere in the list of site selection criteria for new VLBI sites.

A shortcoming of considering the VLBI system in isolation is that the complementary nature of GNSS and VLBI observations is not explored. In particular, the neutral atmosphere affects the observables of both techniques the same way, and with collocated instruments there will be a very high correlation of the atmosphere delays. The estimation of a common atmosphere should be of great benefit.

## 2.2. Increase Observation Density

Another approach for reducing the impact of the random delay error is to increase the number of observations per unit time, i.e. the observation density. Simulations and results support this strategy. Increasing the observation density may benefit performance several ways:

- **Improve robustness of adjustments.** Variations in data analysis have a surprisingly large impact on final VLBI results. It is hypothesized that this fragility results from the fact that VLBI solutions are highly parameterized relative to the number of observations. Increasing the observation density will improve this situation.
- **Increase precision through averaging.** Provided that model complexity does not increase more rapidly than observation density, increasing the number of observations will

increase the number of degrees of freedom in adjustments. To the extent that the unmodeled errors are independent, final results will become more precise.

- **Permit reduction of unmodeled effects.** As the number of observations increases, it is possible to improve the accuracy of the underlying geophysical and instrumental models. A balance must be maintained between the two competing tendencies of increasing parameterization in order to reduce unmodeled effects and limiting parameterization in order to increase robustness and improve precision.
- **Improve ability to estimate troposphere parameters.** Significantly increasing observation density will allow the troposphere to be sampled at many more values of azimuth and elevation during its characteristic time for variability. To the extent that errors due to unmodeled anisotropy of the atmosphere delay are independent, the added observations will improve final results through averaging.
- **Reduce correlation between the troposphere delays, clock errors, and the vertical component of the baseline.** The creative use of scheduling has been an effective approach for separating the effects of geometry, clocks, and the troposphere in VLBI parameter adjustments. To be effective, the density of observations must be, at the minimum, sufficient to sample the troposphere at several values of elevation and azimuth within the characteristic time for variability (typically approximately twenty minutes). For the current level of sensitivity of the observations, the density is twelve to fifteen observations per hour, which results in formal errors in height of approximately 3 mm. At this sampling density and with the scheduled source elevation distribution, it appears that correlation is greatly reduced between the vertical component and the time-dependent terms of the troposphere and clock, leaving mainly correlation between the vertical component and the constant terms.

### 2.3. Reduce Systematic Errors

In order to achieve 1 mm long-term accuracy it is necessary that the sum of all systematic errors be less than that. In some cases these systematic effects have a spectral characteristic similar to that of the reference oscillators and are removed as part of the clock terms. In this case the apparent clock performance is degraded. There are four broad areas of systematic error that afflict VLBI:

- instrumental errors (e.g. temperature and voltage dependent errors associated with analog components, polarization impurity, variability in the feeds, etc)
- mechanical errors (e.g. thermal and gravity distortion of the dish, mechanical play in bearings, geological instability, connection to the local geology, etc)
- loading errors (e.g. due to the atmosphere, hydrology, oceans, etc)
- radio-source structure errors

These effects are expected to become significant sources of error when the per-observation measurement error is reduced by a factor of approximately four, as proposed. Therefore either great care must be taken to reduce all known defects considerably, or they must be calibrated in a more complete way than has been accomplished for the existing systems. Obviously, a combination of these approaches would have the greatest effect. Also, the use of identical stations will be

beneficial due to common calibrations and antenna models, as well as for cost and efficiency of maintenance.

In the case of instrumental errors, the use of digital signal processing beginning as early as possible in the signal chain will have a significant effect on mitigating the RF/IF/baseband errors.

The requirement placed on mechanical accuracy and stability of antenna structures is extremely stringent. Not only must the structure be stable to a small fraction of a millimeter under all observing conditions, it should maintain this accuracy for decades. Since it is somewhat unrealistic to expect such longevity, monumentation should be included from the beginning to allow connection of the reference point of the antenna to a stable reference marker on the ground.

In the case of source structure error, observing a larger number of sources on a regular basis will result in a more robust connection to the CRF. In particular, more complete time series of source positions will make source variability easier to evaluate, while the effect on geodetic results will be reduced through averaging over a larger ensemble. If this is not sufficient to render the effect negligible, a means of measuring and applying source structure corrections must be considered.

#### **2.4. Increase the Number of VLBI Sites and Improve Their Geographic Distribution**

The experience of the GNSS community has demonstrated the value of increasing the number of receiving sites and improving the geographic distribution. The present geodetic VLBI network has a very irregular distribution of antennas over the surface of the Earth; Africa, South America, and Asia are particularly under-represented compared to the other continents. Thus, important considerations for the planning of a new network are the number and locations of the sites needed to achieve the 1 mm goal.

Although the detailed choices for deployment of new stations will be driven by a combination of science, economics, and politics, two quantitative estimates can serve to bound the value for the number of sites.

- The goal of combining GNSS, VLBI, and SLR geodetic networks sets a guideline for the number of VLBI sites. The current uncertainty in GNSS daily horizontal measurements for a global network is approximately 3 to 5 mm and is unlikely to improve significantly. In contrast, the repeatability in regional GNSS networks of  $\sim 1000$  km is down to approximately 1 to 2 mm. For VLBI the horizontal repeatability of the VLBA antennas has been 1.5 to 3 mm over the past decade, while for the new VLBI system the horizontal accuracy is expected to be better than 1 mm. In order to take advantage of the best attributes of both GNSS and VLBI, the spacing of combined VLBI/GNSS sites should be on the order of 2000 km. Such spacing would require approximately forty sites (Eurasia (14), Africa (7), Australia (2), Antarctica (2), Greenland (1), North America (6), South America (6), Southern Pacific (2)).
- If the minimum goal is set to only three sites per continental land mass (Africa, Eurasia(2), North America, South America, Australia) plus one site in Greenland, one in Antarctica, and one in the southern Pacific, then a network of approximately twenty sites is needed.

Additionally, the minimum number of sites can be assessed from the history of geodetic VLBI measurements. The best results in terms of both site position and EOP uncertainties, confirmed by the repeatability of baseline lengths, are for the sessions that include the ten VLBA antennas and up to ten of the geodetic antennas. Similarly, increasing the number of antennas from eight to sixteen in recent sessions has shown a significant reduction in EOP uncertainty. Thus it would

appear that the minimum network size should be at least twenty sites. In order to strengthen complementarity and ties among the space geodetic techniques, as many sites as practical should have collocated GNSS, VLBI, and SLR systems.

For the highest accuracy the global networks must be tied together. Automated systems must be developed to provide continuous measurement of the relative three-dimensional positions of the antennas and telescopes at each site and of their locations relative to the reference position for that complex. This monitoring, which should have an accuracy of better than one millimeter, will make it possible to account for factors such as thermal and mechanical deformation of the mounting structures, as well as local ground motion.

## 2.5. Reduce Susceptibility to External Interference

Recently, new sources of radio-frequency interference (RFI) have appeared, particularly at S-band. Due to hardware limitations, there is no option for replacing the impacted channels. Therefore, an important objective for a new system must be to provide options for mitigating the effects of RFI. Two options have been considered:

- To continue with the current model of correlating individual channels of data, the new system would offer continuous frequency coverage over a very wide range, for example from 1 GHz to 14 GHz, but the channels and frequencies actually used would be selected as those that are most free from RFI at all sites. This capability has become possible to consider only recently with the development of very wideband feeds and low noise amplifiers, pioneered by the Allen Telescope Array engineering [1].
- An alternative approach would be to record/transmit the entire available RF band, but with a low duty cycle, so that the average data rate yields sufficient SNR. Frequency ranges with RFI may then be excluded from correlation processing on an individual baseline basis, allowing considerable flexibility without having to know the details of RFI at each site. If designed properly, this approach can respond in real time (or after the fact) to changes in the RFI environment, making it more effective against dynamically changing conditions.

Both of these approaches may have implications for the maintenance of the CRF since the effect of varying source structure with frequency must be accommodated.

## 2.6. Develop New Observing Strategies

A detailed study of possible new and/or augmented observing strategies is contained in the sub-group report on observing strategies [25]. The most important points to be noted from this report are:

- The availability of a global array of small fast-moving antennas will allow many more observations per day than can be currently accomplished, by as much as a factor of 5 or more, resulting in over a thousand observations per day (i.e. on the order of 1 observation/minute).
- The continuing refinement of the precision of the data will lead naturally to improvement in the models underlying the geodetic analysis, which will in turn lead to a continuing evolutionary process in improving observing strategies.
- With low-cost observing systems, it may be possible to place two or more antennas at a site while sharing data recording and transmission resources. Using two antennas at a site

provides the opportunity to substantially increase the observing density by always observing with one antenna while the other is moving. This improved observation density also allows much faster and more diverse sampling of the atmosphere to help reduce systematic atmospheric effects. Alternatively, simultaneous observations of different sources with two or more antennas may reduce clock stability requirements, as well as correlations between atmosphere, clocks, and the local vertical component. Multiple antennas also provide a measure of redundancy in the event one fails.

## 2.7. Improve Data Analysis

Analysis of both existing data and data to be acquired in the future will benefit from two types of improvement: better models and better strategies. The modeling changes are mentioned in other parts of this report and fall into three general areas:

- geophysical (atmosphere, loading, hydrology)
- astronomical (radio source structure)
- mechanical (thermal and gravitational deformation of the antennas).

In addition, the analysis strategies should also be re-considered. Several proposals are given in the sub-group report on data analysis [30], of which the most important ones are to:

- improve robustness and reliability of VLBI solutions
- develop complete solutions with consistent TRF, EOP, and CRF
- generate rigorous intra-VLBI combinations of complete solutions
- investigate differences in analysis software packages
- obtain phase-delay solutions for all baseline lengths.

## 3. Recommendations for Next-Generation System

The implementation of the strategies and goals aimed at achieving 1 mm measurement accuracy, as discussed in Section 2, will require the development and deployment of a next-generation VLBI data-acquisition system, including antenna, and a major upgrade of many elements in the VLBI signal and analysis chain. The centerpiece of the new system is a small-antenna observing system, coupled with the use of global high-speed fibers where possible, plus upgrading and automation of tasks from acquisition to final analysis. The key characteristics of this new system are summarized in Table 2. In this section we will review each major VLBI subsystem and make recommendations in accordance with the goals stated in Section 1.

### 3.1. Design New Observing System Based on Small Antennas

The implementation of a relatively small antenna system to meet the stated goals is a significant departure from present practice of  $\sim 20$  m diameter systems. Advances in engineering and production allow high-performance antennas in the 10–12 m class to be constructed for far lower cost than the traditional larger antennas. Coupled with advanced high-bandwidth receivers, feeds, and data systems, this new class of small antennas promises to considerably reduce costs,



Table 2. Key characteristics of next-generation VLBI system.

Antenna	$\sim 10\text{--}12$ m dish, 60% efficiency, $> 5^\circ/\text{sec}$ slew
Feed	Dual polarization; low cross-polarization leakage
Front end	$\sim 1$ GHz to $\sim 14$ GHz continuous RF coverage; $T_{\text{sys}} \sim 45\text{K}$
Back end	Digitize signals as early as possible after receiver; channelize into several frequency segments selected from front-end bandwidth, totaling 4 to 8 GHz
Calibration system	Upgraded phase and cable calibration systems
Data rate	2–4 Gbps initially, expanding to 8–16 Gbps, potentially to 32 Gbps
Frequency standard	H-maser
Network design	20–40 antennas, globally distributed, co-located with other space-geodetic techniques, including sufficiently capable existing geodetic VLBI antennas
Data transport	Mixture of disk-based recording and high-speed network transfer
Correlation	Near real time, perhaps distributed among a network of processors
Products	Near real time automated generation of rapid response products, later complete analysis
Data archiving	Data may be retrieved from clearinghouse on any timescale

while at the same time providing better overall system performance. This new observing system can act as a standalone system for many TRF and EOP measurements, and will participate with existing larger antennas for maintenance and improvement of the CRF. The following discussion will examine each of the main elements of this new system.

### 3.1.1. Antenna Size and Performance

The sub-group report on observing strategies [25] shows that a minimum signal-to-noise ratio (SNR) of  $\sim 24$  is sufficient to reach the goal of  $\sim 4$  psec in the group-delay measurement. Figure 1 shows the antenna diameter required to reach this SNR level as a function of source correlated flux density and the number of bits collected during a scan.

Approximately 100 sources are currently used for standard geodetic observing. As discussed in [25], this number of sources is available if a minimum correlated flux density of  $\sim 0.5$  Jy is chosen. According to Figure 1, an interferometer of 10 m diameter antennas will achieve the requisite SNR with a  $\sim 60$  Gb observation (2 Gbps for 30 secs, for example). On the other hand, the minimum correlated flux density drops to a level of a few tenths of a Jy for the larger number of sources desired to maintain the CRF. In this case Figure 1 indicates that a 10 m antenna with a  $\sim 300$  Gb scan, or a 12 m antenna with a 240 Gb scan, is necessary to achieve the desired minimum SNR at a correlated flux-density level of  $\sim 0.2$  Jy. Of course, if larger antennas are used as part of the network, even weaker sources can be observed, though slower moving antennas can severely constrain the rate at which observations can be taken. In order that the network of new small-antenna stations can stand alone for EOP, TRF, and CRF observations, a 12 m diameter antenna appears to be the best choice for the new observing system, though a 10 m antenna could be considered.

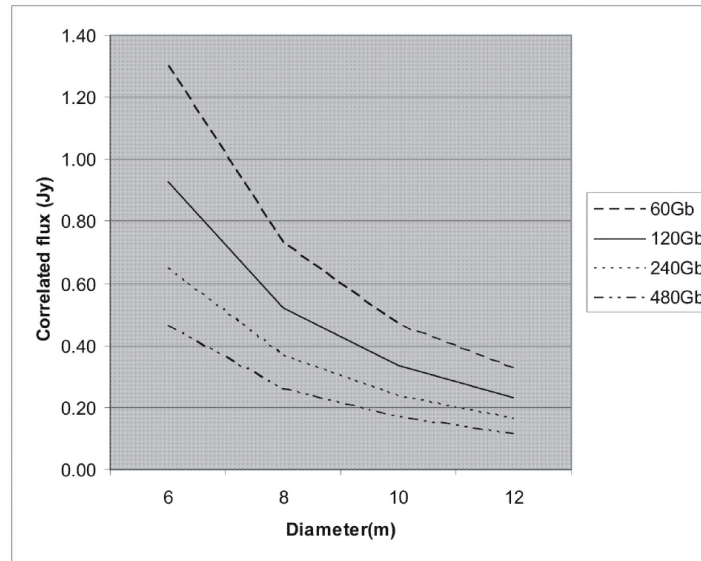


Figure 1. Antenna diameter required to reach an SNR of 24 as a function of correlated flux density for various per-antenna scan-data volumes (for example, 120 Gb is equivalent to a scan of 1 Gbps for 120 sec, 2 Gbps for 60 sec, etc); antennas in the VLBI network are assumed to be identical with  $T_{\text{SYS}}=45\text{K}$ , efficiency=60%.

Other important mechanical criteria must also be met in order to support the goal of 1 mm accuracy:

- **High slew rates.** In order to reach the goals of significantly increased observation density, the antennas need to support a slew speed of at least 5 deg/sec in both azimuth and elevation. This will allow the antenna to move between most points in the sky in less than  $\sim 30$  seconds (only excluding near- $360^\circ$  azimuth slews that are sometimes required to manage cable wrap limits) and maintain a 50% observing duty cycle for 30-second observations that are typically the minimum scheduled length for individual geodetic observations.
- **Rugged and stiff mount.** Mount ruggedness and stiffness are of primary concern for the antenna. The reference point of the antenna should be stable to  $\sim 0.1$  mm, including observing under windy conditions. The mechanical quality must guarantee long periods of trouble-free operation under rapid high duty-cycle observations; mechanical changes and repairs always run the risk of movement of the antenna reference point with respect to local geodetic markers, requiring re-calibration and re-alignment.

### 3.1.2. Radio Frequency Range, Feed and Receiver

Modern antenna, feed, and receiver systems have been built that span much broader frequency ranges than legacy VLBI systems. For example, the ATA antenna/feed/receiver system spans  $\sim 1$ – $11$  GHz [1]. For geodetic VLBI, a continuous spanned bandwidth from  $\sim 1$  GHz to  $\sim 14$  GHz appears to be a desirable target for several reasons:

- covers existing S and X bands for backwards compatibility

- allows group-delay determination over a much broader RF band than current practice
- provides options for choosing RF observing channels free of interference

As an additional benefit, if the lower bound of  $\sim 1$  GHz can be reached, Global Navigation Satellite System (GNSS) satellites can be observed by VLBI so that the GNSS-based reference frame can be directly related to the VLBI reference frame.

The most critical component in realizing this broad frequency range is the feed system, though this scale of frequency range has already been demonstrated by the ATA feed and receiver system ( $\sim 0.5\text{--}11$  GHz) [1] and should be scaleable to our desired frequency range. Circular polarization is preferred; however, in order to achieve this broad continuous frequency range, it may be necessary that the feed be of a dual-linear polarization design. Dual-linear polarization could increase the correlation load if all cross-polarization products are formed, but dual linear or circular polarization will have the important benefit of virtually eliminating the potentially large systematic instrumental delay errors caused by cross-polarization leakage.

A low-noise receiver system to achieve an average  $T_{\text{SYS}}$  of  $\sim 45\text{K}$  across the observing band is within the range of existing technology, a similar system already having been demonstrated by the ATA [1].

A dual-band X/Ka (Ka $\sim 32$  GHz) frequency system, analogous to the current S/X system, was considered as a possible alternative and is attractive because it would be compatible with frequency ranges being implemented in new NASA tracking systems. Furthermore, such coverage would extend the Celestial Reference Frame to the higher frequencies. However, the lower frequency range of  $\sim 1\text{--}14$  GHz has the advantages of less stringent antenna requirements, less expensive and more sensitive receivers, stronger source flux densities, less degradation due to atmospheric effects, and, most importantly, compatibility with the current S/X system. The combination of these factors tips the scales in favor of the lower frequency range, at least for the initial implementation.

### 3.1.3. Backend System

The received signal will be digitized by the backend system as early as possible in the signal chain, and all further processing of the signals will be entirely digital. In the present design concept, the  $\sim 13$  GHz bandwidth of the receiver output will be processed by a bank of perhaps 4 identical digital processors, each of which may flexibly select any 1–2 GHz bandwidth slice from each of the receivers (two receivers in the case of a dual-polarization system) and process the bandwidth slice for presentation to the data-recording/data-transfer system. In this way, 4 to 8 GHz of observed bandwidth (in each polarization) of the  $\sim 13$  GHz available from the receiver(s) can be acquired, allowing the maximum system data rate to eventually expand to as much as 32 to 64 Gbps as data recording and transmission systems become more capable (64 Gbps corresponds to 8 GHz of bandwidth observed in each of two polarizations and sampled at 2 bits/sample).

Dual-polarization observing will require a separate frontend and backend system for each polarization, though resources such as LO systems can be shared. However, observing in dual-polarization mode will not increase the total observing bit rate required to reach the desired signal-to-noise ratio.

### 3.1.4. Frequency Standard

Analysis of frequency-standard requirements to reach the goal of 1 mm accuracy indicates that, with a single antenna at each site and with current observing strategies, frequency-standard performance must reach a stability level of a few parts in  $10^{16}$  for averaging times longer than about 1 hour (see Figure 2). This level of performance is not reached by H-masers currently deployed, which tend to have stability of at best a few parts in  $10^{15}$  for averaging times of  $\sim 1$ –24 hours. Although increasing the observation density and/or making other changes in observing strategy, as recommended in Section 2, may somewhat relax demands on H-maser stability, further study is needed to fully understand the possible tradeoffs and the impact on both accuracy and cost ([9], [10]).

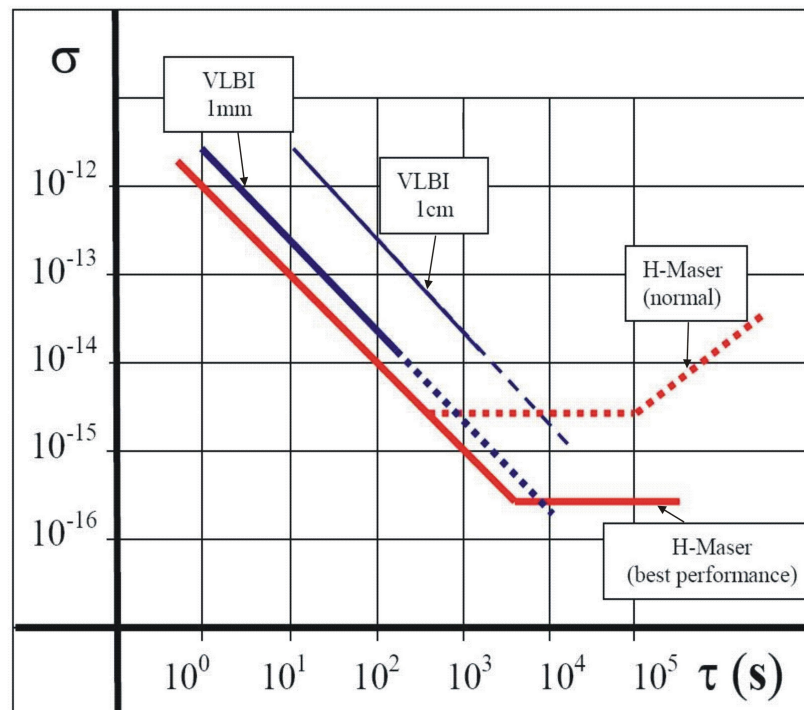


Figure 2. VLBI requirements versus H-maser stability.

Attention should also be paid to promising new experimental oscillator types and to a possible alternate approach whereby a 2-way satellite link may be used to frequency lock widely separated reference oscillators, though it is too early to determine whether any of these approaches will be sufficiently robust and/or cost effective for use in a global VLBI array.

### 3.1.5. Upgrade Existing Stations Where Possible

As indicated in Section 2, it is planned to integrate as many as possible of the existing antennas into the next-generation geodetic array, both for continuity of the TRF and for the enhancement and maintenance of the CRF. These stations will need to upgrade their systems as much possible to be compatible with RF and backend specifications discussed above, though full compatibility

with the RF bandwidth may not be possible in some cases. The largest technical hurdle to full RF compatibility is likely to be the antenna feed, particularly in cases where the  $f/D$  ratio of the existing antennas is different than that of the new small-antenna systems. A detailed study of existing antennas will be required to determine the full extent of the compatibility that can be achieved in this regard. In any case, existing stations should update all other subsystems to meet the specification of the next-generation small-antenna system.

### 3.2. Transfer Data with Combination of High-Speed Networks and High-Data-Rate Disk Systems

The rapid advance of both magnetic-disk technology and global high-speed network technology will be utilized in the next-generation system. A more complete discussion of this subject and the impacts on observing is included in sub-group reports on data-acquisition and transport [28] and on observing strategies [25]. A few important points are summarized here:

- An array of antennas directly connected to the correlator via high-speed network provides the possibility for real-time or near-real-time processing to produce geodetic results in a matter of hours, which is particularly important to the rapid turnaround of EOP results.
- Modern magnetic-disk-based recording systems will allow economical recording at rates to several Gbps. With ever expanding disk capacities, stations will be able to operate unattended for periods of a day or more at a time, needing attention only for disk-module changes, and thus enabling continuous observations even for sites not connected via high-speed fiber.
- The existing global grid of research and education networks spans all the continents except Antarctica at minimum rates of 10 Gbps, and continues to rapidly improve in speed. This global grid may, with suitable agreements, be available for transmitting geodetic VLBI data.
- High-speed network connections to antenna sites must be implemented for at least a substantial subset of the sites. In many cases, sites are within a few km of a potential connection point, but some more remote sites are considerably more distant. Relatively inexpensive free-space optical links should be considered for some sites where fiber installation is otherwise too expensive or difficult.
- All data collection and transmission interfaces and formats should adhere to the set of internationally agreed VLBI Standard Interface (VSI) specifications [22].

### 3.3. Examine Opportunities for New Correlator Systems for Higher Data Rates

In the early stages of the operation of the next-generation system, when station data rates do not exceed  $\sim 2$  Gbps, the existing set of correlators (with suitable software upgrades) will suffice. However, beyond these early stages it will be necessary to devise new correlator architectures to deal with the vast amount of data that will be collected at high rates. There are several options for such architectures [29]:

- a new large centralized correlator, perhaps modeled after the purpose-built EVLA WIDAR correlator. The WIDAR correlator is dedicated to the EVLA array and is capable of processing up to  $\sim 32$  stations at bandwidths up to 8 GHz per polarization. One possible drawback of such a correlator is the extreme concentration of network bandwidth that would be required

at the correlator to simultaneously bring high-rate real-time data from a large number of stations.

- a distributed correlator system based on commodity PCs, with perhaps special purpose internal hardware, to which data to be correlated are transmitted over the global high-speed network. Such a distributed system could be dedicated or might be shared with other non-VLBI users. One advantage of such a distributed system is the spreading of the communications load over a large geographic area. A correlation strategy which time-slices the data and sends each time slice to a different node (processing all baselines of that time slice) minimizes the required communications resources. Such a system will be more robust against failure than the centralized correlator if the distribution can be dynamically re-allocated.

Further study needs to be undertaken to determine the most cost-effective strategy to be adopted, and the choice may depend critically on the required timeline for development. If dual linear polarization operation proves necessary, the correlation processing load will be approximately doubled. This may impact the choice of correlator architecture.

A standardized correlator certification process should be developed that can be applied equally to all correlators to ensure that the processed results are of the highest quality, regardless of the correlation site or system.

### 3.4. Improve Data Analysis

While the development and deployment of a next-generation VLBI antenna and data-acquisition system is a discrete process, upgrading the software used for data analysis should proceed continually. It is clear that the goal of 1 mm measurement accuracy on global baselines requires significant improvements in existing VLBI software, particularly in the refinement of models. Known improvements should be in place and verified before the deployment of the next-generation geodetic VLBI system. With respect to the data analysis the main targets seen at this time are:

#### 3.4.1. Troposphere

Several areas regarding tropospheric effects on VLBI results need further investigation:

- **New mapping functions:** In recent years mapping functions such as the Isobaric Mapping Functions (IMF) [14] and the Vienna Mapping Functions (VMF) [2] have been developed to make use of information on the state of the atmosphere contained in numerical weather models (NWM). The potential of NWMs with high temporal and spatial resolution and prediction capacity for the determination of mapping functions has been shown ([14], [15], [3], [20]). Additional work is needed to fully integrate NWMs into data analysis software.
- **Gradient models:** In addition to their application for the generation of a priori hydrostatic gradients, as calculated within IMF, numerical weather models should be used to investigate the azimuthal and zenithal deviations from the standard gradient models (e.g., [5], [4]).
- **Turbulence models:** The application of spatial and temporal turbulence models to describe the inhomogenous atmosphere, rather than using conventional gradient models, should be studied.

### 3.4.2. Loading Effects

Refinement of mass-loading models is necessary to reach the global 1 mm accuracy goal. The IERS Special Bureau for loading now provides atmospheric loading corrections on a global scale. Recent global ocean tide loading models explain more of the observed site displacement at tidal frequencies than the earlier models, though it would be desirable to also develop local ocean models for regions near some VLBI stations. Mass loading models for hydrological variables, including snow, surface liquid water and groundwater, need significant improvement. (See IERS Special Bureau for Loading description [21].)

### 3.4.3. Antenna Deformation

Thermal deformation of the antenna structure can be improved through direct measurement and through modeling of the structure using material expansion coefficients and measured temperatures ([16], [8], [11]); both horizontal and vertical deformations must be considered. A reference temperature must be established, preferably by agreement with other space geodetic techniques. In addition to thermal deformations, gravitational deformations of the telescope structures and their effect on the group-delay observables must be carefully considered and measured or modeled as necessary.

### 3.4.4. Source Structure Effects

Most of the sources observed by geodetic VLBI exhibit the standard core-jet morphology to some degree. Fey and Charlot [6] have developed a source-structure index that increases with the level of source-structure complexity, providing a simple but powerful tool for choosing low-structure sources for geodetic/astrometric observations. Nevertheless, a certain fraction of sources, particularly in the source-dense CRF observations, show significant structure. It is important to determine whether sufficiently accurate brightness temperature maps can be made of these complex sources so that corrections to the group-delay observables can be computed and applied.

### 3.4.5. Data Analysis Strategies

In addition to improving the models for the effects discussed above, new analysis strategies must be developed, tested, and applied.

- **Robust and reliable VLBI solutions:** In recent years, refined modeling of the many auxiliary parameters has led to an increase in the number of parameters estimated, with constraints introduced to a much greater degree. This procedure has resulted in a loss of robustness of the solution, with the consequence that the numerical results vary rather strongly depending on individual delay observables excluded from or included in the adjustment process. Robustness and reliability of VLBI solutions are key elements of the quality of VLBI results. Therefore, improved analysis strategies, together with observation scheduling, require development to reduce the influence of single observations on the results.
- **Consistency of TRF, EOP, and CRF:** An important goal for 2010 is the generation of consistent VLBI multi-purpose solutions for TRF, EOP, and CRF (VLBI complete solutions). For this, investigations must be started on the propagation of systematic effects between reference frames in VLBI complete solutions. The consistency of the VLBI products is

of particular importance with respect to their contribution to the IERS and to the new IAG project GGOS. Since the main goal of GGOS is the integration of all space geodetic techniques, regular precise surveys of the local ties at stations with more than one technique are required.

- **Intra-VLBI combinations of complete solutions:** The generation of VLBI complete solutions will offer unique opportunities for combinations of analyses by different analysis centers which are rigorous to the utmost extent. These combined solutions can be used for the combination on the next level, i.e. between the various space techniques, by the IERS and/or within GGOS.
- **Investigations of differences in analysis software packages:** Comparisons among software packages have been rather sparse in recent years. In order to understand differences and to improve the overall quality of the results, it is of great importance that intercomparisons at regular intervals become a general task of the Analysis Centers.
- **Phase solutions for all baseline lengths:** Investigations have shown that phase-delay observables can be used under very special conditions. To date, phase-delay solutions have been successful only if stations are employed which provide very stable hardware in terms of inherent phase variations. As soon as more stations update their hardware with phase-stable components, phase-delay solutions will become more practical and may be realized on a routine basis.

### 3.5. Automate Operations and Procedures at All Stages

Automation at all levels of operations will be required for the smooth operation of the next-generation system. This subject is discussed in more detail across several sub-group reports; here we will emphasize a few particular areas where automation is critical:

#### Observing

- Automated observation scheduling tailored to the purpose of each observing session (EOP, TRF, CRF, etc), taking into account the array of available stations
- Flexibility to add/subtract stations on short notice in case of unexpected failures or unavailability
- Flexibility to change observing frequencies to avoid RFI
- Logistical management of disk modules and/or automated e-VLBI data transfers
- Automated diagnostic procedures and notification of personnel when necessary

#### Data transfer

- Automated scheduling for shipping and management of disk modules
- Automated scheduling, as necessary, for high-speed network resources for data transfer

#### Correlation

- Assignment and scheduling of correlator resources
- Review of correlation results and flagging of problems



- Network transfer of correlation results to analysis center

#### Geodetic analysis

- Fully pipelined analysis system, including
  - Filtering and flagging of data for obvious problems
  - Creation of databases
  - Analysis for geodetic products
  - Distribution of products to final consumers
  - Maintenance of product archive

The development of these automated systems and procedures is particularly important for the timely production of EOP results, but will also significantly add to the robustness and productivity of the system and lead to higher quality geodetic products.

## 4. Next Steps

In order to develop, deploy, and bring to operation the system described in Section 3, several studies and development efforts must be completed. The work can be grouped into two categories.

- **System studies and simulations** are needed to clarify issues, verify calculations, or refine estimates. Six such studies are described below. These studies, concentrated in the areas of observing strategies, network deployment, and transition planning, can be started now, and most can proceed in parallel.
- **Development projects and prototyping** are needed in the areas of the small antenna system, the correlator, backend, and data management and analysis. Some decisions about the antenna system depend on the results of the system studies and simulations. Seven such projects are described.

In this section we will address each of these efforts, with the objective of realizing a fully deployed system that meets the three major goals of 1 mm accuracy, continuous operation, and rapid results.

### 4.1. System Studies and Simulations

As indicated in the previous sections, several studies need to be undertaken that will impact how some parts of the system are to be built and how the system is to be deployed and used. Some of these studies must take place during the early stages in the development of the new system, before any work can begin on antenna development. Others may proceed in parallel. This section describes the major studies that were suggested by the discussion of Section 3.

#### 4.1.1. Error Budget

A complete and detailed system error budget needs to be developed. Major issues to be considered in the error budget include:

- the interaction of observation density, atmosphere estimation, and reference frequency and timing characteristics

- instrumental error effects including, for example, polarization impurity, cable and phase calibrations
- the effects of source structure on the delay observable

#### **4.1.2. Observing Frequencies**

Though the current analysis favors an RF band extending from 1 or 2 GHz to approximately 14 GHz, the dual-band system X/Ka ( $\sim 8\text{--}9$  GHz and  $\sim 32\text{--}36$  GHz) should be further examined as a possibility. The tradeoffs between these choices must be carefully evaluated. The TRF requirements, including continuity, are likely to be satisfied both technically and economically with observations at frequencies below 15 GHz. The primary drivers to inclusion of the higher frequency band are compatibility with operations of the DSN and enhancement and maintenance of the CRF.

#### **4.1.3. The Number and Distribution of Sites for Deployment**

Studies need to be made of detailed site-placement options so as to improve the distribution of stations. Tradeoffs, such as between geographical location and infrastructure support, need to be enumerated and evaluated, and site requirements must be developed.

#### **4.1.4. Number of Antennas per Site**

Two or more antennas per site will enhance the observation density as well as allow better determination of systematic effects. The ability to define, measure, and maintain a reference point for multiple antennas at a site must be studied, as well as the tradeoff between the advantages of multiple antennas and cost.

#### **4.1.5. New Observing Strategies**

Faster antennas, and perhaps multiple antennas at a site, will require the development of new observing strategies, including optimal use of existing large antennas in conjunction with the new antennas.

#### **4.1.6. Transition Plan and Upgrade Path**

A carefully constructed and executed plan for the transition to the proposed new system is critical for maintaining continuity of the historical record of geodetic VLBI results while reaping the benefits of the new technology. A good transition plan must include a deployment schedule, plan for mixed operations and a schedule for upgrading the existing antennas.

### **4.2. Development Projects and Prototyping**

The data-acquisition system requires the development of several new hardware components (antenna, feed, receiver, backend), as well as the augmentation of existing sub-systems (data recording/transmission, frequency standard (H-maser) and timing system, monument measurement). The final decision about an antenna system for prototype deployment will depend on results of the system studies described in Section 4.1.

#### **4.2.1. Antenna and Mount**

The designs of antennas for arrays such as the Allen Telescope Array and the NASA Deep Space Network Array give us some insight into the capabilities and costs of a small-antenna system. A preliminary report [17] describes possible development of a prototype system based on either of these designs. However, in parallel with the detailed system studies that will provide guidelines on the size of antenna needed, additional work must be done to complete the evaluation of those designs. Critical design areas are mechanical stiffness and thermal stability, durability of the mount and drive train under the continuous and demanding observing program, and the method of tying the reference point to the local reference monuments.

#### **4.2.2. Feed and Receiver**

To achieve very broadband frequency response in a reflector antenna requires ingenuity in feed design. Examples are the ATA feed/LNA construction and the low profile feeds under development at Chalmers University for the SKA. Studies are needed to determine whether these designs can be brought into alignment with our requirements. Instrumental calibration, including phase and delay calibration systems, must be integrated into the front-end design.

Detailed design studies of the small-antenna system must be completed before it will be possible to accurately estimate the costs for prototype development. This is a necessary study prior to commitment of funds.

#### **4.2.3. Frequency and Timing Improvements**

As described in Section 3, the suitability of the performance of existing hydrogen masers, and the propagation of that stability through the system, must be evaluated. If improvement is required, based on the error budget studies, an improved maser or alternative frequency standard must be found, or the delay calibration must be improved, or both. The frequency stability at all stations must be brought to the necessary level of performance.

#### **4.2.4. Higher Data Rate System**

Continued technological advances are inevitable and will permit further improvement in sensitivity and accuracy. This will involve increases in data rate, through enhancement of the recording and transmission capability and through development of new correlator architectures. Some of these projects have begun already and should be considered as part of this plan.

A higher performance, larger capacity, disk-based recording system, based on commercially available technology, should be developed in collaboration with industry. The capacity of disk storage continues to increase while the cost of disk storage per GB continues to drop, as shown in Figure 3, so that expansion of VLBI recording capability over time becomes increasingly economical. A clear path to the next generation correlator design must be compatible with the higher data rates.

#### **4.2.5. Correlator**

Though the early stages of development and testing of the new system can utilize existing correlators, a new correlator system must be developed for data rates above 2 Gbps/station. A

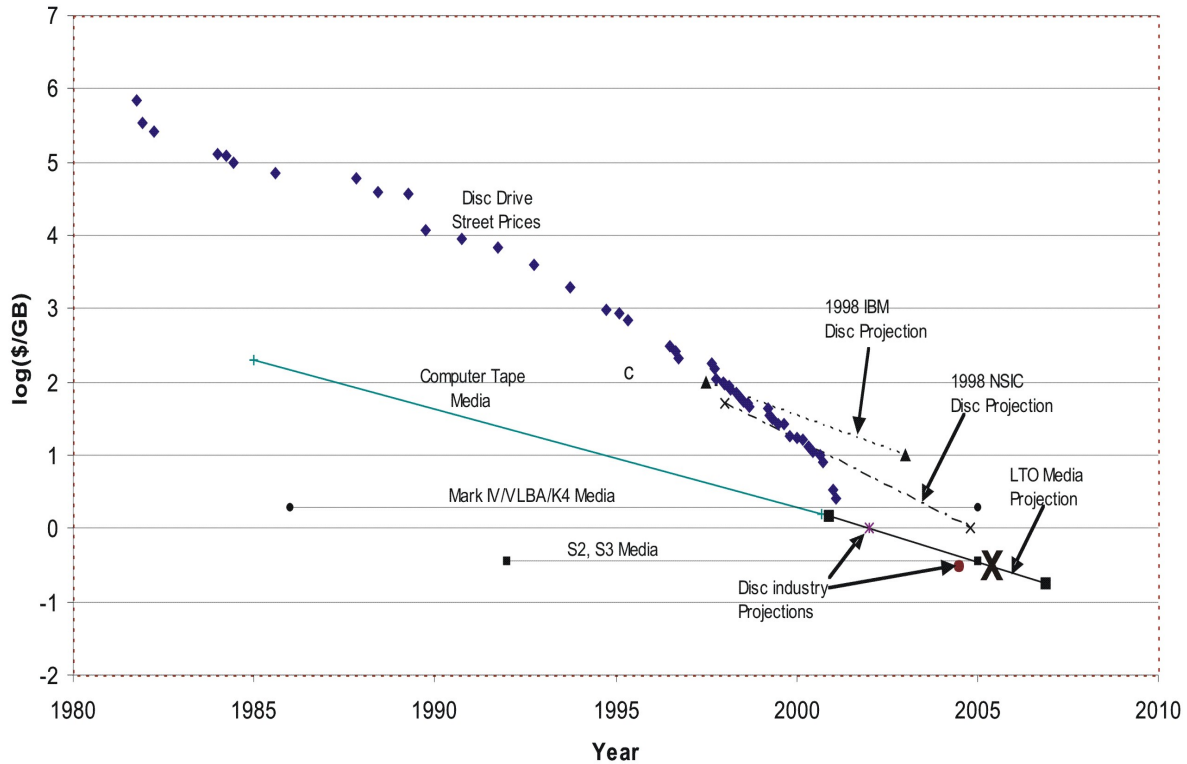


Figure 3. Disk storage price as a function of time. Large 'X' marks approximate price at mid-2005.

small prototype multi-PC correlation system has already been built in Japan [12] and could form the basis for a new large correlator system for high data rates. A distributed multi-PC system is particularly attractive for real-time observations since it avoids the network congestion issues inherent with a centralized correlator. Another possibility is a clone or near-clone of the large centralized correlator system developed for the eVLA project, which would be capable of handling the data from the proposed new geodetic VLBI system.

#### 4.2.6. Backend

It is anticipated that the entire broadband analog output of the receiver will be transmitted via optical fiber to a remotely located backend system. Figure 4 shows a simplified block diagram of a proposed RF-to-baseband converter module currently under development. A 1 GHz slice of the RF input is selected and converted to baseband using a standard digital polyphase filter bank to generate a 4 Gbps data stream. Up to eight such modules, each selecting a different 1 GHz slice of the RF input, can be used, thus providing a sampling of 8 GHz of bandwidth. For lower portions of the RF frequency band, direct digital sampling in higher Nyquist zones may

be possible, eliminating the need for analog up/down conversion before A/D conversion, thus simplifying the backend system. An alternative architecture would place individually controlled digital down-converters at desired frequencies within the IF band.

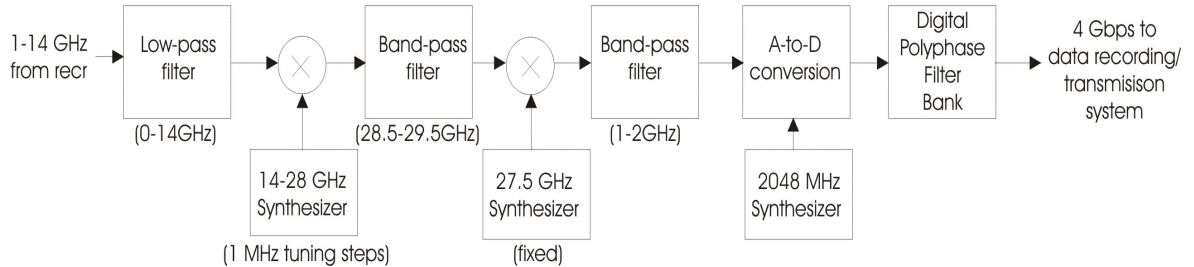


Figure 4. Simplified RF-to-baseband module block diagram.

#### 4.2.7. Automated Data Management and Analysis Software

Automated software procedures in the entire data chain from scheduling through final analysis are required to meet the goals of the next-generation system. In addition, enhanced software is needed in some areas, such as advanced scheduling algorithms to implement new observing strategies. Such software will also be invaluable for studying and evaluating other important aspects of the system, such as the option to place multiple antennas per site. In any case, automated software procedures will also benefit current observing, and development of these tools should proceed concurrently with the existing program.

## 5. Summary

WG3 was formed to develop a vision for the future of geodetic VLBI. At the time, the IVS had reached a level of maturity where it was recognized that a long-term plan for the future is required to focus the activities of the organization. Three separate converging elements added urgency to this realization. First, the science case for geodesy implies that 1 mm long-term accuracy is required of VLBI measurements. This rather daunting increase in accuracy will require significant changes to the way VLBI is done, including significant improvements in models and strategies for analysis. Second, it was readily apparent that much of the hardware in use today is, for the most part, badly outdated or at least rapidly aging; furthermore, the cost of current manpower-intensive operations cannot be sustained even for existing goals such as continuous monitoring of EOP. Third, technological advances in the manufacture of antennas, digital electronics, and data storage and transmission have opened the door to cost effective solutions to these challenges. These advances, which have emerged only over the past few years, have provided both opportunities and incentive for large-scale renewal of the global geodetic VLBI system, including operations, analysis, and product generation.

Based on science and operational drivers, three performance goals have been identified:

- Accuracies of 1 mm for site position and 1 mm/year for velocity (TRF)
- Continuous measurements for EOP
- Rapid generation and distribution of the IVS products

Achieving the latter two of these goals appears comparatively straightforward. A widespread introduction of automation and continued development of e-VLBI will be the key factors required to make it happen. Although significant effort and some uncertainty are still involved, the path forward is reasonably well understood. In contrast, it is recognized that achieving the 1 mm accuracy target is unprecedented and that the path forward will require greater consideration. At the same time, the importance of achieving this target is emphasized by the realization that, although achieving this accuracy will require the integration of the complementary capabilities of all three of the space geodetic techniques, it cannot be accomplished without VLBI.

A number of strategies are proposed to improve the long-term accuracy of VLBI with an eye to achieving the 1 mm long-term accuracy target:

- Reduce the random component of the delay observable error, i.e., the per-observation measurement error, the stochastic properties of the clocks, and the unmodeled variation in the atmosphere
- Increase observation density, i.e. the number of observations per unit time
- Reduce systematic errors
- Increase the number of sites and improve their geographic distribution
- Reduce susceptibility to external radio frequency interference
- Develop new observing strategies
- Improve data analysis by refining models and revising analysis strategies

Based on the specified performance goals and the strategies listed above, four broad recommendations are made:

- Design a new observing system based on small antennas
- Transfer data with a combination of high-speed networks and high-data-rate disk systems
- Examine the opportunities for new correlator systems for higher data rates
- Automate operations and procedures at all stages

In the process of preparing this report much has been learned about the opportunities and needs for future development of geodetic VLBI, but it has become apparent that specific recommendations are often difficult to identify. Out of this effort thirteen areas have emerged that require further study, proof of concept demonstrations, or prototype development. These topics are critical for filling in the details of a coherent and rational plan for the future.

Realizing the goals of the WG3 study will produce an instrument that will provide an outstanding data record into the future for a better understanding of planet Earth. However, it is also clear that the path requires significant resources and effort. In order to be successful, it is essential that the IVS make a concerted and unified commitment to this process, and that concrete actions be taken to move forward based on the recommendations of WG3. Of immediate importance is the list of thirteen areas for further study and development described in Section 4. Most of the studies can be begun today, can be done in parallel, and, as an added benefit, will lead to improved understanding of the current system.

It is important that the IVS make a strong recommendation that some of the resources dedicated today to routine product generation and technology development be directed to address

the studies and projects recommended in this report. These studies must move forward so that a detailed plan can be generated, including defensible costs and schedules. Building on the efforts of WG3, the results of these studies and projects will provide the final element required for IVS members to move forward with requests for augmented funding to implement the new vision. We believe that this vision will renew the interest of current funding resources and inspire new interest from universities, industry, and government based on the exciting possibilities for a more accurate and data-rich geodetic VLBI system.

## 6. Acknowledgment

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# IVS Coordination

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# Coordinating Center Report

*Dirk Behrend*

## Abstract

This report summarizes the activities of the IVS Coordinating Center during the year 2005, and forecasts activities planned for the year 2006.

## 1. Coordinating Center Operation

The IVS Coordinating Center is based at 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 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 2005

During the period from January through December 2005, the Coordinating Center supported the following IVS activities:

- Directing Board support: Coordinated, with local committees, two IVS Directing Board meetings, in Noto, Italy (April 2005) and Washington, DC, USA (September 2005). Notes from each meeting were published on the IVS web site.
- Communications support: Maintained the web pages, e-mail lists, and web-based mail archive files. Printed and distributed the final report of Working Group 3 “VLBI2010”.
- Publications: Published the 2004 Annual Report in spring 2005. Published three editions of the IVS Newsletter in April, August, and December, 2005. All publications are available electronically as well as in print form.
- 2005 Master Schedule: Generated and maintained the master observing schedule for 2005. Coordinated VLBI resources for observing time, correlator usage, tapes and disk modules. Coordinated the usage of Mark 5 systems at IVS stations and efficient deployment of disk modules. Coordinated the continuous VLBI campaign CONT05 (see Section 3).
- 2006 Master Schedule: Generated the proposed master schedule for 2006 and received approval from the Observing Program Committee.
- Meetings: Coordinated, with the Local Committee, the third IVS Technical Operations Workshop, held at Haystack Observatory, USA in May 2005. Chaired the Program Committee for the workshop. Coordinated, with the Local Committee, the fourth IVS General Meeting, held in Concepción, Chile in January 2006. Chaired the Program Committee for the meeting.

- Observing Program Committee (OPC): Coordinated meetings of the OPC to monitor the observing program, review problems and issues, and discuss changes.

### 3. CONT05 Campaign

In the period September 12–27, 2005 the 15 days of the continuous VLBI campaign CONT05 were observed. The Coordinating Center was responsible for:

- the overall planning and coordination of the campaign,
- the media usage and shipment schedule, and
- the preparation of the detailed observing schedules and notes.

The schedules were generated using the automatic scheduling algorithms of the NASA sked program. The best combination of scheduling parameters, minimum SNR levels, source list, and flux models were investigated. The chosen solution was based on a compromise between the optimum simulated formal errors, number of observations, number of scans per hour, sky coverage, and robustness.



Figure 1. Geographical distribution of the 11 CONT05 stations.

The recording mode corresponded to the IVS-R1 rapid turnaround experiments with a data rate of 256 Mbps. Based on simulations, the expected formal errors for the EOPs were at the 35 micro-arcsec level (or better) for pole position and 1.4 micro-sec for UT1. The actual results are in the range of the expected precision reflecting the excellent work done at the stations and correlators.

More information about the CONT05 campaign can be found on the IVS web site under the URL <http://ivscc.gsfc.nasa.gov/program/cont05>.

#### 4. Staff

The staff of the Coordinating Center is drawn from individuals who work at Goddard. The staff and their responsibilities are:

Name	Title	Responsibilities
Dirk Behrend	Director	Web site and e-mail system maintenance, Directing Board support, meetings, publications, session web pages monitoring
Cynthia Thomas	Operation Manager	Master schedule (current year), resource management and monitoring, meetings 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	Publication Programmer and Editor	Publication processing programs, Latex support and editorial assistance



Figure 2. IVS Chair Wolfgang Schlüter (left) presents Nancy Vandenberg (right), the outgoing Coordinating Center Director, with a bouquet of flowers.

In September 2005 Nancy Vandenberg retired as IVS Coordinating Center Director ending a year-long transition period in which she gradually passed on her duties to Dirk Behrend as her successor. The official change of directorship occurred at the IVS Directing Board meeting in Washington.

#### 5. Plans for 2006

The Coordinating Center plans for 2006 include the following:

- Maintain IVS web site and e-mail system; implement new station pages.
- Publish the 2005 Annual Report (this volume).

- Publish Proceedings of the fourth IVS General Meeting.
- Coordinate, with the local committee, the fourth IVS General Meeting, to be held in Concepcion, Chile, in January 2006.
- Support Directing Board meetings in 2006.
- Coordinate Directing Board elections.
- Coordinate the 2006 master observing schedule and IVS resources.
- Publish Newsletter issues in April, August, and December.
- Publish an IVS color brochure.

# Analysis Coordinator Report

A. Nothnagel, M. Vennebusch, S. Böckmann

## Abstract

IVS analysis coordination issues in 2005 are reported here.

## 1. General Issues

The “Sixth IVS Analysis Workshop” was held at Noto Astronomical Observatory, Italy, on May 21 and 22, 2005. Detailed information on presentations and discussions can be found in [5].

As from August 1, 2005, Mrs. Sarah Böckmann (boeckmann@uni-bonn.de) has taken over responsibility for the EOP combination activities at the IVS Analysis Coordinator’s office.

## 2. IVS Operational Data Analysis and Combination

### 2.1. Antenna Axis Offsets

In late 2004, it was discovered that the axis offset files used by the individual analysis centers did not agree and even contained large discrepancies. Since the axis offsets directly affect all parameter estimates from topocentric heights of the stations to EOP it was decided that an official list of antenna axis offsets be generated and made available to all analysts [2].

Unfortunately, there are still a number of telescopes for which the antenna axis offsets are only poorly determined. Compared to the general effort of performing VLBI observations, processing and analysis, the determination of the axis offsets does require relatively little work using standard surveying equipment and procedures. We should stress this once again that we strongly encourage the observatories with unreliable axis offset information to carry out the necessary measurements. Please contact the authors if you need further advice.

### 2.2. Terrestrial Reference Frame

In early 2005, several realizations of terrestrial reference frames (TRF) have been made available by different IVS Analysis Centers, i.e. by *Deutsches Geodätisches Forschungsinstitut* (DGFI) in Munich, Germany, using the OCCAM VLBI software together with a DGFI combination program called DOGS-CS, by *Geoscience Australia* (GA), Belconnen, Australia, using the OCCAM software with a Kalman Filter setup, by the *Main Astronomical Observatory* (MAO), Kiev, Ukraine, with the software package SteelBreeze as well as by *Bundesamt für Kartographie und Geodäsie* (BKG) and *NASA Goddard Space Flight Center* (GSFC) both using the Calc/Solve software package. A combination has been carried out on the basis of coordinates, velocities and their formal errors mapping them onto the ITRF2000 datum using only those sites which carry the largest amount of the observing load today [4]. The resulting coordinates and velocities (VTRF2005) are now widely used for EOP and atmosphere parameter estimation.

### 2.3. IVS EOP Series

In 2005, the input series of five IVS Analysis Centers (GA, BKG, GSFC, IAA and USNO) have been used for combination of the official IVS EOP series (see IVS Analysis Coordinator's Web page). Lately, the agreement between the individual input series has suffered from the fact that biases and drifts have still been based on earlier data. This was corrected in December 2005.

The IVS Coordinator's Web page was complemented with additional information about comparisons with IGS polar motion results for external evaluation.

In order to generate transparency of the timeliness issue, a web page is automatically updated which states the submission dates of the individual analysis centers. This should help to straighten out unnecessary delays in the availability of the raw data and of the EOP submissions. One of the consequences of this exercise was that the sequence of mirroring tasks of the IVS Data Centers was reduced from one hour to 15 minutes resulting in a new complete cycle time of 1.5 hours instead of six hours.

### 3. Official IVS Contribution to the IERS ITRF2005 Initiative

On December 23, 2004 the IERS had called for input to the ITRF2005 combination project asking the IAG Services to submit only combined series of session-wise SINEX files. During 2005 quite some effort was invested into this project in order to deliver combined datum free normal equations of all high precision geodetic VLBI sessions to the IERS in SINEX format. Datum free normal equations are the purest way of transferring the inherent information of the solutions like the covariances to further combination steps. Submitting the postfit variance-covariance matrix of a constrained solution does require additional steps in the combination process which cause further complications. In submitting datum-free normal equation matrices the IVS is ahead of all other techniques and we are grateful for the efforts which have been invested by the seven IVS Analysis Centers to achieve this goal.

So far, several iterations between the analysis centers, the IVS Analysis Coordinator's office and the IERS ITRF Product Center have taken place. The last inconsistencies are being ironed out as of now. The status of the IVS ITRF2005 activities can be monitored at [3].

### 4. IVS Pilot Project "Baseline Lengths"

In the second quarter of 2005 the first results of the IVS Pilot Project "Baseline Lengths" were made available on a dedicated Web page and have been updated subsequently. Seven IVS Analysis Centers regularly contribute to this project. The results and statistics will help to give a clear insight into the current quality of geodetic VLBI data analysis and may help to detect deficiencies in analysis software and analysis strategies. Graphs and tables can be found at [1].



## 5. Personnel

Table 1. Personnel at the IVS Analysis Coordinator's office

Sarah Böckmann (from Aug 1, 2005)	++49-228-732623	boeckmann@uni-bonn.de
Axel Nothnagel	++49-228-733574	nothnagel@uni-bonn.de
Markus Vennebusch	++49-228-733565	vennebusch@uni-bonn.de

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# Network Coordinator Report

*Ed Himwich*

## Abstract

This report includes an assessment of the network performance in terms of the yield of usable data over a 12 month period. Overall, the data loss for 2005 was about 14.4%. A table of relative incidence of problems with various subsystems is presented. The most significant causes of data loss were antenna reliability (accounting for about 24.4%), receiver problems (24.2%), clock problems (14.5%), and recorder problems (8.9%). The closing of the Gilcreek station is described. The current situation for the handling of correlator clock adjustments by the correlators is reviewed. The handling of these adjustments directly impact the UT1-UTC estimates from VLBI data. A change in the handling of correlator clock adjustments at the Mark IV correlators has improved the situation markedly from previous years. However some clock offset work remains to be done for S2 recordings and the VLBA correlator.

## 1. Network Performance

The network performance report is based on correlator reports for experiments in calendar year 2005. This report includes the 154 non-RDV 24 hour experiments that had detailed correlator reports available as of February 3, 2006. There are six RDV experiments that have been processed by the VLBA, but those results were left out of this analysis since the filed reports tend to be less detailed than those from other correlators. There are another 36 experiments from the calendar year that had not been processed or the correlator results were not available. Most of these missing experiments are being processed by the Penticton correlator, are waiting for tapes from Antarctica, or are from the latter part of the year. Roughly 80% of the scheduled experiments for 2005 are accounted for.

An important point to understand is that in this report the data loss 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 only recording one-third of the expected bits. In a similar fashion, poor pointing can be converted into an equivalent lost sensitivity and then equivalent lost bits. Poor recordings can be 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. 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 will indicate 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. Similar problems occur for intermittent poor playback. 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 for the quality of each station's performance. As mentioned above the results themselves are only approximate. In addition, some problems are beyond the control of the station, such as weather and power failures. Instead the results should be viewed in aggregate as an overall evaluation of how much of the data the network is collecting as a whole. 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 lost observing time per station is not equal to the overall loss of VLBI data. Under some simplifying assumptions, the loss of VLBI data is roughly about twice the loss of observing time. The argument that supports this has been described in the Network Coordinator's section of the 2002 Annual Report.

For the 154 experiments from 2005 examined here, there are 1085 station days or slightly more than 7 stations per experiment on average. Of these experiment days about 14.4% (or about 157 days) of the observing time was lost. For comparison to earlier years, see Table 1.

Table 1. Lost Observing Time

Year	Percentage of Days Lost
1999-2000*	11.8
2001	11.6
2002	12.2
2003	14.4
2004	12.5
2005	14.4

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

The lost observing time for 2005 was slightly greater than for 2004, but has returned to the level of loss seen in 2003. If these observing time losses are converted into VLBI data yield losses, then 2005 had about 29% VLBI data loss, 2004 about 25% and 2003 about 29%. It is not clear whether these variations in lost data reflect real changes in the performance level or simply variations due to inaccuracies in the analysis method. It does seem however that despite the approximations in the analysis method, the calculated observing time loss has been running fairly consistently at the 12-14% level for several years. It is notable however that some unusual circumstances occurred in 2005. In particular there were some unusual and significant losses associated with clock problems at Gilcreek and Westford in particular.

An assessment of each station's performance is not provided in this report. While this was done in some previous years, this practice seems to be counter-productive. Although many caveats were provided to discourage people from assigning too much significance to the results, there was feedback that suggested that the results were being over-interpreted. 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 not least, there seemed to be some interest in attempting to "game" the system to improve the individual results. Consequently, only summary results are

presented here.

For the purposes of this report, the stations were divided into two categories: (A) those that were included in 20 or more network experiments, and (B) those in 13 or fewer. More than a third of the stations in the former category had been included in more than 70 experiments. The distinction between these two groups was made on the assumption that the results would be more meaningful for the stations with more experiments.

There are 15 stations in the 20 or more experiment category. Of these, eight successfully collected data for approximately 90% of their expected observing time. Five more stations collected 80% or more. One station in this group collected slightly less than 75%. One station in this group collected only about 66% of its data. These statistics are almost unchanged from last year, except for the station with poorest performance. That station had unusually severe problems. In general, the pattern is that among the best performing stations, performance is improving.

There are 22 stations in the 13 or fewer experiment category. The range of successful observing time for stations in this category was 0%-100%. The median success rate was about 66%. Overall the stations in this category observed successfully about 41% of the 95 station days (9% of the total analyzed) that fall in this category. It is notable that the performance for the stations that were in the fewest experiments became somewhat worse. This may be because they have less practice and less opportunity to work out problems in their systems.

Although the results are not being reported for individual stations, a few stations deserve special recognition for how much their data collection improved from the previous year. Four stations improved the percentage of data they collected by more than 5%. These stations are Hobart, Ny-Ålesund, HartRAO, and Wettzell. Given the high level of reliability of these stations had already achieved, it was quite impressive that they were able to improve their performance this much. It will be impossible for them to improve by this much again next year.

The losses were also analyzed by sub-system for each station. Individual stations can contact the network coordinator ([weh@ivscc.gsfc.nasa.gov](mailto:weh@ivscc.gsfc.nasa.gov)) for the break-down for their individual station. A summary of the losses by sub-system (category) for the entire network is presented in Table 2.

Table 2. Data Lost by Sub-system

Sub-System	Percentage lost
Antenna	24.4
Receiver	24.2
Clock	14.5
Recorder	8.9
Miscellaneous	8.0
RFI	6.2
Rack	5.1
Operations	4.7
Unknown	3.3
Software	0.5
Shipping	0.2
Total	100.0

The categories in Table 2 are rather broad and require some explanation. The “Antenna” category includes all antenna problems including mis-pointing, antenna control computer failures, and mechanical break-downs of the antenna. The “Receiver” category includes all problems related to the receiver including out-right failure, loss of sensitivity because the cryogenics failed, design problems that impact the sensitivity, and loss of coherence that was due to LO problems. In addition, for lack of a better choice, loss of sensitivity due to upper X band Tsys problems were assigned to this category. The “Recorder” category includes all electrical and mechanical problems related to the recorder system (tape or disk). This includes passes that are unrecoverable because of overwriting. The “Unknown” category is a special category for cases where the correlator did not state and it was not possible to determine a cause of the loss. The “Miscellaneous” category includes several small problems that do not fit into other categories, including errors in the observing schedule provided by the Operation Centers. Power failures are also included in this category. The “Rack” category includes all failures that could be attributed to the rack (DAS) including the formatter and BBCs. The “Operations” category includes all operation errors, such as DRUDG-ing the wrong schedule, starting late because of shift problems, problems changing tapes and others. The “RFI” category includes all losses directly attributable to interference. The “Shipping” category includes data that could not be correlated because the media was either lost in shipping or held up in customs long enough that it could not be correlated with the rest of the experiment data. The “Clock” category includes situations where correlation was impossible because either the clock offset was not provided or was wrong leading to no fringes. Maser and coherence problems that could be attributed to the maser were also included in this category. The “Software” category includes all instances of software problems causing data to be lost. This includes crashes of the Field System, crashes of the local station software, and errors in files generated by DRUDG.

From the results it can be seen that antenna and receiver together account for almost 50% of the losses, down slightly from last year. This was in spite of the fact that some problems were shifted to the receiver category from “Unknown”. For 2005 some stations had significant antenna problems: Gilcreek, Svetloe, Noto, TIGO, and Matera in particular. Kokee’s antenna problems of two years ago seem to have been resolved. These results discounted the inability of Matera to observe during the first third the year because of a problem with the antenna rail, i.e., the results for Matera would have been worse if this had been accounted for. However, other stations were substituted for Matera in some cases. This issue appears to have been resolved unless more extensive work is needed on the rail in the future.

Stations with significant receiver problems include TIGO, Simeiz, Seshan, Gilcreek, and Fortaleza. Most of these problems are in the category of reliability problems with the cryogenics, power supplies or amplifiers, but for Seshan the most significant issue is the roll-off in the X-band bandpass, which has been included in this category. Also the loss at the upper end of X-band, for TIGO in particular, but Gilcreek and Fortaleza as well, were included in this category. This problem represents the most significant overall loss for the network, almost 25% of the total loss. It represents almost half of TIGO’s loss as a station.

The “Clock” category represented much more of the loss than in previous years. This was due primarily to significant maser problems at Gilcreek and Westford. However, loss of coherence at other stations (Kokee and Svetloe) contributed significantly as well, although it may be that for these stations these losses had other causes.

The other most significant problem areas were Recorder, Miscellaneous, RFI, Rack, and “Un-

known”. Of these Recorder is by a small amount the most substantial. Losses in this category are down slightly from last year. Most of the items in this category are tape related. However, a small fraction represent problems with Mark 5 and other disk type recording systems. The improvement in this category may finally be reflecting the “disk dividend” we have been hoping to get as tape use is curtailed. If so, we would expect to see the losses in this category to continue to decrease. This should be easily accomplished since more than one-third of 2005’s Recorder losses were due to tape problems at Fortaleza, which is now using Mark 5 exclusively for recording. The RFI category represents about a 6% loss. However, the actual number may be higher because some problems that were classified as either Receiver or “Unknown” due to lack of information might be more correctly attributed to RFI. It may be that the RFI losses should be as large of 10%, which is more in line with the result from two years ago of 9.3%.

A significant item that gets some attention in the correlator reports is that Gilcreek’s Maser developed significant problems in the last third of 2004. This problem continued into 2005 and was not resolved until about a third of the way into the year.

The performance of the stations in CONT05 was excellent. The overall loss for these experiments was about 4%. This compares to an overall loss of about 16% for the other experiments of 2005.

## 2. Gilcreek Closure

NASA decided at the end of 2005 to cease operations at the Gilmore Creek station. This decision was forced by administrative issues, but was probably inevitable. The performance of the station had sagged considerably over recent years due largely to the aging of the equipment and the lack of continuity of personnel knowledgeable enough to maintain it. Although the station’s performance was starting to recover at the end of the year due to new personnel working there, administrative problems forced the issue. Despite the long history and central role of this station in the geodetic VLBI network, the closing of the station could not be avoided. The positive note that comes out of this is that NASA reports that the money that was being used for the operation of this station will be reprogrammed to support development of the next generation, “VLBI210”, system.

## 3. Clock Offsets

As noted in the Network Coordinator’s reports for the last few years, it is important to develop consistent procedures for handling the clock offsets during the correlation process. Stations measure the offset between their formatter and the UTC time provided by GPS. The correlators typically apply a small, few  $\mu$ seconds or less, adjustment to the measured offsets in order to align the data to get fringes. If the adjustments are not applied in a consistent fashion by all correlators a corresponding error will be made in the UT1-UTC parameter adjustments. This will affect the quality of IVS UT1-UTC products at the level of the inconsistency in the adjustments applied for correlation. This could be corrected during the data analysis, but currently no analysis packages do this. It would require a significant amount of bookkeeping to add this feature now.

The Network Coordinator’s report from three years ago recommended that the correlators develop a consistent table of adjustments for correcting the local measurements of the formatter offsets relative to GPS. This would remove a source of correlator-to-correlator and experiment-

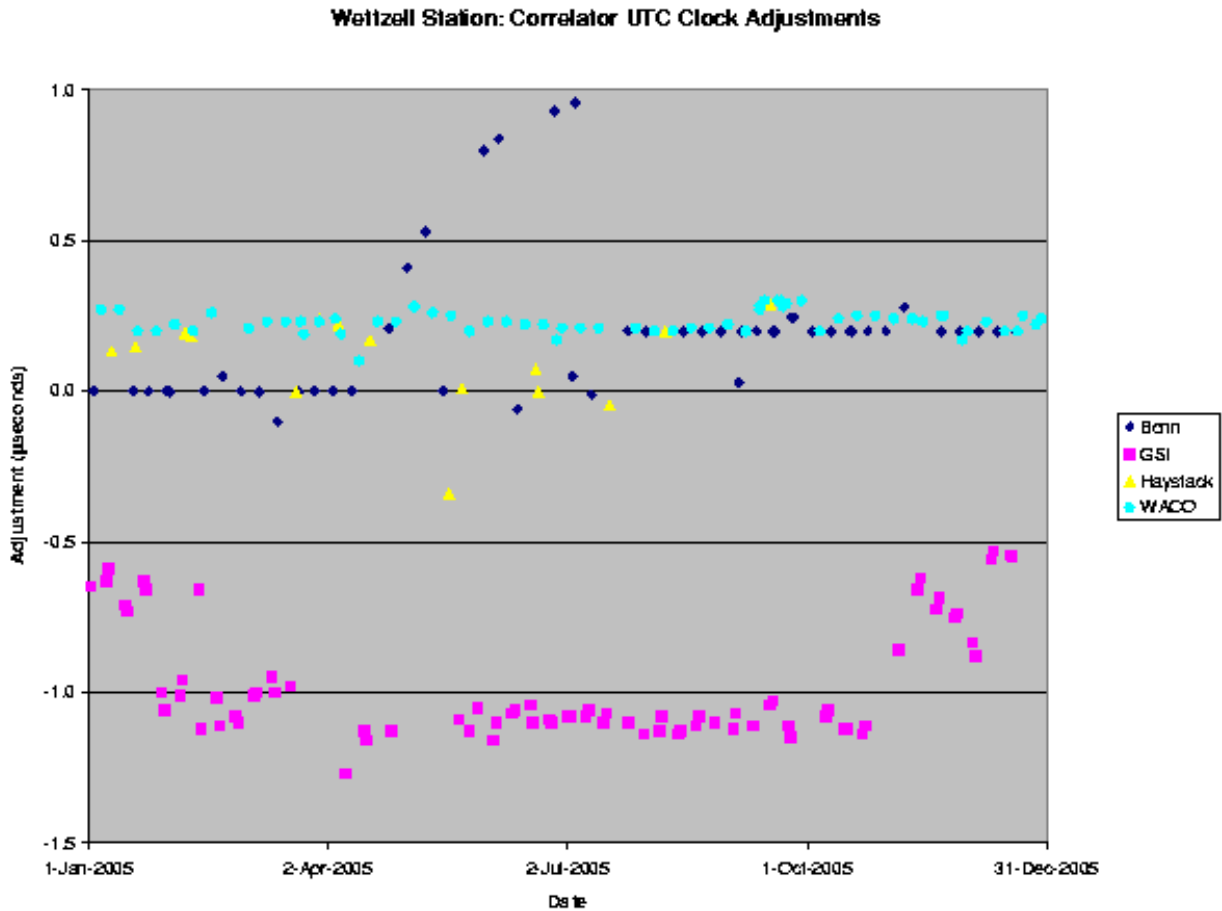


Figure 1. Wettzell Correlator UTC Clock Adjustments

to-experiment variability in the UT1-UTC results. It was suggested that in developing this table the applied correction for Kokee should be artificially set to zero (when Kokee uses the VLBA formatter, when they use a Mark IV, the correction should be increased to about  $0.4 \mu\text{seconds}$ ). Although not strictly correct, it is a simple approach and will maintain a level of consistency with old data, much of which was processed by WACO with a correction of zero for Kokee. However, the “true” adjustment will have to be compensated for when an effort is made to align the ICRF and ITRF at this level. It was also recommended in the report from two years ago that a reference for the clock rate should be established at the same time.

Significant progress was made in 2005 in implementing this recommendation. As of about August, the three Mark IV correlators started using consistent correction values [K. Kingham (USNO), B. Corey (Haystack Observatory), and A. Mueskens (University of Bonn), private communication]. An example of the improvement can be seen in Figure 1, which shows the clock corrections used for Wettzell. Until approximately August, the adjustments used by the three Mark IV geodesy correlators (Bonn, Haystack, and WACO) can be seen to vary by as much as a  $\mu\text{second}$ . After August, the variations are much smaller, on the order of  $0.1 \mu\text{seconds}$ . This

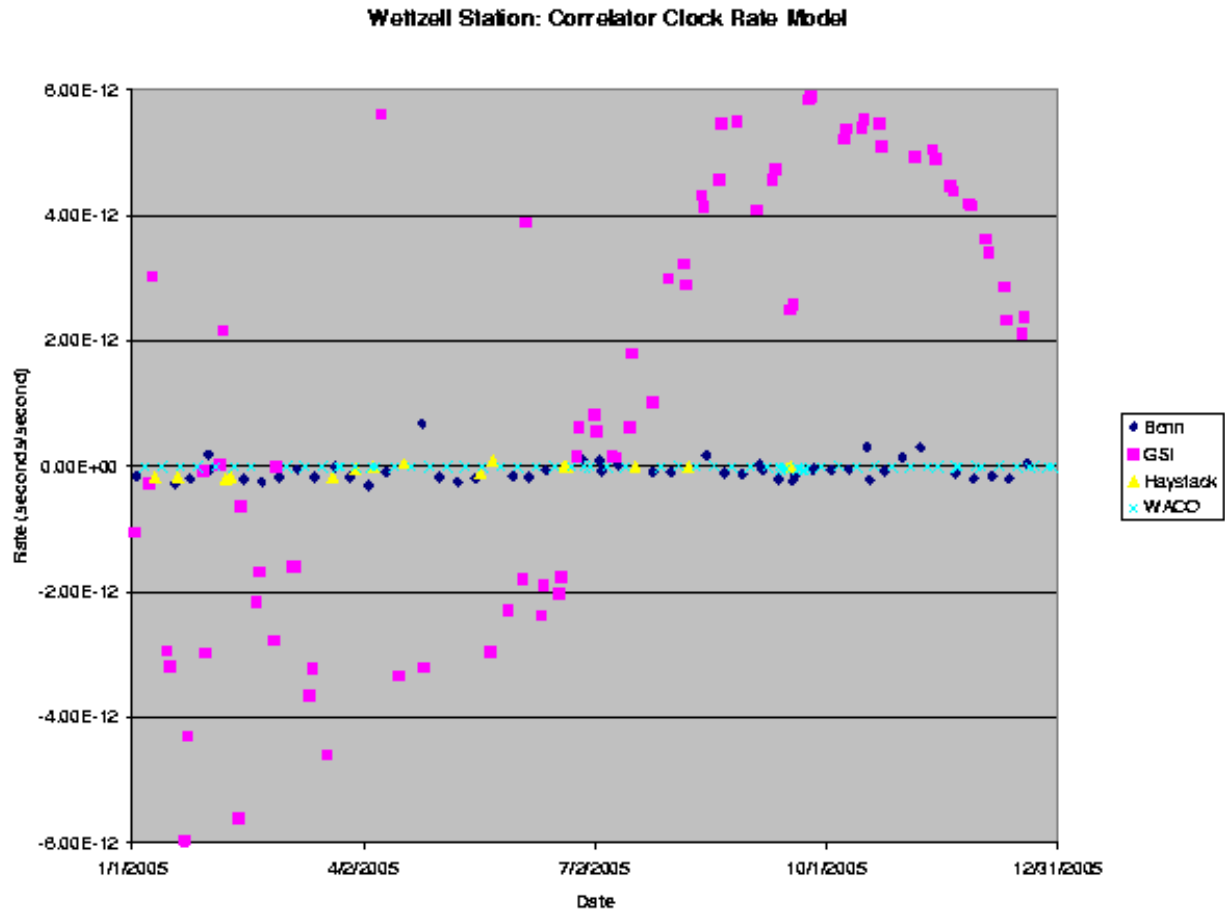


Figure 2. Wettzell Correlator Clock Rate Model

is a significant improvement and will lead to better accuracy of the UT1-UTC estimates. It is interesting to note that the offsets used by the GSI correlator are biased by about  $1 \mu\text{second}$  compared to those used by the Mark IV correlators. If this is correct it would bias UT1-UTC estimates from GSI correlated experiments compared to Mark IV correlated experiments. As it happens, the GSI correlator is currently used only for “K” type Intensives and domestic Japanese 24 hour experiments. The UT1-UTC precision of these experiments is much less than that of the 24 hour international experiments, around  $10\text{-}20 \mu\text{seconds}$  compared about  $1\text{-}2 \mu\text{seconds}$ . Consequently, this bias does not significantly impact the results. However, it should be corrected. Discussions about how to handle this have begun [K. Takashima (GSI) and Y. Koyama (NICT), private communication]

A further issue is how stable the UT1 rate measurements are. This depends on the accuracy of the correlator models for the Maser rates for the observing stations and the accuracy of the Maser rates themselves. The desired accuracy of the IVS Working Group 2 report was for  $0.3\text{-}0.5 \mu\text{seconds/day}$ . This translates into a clock rate of about  $3.5\text{e-}12$  to  $5.8\text{e-}12$ . It would be desirable to have the correlator clock models consistent at a level 10% of that,  $3\text{e-}13$ , or better.



A plot of the Correlator Clock Rates for Wettzell are shown in Figure 2. It is difficult to see on the scale of the plot, but the clock rates used by the Mark IV correlators vary at about the desired level, about  $6\text{e-}13$  (peak-to-peak, i.e., simplifying by saying the peak-to-peak is about twice the RMS). This is about good enough, but perhaps could be improved. The rates for Wettzell used by the GSI correlator vary by about  $1.2\text{e-}11$  (peak-to-peak). These exceeds the desired level by a factor of about 20. As with UT1-UTC estimates for GSI, this is probably not an issue given the lower precision of the experiments processed by this correlator. However, this should probably be improved.

A further issue is how close the rates of the underlying Maser are to UTC. The *de facto* standard for the Maser rates is that Kokee's Maser is assumed to be "zero" by the correlators. Contrary to past Network Coordinator reports it is not known what the rate of the Kokee Maser relative to UTC is (there was a misunderstanding because there are two Masers at Kokee). The actual rate of the Kokee Maser and how to handle the rates in the future is being investigated. It may be a better solution for rates to use the actual measured rates at each station rather than working to the assumption that one station has zero rate.

Another area of concern is that different recording systems may require different adjustments. There is a difference between Mark IV and VLBA formatters of about  $0.4\ \mu\text{seconds}$  [K. Kingham (USNO), private communication]. This was accounted for when Kokee changed from using VLBA to Mark IV formatters. There is also a measured value between the K-5 and the Mark IV formatters [Y. Koyama, NICT, private communication]. However, this is not of much concern since Tsukuba and Kashima which use K-5 formatters have had their offsets determined relative to the Mark IV formatter stations by the Mark IV correlators already. There should be no problem as long as they do not change the formatters that they use, or if they do, it is done in a experiment with a population of Mark IV formatters. This is true in general for any station. A different issue is how stations that use S2 formatters will be aligned relative to stations that are already aligned. This question is being investigated [B. Petrachenko (NRCAN) and A. Whitney (Haystack Observatory), private communication].

One remaining issue besides the K-5 (GSI) and S2 correlator data is aligning the clock offsets used by the VLBA correlator with those used by the Mark IV correlators. The VLBA is planning to do this [C. Walker (NRAO), private communication].

# IVS Technology Coordinator Report

*Alan Whitney*

## Abstract

The efforts of the Technology Coordinator in 2005 were primarily in the following areas: 1) completion of the IVS Working Group 3 “VLBI2010” study, 2) continued development and deployment of e-VLBI, 3) support of the 4th annual e-VLBI Workshop held in Sydney, Australia. We will describe each of these briefly.

## 1. IVS Working Group 3 - VLBI2010

The report of IVS Working Group 3, aka ‘VLBI2010’, was released in September 2005. The report examined all aspects of the geodetic-VLBI system, including all hardware and software, and recommends the next steps to be taken to create a global VLBI system that is significantly better than the system in place today, with a strategic goal of 1mm global accuracy. Among the issues explored were:

- Modernization of VLBI data-acquisition systems for higher stability and reliability, wider bandwidth, lower cost
- Small, low-cost, fast-moving antennas
- New observing strategies
- Optimum and practical observing frequencies
- Fully automated observations; remote monitoring
- Transmission of data via high-speed network (e-VLBI)
- Possible correlator upgrades
- Fast turnaround of results by full pipelining of data from antennas to correlator to final analysis

The VLBI2010 study concluded that, in order to develop and deploy this next-generation system, two classes of projects should be undertaken in the immediate future:

1. System studies and simulations are needed in the areas of observing strategies, network deployment, and transition planning.
2. Development projects and prototyping are needed in the areas of small antenna systems, the correlator, backend, and data management and analysis.

Thirteen specific areas of study and prototype development were identified as key enablers of the next-generation system. Many thanks are due to all those contributing to the VLBI2010 study, including particularly the following subgroup leaders:

- Brian Corey - antennas, RF/IF systems, calibration
- Hayo Hase - antenna systems

- Ed Himwich - control, data management
- Hans Hinteregger - digital backend systems, correlators
- Tetsuro Kondo - data systems, data transport, real-time
- Yasuhiro Koyama - data systems, data transport
- Chopo Ma - post-correlation analysis; data management
- Zinovy Malkin - post-correlation analysis
- Arthur Niell - atmospheric calibration, analysis
- Bill Petrachenko - antenna arrays, multi-beam VLBI, frequency standards
- Wolfgang Schlueter - antennas, observing strategies, frequency standards
- Harald Schuh - post-correlation analysis, cross-technique use
- Dave Shaffer - observing strategies, systems, analysis
- Gino Tuccari - digital backend systems
- Nancy Vandenberg - scheduling, observing strategies
- Alan Whitney - data systems, data transport, correlators

The final report of Working Group 3, entitled ‘VLBI2010: Current and Future Requirements for Geodetic VLBI Systems’, is reproduced as a special report in this volume.

## 2. e-VLBI Development

e-VLBI development is continuing on a number of fronts, which we will briefly mention here:

### 2.1. VSI-E Beta Testing

A reference implementation of the proposed VSI-E specification has been developed and is undergoing testing. The primary purpose of VSI-E is to provide a standardized specification for e-VLBI data formats and protocols that is compatible between both homogeneous and heterogeneous VLBI data systems. The VSI-E framework provides signaling, control, framing and statistics support and is an extension to the Internet standard RFC3550. It also provides flexibility for users to choose the transport protocol that best suits their networking environment (e.g. UDP, TCP or other variants). The first live testing of VSI-E is currently ongoing between Kashima and Haystack. This is a particularly useful testbed since data are collected on the K5 at Kashima, while Haystack uses Mark 5A systems, enabling testing on heterogeneous systems. Once the reference implementation is fully checked out, attention can be turned to optimizing the code for high-speed operation, followed by broader deployment.

### 2.2. Continuing Expansion and Development of Routine e-VLBI Data Transfers

Routine use of e-VLBI continues to grow. All data recorded on K5 systems at Tsukuba and Kashima are currently transferred via e-VLBI to Haystack Observatory, where it is transferred to Mark 5 disk modules and sent to target correlators at Haystack, USNO or MPI; approximately 100TB have been transferred over the last year, including all Tsukuba data from the CONT05

experiment. Daily UT1 Intensive data from Wettzell are transferred via e-VLBI to a site near USNO in Washington, D.C., where it is picked up and taken to USNO for correlation. Additionally, monthly UT1 Intensive data are transferred from Tsukuba to MPI for correlation. Regular e-VLBI data transfers from Ny-Ålesund are expected to begin within the next few months.

Transfer rates, especially across international networks continue to improve. Japan/U.S. transfer rates as high as  $\sim 900$  Mbps have been observed, with sustained rates as high as  $\sim 700$  Mbps. Real-time e-VLBI experiments are being conducted within the U.S. and between Europe and U.S. In November 2005 a successful 3-station real-time e-VLBI demonstration was conducted by sending data at 512Mbps from Westford, GGAO and Onsala to the Mark IV correlator at Haystack Observatory. We hope to soon include Japan in these real-time demonstrations as well. The biggest impediment to rapid e-VLBI expansion continues to be station connectivity to high-speed networks, but the situation is improving. Tsukuba, Kashima, Onsala, Westford, and Medicina are all connected with 1 Gbps links, though some issues remain in actually using some of the links at full speed. Wettzell is connected at  $\sim 30$ Mbps and TIGO at  $\sim 2$ Mbps. Projects are underway to connect Ny-Ålesund, Hobart, Fortaleza and Svetloe in 2006.

### 3. 4th International e-VLBI Workshop Held in Sydney, Australia

The 4th e-VLBI Workshop was held in Sydney, Australia July 12-14 and followed the success of the previous e-VLBI workshops held at Haystack (2002), JIVE (2003) and Tokyo (2004). It was organized and hosted by the Australia Telescope National Facility (ATNF) at its headquarters in Marsfield, Sydney. The workshop was generously sponsored and supported by the Australia Academic and Research Network (AARNet) and the LBA partners ATNF, the University of Tasmania and Swinburne University of Technology. It was attended by about 60 participants from 9 countries.

The workshop presented a new opportunity to share the experience of progress and developments in e-VLBI around the world and to explore possibilities for coordination and cooperation. The standard of presentations was again very high and many new results and plans were presented. e-VLBI is set for rapid progress around the world in the next few years.

The recently funded European EXPRoS e-VLBI project will result in a production e-VLBI network at 1 Gbps within the next 3 years. All presentations from the workshop are available online at <http://www.atnf.csiro.au/vlbi/evlbi2005/>.

CSIRO announced that funds will be made available to build the 'last mile' fibre tails to the ATNF antennas (ATCA, Mopra, Parkes) and connect these antennas via the AARNet3 regional network. The CSIRO contribution is about A\$2M and represents a very significant step towards eVLBI in Australia.

The workshop was followed by a quick "observatories tour" of the ATNF telescopes at Narrabri (ATCA,  $6 \times 22$ m), Mopra (22m), Parkes (64m) and the NASA DSN station at Tidbinbilla (70m, 34m). These are spread over great distances in New South Wales, Australia and the tour covered 1800km over 3 days! The tour also included a visit at a local vineyard and winery and it was greatly enjoyed by all participants, despite the long driving distances.

The workshop completes the first cycle of annual e-VLBI workshops around the world. A new cycle will commence with the next e-VLBI workshop in 2006 to be hosted by the Haystack Observatory.

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# Network Stations

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# Algonquin Radio Observatory

*Mario Bérubé, Anthony Searle*

## Abstract

The Algonquin Radio Observatory (ARO) is situated in Algonquin provincial park, about 250 km north of Ottawa and is operated by the Geodetic Survey Division (GSD) of Natural Resources Canada as a primary site for the Canadian Spatial Reference System.

The antenna is involved in a large number of international geodetic VLBI sessions each year and is a key site in the ongoing Canadian S2 developments. The ARO antenna is the most sensitive IVS Network Dish.

This report summarizes recent activities at the Algonquin Radio Observatory.



Figure 1. Algonquin Radio Observatory 46m Antenna

## 1. Overview

The ARO 46 m antenna was used in the first successful VLBI experiment in 1967 and was involved as early as 1968 in geodesy, when the baseline length between the ARO and a telescope in Prince Albert, Saskatchewan was measured to be 2143 km ( $\sigma=20\text{m}$ ).

The GSD also maintains a permanent GPS monitoring station at Algonquin which is used by all IGS Analysis Centers as a fiducial reference. The site acts as a primary location for the Canadian Spatial Reference System (CSRS), and ensures global consistency for reference frame users in Canada. Absolute gravity observations are available for the site which is located on the stable Precambrian Canadian Shield. A Satellite Laser Ranging observation campaign was conducted in 1993. Local site stability has been monitored regularly using a high-precision network.

## 2. Site Improvements

No major improvements were made to the ARO antenna this year. Two new GPS pillars were installed at the site.

## 3. General Specifications

- Latitude : N 45° 57' 19.812"
- Longitude : E 281° 55' 37.055"
- Elevation : 260.42m
- Reflector : 46m diameter with first 36.6m made of 0.634cm steel plates surrounded by 4.6m of steel mesh.
- Foci : S and X band at prime focus. Gregorian capability with 3m elliptical subreflector.
- Focal length : 18.3m (prime focus)
- Focal ratio :  $f/D = 0.4$  for full surface and 0.5 for solid surface.
- Surface accuracy : 0.32cm for solid portion and 0.64 for mesh.
- Beamwidth : 3.0 arcmin at 3cm wavelength (10GHz)
- Azimuth speed : 24 degrees per minute
- Elevation speed : 5 degrees per minute
- Receiver : S and X cryogenic receiver.
- VLBI equipment : VLBA4 with thin tape drive and Mark 5 Disk recorder. S2 DAS and RT.
- PCFS version : 9.7.7
- Time standard : NR Maser
- GPS receiver : BenchMark
- Timing receiver : CNS clock

## 4. Antenna Survey

The antenna is surrounded by a high stability network consisting of thirteen concrete piers. This network has been precisely measured five times to obtain the geodetic tie between the VLBI, the GPS, and the SLR reference points with a precision of a few mm. The VLBI antenna itself requires a special indirect survey since the reference point cannot be accessed directly. Previous surveys were reanalyzed with refined models in 2005.

## 5. Algonquin Operations

In the summer of 2005, alarm software was installed which allowed remotely monitored operations. Since that time ARO has operated with fewer staff during observations.



In December, a major snowfall resulted in a prolonged power failure resulting in the absence of ARO for several sessions.

Algonquin Radio Observatory is involved in several International VLBI networks. Geodetic VLBI activities are summarized below.

### 5.1. Sessions Performed January 1, 2005 - December 31, 2005

Session Type	Number of Sessions
R4	45
E3	11
R&D	9
T2	3
CONT	14
RVD	4
Total	86

## Fortaleza Station Report for 2005

*Pierre Kaufmann, A. Macílio Pereira de Lucena, Adeildo Sombra da Silva,  
Claudio E. Tateyama*

### Abstract

This is a brief report on the activities carried on at Fortaleza geodetic-VLBI Station (ROEN: Rádio Observatório Espacial do Nordeste), located in Eusébio, CE, Brazil, in 2005. Observing activities consisted of 64 VLBI sessions and continuous GPS monitoring recordings. In this year, the VLBI acquisition system was upgraded to Mark 5 recording system and a new GPS receiver was installed. High speed data link (2.5 Gbps) to ROEN is currently being installed, to allow e-VLBI operations in near future.

### 1. Introduction

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. During that time the antenna and instrumental facilities were erected, and it was the beginning of the activities sponsored by U.S. agency NOAA, Brazilian Ministry of Science, and Technology's FINEP agency. ROEN is currently coordinated by CRAAM, Center of Radio Astronomy and Astrophysics, Mackenzie Presbyterian University, São Paulo, in agreement with the Brazilian National Space Research Institute, INPE. A new contract was signed in May 2004 between NASA and CRAAM, Mackenzie Presbyterian Institute and University to partially support the activities at ROEN until 2009. This contract is a consequence of the Agreement of Cooperation signed between NASA – representing research interests of NOAA and USNO – and the Brazilian Space Agency, AEB, in 2002. The counter-part of the operational costs, staff, and support of infrastructure are provided by INPE and by Mackenzie.

### 2. Brief Description of ROEN Facilities

The largest instrument of ROEN is the 14.2 m radio telescope, on one alt-azimuth positioner. It is operated at S- and X-bands, using cryogenic radiometers. The system is controlled by Field System, Version 9.7.7 program. Observations are recorded with a Mark 5 system. One Sigma-Tau hydrogen maser clock standard is operated at ROEN.

GPS monitoring is performed in a cooperation program with NOAA, USA. Two stations are operated: one dual frequency GPS Rogue receiver and the recently installed Leica System 1200, both operated continuously. The collected data are provided to the NOAA/IGS center, as well to Brazilian IBGE center. ROEN has all basic infrastructures for mechanical, electrical and electronic maintenance of the facilities.



Figure 1. Fortaleza's station team repairing the 14.2 m antenna

### 3. Space Geodesy Team

The Brazilian space geodesy program is coordinated by Prof. Pierre Kaufmann, from São Paulo main office at CRAAM (CRAAE)/Instituto and Universidade Presbiteriana Mackenzie, receiving scientific assistance from Dr. Claudio E. Tateyama, and partial administrative support from Valdomiro S. Pereira and Neide Gea Escolano. Partial technical assistance is given by Itapetinga Radio Observatory staff, near São Paulo, also operated by INPE/Mackenzie.

The Fortaleza Station facilities and geodetic VLBI and GPS operations are managed on site by Eng. A. M. P. de Lucena (CRAAE/INPE), assisted by Eng. Adeildo Sombra da Silva (CRAAE/Mackenzie), the technicians Avicena Filho (CRAAE/INPE) and Carlos Fabiano B. Moreira (CRAAE/Mackenzie).



Figure 2. Fortaleza's station team

#### 4. Geodetic VLBI Observation

Fortaleza participated in the following geodetic VLBI experiments, as detailed in the table below for the year 2005.

Experiment	Number of Sessions
IVS-R4	49
IVS-T2	06
IVS-CRF	03
IVS-OHIG	06
IVS-R1	02

#### 5. Development and Maintenance Activities in 2005

Considerable attention was given to technical maintenance problems, specially to the following ones:

1. Tests and electrical alignment of the DC motors in both axes.
2. Installation of Mark 5 recorder.
3. Repair of cryogenic system with replacement of dewar O-rings, vacuum valve and helium lines.
4. Repairs on the following circuits, modules, or systems: Mark III video converters, Mark III power supplies, Mark III IF3 module and Mark IV formatter.
5. Maintenance of web site (<http://www.roen.inpe.br>) and the local server computer.

#### 6. GPS Operation

The IGS network GPS receiver operated regularly at all times during 2005. Data were collected and uploaded to IGS/NOAA computer.

#### 7. Upgrading NOAA GPS Monitoring

Drs. Miranda Chin and David Crump, from IGS/NOAA, visited ROEN for installing a new GPS receiver system, a Leica system 1200 in early 2005. It will be working simultaneously with the Turbo Rogue receiver for some time.

#### 8. Major Maintenance and Upgrades

Major mechanical repairs were done on the antenna azimuth reduction boxes drives, to be completed in 2006.

It is planned to complete the Mark IV updating during 2006. It is still necessary to install new filter boards and upgrade the mixer board in the video converters to accomplish the Mark IV upgrading. The installation of a Mark 5 recorder was performed during this past year. Supporting instruments and facilities are expected to be provided in order to accomplish these complementary installations and allow fully operational activities.

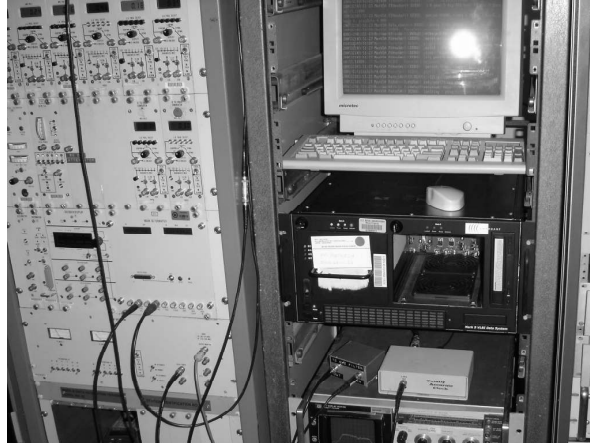


Figure 3. The Mark 5 recorder installed in the equipment rack

## 9. New Agreement for Research Cooperation

An agreement for cooperation in research related to ROEN activities was signed between the Ceará State University, UECE, Fortaleza and Mackenzie Presbyterian University, São Paulo. The collaboration is intended to have UECE's Physics Department exploring the GPS and VLBI inferred information on atmospheric water vapor content and upper atmosphere total electronic content and compare them to regional meteorology and cloud physics.

## 10. High Data Speed Connection

With the financial support from Brazilian Ministry of Science and Technology and Ministry of Education, it has been contracted a high speed network connected to ROEN, to become operative in the first months of 2006, at a cost of about US\$ 1.5 M. Initial 2.5 Gbps rate will allow ROEN to participate in e-VLBI experiments.

## 11. Publications

Kaufmann, P., Aplicações de Geodésia Espacial, Anais do 6o Workshop da Rede Nacional de Ensino e Pesquisa, 9 e 10 de Maio de 2005, Fortaleza, CE, Brazil ([http://www.rnp.br/\\_arquivo/wrnp/2005/kaufman.pdf](http://www.rnp.br/_arquivo/wrnp/2005/kaufman.pdf)).

# Gilmore Creek Geophysical Observatory

*Richard Strand*

## Abstract

The following report provides a general technical description and operational overview of the Gilmore Creek Geophysical Observatory located near Fairbanks, Alaska.



Figure 1. Gilmore Creek Geophysical Observatory's telescope and building, Fairbanks, Alaska.

## 1. GCGO at Fairbanks

Gilmore Creek Geophysical Observatory (GCGO) is located 22 km northeast of Fairbanks, Alaska. The observatory is co-located with the NOAA weather satellite command and data acquisition station. The station sits on an 8,500 acre reservation that is mostly undeveloped wilderness. Ten antennas are in operation. GCGO was instrumented by NASA's Crustal Dynamics Project in the mid 80's for the Alaskan mobile VLBI campaign and used as the base station for those geodetic measurements. The GCGO is part of the NASA Space Geodesy program in cooperation with the U.S. Naval Observatory.

## 2. Technical Parameters of GCGO

The 26 meter telescope, monument number 4047, X-East Y-North, latitude N 64° 58' 43.81288" and longitude E 147° 29' 42.18552" height 306.418 meters, is hydraulic-operated and controlled by a Modcomp computer system (see Table 2). Data acquisition is by the VLBA terminal and a Mark 5A, VLBA and S2 recording system with the Mark IV. The X/S band microwave receiver uses a cryogenic low noise front end. VLBI Field System version 9.5.7 is used to control the VLBA rack. GCGO has a Hydrogen Maser NR 5 time standard with a HP Cesium for the telescope computer. A CNS timing GPS receiver is used to provide the GPS offset measurements. The JPL GPS scintillation project is observed using an Ashtech GPS receiver. The Institut Geographique National in France operates a DORIS beacon located near the NOAA VHF transmitter building. CLS from France operates the ARGOS and ARGOS-NEXT beacon. The ARGOS-NEXT platform is located next to the NOAA 26 meter antenna.

Table 1. Address of GCGO near Fairbanks.

Gilmore Creek Geophysical Observatory NOAA/NESDIS FCDAS 1300 Eisele Road Fairbanks, AK 99712 <a href="http://www.fcdas.noaa.gov">http://www.fcdas.noaa.gov</a>
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Table 2. Technical parameters of the GCGO radio telescope for geodetic VLBI.

Parameter	GCGO
owner and operating agency	NOAA/NASA
year of construction	1962
receiving feed	primary focus
diameter of main reflector	26 meters
focal length	10.9728 meters
surface accuracy of reflector	889 mm rms
X Y mount	1 degree per second
S-band	2.2 – 2.4, GHz
$T_{sys}$	62 K
$SEFD(CASA)$	650 Jy
$G/T$	35.3 dB/K
X-band	8.1 – 8.9, GHz
$T_{sys}$	58 K
$SEFD(CASA)$	550 Jy
$G/T$	44.5 dB/K

### 3. Staff of the Gilmore Creek Facility, Fairbanks, Alaska

GCGO is co-located with the NOAA Fairbanks command and data acquisition facility. The NOAA Manager is Lance Seman. The site is operated by Space Mark International. Roger Kermes is project Manager. Technical staff members include R. Morgain, retired in July, Dave Eubanks transferred back to NOAA in the fall and Carol Homchick who assumed all duties of operating and maintaining the GCGO with help from local staff T. Knuutila, Z. Padilla, and Rich Strand, as well as Ed Himwich by e-mail, telephone and station visits. The telescope's hydraulic system is maintained by M. Meindl, A. Sanders and F. Holan. Day-by-day scheduling is done by Cindy Thomas (NVI, Inc.) and VLBI technical directives/contract modifications by Steve Bailey (NASA/GSFC).



Figure 2. Carol Homchick, SMI with Rich Strand, NVI. Final GCGO staff photo.

### 4. Status of Gilmore Creek Geophysical Observatory

In 2005 GCGO was scheduled for over 100 sessions and the CONT05 campaign. Normal observatory problems continued into 2005. Some sessions were lost due to telescope hydraulic failures. Dewar failures and lost tracks in the Mark 5A system also caused problems. Maser problems were solved and receiver communications were corrected but caused data quality loss. TDPS and DAT rack power supplies also caused data loss during the year. These failures and others were compounded with a new station staff. Rich Strand with help from Dave Eubanks and Carol Homchick repaired the Mark 5A, receiver communications, dewar replacement and cooling along with station equipment maintenance to conduct the necessary CONT05 reliability tests to successfully observe that campaign. Carol received additional support from Brian Corey, Ed Himwich, Irv Diegel, among others at Haystack, GSFC and Honeywell.

### 5. Outlook

GCGO suspended VLBI operations at the end of 2005. We hope to restart operations with a VLBI2010 system, when it becomes available.



# Goddard Geophysical and Astronomical Observatory

*Jay Redmond, Charles Kodak*

## 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 previous year. The outlook lists the outstanding tasks to improve the performance of GGAO.

## 1. GGAO at Goddard

The Goddard Geophysical and Astronomical Observatory consists of a radio telescope for VLBI, SLR site to include MOBLAS-7, SLR-2000 (development system), a 48" telescope for developmental two color Satellite Ranging, a GPS timing and development lab, meteorological sensors and a H-maser. In addition, we are a fiducial IGS site with several IGS / IGSX receivers.

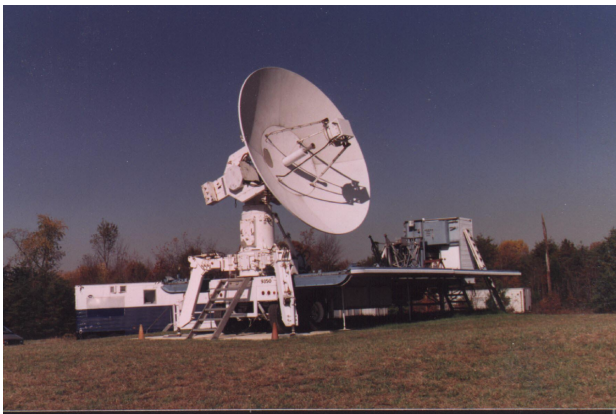


Figure 1. Old semi permanent MV3 VLBI antenna.



Figure 2. New permanent MV3 antenna.

GGAO is located on the east coast of the United States in Maryland. It is about 15 miles NNE of Washington D.C. in Greenbelt, Maryland (Table 1).

## 2. Technical Parameters of the VLBI Antenna at GGAO

The radio telescope for VLBI at GGAO (MV3) was originally built as a mobile or transportable station. It was previously known as Orion and was part of the original CDP. It is now being used as a fixed site having been moved to Goddard and semi-permanently installed here since the spring of 1991 as shown in Figure 1. In the winter of 2002 the antenna was taken off its trailer and permanently installed at GGAO as shown in Figure 2. The design criteria were

- transportability on two tractor trailers utilizing a 5 meter dish size to maximize receive and mobility considerations,
- setup of the radio telescope within eight hours (although it has been used as a fixed site since the spring of 1991)

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	
<a href="http://www.gsfc.nasa.gov">http://www.gsfc.nasa.gov</a>	

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

Table 2. Technical parameters of the radio telescope of GGAO for geodetic VLBI.

Parameter	GGAO-VLBI
owner and operating agency	NASA
year of construction	1982
diameter of main reflector $d$	5m
azimuth range	0... 540°
azimuth velocity	3°/s
azimuth acceleration	1°/s <sup>2</sup>
elevation range	0... 90°
elevation velocity	3°/s
elevation acceleration	1°/s <sup>2</sup>
X-band	8.18 – 8.98 GHz
receiving feed	Cassegrain focus
$T_{sys}$	24 K
Bandwidth	800MHz, -2dB
$G/T$	32.1 dB/K
S-band	2.21 – 2.45GHz
receiving feed	primary focus
$T_{sys}$	19 K
Bandwidth	240MHz, -2dB
$G/T$	21.2 dB/K
VLBI terminal type	Mark IV
recording media	thin-tape, Mark 5
Field System version	9.7.1 (9.5 BETA)

### 3. Technical Staff of the VLBI Facility at GGAO

The GGAO VLBI facility gains from the experiences of the staff from the Research and Development VLBI support staff. GGAO is a NASA R&D and data collection facility, operated under

contract by Honeywell Technology Solutions Incorporated (HTSI). Table 3 lists the GGAO station staff that are involved in VLBI operations.

Table 3. Staff working at the MV3 VLBI station at GGAO.

Name	Background	Dedication	Agency
Jay Redmond	engineering technician	100%	HTSI
Skip Gordon	engineering technician	20%	HTSI

#### 4. Status of MV3 at GGAO

GGAO participated in several VLBI experiments which are listed in Table 4. In addition to the scheduled experiments listed in Table 4, MV3 has participated in several unscheduled experiments for VLBI developmental purposes and various other developmental activities.

Table 4. Participation of GGAO in VLBI Experiments from February 1, 2005 to December 20, 2005.

Date	Experiment
2005-02-01	T2037
2005-02-09	RDV49
2005-04-27	RDV50
2005-06-29	RDV51
2005-08-24	RDV52
2005-09-18	T2040
2005-09-26	IG269
2005-09-28	RDV53
2005-10-14	sc5318
2005-12-14	RDV54
2005-12-20	T2042

#### 5. Outlook

GGAO will continue to support both scheduled experiments and developmental activities. The plan for 2005 consists of:

1. Continue testing of pre-release versions of PC-FS and new Linux kernel releases.
2. Continue with research on Mark 5 hardware development.
3. Continually striving to improve the performance of the entire Mark IV data collection and station specific equipment.
4. MV3 has installed the Mark 5 and e-VLBI hardware and has begun testing real-time from GGAO to Haystack. Correlation with the Westford data on the Mark IV correlator was successful. (Oct 24, 2002).

5. The MV3 antenna at GGAO has been permanently fixed to the ground and has been resurveyed. (Oct. 2003)

# Hartebeesthoek Radio Astronomy Observatory (HartRAO)

*Ludwig Combrinck, Marisa Nickola*

## Abstract

HartRAO, the only fiducial geodetic site in Africa, participates in VLBI, GPS and SLR global networks. This report provides an overview of our geodetic VLBI activities during 2005. The status of the 26m radio telescope surface upgrade is reported. In order to meet future requirements of geodetic VLBI, we have initiated the first steps towards founding a new space geodetic station which will cater to new developments and challenges as addressed by VLBI2010 and future requirements of GPS and SLR/LLR.

## 1. Geodetic VLBI at HartRAO

Hartebeesthoek is located 65 kilometers north-west of Johannesburg within the World Heritage Site known as the Cradle of Humankind, just inside the provincial boundary of Gauteng, South Africa. The nearest town, Krugersdorp, is 32 km distant. The telescope is situated in an isolated valley which affords protection from terrestrial interference. HartRAO uses a 26-metre equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961. The telescope was part of the NASA deep space tracking network until 1975 when the facility was converted to an astronomical observatory. The telescope is co-located with an SLR station (MOBLAS-6) and an IGS GPS station (HRAO). HartRAO joined the EVN as an associate member during 2001. Astronomical and geodetic VLBI have been allocated equal shares (15% each) of telescope time.



Figure 1. Radio telescope with beam of SLR passing overhead and Moon and Venus to the left.



Figure 2. Anemometer on roof—the radio telescope is parked at zenith for 5 minutes when the wind speed exceeds 50 km/h.

## 2. Technical Parameters of the VLBI Telescope of HartRAO

The feed horns used for 13 cm and 3.5 cm are dual circularly polarised conical feeds. The RF amplifiers are cryogenically cooled HEMTS. Tables 1, 2 and 3 contain the technical parameters of

the HartRAO radio telescope, its receivers and recording systems. Our Mark 5 recording unit has been in use since mid-May 2004 and the majority of 2005 experiments have been recorded to disc (exceptions being the use of tape in an RDV, the 6 OHIGs and 2 CRDSs).

Table 1. Antenna parameters.

Parameter	HartRAO-VLBI
Owner and operating agency	HartRAO
Year of construction	1961
Radio telescope mount	Offset equatorial
Receiving feed	Cassegrain
Diameter of main reflector $d$	25.914 $m$
Focal length $f$	10.886 $m$
Focal ratio $f/d$	0.424
Surface error of reflector	< 0.5 $mm$
Wavelength limit	< 1.0 $cm$
Pointing resolution	0.001°
Pointing repeatability	0.020°

Table 2. Receiver parameters with dichroic reflector (DR), used for simultaneous S-X VLBI, off or on.

Parameter	X-band	S-band
$T_{sys}$ (DR off) ( $K$ )	60	44
$T_{sys}$ (DR on) ( $K$ )	70	50
$S_{SEFD}$ (DR off) ( $Jy$ )	684	422
$S_{SEFD}$ (DR on) ( $Jy$ )	1330	1350
Point source sensitivity (DR off) ( $Jy/K$ )	11.4	9.6
Point source sensitivity (DR on) ( $Jy/K$ )	19	27
3 dB beamwidth (°)	0.092	0.332

Table 3. VLBI recording systems.

Parameter	HartRAO-VLBI
VLBI terminal	Mark IV
VLBI recorder	Mark 5A, Mark IV, S2

### 3. Staff Members Involved in VLBI

Table 4 lists the HartRAO station staff who are involved in geodetic VLBI. Jonathan Quick (VLBI friend) has continued to provide technical support for the Field System as well as for hardware problems.

Table 4. Staff supporting geodetic VLBI at HartRAO.

<b>Name</b>	<b>Function</b>	<b>Programme</b>
Ludwig Combrinck	Programme Leader	Geodesy
Jonathan Quick	Hardware/Software	Astronomy
Sarah Buchner	Training	Astronomy
Marisa Nickola	Logistics/Operations	Geodesy
Pieter Stronkhorst	Operator	Technical
Attie Combrink	Operator	Geodesy
Gert Agenbag	Operator	Geodesy - student
Roelf Botha	Operator	Geodesy - student
Sakia Madiseng	Operator	Geodesy - student
Mojalefa Moeketsi	Operator	Geodesy - student
Vasyl Suberlak	Operator	Geodesy - post doctoral researcher

#### 4. Current Status

During 2005 HartRAO participated in 69 experiments, including 15 CONT05 experiments (Table 5), compared to 56 in the previous year, which utilised the telescope time allocated to geodetic VLBI to its fullest extent.

Table 5. Geodetic VLBI experiments HartRAO participated in during 2005.

<b>Experiment</b>	<b>Number of Sessions</b>
R1	20
C05	15
CRDS	9
R4	6
OHIG	6
CRFS	4
CRF	4
T2	3
RDV	3
CRF	3
Total	69

During the CONT05 campaign HartRAO was joined by TIGO in Chile, boosting the number of southern hemisphere participants to two. At HartRAO, geodetic VLBI was supported by co-located SLR and GPS, as well as DORIS at the adjacent Satellite Application Centre of the CSIR. Two water vapour radiometers (WVRs) made their home at HartRAO, one on long-term loan from BKG, Germany, the other on a 6-month loan from ETHZ, Switzerland. The new high-accuracy surface on the 26-m telescope and the consequential rebalancing of the structure with three tonnes of lead required the implementation of a new pointing model which Jonathan Quick had ready in



Figure 3. *Attie Combrink inspects one of the water vapour radiometers on the roof of the main observatory building.*



Figure 4. *Holographic setup—reference antenna to collect 12 GHz signal transmitted from geostationary satellite.*

time for the start of the CONT05 campaign on September 12. Astronomer Dr Mike Gaylard, also lent his support for the CONT05 campaign by creating and maintaining a CONT05 webpage.

The **antenna surface upgrade** has now reached the stage where microwave holography is to be used to determine the overall shape of the dish. Based on the results of the holography, individual panels will be adjusted to obtain the best overall surface shape. Several **antenna sub-system upgrades** have been undertaken: A membrane dryer replaced the dry air compressor to supply dry air to the receiver systems and radomes. A new Drytel rotary-vane and turbo combination vacuum pump, which works at any orientation, and remote-controlled electro-pneumatic vacuum valves replaced the old “wet” rotary-vane vacuum pump and manual valves allowing for continued operation *even when pumping and cooling down warmed-up systems*. An anemometer was installed to monitor wind speeds on site. When the computer detects instantaneous wind speeds in excess of 50 km/h, the antenna is automatically stowed to zenith for 5 minutes.

## 5. Future Plans

We have started initial steps towards the development of a new integrated Space Geodesy Facility which will support SLR, LLR, VLBI and GPS as well as host other earth science instrumentation. This will mean the construction of a new site, development and implementation of new state of the art equipment and will place the southern hemisphere and especially Africa securely in the space geodesy arena for the next several decades. We would like to invite possible participants in this venture to contact us. The Geodesy Programme is an integrated programme, supporting VLBI, SLR and GPS and is active in several collaborative projects with GSFC, JPL, GFZ (Potsdam) and local institutes.



# Hobart, Mt. Pleasant, Station Report for 2005

*Brett Reid, Simon Ellingsen, John M. Dickey*

## Abstract

This is a brief report on the activities carried out at the Mt. Pleasant Radio Astronomy Observatory at Hobart, Tasmania. During 2005, the Observatory participated in 43 VLBI observing sessions with IVS.

## 1. Introduction

The Mt. Pleasant Observatory is located about 15 km north-east of Hobart at longitude 147.5 degrees East and latitude 43 degrees South. Hobart is the capital city of Tasmania, the island state of Australia located to the south of the mainland. The station is operated by the School of Mathematics and Physics at the University of Tasmania with financial support from the University and with the aid of an Australian Research Council (ARC) Linkage grant in conjunction with Geoscience Australia. The station has participated in geodetic VLBI programs since 1988 but only joined IVS in 2002 when we were able to secure funding support for geodetic observations for a five year period. The station has a co-located GPS receiver and a site which is used for absolute gravity measurements. The Grote Reber Memorial Conference, "New Techniques and Results in Low Frequency Radio Astronomy", was held at the University of Tasmania, Hobart, from 6-10 December. The meeting attracted 89 participants, almost half from overseas.

## 2. Brief Description of VLBI Facilities

The antenna is a 26m prime focus instrument with an X-Y mount. The focus cabin has recently been upgraded to include a feed translator with provision for four different receiver packages which enables rapid change over between geodetic and astronomical requirements. Standard receiver packages provide for operation at L band, S, C, X and K bands. There is also the dual frequency S/X geodetic receiver. All of these receivers are cryogenically cooled. The antenna has a maximum slew rate of 40 degrees per minute about each axis. The station is equipped with a Mark IV electronics rack and a Mark 5 VLBI recording system as well as S2 recorder. There is also another disk based recording system as used by other Australian VLBI antennas.

## 3. Staff

Staff at the observatory consisted of academics, Prof. John Dickey (director), Dr. Simon Ellingsen, Dr. Melanie Johnston-Hollitt and Prof. Peter McCulloch who has had a large input into the receiver design and implementation. Dr. Giuseppe Cimó and Dr. Jamie Stevens are research fellows and have had input into the Linux systems at the observatory. Jamie is also working on the fiber optic link to Mount Pleasant which is due for commissioning in the 3<sup>rd</sup> quarter of 2006. 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 funded through the ARC grant and a half time mechanical technical officer, Mr. Geoff Tonta. For operation of the observatory



Figure 1. The Mt Pleasant 26m antenna

during geodetic observations we rely heavily on support from astronomy PhD and post-graduate students.

#### **4. Geodetic VLBI Observations**

Hobart participated in 43 geodetic VLBI experiments during 2005. These were divided between the R1, OHIG, CRF, CRDS, T2, and APSG programs. All experiments were recorded using Mark 5. The MET3 sensor has been implemented and will give improved accuracy over the station's previous sensor.

#### **5. Future Plans**

Funding has been secured under ARC LEIF (Large Equipment and Infrastructure Funding) for a 10 Gb/s fibre optic link between the Mt. Pleasant VLBI site and the university campus. The expected completion date for this project is third quarter 2006.

# Kashima 34-m Radio Telescope

*Eiji Kawai, Hiroshi Takeuchi, Hiromitsu Kuboki*

## Abstract

National Institute of Information and Communications Technology (NICT) formerly CRL (Communications Research Laboratory), operates Kashima 34-m radio telescope continuously as a facility of the Kashima Space Research Center in Japan. This is the network station report mainly focused on the telescope facilities.

## 1. Introduction

The Kashima 34-m telescope (Figure 1) was constructed by National Institute of Information and Communications Technology (NICT), formerly Communications Research Laboratory (CRL), in 1988. The telescope is located about 100 km east of Tokyo, Japan. During 17 years of operation, the telescope has been kept in a fairly good condition and the antenna has participated in various VLBI and single-dish observations. The 34-m telescope is operated by the Radio Astronomy Applications Group of Kashima Space Research Center (KSRC), NICT.



Figure 1. The Kashima 34-m radio telescope.

## 2. Highlights

Since the original configuration of the X-band receiver system of Kashima 34-m antenna did not cover upper frequency range above 8600 MHz, which is required by some IVS sessions, we started to try to expand the X-band receiver frequency coverage up to 9080 MHz. The expansion was preliminary realized by replacing the RF bandpass filter. Although the performance of the expanded frequency is not satisfactory, especially near the upper edge of the band, we have suc-

Table 1. Main specification of the 34-m Radio Telescope.

Main reflector aperture	34.073 m
Latitude	N 35° 57' 50.76"
Longitude	E 140° 39' 36.16"
Height of AZ/EL intersection above sea level	43.6 m
Height of azimuth rail above sea level	26.3 m
Antenna design	Modified Cassegrain
Mount type	AZ-EL mount
Drive range azimuth	North $\pm 270^\circ$
Drive range elevation	7°-90°
Maximum speed azimuth	0.8°/sec
Maximum speed elevation	0.64°/sec
Maximum operation wind speed	13 m/s
Panel surface accuracy r.m.s.	0.17 mm

ceeded in detecting fringes from all X-band channels allocated for the CONT05 sessions by using the KASHI34-TSUKUB32 baseline. Details are described in Section 3.2.

The International Academy of Astronautics (IAA) awarded its Laurels for Team Achievement Award for 2005 to the VLBI (Very Long Baseline Interferometry) Space Observatory Programme (VSOP) Team. The award was presented at the 56th International Astronautical Congress in Fukuoka, Japan, on October 16, 2005. The award is a tribute to the efforts of the entire VSOP team, including Kashima 34-m antenna, and many other observatories, who made it possible to realize a radio telescope bigger than the earth.

### 3. Telescope Status

#### 3.1. Receiver Systems

The receivers currently available at the Kashima 34-m telescope can observe L, C, K, Ka, Q, S, and X-bands. The measured performance of the receivers are summarized in Table 2. If the polarization of the receiver is switchable to both RHCP and LHCP polarizations, it is indicated as R/L. If the polarization cannot be switched, but it is still possible to change the polarization by changing the wave guide configuration, it is indicated as R(L) or L(R). Ka-band efficiency in Table 2 is a provisional value. All receivers, except for the C-band receiver, are using cooled HEMT LNA which are kept around 12 K physical temperature. The C-band LNA is using an ambient FET LNA. The low noise amplifiers of the Ka and K-band receivers are placed inside a dual-band dewar. The low noise amplifiers of S and X-band receivers are also placed inside a cooled dewar. Only L and Q-band LNAs are placed in a dedicated cooled dewar for each band.

To mitigate Radio Frequency Interference (RFI), additional filters were installed in the L and S-band receivers. For the S-band receiver, a High Temperature Superconductor (HTS) filter is used [2]. A coaxial bandpass filter with 11 sections was employed for 1350-1450 MHz in the L-band to avoid the influence of RFI.

The IF (intermediate frequency) signals of the receivers are transmitted from the telescope to the observation room via optical fibers. Higher frequency band receivers (K, Ka, and Q) use

Table 2. Receiver Specification of the 34-m Radio Telescope.

Band	frequency (MHz)	Trx (K)	Tsys (K)	Efficiency	SEFD (Jy)	Polarization
L	1350-1750	18	43	0.68	190	R/L
S	2193-2350	19	83	0.65	390	R/L
C	4600-5100	100	127	0.70	550	L(R)
X	8180-9080*	41	52	0.68	230	R/L
K	21800-23800	75	160	0.5	970	L(R)
Ka	31700-33700	85	150	0.4	1100	R(L)
Q	42300-44900	180	300	0.3	3000	L

\*: X-band receiving frequency is a result of preliminary expansion of the receiving frequency range. See section 3.2 in this report for details.

frequency range of 5-7 GHz as the IF signals. IF signals are then converted to base band signals or other IF signals in the observation room.

### 3.2. On the Expansion of the Frequency Coverage of an X-band

The original nominal frequency coverage of the X-band receiver of the Kashima 34-m antenna was from 7860 MHz to 8600 MHz. This frequency coverage was chosen to cover a wide frequency range to improve the time delay measurements in domestic geodetic VLBI experiments. However, after the 34-m antenna was constructed, international wide band geodetic VLBI experiments began to be performed by expanding the X-band receiving frequency to the upper frequencies up to 9080 MHz. Therefore, we decided to try to expand the frequency range of the X-band receiver of the 34-m antenna up to 9080 MHz so that it can participate in the international wide band geodetic VLBI experiments. At first, we replaced the RF bandpass filter of the X-wL subsystem from its original filter (7860-8360 MHz) to the new filter (8580-9080 MHz) as shown in Table 3. To convert the new frequency range of the X-wL subsystem, the local frequency signal (8080 MHz) for the X-n subsystem was temporally removed and connected to the mixer of the X-wL subsystem. As the result, the X-n subsystem is currently unavailable for observations. After these changes, SEFD of the X-band receiver was measured on September 6, 2005. As shown in the Figure 2, the average SEFD of lower band (8180-8600 MHz) was 232 Jy whereas the average SEFD of the upper band (8600-8850 MHz) was 237 Jy. On the other hand, the SEFD increases to 250 Jy at 8900 MHz and 430 Jy at 9890 MHz. The reason of the poor performance of the upper edge of the receiver is likely due to an inadequate down converter configuration. In the near future, we will try to figure out the cause of this poor performance and improve the SEFD in the upper frequency edge up to 9080 MHz. To evaluate the expanded X-band receiver performance, we performed observations during the c0505 session on September 16, 2005 and only the TSUKUB32-KASHIM34 baseline was correlated. We succeeded in detecting fringes on all channels observed in the c0505 session and basic performance of the expanded X-band receiver was confirmed.

### 3.3. Mechanical System

The occurrence of the failures of the Antenna Control Unit (ACU) has increased recently because of its aging. Most typical failures are occasional emergency brakes during observations

Table 3. X-band nominal receiving frequency range of Kashima 34-m antenna before and after the preliminary expansion.

Receiver	Frequency Coverage (MHz)	
	Before	After
X-n	8180-8600	—(*)
X-wL	7860-8360	8580-9080
X-wH	8180-8600	8180-8600

\*: To use local oscillator signal for X-wL subsystem, X-n subsystem is temporally unavailable.

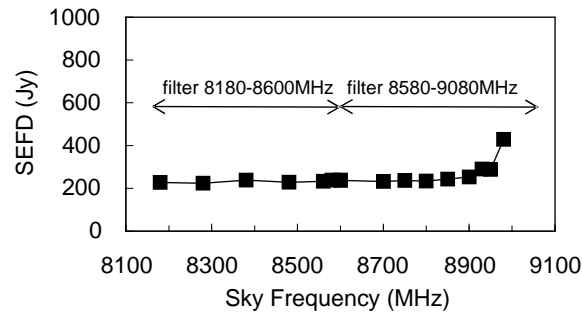


Figure 2. SEFD of the expanded X-band receiver of the 34-m antenna

and tracking mode change failures. To prevent observations from failing, we replaced the ACU with a new unit in January, 2005. In February, 2005 the remaining part the backup structure of the main reflector which has never been repaired was repaired by removing the rust and by welding reinforcement plates. The corroded nut-plates which are used to fix the main reflector plates to the backup structure were also replaced.

#### 4. Technical Staffs of the Kashima 34-m Radio Telescope

Engineering and technical staffs of the Kashima 34-m telescope are Eiji Kawai (responsible for operations and maintenance), Mamoru Sekido (software and reference signals), Hiroshi Takeuchi (software and hardware), Hiromitsu Kuboki (mechanical and RF related parts), Junichi Nakajima (research and developments for observing system), Yasuhiro Koyama (international e-VLBI), and Tetsuro Kondo (software correlator developments and e-VLBI).

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# Kashima and Koganei 11-m VLBI Stations

*Yasuhiro Koyama*

## Abstract

Two 11-m VLBI stations at Kashima and Koganei used to be a part of the Key Stone Project VLBI Network. The network consisted of four VLBI stations at Kashima, Koganei, Miura, and Tateyama. Since Miura and Tateyama stations have been transported to Tomakomai and Gifu, Kashima and Koganei 11-m stations are remaining as IVS Network Stations. After the regular VLBI sessions with the Key Stone Project VLBI Network terminated in 2001, these stations are mainly used for the purposes of technical developments and miscellaneous observations. In 2005, a geodetic VLBI test experiment using the multi-channel 1 Giga-bit AD sampler unit ADS2000 was performed between Kashima and Koganei 11m VLBI stations. Many observations were also performed to determine precise orbit of the spacecraft Hayabusa.

## 1. Introduction

The Key Stone Project (KSP) was a research and development project of the National Institute of Information and Communications Technology (NICT, formerly Communications Research Laboratory) [1]. Four space geodetic sites around Tokyo were established with VLBI, SLR, and GPS observation facilities at each site. The locations of the four sites were chosen to surround Tokyo Metropolitan Area to regularly monitor the unusual deformation in the area (Figure 1).

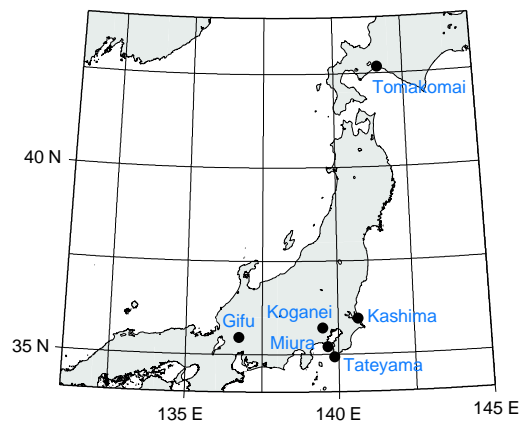


Figure 1. Geographic locations of four KSP VLBI stations and two stations at Tomakomai and Gifu.

Therefore, the primary objective of the KSP VLBI system was to determine precise site positions of the VLBI stations as frequently and fast as possible. To realize this objective, various new technical advancements were attempted and achieved. By automating the entire process from the observations to the data analysis and by developing the real-time VLBI system using the high speed digital communication links, unattended continuous VLBI operations were made possible. Daily continuous VLBI observations without human operations were actually demonstrated and the results of data analysis were made available to the public users immediately after each VLBI

session. Improvements in the measurement accuracies were also accomplished by utilizing fast slewing antennas and by developing higher data rate VLBI systems operating at 256 Mbps.

11-m antenna and other VLBI facilities at Miura and Tateyama stations have been transported to Tomakomai Experimental Forest of the Hokkaido University and to the campus of Gifu University, respectively. As a consequence, two 11-m stations at Kashima and Koganei (Figure 2) are remaining as IVS Network Stations. After the regular VLBI sessions with the Key Stone Project VLBI Network terminated in 2001, 11-m VLBI stations at Kashima and Koganei are mainly used for the purposes of technical developments and miscellaneous observations.



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

## 2. Activities in 2005

For technical developments, the baseline between Kashima and Koganei is now used as a test bed for real-time VLBI observations based on the Internet Protocol (IP). The two stations used to be connected by high speed Asynchronous Transfer Mode (ATM) network in collaboration with the NTT Laboratories until July 2003. From April 2004, NICT started to operate high speed research test-bed network called JGNII and both the Kashima and Koganei stations are connected to the JGNII backbone with OC-192 (10 Gbps) connection. JGNII is a follow-on project of the JGN (Japan Gigabit Network) which was operated by the Telecommunications Advancement Organization of Japan (TAO) for 5 years from 1999. When TAO was merged with Communications Research Laboratory to establish NICT as a new institute, JGNII succeeded the JGN project. Whereas the JGN project was operated based on the ATM architecture, the new JGNII network mainly uses IP. One GbE (Gigabit Ethernet) interface is installed at Koganei station and two GbE interfaces are connected at Kashima station. This environment is providing us an ideal opportunity for e-VLBI research and developments.

The use of old operating software of the antenna and VLBI observing system at Kashima 11-m station was terminated in 2004 by installing the fs9 software that then became the main operating



software of the station. At the time of writing, the fs9 operating system was copied to a new PC system to use it as the replacement for the Koganei 11-m VLBI station as the main operating software.

In the year 2005, a 24h geodetic VLBI test experiment was performed on March 11 and 12 by using the newly developed multi-channel Giga-bit sampler units called ADS2000 [1]. By using the ADS2000 and the K5/VSI system, the 16 channels of data (10 for X-band and 6 for S-band) were recorded to the hard disks in the K5 system at the total data rate of 1024Mbps. Each channel was sampled at the sampling rate of 32Msps and the digitization level of 2 bits/sample. The observed data were processed by the K5 software correlator and then analyzed by the SOLVE/CALC software. From this experiment, the baseline length was estimated with an RMS uncertainty of 1.3 mm and the performance of the system was confirmed.

Many observations were also performed to determine precise orbit of the spacecraft Hayabusa. The spacecraft was launched by Japan Aerospace Exploration Agency on May 9, 2003 to approach the asteroid Itokawa. The X-band telemetry signal from the spacecraft was used to demonstrate precise orbit determination by means of differential VLBI observations. Since precise orbit determination of the spacecraft Hayabusa was required to efficiently navigate the spacecraft to approach the asteroid Itokawa. Many VLBI stations in Japan including the 11-m VLBI stations at Kashima and Koganei participated in the observations. The spacecraft Hayabusa approached the asteroid Itokawa in September 2005 and precise orbit determination of the spacecraft was performed before and after the arrival of the spacecraft to the asteroid.

### 3. Staff Members

The 11-m antenna stations at Kashima and Koganei are operated and maintained by the Radio Astronomy Applications Group at Kashima Space Research Center, NICT. The staff members of the group are listed in Table 1. The operations and maintenance of the 11-m VLBI station at Koganei is also greatly supported by the Optical Space Communications Group and Quasi-Zenith Satellite System Group at Koganei Headquarters of NICT. We are especially thankful to Jun Amagai and Futaba Katsuo for their support.

Table 1. Staff members of Radio Astronomy Applications Group, KSRC, NICT

Name	Main Responsibilities
Tetsuro KONDO	Research Center Supervisor / Software Correlator
Yasuhiro KOYAMA	Group Leader / International e-VLBI
Eiji KAWAI	Antenna system
Ryuichi ICHIKAWA	Spacecraft VLBI
Junichi NAKAJIMA	VLBI System Developments
Mamoru SEKIDO	Spacecraft VLBI
Hiroshi TAKEUCHI	VLBI System Developments
Moritaka KIMURA	VLBI System Developments
Hiromitsu KUBOKI	Antenna System
Masanori TSUTSUMI	System Engineer
Atsutoshi ISHII	Developments for Small Antenna System

#### 4. Future Plans

In 2006, we plan to continue VLBI observations to the spacecraft Hayabusa and Geotail for the precise determination of their orbits. The use of phase delay measurements will be investigated to improve the accuracy and precision of the determination of the orbit. We will also continue to install new fs9 operating software at the Koganei 11-m VLBI station. It is also planned to increase the network speed of ATM connection between Kashima and Koganei from its current speed of 2.4Gbps to 4.8Gbps by using two connections for domestic e-VLBI observations in addition to the current IP network connection between the two sites (two 1Gbps links).

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# Kokee Park Geophysical Observatory

*Clyde A. Cox*

## Abstract

This report summarizes the technical parameters and the technical staff of the VLBI system at Kokee Park on the Island of Kauai. Included is an overview of the VLBI activities for the year 2005.

## 1. KPGO

Kokee Park Geophysical Observatory is located on the Island of Kauai in the Hawaiian Islands; Kauai is the most northwestern (inhabited) Island. The site is in a State Park (Kokee State Park) hence its name. It is located at an elevation of 1100 meters near the Waimea Canyon, which is often referred to as the Grand Canyon of the Pacific.

Kokee Park Geophysical Observatory first participated in VLBI operations as part of the GAPE experiments in 1984. At that time the station was part of NASA's STDN (Satellite Tracking Data Network). The 9-m system was modified by installing a focal point receiver, hydrogen maser, data acquisition terminal, tape drive and computer system. This was operational for the summer of 1984. The system was removed after the GAPE '84 experiments and reinstalled again for the summer of 1985. It was not until 1986 that we became a continuous participant in VLBI operations.

In October 1989 NASA phased out the STDN operation on Kauai and the station was transferred to the Crustal Dynamics Project at the Goddard Space Flight Center. The station started weekly operation for the U.S. Naval Observatory as part of the NAVNET network.

Early in 1992 construction of USNO's present 20-meter antenna was started. The foundation work was completed in August 1992 and the structure was started in September just as Hurricane Iniki struck on September 11, 1992. Installation was completed in 1993 and first light was in June 1993. Later in 1993 the use of the 9-meter system was discontinued.

Starting in July 2000 Kokee Park began daily (Monday through Friday) participation in the Intensive schedule for USNO.

S-2 recorder system was installed in 2000. Mark IV system was installed during 2001.

In May of 2002 Mario Bérubé and Bill Petrachenko arrived on site for installation and testing of a S-2 DAS. We have since that time supported the E-3 series of experiments on a monthly basis.

In May of 2002 Kokee Park received a Mark 5 system which was first run in parallel with the tape drive during the daily Intensive sessions (three times a week). Correlation was first done at Haystack; after several weeks of comparison we then started to ship the disk to USNO. During CONT02 the Mark 5 was used in stand alone mode. Switching between Intensive sessions and other experiments became a pleasure.

During November 2002 the survey team was on station to verify our antenna footprint and to survey the new (replacement) Doris beacon antenna.

A new MET package (MET3) was installed in February 2003.

Mid 2004 we started having problems with our Azimuth Gear Reducers. One was removed and shipped back to the manufacturer for refurbishment (this was found to be too expensive), and an additional unit was procured. The new Gear Reducer was finally received and installed in time for CONT05.

New F.S. Computer was installed in 2005



Figure 1. Kokee Park Geophysical Observatory 9m & 20m antennas.

Table 1. Location and Addresses of Kokee Park Geophysical Observatory

Longitude	159.665° W
Latitude	22.126° N
Kokee Park Geophysical Observatory P.O. Box 538 Waimea, Hawaii 96796 USA	

## 2. Technical Parameters of the VLBI System at KPGO

The receiver is of NRAO (Green Bank) design (dual polarization feed using cooled 15 K HEMT amplifiers). The DAR rack and tape drive were supplied through Green Bank. The antenna is of the same design and manufacture as those used at Green Bank and Ny-Ålesund.

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

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. Technical Staff of the VLBI System at KPGO

The staff at Kokee Park during calendar year 2005 consisted of six people who are employed by Honeywell under contract to NASA for the operations and maintenance of the Observatory. Staffing will be reduced in 2006 due to budget reductions. VLBI operations were conducted by Kelly Kim, Matt Harms, and Kawika Fujita.

Table 2. 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	0.020inchesrms
azimuth range	0 ... 540°
azimuth velocity	2°/s
azimuth acceleration	1°/s <sup>2</sup>
elevation range	0 ... 90°
elevation velocity	2°/s
elevation acceleration	1°/s <sup>2</sup>
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
$\eta$	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
$\eta$	0.539
VLBI terminal type	VLBA/VLBA4-Mark 5
Field System version	9.7.6

#### 4. Status of KPGO

Kokee Park has participated in many VLBI experiments since 1984. We started observing with GAPE, continued with NEOS and CORE, and are now in IVS R4 and R1. We also participate in the RDV experiments.

We averaged 1.5 experiments per week during calendar year 2000 and increased to an average of 2 experiments of 24 hours each week with daily Intensive experiments during year 2002 and into 2005.

Kokee Park also hosts other geodetic measurement systems, including PRARE, a DORIS beacon, and a Turbo-Rogue GPS receiver. Kokee Park is an IGS station.

#### 5. Outlook

e-VLBI was expected to make its debut during the first part of 2003. However, we are delayed due to the common “last mile” problem in 2004 and budget reductions in 2005.

Upgrading of our SX receiver and its interface drawer has been put on hold for the time being.



Figure 2. Kokee Park also hosts other systems; DORIS Beacon, PRARE, and IGS (GPS).

# Matera CGS VLBI Station

*Giuseppe Colucci, Domenico Del Rosso, Luciano Garramone*

## Abstract

This report describes the status of the Matera VLBI station[1]. A major hardware failure that had happened at the beginning of 2004, was fixed and in July 2005 operations restarted. Also an overview of the station, some technical characteristics of the system and staff addresses are given.

## 1. General

The Matera VLBI station is located at the Italian Space Agency “Centro di Geodesia Spaziale” (CGS) near Matera, a small town in the South of Italy. The CGS came into operation in 1983 when



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

a Satellite Laser Ranging SAO-1 System was installed at CGS. Fully integrated in the worldwide network, SAO-1 has been in continuous operation from 1983 up to 2000, providing high precision ranging observations of several satellites. The new Matera Laser Ranging Observatory (MLRO), the most advanced Satellite and Lunar Laser Ranging facility in the world, has been installed in 2002 and has replaced the old SLR system. CGS hosted also 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 radiotelescope. Since then, Matera performed 656 sessions up to December 2005.

In 1991 we started GPS activities, participating in the GIG 91 experiment installing in 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 WWW server GeoDAF (<http://geodaf.mt.asi.it>).

Thanks to the co-location of all precise positioning space based techniques (VLBI, SLR, LLR and GPS), 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 in remote sensing activities for present and future missions (ERS-1, ERS-2, X-SAR/SIR-C, SRTM, ENVISAT).

## 2. Technical/Scientific Overview

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

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.

The control computer is a SWT Pentium/233 PC running Linux and FS version 9.7.7.

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 2 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 Matera VLBI station is provided in Table 2.

Table 2. Matera VLBI staff members

Name	Agency	Activity	E-Mail
Ing. Luciano Garramone	ASI	VLBI Manager	luciano.garramone@asi.it
Domenico Del Rosso	Telespazio	Operations Manager	domenico_delrosso@telespazio.it
Giuseppe Colucci	Telespazio	VLBI contact	giuseppe_colucci@telespazio.it



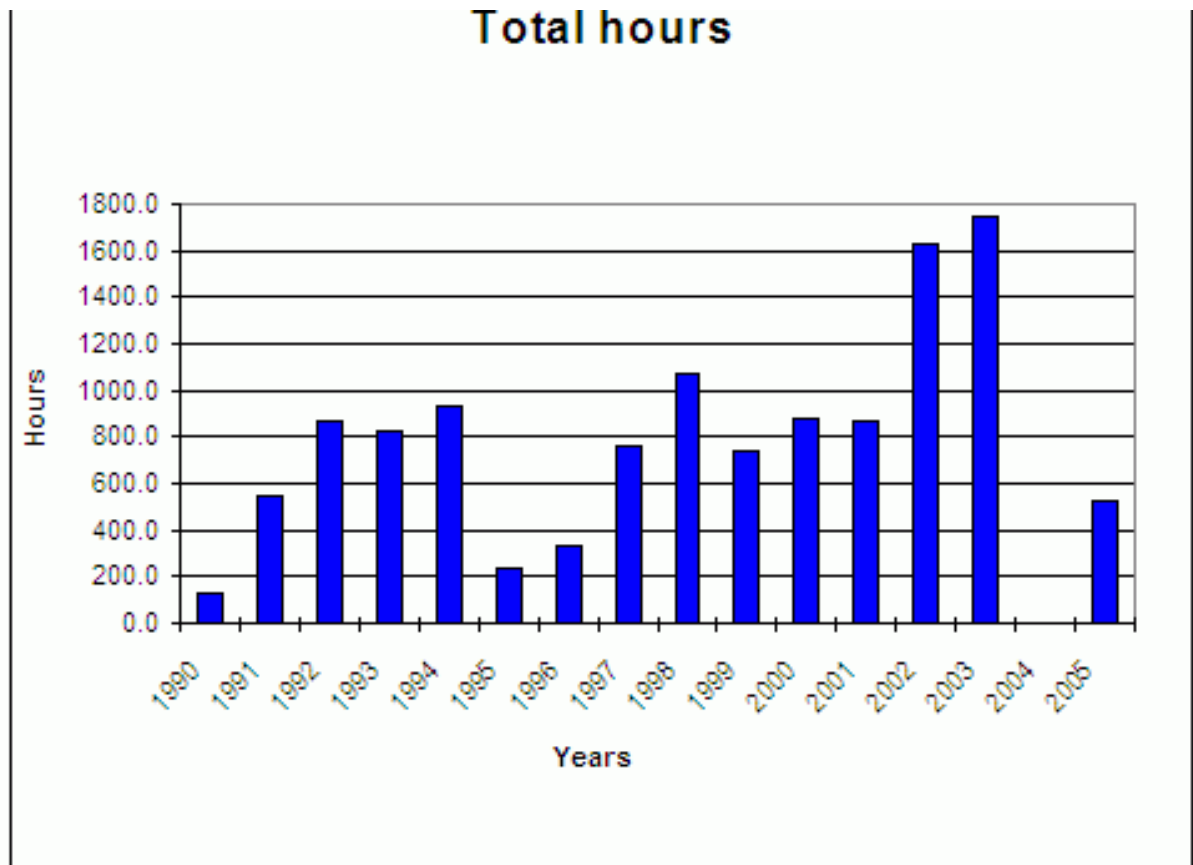


Figure 2. Yearly Acquisitions Summary

#### 4. Status

After rail repair, operations restarted in July 2005. Till December 2005, 22 sessions were acquired. Fig. 2 shows the total Yearly Acquisitions Summary.

In May 2004, even though the station was not operating, a major upgrade was performed on the system. The new Mark 5 Recorder was installed and 7 memory modules (8x200 GB each) were bought to be included in the IVS pool.

In 2004, in order to fix all the rail problems, a complete rail replacement was planned. In 2005, due to financial difficulties, it was instead decided to rebuild concrete under the existing rail only. After concrete rebuilding, an epoxy resin (Epojet LV MAPEI) was injected under each plate supporting the rail. Before and after these works, several measurement sets were performed to verify circularity and planarity of the rail and to monitor the rail movements. Particularly, the rail movements were measured while an antenna wheel was running on top of the measuring point as showed in Fig. 3. Fig. 4 shows the vertical movements measure of before and after the repair work. Detailed measurements (horizontal movements and measures made on different plates) are described in Ref.[2]. The conclusions are good; the main rail problem seems to be fixed. Only marginal movements were noted and they are due to non-perfect status of the rail itself. The

option to replace the rail with a new shape one is still valid.

Before restarting operations, other activities, including RFI measurements, were carried out in order to have a complete check-up of the system. Details are described in [3] and [4].



Figure 3. Rail measurement

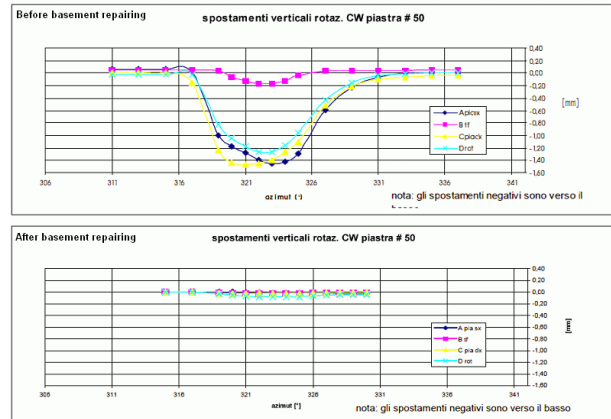


Figure 4. Rail measurement results

## 5. Outlook

Operations restarted, but the plan is to continue to work on the rail. The goal is to replace it with a new shape one and to replace the 4 azimuth wheels also.

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## The Medicina Station Status Report

*Alessandro Orfei, Andrea Orlati, Giuseppe Maccaferri, Pierguido Sarti, Monia Negusini,  
Franco Mantovani*

### Abstract

General information about the Medicina Radio Astronomy Station, the 32 m antenna status and the staff in charge for VLBI observations, are provided. In 2005 the data from geodetic VLBI observations were acquired using the Mark 5A recording system with good results. An intense activity of local terrestrial measurements was performed and is 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 about 33 km East of Bologna. The Consiglio Nazionale delle Ricerche was the funding agency of the Istituto di Radioastronomia till the end of 2004. Since January 1st, 2005 the funding agency is the Istituto Nazionale di Astrofisica (INAF).

The antenna, inaugurated in 1983, takes regularly part in IVS observations since 1985. A permanent GPS station, which is part of the IGS network, is installed in the vicinity. The antenna is also an element of the European VLBI Network.

### 2. Antenna description

The Medicina antenna has a Cassegrain optics, consisting of a primary mirror of 32 m in diameter, and a secondary mirror, called subreflector, of convex shape and about 3 m in diameter. The subreflector, mounted on a quadrupode, is placed opposite the primary mirror, and focuses the radio waves at its centre, 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. 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 is flexible in changing the operative receiver: only 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 are taking care of the observations. However, there is a limited number of people that is dedicated to maintain and improve the reliability of the antenna during the observations: Alessandro Orfei is the Chief Engineer, expert in micro-wave receivers; Giuseppe Maccaferri is the Technician in charge of the telescope's backend; Andrea Orlati is the Software Engineer who takes care of the observing schedules and regularly implements SKED&DRUDG and the Field System.



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

During 2005 the Field System version 9.7.7 was installed. The Mark 5A recording system works fine. Almost all observations are made by using hard disks. A total storage capacity of 93TB is available at the station.

##### 4.1. Front-end and Back-end Upgrading

A 7-horn multi-feed receiver is under construction. Almost all parts are available to be integrated in a complete receiver. A dual-feed system for contemporary observations at 305-425MHz and 1.3-1.8GHz is under design, as well as a 5.8-7.8GHz receiver (Figure 2).

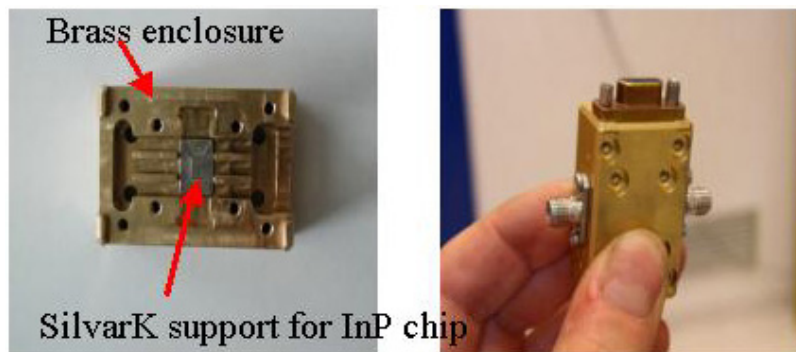


Figure 2. The 9 locations for Cassegrain receivers.

Medicina has completed the capability for changing all receivers in a fast and automatic way. Now up to 9 receivers can be placed in the Cassegrain cabin, each one to be selected for observing by tilting the subreflector (Figure 3). The changing between primary and Cassegrain receivers is accomplished by moving aside the secondary mirror (Figure 4).

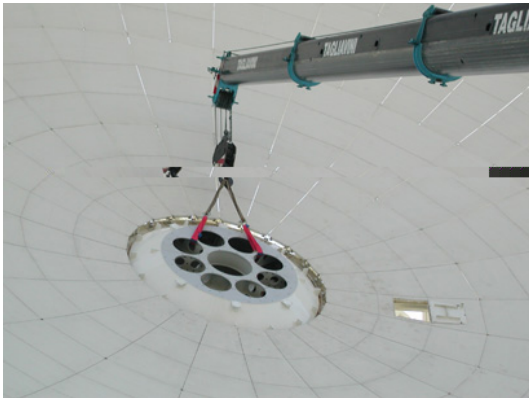


Figure 3. The 9 locations for Cassegrain receivers.



Figure 4. The primary focus receiver box and the subreflector.

## 4.2. Optic Fiber Link

The Institute of Radioastronomy, the Emilia-Romagna Regional Government and GARR (Italian Academic and Research Network) have signed an agreement under which the Regional Government provides a fiber optical link at 1 Gb/s between the Medicina Station and the GARR backbone in Bologna. The connection is now available. In 2006 EVN will perform many tests to routinely transfer observations using this data link.

## 5. Geodetic VLBI Observations

During 2005, the Medicina 32 m dish took part in 25 geodetic VLBI sessions, namely 2 IVS-T2, 8 IVS-R1, 11 IVS-R4 and 4 EUROPE experiments. Some of the above projects were observed by Medicina as substitute for the Matera antenna, which was stopped by failure in the azimuth rail. This was agreed upon after request from the IVS Coordinating Center.

## 6. Local Survey Activities

At Medicina, summer and early fall 2005 have been seasons of intense terrestrial surveying. The four levelling bolts mounted on the ground pillar of the VLBI antenna were surveyed using spirit levelling; similarly, levelling of the bolts installed on the pillars of the local network was performed. This set of measurements was performed in July 2005 as part of the surveying campaign carried out on the wide levelling network of Regione Emilia Romagna. The local ground control network in Medicina has also been surveyed in September 2005 in the context of the fourth local tie performed on the VLBI-GPS eccentricity. On this occasion, the structure of the VLBI radiotelescope was measured using targets on which triangulation and trilateration were performed. Furthermore, the dish was laser scanned at different elevations and this set of measurements was linked to the local network using targets observed by both terrestrial and laser scanning surveys. Similar surveys were performed in September 2005 on the VLBI radiotelescope in Noto, using the same methods and surveying approaches. Data acquired at both observatories are now being processed and should contribute in showing the presence as well as quantifying the magnitude of the possible gravitational deformations that might affect the observations of the two radiotelescopes.

## Noto Station Status Report

*G. Tuccari, G. Nicotra, S. Buttaccio, P. Cassaro, C. Contavalle, P. Leto, L. Nicotra,  
C. Nocita, L. Papaleo, M. Paterno, F. Schilliro*

### Abstract

Noto station was confronted with several important problems in 2005, obliging the antenna to remain non-operative for more than six months. A report is given about the encountered hardware failures and a description of the plan for taking the station back to optimal operative behavior.

### 1. Antenna Drive System Problems

The observative activity was suddenly interrupted in June 2005 during the EVN session, due to a severe failure, that involved several parts in the azimuth axis of the antenna driving system. In particular two Lenze amplifiers and a motor encoder were damaged. Some non-standard spare parts were necessary for the first part of the repair process, including the azimuth motor, whose realization took several months.

At the end of December the repair process was completed with the help of the Vertex company, that furnished the entire driving system in 2002. It was discovered that, due to a firmware bug, the broken parts were not detected as defective by the Antenna Control Unit, producing a failing status of the antenna system.

The long inactivity produced the cancellation of nine geodetic observations, two EVN sessions and numerous single dish programs.

In the first part of January 2006 a program of antenna calibration is under way in order to re-establish the proper pointing and amplitude calibration status. Moreover the mechanical inactivity produced some blocking in the azimuth cable wrap, so that the entire January will even be used to test the mechanical performance.

### 2. Activity Plan

A program is going to be started with a structured organization of the Noto station personnel. This includes the ordinary maintenance, as well as particular operations like the introduction of the wide band receiver, the renewing of the antenna driving software, the implementation of software dedicated to single dish measurements.

The renewal of the antenna driving software is planned in order to take advantage of the different driving modes available for different antenna functionality. So it will be possible to easily implement different scanning functions and dedicated tracking methodologies for the higher frequency observing bands.

As soon as funds will be available the remaking of the grout and azimuth rail will be realized. Better performance are expected in terms of tracking and pointing precision.

### 3. Receivers and Microwave Technology

The new SX receiver will be installed in a three step process in order to minimize the effects on the observing time. The control part will be in operation first, then the parts involving the vertex

room and finally, as soon as all the other parts will be tested and in operation, the actual receiver will be placed in the primary focus. The date of installation is not yet decided.

The 86 GHz receiver in Noto is not yet operative for VLBI and a relative long period of pointing and calibration time is expected. During 2006 time slots are planned for such activity, taking into consideration that due to the closeness of the Noto antenna to the sea, the weather plays a very critical part.

#### 4. Acquisition Terminal and Digital Technology

The Mark 5A recorder is today the standard recording system in Noto. A large number of disk packs has been acquired in 2005, and several more units are planned to be bought in 2006.

The NRTV, a narrow band recording system, is used for RadarVLBI observations, connecting through the standard Internet network more stations with Noto, including Bear Lakes, Simeiz, Evpatoria, Urumqi. The maximum recording bit rate for this system is going to be widely increased with the introduction of a new terminal, called rDBBC, that includes together with the down-conversion functionalities, recording and e-VLBI capabilities.

The DBBC development group, established with EVN support for the realization of a digital base band converter system, was fully operative and a complete prototype has been produced. At the end of 2005 a 64 channel prototype is ready to be used for testing in the radiotelescopes, and the realization of a second system started.

Good performance in conversion and tuning have been measured up to 2.5 GHz with selected AD converters. With an appropriate Nyquist zone pre-selection, L and S band can be directly down-converted and recorded.

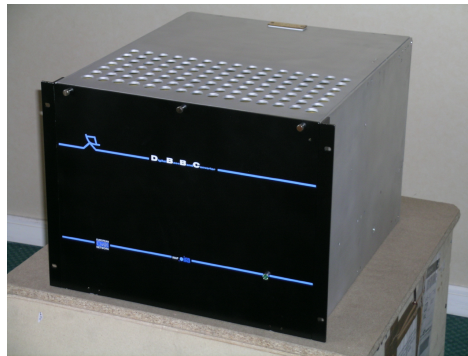


Figure 1. DBBC

#### 5. Geodetic Experiments in Noto during 2005

During 2005 the Noto radiotelescope participated in the following geodetic experiments: CRF31 (JAN 26), T2037 (FEB 2), EURO75 (MAR 23), while other nine experiments have not been observed due to the antenna failure.



# NYAL Ny-Ålesund 20 Metre Antenna

*Helge Digre*

## Abstract

For the year 2005, the 20-meter VLBI antenna at the Geodetic Observatory, Ny-Ålesund has participated in VLBI experiments at the scheduled level. In addition to that, Ny-Ålesund also participated in CONT05. For 2005, there has been one person at the station because of a general reduction in the Norwegian Mapping Authority's budgets. The station is now a Mark 5 station only. Maintenance and repair have been done at a minimum level, given the personnel situation. No errors are corrected during unmanned operation. CONT05 tests were performed with one extra person present, and the CONT05 campaign was done with two extra persons at the station.

## 1. General Information

The Geodetic Observatory of the Norwegian Mapping Authority at 78.9 N and 11.87 W is located in Ny-Ålesund, in Kings Bay at the west side of the island of Spitsbergen, the biggest island in the Svalbard archipelago. In 2005, Ny-Ålesund was scheduled for 87 VLBI experiments within R4, R1, EURO, VLBA/RDV, RD, T2 and ICRF, including the 15 days of the continuous VLBI campaign CONT05. 86 experiments were run during the year. In addition to the 20-meter VLBI antenna, the observatory has two GPS antennas in the IGS system and a Super Conducting Gravimeter is installed on the site. On the site, there is also a CHAMP GPS and a PRARE installation. There is also a SATREF (dGPS) installation at the station.

The Geodetic Observatory of the Norwegian Mapping Authority at 78.9 N and 11.87 W is located in Ny-Ålesund, in Kings Bay at the west side of the island Spitsbergen, the biggest island in the Svalbard archipelago. In 2005, Ny-Ålesund was scheduled for 78 VLBI experiments within R4, R1, EURO, RD, T2 and 15 within CONT05, totally 93 experiments. 93 experiments were run during the year. NMA provided 10 new 2000 GB Mark 5 modules for CONT05. David Holland was on sick leave until the end of his contract in June. The contract was not renewed because of the NMA budget situation. In addition to the 20-meter VLBI antenna, the observatory has two GPS antennas in the IGS system and a Super Conducting Gravimeter in the Global Geodynamics Project (GGP) installed on the site. There is also a CHAMP GPS and a SATREF (dGPS) installation at the station.

## 2. Component Description

The antenna is intended for geodetic use, and is designed for receiving in S- and X- band. The equipment is Mark 5. Station configuration file: [ivscc.gsfc.nasa.gov/pub/config/ns/nyales.config](http://ivscc.gsfc.nasa.gov/pub/config/ns/nyales.config). Ny-Ålesund is located so far north that it has daytime aurora in winter. The location of the antenna enables signal reception over the North Pole. (In 1998, Ny-Ålesund was the only antenna that could receive signals from the Mars Global Surveyor for 24 hours.)

## 3. Staff

Leif Morten Tangen attended the TOW 2005 meeting at MIT Haystack Observatory. David Holland was on sick leave until the end of his contract. The contract was not renewed due to the



Figure 1. Ny-Ålesund 20 meter antenna

Table 1. Staff related to the operation of the VLBI in Ny-Ålesund.

Hønefoss:	Section manager:	Rune I. Hanssen	
	Station responsible, Hønefoss:	Svein Rekkedal	
Ny-Ålesund:	Station commander:	Leif Morten Tangen / Helge Digre	
	Engineer	David Holland	

budget situation. All the experiments are done during the normal working hours of one person, except CONT05, where 2 extra persons participated so 24 hours manned operation was possible.

#### 4. Current Status and Activities

Ny-Ålesund has participated in VLBI experiments at the scheduled level. Ny-Ålesund is a Mark 5A only station. Both the FS and Mark 5 are upgraded to the latest software versions. Two new FS computers have been bought, and they have some final testing to pass before they can be used for experiments. The Super Conducting Gravimeter placed on the same fundament as IGS-GPS NYA1, has been running without problems. The yearly service on the system includes refilling of liquid Helium and was performed by Professor Tadahiro Sato and Dr. Ikeda in the first week of August. The Ministry of Environment funds the Norwegian Mapping Authority (NMA). In 2005, the Norwegian Mapping Authority ran the Geodetic Observatory, Ny-Ålesund on the

same minimum mode as for the 2nd half of 2004. The given reason is the budget situation. The Geodetic Observatory, Ny-Ålesund, has been run as a one man, Mark 5 only, station also for the entire 2005, except for CONT05, when the 24 hour manned operation made it necessary to have 3 persons present. David Holland was on sick leave until his contract ended this summer. The contract was not renewed because of the budget situation.

## **5. Future Plans**

Ny-Ålesund will continue to participate in the experiments the antenna is scheduled for, and will try to do as many experiments as possible, given the personnel situation at the station. Parts of the experiments will continue to go unmanned, due to the personnel situation. NMA plans to hire a second person for Ny-Ålesund in 2006. The new Field System computers will be set in use very early next year. A direct high-speed data link from Ny-Ålesund Geodetic Observatory to Haystack will be tested in January. The high-speed data link will be able to transfer 100 Mbps. The Ny-Ålesund high-speed data-link project is a cooperative effort between the Norwegian Mapping Authority (NMA), UNINETT, NORDUnet, NASA Goddard Space Flight Center and MIT Haystack Observatory. Responsible person at NMA: Rune I. Hanssen. The SCG has to be refilled with liquid Helium each year, and the lift has to be re-certified every year.

# German Antarctic Receiving Station (GARS) O'Higgins

*Wolfgang Schlüter, Christian Plötz, Walter Schwarz, Reiner Wojdziak*

## Abstract

In 2005 the German Antarctic Receiving Station (GARS) in O'Higgins contributed to the IVS observing program with 8 observation sessions. Mark 5 system has been used. Remote Control Software and Hardware has been improved. A new feed ring was mounted to overcome corrosion and to keep the feed system operational. A new power generator was installed in 2004 to support the station with sufficient power all over the year. Unfortunately the electronic control system failed and the station was not powered during a period from August 23 to September 22, 2005.

## 1. General Information

The German Antarctic Receiving Station (GARS) is jointly operated by the Federal Agency of Cartography and Geodesy (BKG), the German Aerospace Center (DLR) and the Institute for Antarctic Research Chile (INACH). The 9m Radiotelescope at O'Higgins is used for geodetic VLBI and for Remote Sensing. The access to the station is organized campaign-wise during the Antarctic spring and summer. In 2005 the station was occupied from January to March and from October to December. DLR and BKG jointly send engineers and operators for the campaigns together with a team which maintains the infrastructure such as the provision of power etc. Special flights with "Hercules"-aircrafts and small TwinOtters-aircrafts were organized by INACH in close collaboration with the Chilean Army, Navy and Airforce in order to transport the staff, the technical material and also the food for the entire campaign from Punta Arenas via Island Frey to the station O'Higgins on the Antarctic Peninsula. Sometimes the staff and material travelled by ship to O'Higgins. Conditions and time schedule are unpredictable and require a lot of security precautions. Arrival time and departure time is strongly dependent on the weather conditions and the general logistic.

After the long Antarctic winter usually the equipment at the station has to be initialized, damages, which result from the strong winter period, have to be identified and repaired. Shipment of spare parts or material for upgrades from Germany needs careful preparation in advance, nevertheless the arrival of material at O'Higgins is often delayed.

In co-location with the 9m Radiotelescope for VLBI

- two GPS receivers are operated in the frame of IGS all over the year, an Alan Osborn ACT (OHI2), which has a long and stable history and a JAVAD receiver (OHI3) for GPS and GLONASS tracking.
- a tide gauge is installed, which has been operating for several years with some interruptions caused by destroyed cables from the scratching ice on the rocks,
- a meteorological station providing pressure, temperature and humidity and wind information, as long as the extreme conditions outside did not disturb the sensors,
- a H-Maser, a Atomic Cs-clock, a GPS time receiver and a Total Accurate Clock (TAC) are employed for the provision of the time and frequency.

The 9m Radiotelescope has a dual purpose: perform geodetic VLBI and receive the remote sensing data from ERS 2, JERS and ENVISAT. Different antenna tracking modes and different receivers have to be activated depending on the application.



Figure 1. GARS O'Higgins Radioteleskop

## 2. Technical Staff

The staff members for operating, maintaining and improving the GARS VLBI component and the geodetic devices are summarized in Table 1.

Table 1. Staff – members

Name	Affiliation	Function	Working for
Christian Plötz	BKG/FESG	electronic engineer	O'Higgins (responsible), RTW
Walter Schwarz	BKG	electronic engineer	RTW, O'Higgins
Reiner Wojdiak	BKG	software engineer	O'Higgins, IVS Data Center Leipzig

## 3. Observations in 2005

During the Antarctic summer campaign (January-March 2005) and during the Antarctic spring campaign (October-December 2005) GARS participated in the following sessions of the IVS observing program:

- 4 sessions during the period January - February (OHIG36, T2037, OHIG37, OHIG38)
- 4 sessions during the period October- December (OHIG39, OHIG40, OHIG41, T2041)

All observations were recorded on disks with Mark 5A. The data were shipped from O'Higgins to Punta Arenas with the earliest possibility after they were recorded. From Punta Arenas, the disks were shipped by regular air transportation to the correlator.

#### **4. Maintenance**

The extreme conditions in the Antarctic require special maintenance and repair of the GARS telescope and of the infrastructure. The effect of corrosion, problems with connectors and capacitors need to be detected; the H-Maser has to set up into operation mode as soon as the operators arrive. The antenna, S/X-band receiver and the data acquisition system have to be activated properly. Those components which were damaged during the previous campaign usually were replaced. In particular the damage of the control electronics of the power generator was fixed. Some work was done to maintain the containers, such as the installation of a new roof and new windows, and also the extension of the air conditioning system.

#### **5. Technical Improvements**

A special ring, which holds the foil in front of the feed, was replaced during the first campaign in 2005 due to strong corrosion. In addition the foil was replaced by a special teflon foil, which is extremely stable and needs no extra shielding during the unmanned winter period. In 2005 the Antenna Control Unit (ACU), was replaced by a completely new system built by VERTEX. This will lead to improved and undisturbed operation of the antenna in satellite mode as well as in VLBI mode.

#### **6. Upgrade Plans for 2006**

During 2006 it is planned to expand the observing capabilities in particular by extending the period of observations by employing the remote control facilities and to increase the Internet capabilities at least by a factor of two (256kbps). The upgrade to Mark 5B is planned for 2006.

# The IVS Network Station Onsala Space Observatory

*Rüdiger Haas, Gunnar Elgered*

## Abstract

This report shortly summarizes the status of the Onsala Space Observatory in its function as an IVS Network Station. We describe the activities during the year 2005, the current status, and future plans.

## 1. Staff Associated with the IVS Network Station at Onsala

The staff associated with the IVS Network Station at Onsala remained mainly the same as reported in the IVS Annual Report 2004 [1]. At the end of November 2005 Prof. Roy Booth retired from the position as director of the observatory and in December 2005 Prof. Hans Olofsson took over this position.

Table 1. Staff associated with the IVS Network Station at Onsala. The complete telephone numbers start with the prefix +46-31-772.

Function	Name	e-mail	telephone
Responsible P.I.s	Rüdiger Haas	haas@oso.chalmers.se	5530
	Gunnar Elgered	kge@oso.chalmers.se	5565
Observatory director	Roy Booth (until 2005.11.30)	roy@oso.chalmers.se	5520
	Hans Olofsson (since 2005.12.01)	hans.olofsson@chalmers.se	5520
Ph.D. students and Postdoc involved in VLBI observation	Sten Bergstrand	sten@oso.chalmers.se	5566
	Camilla Granström	camilla@oso.chalmers.se	5566
	Martin Lidberg	lidberg@oso.chalmers.se	5578
	Tobias Nilsson	tobias@oso.chalmers.se	5575
Field system responsables	Borys Stoew (until 2005.05.31)	boris@oso.chalmers.se	5575
	Biörn Nilsson	biorn@oso.chalmers.se	5557
	Michael Lindqvist	michael@oso.chalmers.se	5508
VLBI equipment responsables	Karl-Åke Johansson	kaj@oso.chalmers.se	5571
	Leif Helldner	helldner@oso.chalmers.se	5576
VLBI operator	Roger Hammargren	roger@oso.chalmers.se	5551
Telescope scientists	Per Bergman (until 2005.03.31)	bergman@oso.chalmers.se	5552
	Lars EB Johansson (since 2005.04.01)	leb@oso.chalmers.se	5564
	Lars Lundahl	lundahl@oso.chalmers.se	5559

## 2. Geodetic VLBI Observations During 2005

In 2005 the observatory was involved in the five VLBI-experiment series EUROPE, R1, T2, RDV, and RD05. Furthermore, we participated in the CONT05 campaign and three e-Intensive experiments with Tsukuba. In total, Onsala participated in 42 geodetic VLBI experiments during 2005 (see Table 2). Only the first RDV experiment was still recorded on tapes, all other experiments were recorded on Mark 5 disc modules or the data were transferred via optical fibre.

Table 2. Geodetic VLBI experiments at the Onsala Space Observatory during 2005.

Exper.	Date	Remarks (problems)	Exper.	Date	Remarks (problems)
RD05-01	01.19	o.k.	C05.01	09.12	o.k. 1 scan lost
RD05-02	02.08	o.k., some scans lost	C05.02	09.13	o.k., encoder problems
RDV-49	02.09	o.k., tape recording	C05.03	09.14	o.k., encoder problems
EURO-75	03.22	o.k.	C05.04	09.15	o.k.
RD05-03	03.30	o.k., at start warm RX	C05.05	09.16	o.k., encoder problems
T2-038	04.05	o.k.	C05.06	09.17	o.k., encoder problems
RD05.04	04.06	o.k., encoder problems	C05.07	09.18	o.k.
R1-170	04.11	o.k., encoder problems	C05.08	09.19	o.k., encoder problems
R1-174	05.09	o.k.	C05.09	09.20	o.k., encoder problems
R1-176	05.23	o.k., encoder problems	C05.10	09.21	o.k.
R1-177	05.31	o.k., encoder problems	C05.11	09.22	o.k., encoder problems
RD05-06	06.21	o.k., encoder problems	C05.12	09.23	o.k., encoder problems
T2-039	06.28	o.k.	C05.13	09.24	o.k., encoder problems
EURO-76	07.04	o.k., encoder problems	C05.14	09.25	o.k.
K05.197	07.10	o.k., warm RX, eVLBI	C05.15	09.26	o.k.
RD05.07	07.12	o.k., RX cooling problem	RDV-53	09.28	no correlation report yet
K05.205	07.24	o.k., warm RX, eVLBI	R1-198	11.14	o.k.
RD05.08	08.17	no correlation report yet	RD05.09	11.15	no correlation report yet
K05.240	08.28	o.k.	RD05.10	12.07	no correlation report yet
EURO-77	09.05	o.k.	EURO-78	12.13	o.k.
R1-191	09.06	o.k., encoder problems	RDV-54	12.14	no correlation report yet

The previously reported problems with the azimuth encoders [1] continued unfortunately also during 2005. During most experiments between 1-15 scans were lost, see Table 2. In order to solve this problem, we started to build a completely new antenna control system that is going to replace the old one during the year 2006. In the summer of 2005 we experienced some problems with the receiver cooling system. A disturbing factor in 2005 was again radio interference in S-band, due to UMTS mobile telephone signals.

### 3. Geodetic eVLBI Activities During 2005

Already since 2003 the Onsala Space Observatory is connected to the Swedish Internet backbone via a 1 Gb/s optical fibre link [2]. This allowed to participate in three Sunday e-Intensive experiments with Tsukuba during the summer of 2005. Data were recorded on Mark 5 modules and transferred after the experiments with fast-ftp to the Tsukuba correlator.

In September 2005, we installed Coarse Wavelength Division Multiplexer (CWDM) equipment at the observatory and at Chalmers. This allows to share the optical fiber link between the Mark 5 unit and the rest of the observatory with different wavelengths, different MTU buffer sizes, and different data rates. The installation of this equipment made it possible to successfully participate in the real-time eVLBI demonstrations iGRID in San Diego and SC05 in Seattle in September and November, respectively. In both demonstrations transatlantic real-time eVLBI fringes with a data rate of 512 Mbps were achieved, sending data from Onsala, Westford and Goddard to the correlator at Haystack. Figure 1 shows the network constellation between the Onsala Space Observatory and



the Swedish University Net (SUNET) after the installation of the CWDM equipment in September 2005. Table 3 lists the geodetic eVLBI activities in 2005.

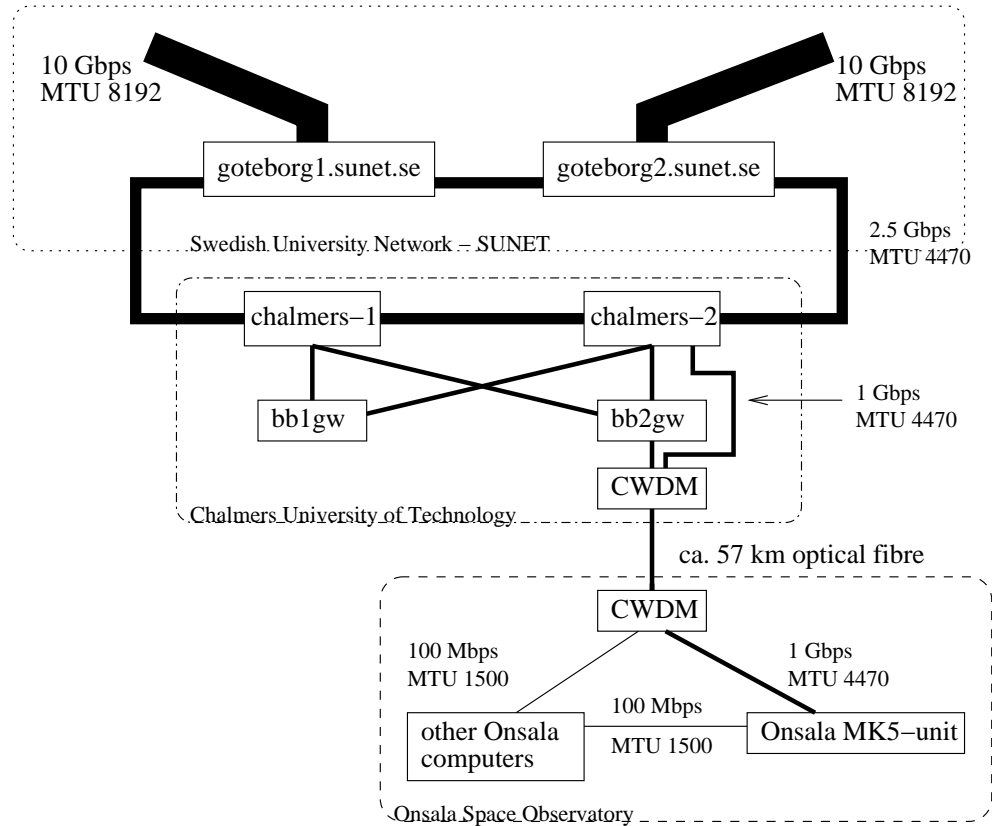


Figure 1. Network configuration between the Onsala Space Observatory and the Swedish University Network (SUNET) after the installation of the CWDM equipment in September 2005.

Table 3. Geodetic eVLBI activities at the Onsala Space Observatory during 2005.

July 10/24, August 28	e-Intensives with Tsukuba
September 29	Real-time demonstration experiment at the iGRID 2005 conference, successful real-time fringes at 512 Mbps Onsala–Westford–Goddard [4]
November 16	Real-time demonstration experiment at the SuperComputing 2005 conference, successful real-time correlation at 512 Mbps Onsala–Westford–Goddard, 512 Mbps real-time fringes for several hours

#### 4. Monitoring Activities

We continued also in 2005 to monitor the vertical height changes of the telescope tower by the invar monitoring system [2], [3], and the campaign based GPS measurements using an antenna mounted on top of the VLBI telescope.

The calibration campaign for the Onsala pressure sensor was continued [2]. Figure 2 shows the difference between the Onsala barometer (Setra Systems) and a Vaisala instrument — borrowed from the Swedish Meteorological and Hydrological Institute (SMHI) — which is calibrated yearly at the SMHI headquarters. A clear annual variation with amplitude of about 0.25 hPa is seen, which we suspect is related to temperature influences on one or both pressure sensors.

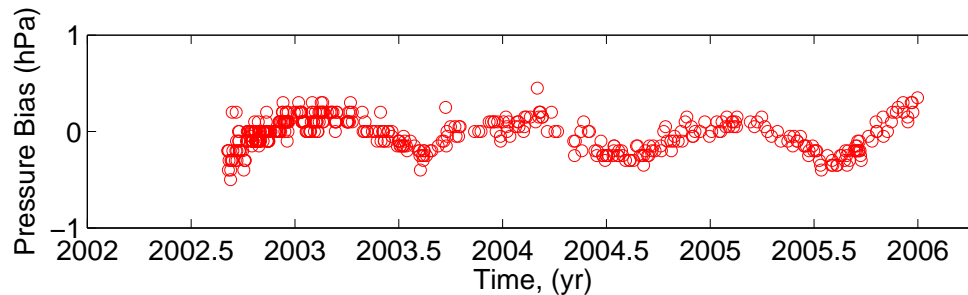


Figure 2. Pressure difference between Setra Systems and Vaisala barometers.

A microwave radiometer is operated continuously at the observatory to monitor the atmospheric water vapor content.

The observatory hosts a gravimeter platform, which is used for repeated absolute gravity measurements since several years. During 2005 a German and a Norwegian team visited the observatory to perform simultaneous observations with absolute gravimeters.

## 5. Outlook and Future Plans

The Onsala Space Observatory will continue to be an IVS Network Station and to participate in the IVS observation series. For the year 2006 a total of 26 experiments in the series EUROPE, R1, T2, RDV, and RD06 are planned. During 2006 we will install a new antenna control system that hopefully will solve the azimuth encoder problems that we suffered from during the last years. We envisage an active participation in further real-time eVLBI experiments during 2006. We will continue to monitor the relevant VLBI system parameters to be able to detect possible error sources as early as possible and to achieve and maintain high quality of the observational data. This monitoring activity includes the stability of the telescope, the local tie, the pressure sensor calibration and the operation of a microwave radiometer.

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- [4] [http://www.interactions.org/sgtw/2005/1019/evlbi\\_igrid\\_more.html](http://www.interactions.org/sgtw/2005/1019/evlbi_igrid_more.html)

# Sheshan VLBI Station Report for 2005

*Tao An, Xiaoyu Hong, Qingyuan Fan, Wenren Wei, Xinyong Huang*

## Abstract

The Sheshan VLBI Station (also known as SESHAN25 in geodetic community), operated by the Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS), is situated in a western suburb of Shanghai. It is a member of IVS, EVN and APT. The present report summarizes various activities on observations and equipment development at the Sheshan VLBI Station during 2005. Observing sessions in 2005 consisted of 44 VLBI sessions organized by the IVS, EVN, APT as well as the Eastern Asia VLBI Network (EAN). The antenna control system was updated in July 2005. A new L-band cryogenic receiver with dual circular polarizations which was developed at ASTRON in Dwingeloo, the Netherlands, was taken in operation in October 2005. The main reflector was re-adjusted in November 2005 using microwave holography. A new S/X feed was installed in December 2005. Optical fiber linking the Sheshan station and the host institute (SHAO) will be available in the first half of 2006.

## 1. General Information

The Sheshan VLBI Station (also called SESHAN25 in Geodetic community) is located at Sheshan, 30 km west of Shanghai. An antenna with a diameter of 25 meter is in operation. The telescope has been in full operation since 1987. It is one of the major astronomical facilities of the Chinese National Astronomical Observatories. The Sheshan VLBI Station is a member of the IVS, EVN and APT. There is a correlator center and an analysis center of IERS of various geodetic observations in the host institute (SHAO).



Figure 1. Overview of Sheshan 25m Radio telescope.

## 2. Brief description of Sheshan Station Facilities

- owner and operating agency : Shanghai Astronomical Observatory (SHAO)

- year of construction (or running) : 1987
- diameter of main reflector  $d$  : 25 m
- Longitude and Latitude of station site :  $121^{\circ}11'58''$  E,  $31^{\circ}05'57''$  N
- Elevation of radio telescope : 5 m above sea level
- Antenna type : Cassegrain beam wave-guide
- Seat-rack type : Azimuth-pitching ring
- Surface accuracy<sup>a</sup> : 0.52 mm (rms)
- Azimuth slewing speed<sup>b</sup> : 1 deg/sec
- Azimuth slewing range<sup>b</sup> :  $-78^{\circ}, 430^{\circ}$
- Elevation slewing speed<sup>b</sup> : 0.6 deg/sec
- Elevation slewing range<sup>b</sup> :  $5^{\circ}, 88.5^{\circ}$
- VLBI rack type : VLBA4
- FS version : 9.7.7
- Time standard : H-maser MHM-2010

<sup>a</sup>: after panel readjustment in November 2005;

<sup>b</sup>: after antenna control system update in July 2005;

### 3. Technical Staff of the Sheshan VLBI Station

Table 1 lists the Sheshan VLBI Station staff who are involved in VLBI operations and technical developments. A senior engineer Quanbao Ling joined the VLBI group in September 2005; he is devoted to the development and maintenance of the VLBI terminal system. Hong Yu became a post-doctoral fellow in early 2005; he is majoring at antenna control system. Two young engineers, Bo Xia and Wei Gou, have been working on day-to-day operations of the antenna since September 2005. Microwave engineer Songlin Chen will leave the group in January 2006.

### 4. Development and Maintenance Activities in 2005

Development and maintenance activities at the Sheshan VLBI Station in 2005 are presented in time sequence.

#### 4.1. Update of the Antenna Control System in July

We have updated the antenna control system in July 2005. The new control system is more flexible than the old one. It slews faster than before and is expected to minimize observing problems due to antenna tracking. The new system has been working in a good condition since October 2005. A general description of the new control system is given in Section 2.

Table 1. Staff working at the Sheshan VLBI Station

Name	Background	Position & Duty	Contact
Xiaoyu Hong	astrophysics	Head of station, Professor	xhong@shao.ac.cn
Qingyuan Fan	ant. control	Chief Engineer, Professor	qyfan@shao.ac.cn
Wenren Wei	electronics	Professor	wwr@shao.ac.cn
Shiguang Liang	microwave	Professor	sgliang@shao.ac.cn
Zhuhe Xue	software	Professor	zhxue@shao.ac.cn
Xinyong Huang	microwave	Senior Engineer	xhuang@shao.ac.cn
Quanbao Ling	electronics	Senior Engineer	qling@shao.ac.cn
Tao An	astrophysics	VLBI friend	antao@shao.ac.cn
Songlin Chen	microwave	Engineer	slchen@shao.ac.cn
Bin Li	microwave	Engineer	bing@shao.ac.cn
Weihua Wang	astrophysics	Assistant Researcher	whwang@shao.ac.cn
Jinqing Wang	electronics	Engineer	jqwang@shao.ac.cn
Huihua Li	electronics	Engineer	hhlee@shao.ac.cn
Lingling Wang	software	Engineer	llwang@shao.ac.cn
Ruiming Tu	electronics	Engineer	trmshao@shao.ac.cn
Hong Yu	ant. control	Post doctor	yuhong@shao.ac.cn
Bo Xia	electronics	Operator	bxia@shao.ac.cn
Wei Gou	electronics	Operator	gouwei@shao.ac.cn

#### 4.2. Changes in the Recording System (REC) since September

Six BBC's and one IF Distributor at the Sheshan VLBI Station were used for testing a new-built 50 m radio telescope in Beijing in late August 2005. Therefore there are only eight BBCs (BBC01–BBC08) and one IF distributor available at the Sheshan VLBI Station since September 2005. For the sake of geodetic purposes, schedulers of the IVS sessions specially designed BBC patching for the SESHAN25 telescope. A new power supply of Mark 5A (for two disk banks with 250 G) will be installed in spring of 2006.

We kept updating the FS software system with the latest version. The current working version 9.7.7 runs well at the Sheshan VLBI Station. The Mark 5A recording system also worked well in IVS and EVN sessions in 2005. In addition we have bought a spare SWT FS computer for software testing and development.

#### 4.3. Installation of a New, Cryogenically Cooled L-band Receiver in September

A new L-band receiver with cryogenic, dual-circular polarization front-end was designed and developed at ASTRON in Dwingeloo and at the Sheshan VLBI Station. The new L-band receiver was installed at the SESHAN25 telescope in September 2005. It replaced the old receiver and has been playing a full role in the past EVN Oct'05 sessions. Quick responses from the EVN NME experiment at L-band (N05L5) showed that the polarizations of the L-band receiver at the Shanghai Station had been swapped. We adjusted the patching of the LHCP and RHCP starting from session EK022B.

#### 4.4. Adjustment of Antenna Panels in November

After the EVN Oct/Nov05 sessions, we have used microwave holography to determine the overall shape of the dish, making use of a 12 GHz transmitter on a geostationary satellite as a reference signal. This project was carried out from 5th to 18th November 2005 with the help of Mr. Michael Kesteven from Australia.

Before adjustments, the surface accuracy (rms) was about 1.2 mm. Most of the deviation was confined to one quadrant. The amplitude distribution in the aperture plane shown in the holography results was not symmetrical; the sub-reflector has also been deviated from the optical axis (as defined by the outer ring of panels) by 15 mm and was also tilted by several degrees from the optical axis.

The measurement and adjustment activities were completed on 18th November 2005. Based on the holography results, individual panels were adjusted to obtain the best overall surface shape. All evidences showed that the antenna performance after adjustments has been much improved, based on the holography data and the sidelobe patterns. The sub-reflector was centralized; it is only tilted by a small amount now. The magnitude was directed by the holography; it was confirmed by the appearance of fairly symmetric sidelobes. The final surface accuracy (rms) is about 0.52 mm.

#### 4.5. Testing Performance of the New H-maser MHM-2010 in December

A new H-maser (MHM-2010) was first used in July 2004. It has been running well for more than one year. In July 2005 we tested its performance including frequency stability and accuracy. The results indicate that it matches the technical specifications and is working in good conditions.

Table 2. VLBI receivers of SESHAN25 antenna

Band	RF (MHz)	Type	$\eta_A^a$ (%)	SEFD(Jy)	Pol.
18 cm	1600–1740	Cryogenic	40	580 <sup>a</sup>	dual circ. pol.
13 cm	2150–2350	room temp.	25	1792 <sup>b</sup>	right circ. pol.
6 cm	4700–5150	Cryogenic	54	640 <sup>c</sup>	dual circ. pol.
3.6 cm	8200–9000	Cryogenic	46	660 <sup>d</sup>	right circ. pol.
1.3 cm	22100–22600	Cryogenic	~ 20	2185 <sup>e</sup>	dual circ. pol.

Measuring date : <sup>a</sup>: measured on 18 October 2005; <sup>b</sup>: measured on 14 October 2003; <sup>c</sup>: measured on 23 October 2005; <sup>d</sup>: measured in January 2006; <sup>e</sup>: measured on 28 September 2004.

### 5. Future Plan

The Sheshan VLBI Station will take on following actions in 2006 for the purpose of keeping a good working condition.

1. A new S/X band feed was fixed in December 2005. A set of new S/X receivers are in development and will be installed in the first half of 2006. It has a wider working frequency range compared with the old one (the currently using one).

2. Fibre link between the Sheshan station and the headquarter (SHAO) is expected to be accomplished in the first half of 2006.

# The IVS Network Station Crimean Astrophysical Observatory: Local Geodetic Network at Simeiz Geodynamics Test Area

*A. Volvach, A. Pushkarev, A. Samoilenko, V. Zaets*

## Abstract

This report gives an overview about the geodetic VLBI activities at the Simeiz station. The positions of the points in the fundamental geodynamics area "Simeiz-Katsively" have been determined by special campaign.

## 1. Observations and Data Analysis

In 2005, we were involved in 11 IVS sessions, but we lost two sessions for LO problems. During last year Simeiz station regularly participated in various radio astronomy programs including the Near Real Time Radar VLBI and single dish observations.

Geodetic VLBI observations at 2 and 8 GHz are used to determine the fine structure of 80 compact extragalactic radio sources. The observations began in 1994 with five-six sessions per year. All ten VLBA antennas together with up to ten additional (geodetic and EVN) radio telescopes participated in the observations. Figure 1 shows image of the radio structure of the source 1308+326 at 2 and 8 GHz.

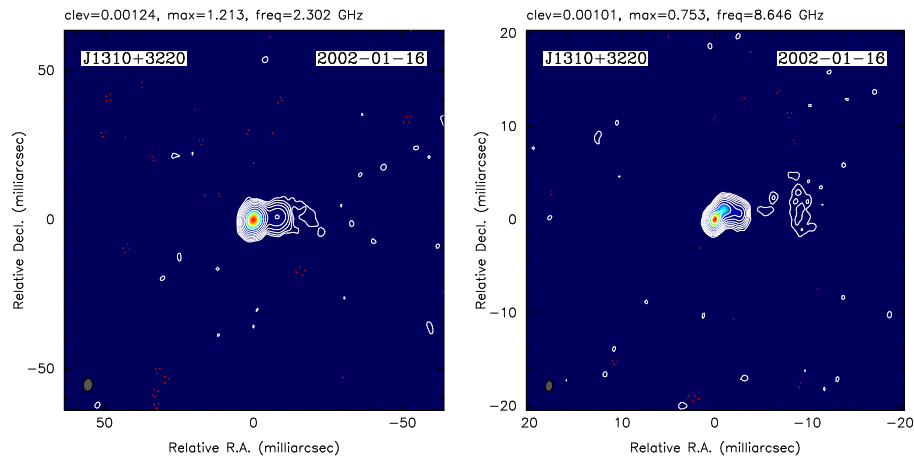


Figure 1. Radio structure of 1308+326 at 2 and 8 GHz.

Figure 2 shows the flux density at 4.8 - 36 GHz. The radio light curves at 36 and 22 GHz were obtained with Simeiz and Metsahovi, and at 14.5, 8.0 and 4.8 GHz at UMRAO.

VLBI imaging of extragalactic sources at frequencies 2 and 8 GHz with integral flux density 4.8 - 36 GHz monitoring are combined. Figure 3 shows the visibility function of 1308+326 for 7 epochs.

The character of the multifrequency flux variations is similar to that predicted by expanding source models; the outburst is unlikely to produce a detectable new cm-VLBI component. In the latter case the multifrequency light curves track each other with no time delays and similar

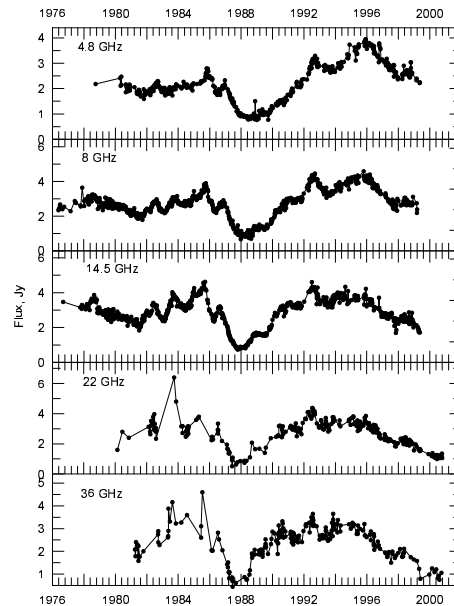


Figure 2. The flux density at 4.8 - 36 GHz.

amplitudes; the outburst is likely to be followed by an ejection of new cm-VLBI component from core.

## 2. The Simeiz Fundamental Geodynamics Area

The Radio Astronomy Laboratory of the Crimean Astrophysical Observatory with its 22-m radio telescope is located near Simeiz 25 km west of Yalta. The Simeiz geodynamics area consists of the radio telescope RT-22, two satellite laser ranging stations, a permanent GPS receiver and a tide gauge. All these components are located within 3 km.

The positions of the points in the Simeiz geodynamics test area have been determined by the special Third GPS Survey Campaign by Main Astronomical Observatory in August 2004. Results are presented in Table 1.

Table 1. Final solution for coordinates of points in the Simeiz area.

Station	X, m	Y, m	Z, m
RT22G	3785230.904	2551207.524	4439796.448
RT22	3785223.388	2551202.451	4439787.574
KATS-SLR	3785944.414	2550780.660	4439461.335
SIMI-SLR	3783902.266	2551405.032	4441257.506
GPS-CRAO	3783897.116	2551404.411	4441264.266

Absolute offsets of reduction points of the radio telescope RT-22 and two satellite laser ranging stations from 1994 to 2004 are given in Table 2.



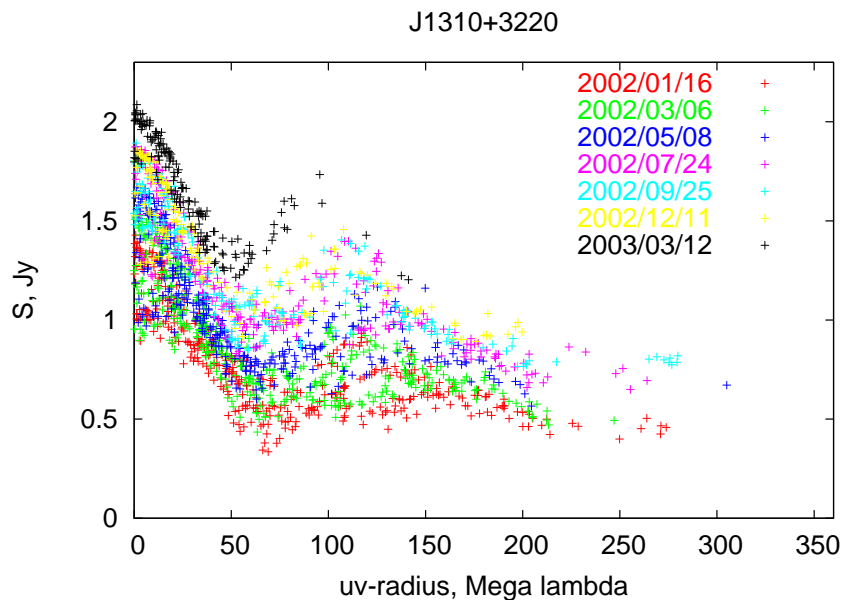


Figure 3. The visibility function for 7 epochs.

Table 2. Offsets for 10 years of the coordinates of points in the Simeiz area.

Station	dX	dY	dZ
RT22G	-0.216	0.126	0.077
KATS-SLR	-0.200	0.137	0.032
SIMI-SLR	-0.230	0.134	0.069



Figure 4. The Simeiz geodynamics area.

### 3. Future Plans

The VLBI activities in 2006 will consist of:

1. carry out modernization of the VLBI equipment (Mark 5 system);
2. creation of the prototype of a system of monitoring of geodynamic phenomena of mountain region of Crimea and geotectonic of the Black Sea basin.

### 4. Acknowledgment

VLBI is possible only as a result of the coordinated efforts of many people. Authors would like to thank I. Srepka and N. Srepka for the maintenance of the receivers at the station, P. Nikitin, A. Shevchenko, I. Denisov and P.Koseko for their efforts in observations as well as the personnel of other VLBI stations and correlators.

This work has been partly supported by INTAS Infrastructure grant "INTAS IA 03-59-11".

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# Svetloe Radio Astronomical Observatory

*Sergey Smolentsev, Ismail Rachimov*

## Abstract

This report provides information about changes in the Svetloe Radio Astronomy Observatory (SvRAO) status in period spanning after the last IVS report. The activities during 2005, the current status, and future plans are described. During 2005 a number of maintenance and upgrade activities were performed at SvRAO. An optical fiber line was put into operation.

## 1. Introduction

Svetloe Radio Astronomical Observatory (SvRAO) was founded by the Institute of Applied Astronomy (IAA) as the first station of Russian VLBI network QUASAR. VLBI network QUASAR has been described in [1].

Sponsoring organization of the project is Russian Academy of Sciences. SvRAO is located at the Karelian Neck near Svetloe village about 100 km north from St. Petersburg. The basic instruments of the observatory are 32-m radio telescope RTF-32 and technical systems provided realization of VLBI observations.

During last year Svetloe observatory regularly participated in various radio astronomy programs including VLBI and single dish observations of quasars and planets.



Figure 1. Svetloe Observatory.

## 2. Participation in the IVS Observing Program

Table 1 summarizes the sessions performed during 2005.

Table 1. The list of IVS sessions observed at SvRAO in 2005.

Session	IVS-R4	T2	EUROPE	E3	CONT05	R11	Intensives
Total	26	2	3	11	15	9	14

## 3. Radio Telescope

- Geodetic survey session was done for accurate tie between the radio telescope and SVTL GPS marker. The data is being processed.
- New electrical facilities have been installed: UPS System Galaxy 3000 (20kVA).
- Put into operation remote video control for radiotelescope and facilities control room.

## 4. Outlook

Our plans for coming year are the following.

- Participation in IVS R4, T2, EURO, E3 and RVD observing sessions.
- Upgrade of rail by means of replacement of the concrete under it.
- To participate in domestic VLBI–1,35 sm observations.

## References

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# JARE Syowa Station 11-m Antenna, Antarctica

*Koichiro Doi, Kazuo Shibuya*

## Abstract

The operation of the 11 m S/X-band antenna at Syowa Station (69.0°S, 39.6°E) by the Japanese Antarctic Research Expeditions (JAREs) started in February 1998 and continues till today (January 2006). The number of quasi-regular geodetic VLBI experiments reached 66 at the end of 2005.

We report firstly that Syowa started to participate in the CRF deep-south (CRD) session instead of the SYW session. Secondly, we fully replaced the K4 back-end terminal with a K5 terminal in January 2005 after the final SYW session in December 2004. Data of all OHIG and CRD sessions in 2005 were recorded on hard disks through the K5 terminal.

Syowa Station will participate in six OHIG sessions and two CRD sessions in 2006. The antenna time drastically decreased as receiving activity of remote sensing satellites became very low. We like to increase, with the help of the observing program committee, the OHIG and CRD sessions than those planned in the 2006 year schedule.

## 1. Overview

Syowa Station has become one of the key observatories in the southern hemisphere geodetic network, as reported in [1]. As for VLBI, Syowa antenna is registered 66006S004 as the IERS Domes Number, and 7342 as the CDP Number. Basic configuration of the Syowa VLBI front-end system did not change from the description in [2].

K5 recording system was introduced to Syowa Station in September 2004 and some tests were carried out to confirm normal data recording. Syowa's recording terminal K4 was fully replaced by K5 simultaneously with the termination of SYW session at the end of 2004. The Syowa experiments consist of OHIG session and CRD session now. VLBI data transfer through Intelsat link became possible following the introduction of the K5 system and it can accelerate the correlation process, though the transfer rate from Syowa Station to NIPR is no more than 0.5 - 1 Mbps. We will try to transfer one or two sessions' whole data through the network link in 2006.

## 2. Notes on System Maintenance

There is no significant problem in the "mechanical system". The hydrogen maser set (Anritsu RH401A; 1001C), which was in good condition until 2003 was brought back to Japan for overhaul (H2 ran out). The 1002C was used for the 2004 and 2005 year observations. JARE-48 will install 1001C again at Syowa Station (planned January 2007). The tube in the Cs frequency comparator has to be changed, and the down-converter/local oscillator has to be replaced with a new one in the near future.

## 3. Session Status

Table 1 summarizes status of processing as of January 2006 for the sessions after 2002. The SYW sessions consisted of Syowa (Sy), Hobart (Ho) and HartRAO (Hh). The OHIG sessions involved Fortaleza (Ft), O'Higgins (Oh) and Kokee Park (Kk) with TIGO Concepcion (Tc) from November 2002, together with the 3 SYW antennas. In 2005 Syowa joined the CRD sessions

instead of SYW sessions and participated in six OHIG sessions and two CRD sessions.

Until 2004, OHIG sessions' data on K4 tapes from Syowa Station were copied to Mark IV tapes at GSI and the Mark IV tapes were sent to the Mark IV correlator for final correlation. After introducing the K5 system, K5 hard disk data brought back from Syowa Station were ftp transferred to MIT Haystack Observatory through NICT server and converted to the Mark 5 format data there.

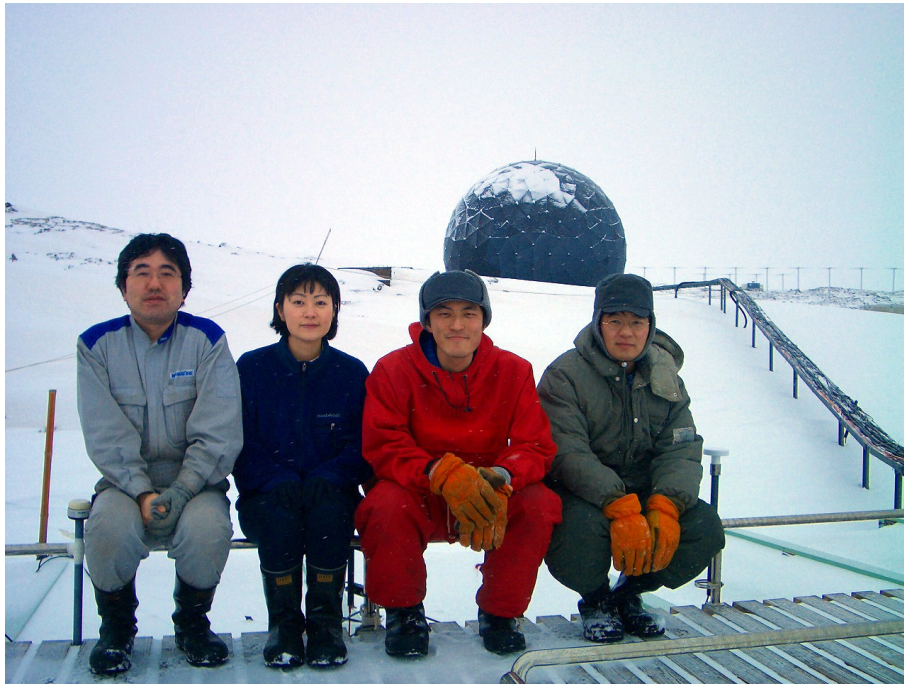


Figure 1. Syowa VLBI staff for JARE-46 (Feb. 2005 - Jan. 2006) in front of the VLBI antenna radome.

#### 4. Staff of the JARE Syowa Station 11-m antenna

- Kazuo Shibuya, Project coordinator at NIPR.
- Koichiro Doi, Liaison officer at NIPR.
- Koichiro Doi (from NIPR), Chief operator for JARE-45 (Feb. 2004 - Jan. 2005).
- Kazuo Fukuhara (from NEC), Antenna engineer for JARE-45.
- Kuniko Egawa (from Japan Hydrographic Association), Chief operator for JARE-46 (Feb. 2005 - Jan. 2006). (second left in Figure 1)
- Isao Okabayashi (from NEC), Antenna engineer for JARE-46. (far left in Figure 1)
- Shin'ya Sakanaka (from Akita University), Operator for JARE-46. (far right in Figure 1)
- Takeshi Uemura (from NIPR), Operator for JARE-46. (second right in Figure 1)

Table 1. Status of SYW and OHIG experiments as of January 2006

Code	Date	Station	Hour	Correlation	Solution	Notes
OHIG19	2002/Feb/11	Ho, Hh, Ft, Oh, Kk	24 h	Yes	Yes	(J43)
SYW022	2002/Apr/29	Ho, Hh	24 h	Yes	Yes	
SYW023	2002/Aug/12	Ho, Hh	24 h	Yes	Yes	
SYW024	2002/Nov/04	Ho, Hh	24 h	Yes	Yes	
OHIG20	2002/Nov/12	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Yes	Yes	
OHIG22	2002/Nov/20	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Yes	Yes	
SYW025	2003/Jan/16	Ho, Hh	24 h	Not yet	Not yet	
OHIG23	2003/Jan/20	Ho, Hh, Ft, Oh, Tc	24 h	Yes	Yes	
SYW026	2003/Apr/10	Ho, Hh	24 h	Yes	Yes	(J44)
SYW027	2003/Aug/06	Ho, Hh	24 h	Yes	Yes	
OHIG27	2003/Nov/19	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Not yet	Not yet	
SYW028	2003/Nov/26	Ho, Hh	24 h	Not yet	Not yet	
OHIG28	2003/Dec/03	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Not yet	Not yet	
SYW029	2004/Jan/07	Ho, Hh	24 h	Yes	Yes	
OHIG29	2004/Feb/10	Ho, Hh, Ft, Oh, Tc	24 h	Yes	Yes	(J45)
SYW030	2004/Apr/07	Ho, Hh	24 h	Yes	Yes	
SYW031	2004/Aug/18	Ho, Hh	24 h	Yes	Yes	
OHIG32	2004/Oct/16	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Not yet	Not yet	
OHIG33	2004/Nov/09	Ho, Ft, Oh, Kk, Tc	24 h	Not yet	Not yet	
OHIG34	2004/Nov/30	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Yes	Yes	
OHIG35	2004/Dec/08	Ho, Hh, Ft, Oh, Kk, Tc	24 h	Not yet	Not yet	
SYW032	2004/Dec/13	Ho, Hh	24 h	Yes	Yes	
OHIG36	2005/Jan/26	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	
OHIG37	2005/Feb/02	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	(J46)
OHIG38	2005/Feb/15	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	
CRDS18	2005/Apr/11	Ho, Hh	24 h	Not yet	Not yet	
CRDS19	2005/May/10	45, Hh	24 h	Not yet	Not yet	
OHIG39	2005/Nov/08	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	
OHIG40	2005/Nov/09	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	
OHIG41	2005/Nov/16	Ho, Hh, Ft, Oh, Kk	24 h	Not yet	Not yet	

(1) 45: DSS45

(J43) JARE-43: op K. Sakura eng M. Abe (J44) JARE-44: op H. Ikeda eng. K. Soeda

(J45) JARE-45: op K. Doi eng K. Fukuhara (J46) JARE-46: op K. Egawa eng I. Okabayashi

## 5. Analysis Results

Until the end of 2005, 42 sessions from May 1999 to November 2004 have been analyzed with the software CALC/SOLVE developed by NASA/GSFC. The data of 6 sessions by JARE-46 (4 OHIG and 2 CRD) are not returned yet.

The length of the Syowa-Hobart baseline is increasing with a rate of  $54.4 \pm 0.9$  mm/yr. The Syowa-HartRAO baseline shows slight increase with a rate of  $11.1 \pm 0.7$  mm/yr. These results

agree approximately with those of GPS. We do not detect obvious change in the Syowa-O'Higgins baseline. Detailed results from the data until the end of 2003 as well as comparisons with the results from other space geodetic techniques are reported in [3].

## References

- [1] Shibuya, K., Doi, K. and Aoki, S. (2003): Ten years' progress of Syowa Station, Antarctica, as a global geodesy network site. *Polar Geoscience*, 16, 29-52.
- [2] Shibuya, K., Doi, K. and Aoki, S. (2002): JARE Syowa Station 11-m Antenna, Antarctica, in *International VLBI Service for Geodesy and Astrometry 2002 Annual Report*, 149-152, NASA/TP-2003-211619, ed. by N.R. Vandenberg and K.D. Baver.
- [3] Fukuzaki, Y., Shibuya, K., Doi, K., Ozawa, T., Nothnagel, A., Jike, T., Iwano, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): Results of the VLBI experiments conducted with Syowa Station, Antarctica. *J. Geod.*, 79, 379-388.



## Geodetic Observatory TIGO in Concepción

*Hayo Hase, Armin Böer, Bernd Sierk, Sergio Sobarzo, Cristobal Jara, Roberto Aedo, Gonzalo Remedi, Carlos Verdugo*

### Abstract

Throughout 2005 TIGO contributed with 118 successful observations, 22 more than in 2004. TIGO participated also in the CONT05 campaign continuously during two weeks. Activities of the VLBI group at TIGO during 2005 and an outlook for 2006 are given.

### 1. General Information

The operation of TIGO is performed by an agreement between Germany and Chile where

- Bundesamt für Kartographie und Geodäsie
- Universidad de Concepción
- Universidad del Bío Bío
- Instituto Geográfico Militar

guarantee their participation until the end of 2007.

TIGO is located near the Universidad de Concepción—500 kilometers to the south of Santiago, Chile's capital—at longitude 73.025 degrees West and latitude 36.843 degrees South.

### 2. Component Description

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

The atomic clock ensemble of TIGO consists of 2 hydrogen masers, 3 cesium clocks and 3 GPS time receivers realizing the Chilean contribution to the Universal Time scale (Circular T, BIPM). A new Septentrio dual-frequency GPS receiver for time-transfers was added in 2005. This receiver is phaselocked to the hydrogen maser used by VLBI operation allowing for new strategies of clock synchronisation.

### 3. Staff

In January 2005 Carlos Verdugo, mechanical engineer, joined the VLBI staff as cryogenics and antenna mechanics expert. Roberto Aedo, Carlos Verdugo and Sergio Sobarzo participated in the 2005 IVS TOW. In 2005 the TIGO-VLBI group consisted of the persons listed in Table 1.



Figure 1. The VLBI radiotelescope in TIGO facility.

Table 1. TIGO-VLBI support staff in 2005.

Staff	Function	Email
Hayo Hase	head	hayo.hase@tigo.cl
Sergio Sobarzo	chief engineer	sergio.sobarzo@tigo.cl
Cristobal Jara	electronic engineer	cristobal.jara@tigo.cl
Roberto Aedo	electronic engineer	roberto.aedo@tigo.cl
Gonzalo Remedi	informatic engineer	gonzalo.remedi@tigo.cl
Carlos Verdugo	mechanical engineer	carlos.verdugo@tigo.cl
any VLBI-operator	on duty	vlbi@tigo.cl
all VLBI-operators		vlbistaff@tigo.cl

#### 4. Current Status and Activities

During 2005 TIGO was scheduled to participate in 130 experiments. Unfortunately we lost 12 experiments mainly due to cryogenics problems when a spare part had to be used and died before we had a spare replacement at hand (see details in Table 2). For the first time TIGO took part in the CONT05 campaign with 15 days of continuous observations.

Throughout 2005 we had not been able to replace our X-band LNA which showed occasionally additional noise in the RF. The available spare part at TIGO was tested in Germany but failed after installation. Finally it was declared broken by the manufacturer. In 2006 we will try to replace it, when a new LNA will be delivered.

The plan to buy a spare dewar for TIGO failed, as no company was able to make an appropriate offer to BKG.

During the CONT05 campaign we suffered from a serious problem with the energy chain of the azimuth part of the radiotelescope. This chain broke and was repaired within 6 hours. The reason for breaking was found in the mechanical use. The chain will be replaced in 2006 when the replacement parts will arrive in Chile.

In 2005 a software for remote VLBI operation was developed. This software runs as a Java applet on any web browser. It can be implemented to become part of the PC-Field System. An example of the applet running in a browser is shown in Figure 2.

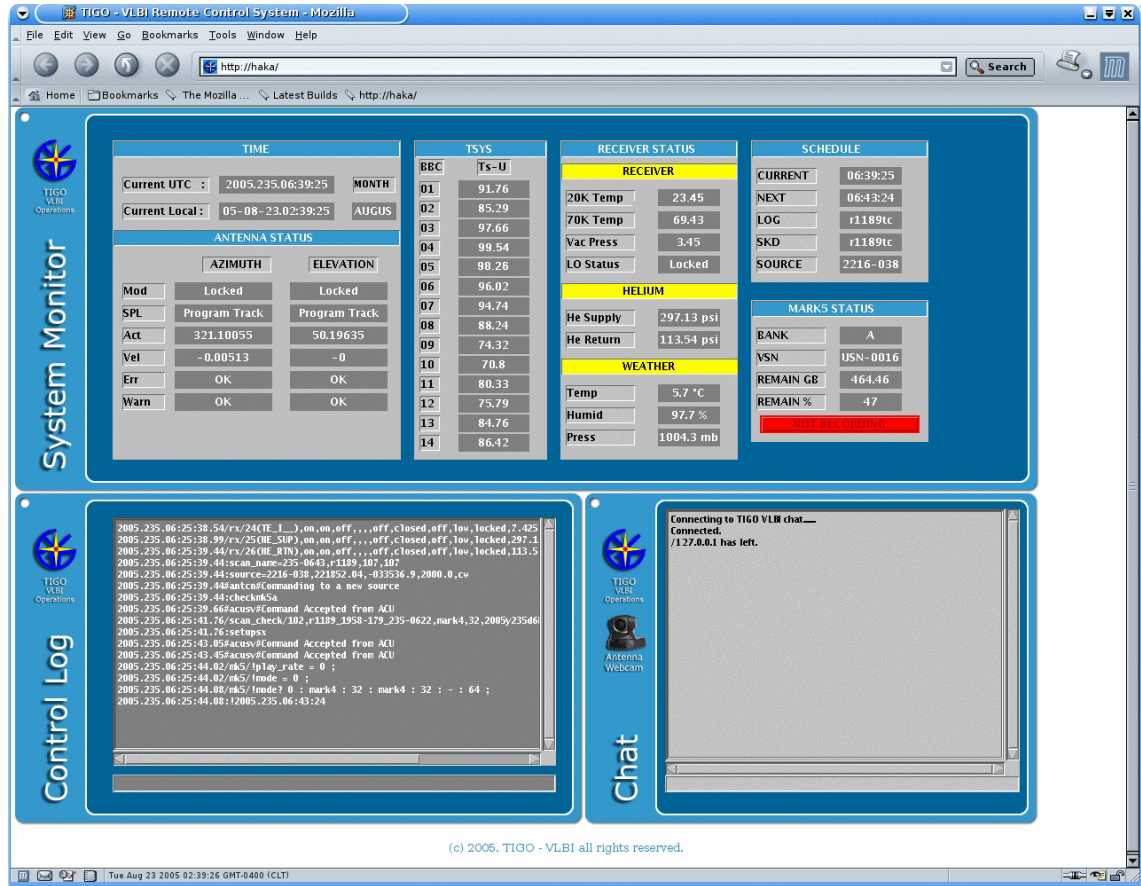


Figure 2. View of the Remote Control applet in a browser.

## 5. Future Plans

The vision VLBI2010 was presented to the Universidad de Concepción with the intention to consider a domestic project on constructing a second radiotelescope. This proposal was taken seriously by the TIGO hosting institution.

The VLBI-activities in 2006 will focus on

- execution of the IVS observation program for 2006,
- investigations on the realization of VLBI2010 in Concepción,

Table 2. TIGO's IVS observation statistics for 2005.

Name	# of exp.	ok	failed
R1xxx	42	37	5
T20xx	6	5	1
E30xx	11	10	1
R4xxx	46	43	3
RDVxx	5	5	-
OHIGxx	5	3	2
C05xx	15	15	-
Total IVS	130	118	12

- investigations related to eVLBI
- fund allocation for eVLBI to get more bandwidth,
- general radiotelescope maintenance including replacement of energy chain and X-LNA,
- experimental satellite trackings,
- repetition of the local survey.

# Tsukuba 32-m VLBI Station

*Junichi Fujisaku, Kensuke Kokado, Kazuhiro Takashima*

## Abstract

This report summarizes the observation activities at the Tsukuba 32-m VLBI station by the Geographical Survey Institute (GSI) VLBI group. In 2005, the station performed a total of 138 domestic/international VLBI sessions including the CONT05 campaign. All of its observations except for the RDV sessions have been performed using the K5 system since mid-May of 2005 and all of international observation data were transferred via the high-capacity global internet.



Figure 1. Tsukuba 32-m VLBI station

## 1. General Information

The Tsukuba 32-m VLBI station (TSUKUB32) is located at GSI in Tsukuba Science City, a core area of public and private scientific research institutes, about 50 km northeast of the capital Tokyo. GSI started VLBI experiments in 1981 with a 5-m mobile station and expanded its activities with a 3.8-m mobile station and the Kashima 26-m station. TSUKUB32 began operation in 1998. This was a turning point, as GSI shifted its aim of experiments from the existing mobile observations to fixed regular ones. TSUKUB32 has been operating as a main dish of GSI with three other permanent VLBI stations (AIRA, SINTOTU3 and CHICHI10) performing geodetic VLBI experiments on a regular basis in a variety of international, domestic and other scientific experiments (Table 3). These four stations, owned and run by GSI, form a network named GARNET. The main purposes of GARNET are to define the framework of Japan and to monitor the plate motions for the advanced study of crustal deformations. For this reason the GARNET stations, centered around TSUKUB32, are placed to surround the Japanese mainland.

## 2. Component Description

The current configuration of TSUKUB32 is shown in Table 1. In 2005, we have made some improvements to our system. The current version of Field System we are using is FS-9.7.7. We

established a semi-automated observation system, based on the K5 system directly recording Linux files with the control utilities from FS9 and checking the raw observation data. This enabled a significant increase in the number of sessions. Additionally we added hot-ejectable Serial ATA disks so that observation data can be shipped to correlator during observation.

Table 1. Configuration of Tsukuba 32m antenna

Site 8-letter code	TSUKUB32	2-letter	Ts
IERS DOMES number	21730S007	CDP number	7345
X band SEFD (Jy)	320	S band SEFD (Jy)	360
X band Tsys (K)	50 (Zenith)	S band Tsys (K)	75 (Zenith)
Az slew 3.0 deg/sec	Range 10.0 - 710.0	El slew 3.0 deg/sec	Range 5.0 - 88.0
S-band w/BPF	2215-2369 MHz	X1-band	7780-8280 MHz
X2-band	8180-8680 MHz	X3-band	8580-8980 MHz

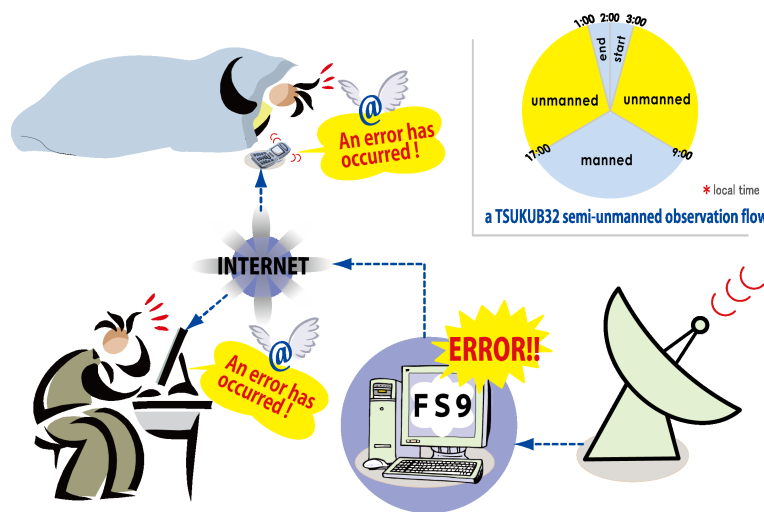


Figure 2. The semi-automated system at TSUKUB32

### 3. Staff

The regular operating staff of the GSI VLBI group are listed in Table 2.

In April 2005, Shinobu Kurihara (Operator) left our group and Kensuke Kokado joined. Shigeru Matsuzaka is a member of the IVS Directing Board (Networks Representative). Yoshihiro Fukuzaki is in charge of the analysis of SYOWA experiments, although he is not a regular member.

Table 2. Staff of the GSI VLBI group

Name	Position	Jobs
Kazuhiro TAKASHIMA	Leader of VLBI group	Management
Morito MACHIDA	Analysis chief	Correlation, Operation
Masayoshi ISHIMOTO	Network chief	Network, e-VLBI, K5, Operation
Junichi FUJISAKU	Operation chief	Experiments coordination, Operation
Kensuke KOKADO	Operator	Analysis, Operation
Daisuke TANIMOTO	Operator	e-VLBI, Field System

#### 4. Current Status and Activities

Table 3 lists all of the regular sessions that TSUKUB32 has performed in 2005. The total number of sessions increased from 108 in 2004 to 138 this year. Details of this increase are as follows: 18 more UT1 sessions with the K4 or the K5 system, 3 more R-sessions and 15 more CONT05 sessions with the K5 system.

Table 3. The regular experiments at Tsukuba 32-m VLBI station in 2005

Experiment	Code	Number
IVS-R	R1158-R1201,	25
IVS-T	T2038,2039,2040,2042	4
CONT05	C0501-C0515	15
VLBA	RDV49,52	2
APSG	APSG16,17	2
JADE	JD0501-0512	12
UT1	K05002-K05352	78
Total		138

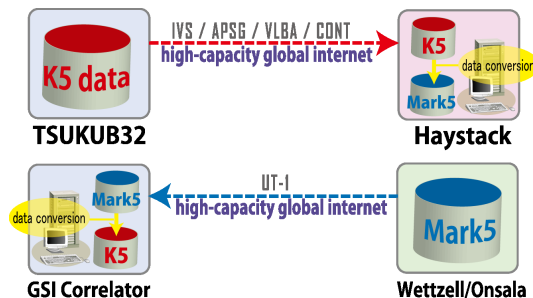


Figure 3. The data transfer in international observations

After trial operations TSUKUB32 went into full-scale operation with the K5 system. In September 2005, TSUKUB32 participated in its first CONT campaign. In CONT05, TSUKUB32 was

the only participant using the K5 system and was quite successful—98.9% data acquisition of all observations. Using Serial ATA disks, we transferred the previous session’s data during the next session via the high-capacity global internet and rapidly completed it within 18 days.

In Intensive series, we had 88 sessions with the TSUKUB32-WETTZELL baseline with the K4 or K5 system and 3 sessions with the TSUKUB32-ONSALA60 baseline with the K5 system. All Intensive sessions with the K5 system have used network data transfer since mid-May of 2005. The Mark 5 data recorded at WETTZELL or ONSALA60 were transferred to the Tsukuba VLBI correlator via internet and were converted to K5 data. The correlator submitted the weekend observation database on Monday. This short latency contributed to the success of the Deep Impact mission, providing the newest UT1 parameter.

All regular international sessions except RDV have been performed using K5 with network data transfer since mid-May. In these sessions, the K5 data recorded at TSUKUB32 were transferred to MIT Haystack Observatory via a large-capacity network and were recorded to Mark 5-diskpack through data conversion. The transfers were managed at Haystack.

All domestic sessions have been performed using K5 system since April. In 2005, as in the previous years, the JADE experiments, while being open to any VLBI stations with the K5 recording system, had several participating stations from outside, including GIFU11 and VERAMZSW. All of the results are available on our website:

<http://vlbdb.gsi.go.jp/sokuchi/vlbi/sess/index.html>.

The optical-connected real-time VLBI observations have been performed in cooperation with universities and research institutes in Japan including the Gifu University and the National Astronomical Observatory of Japan. The data are transferred via a dedicated high-speed optical fiber network (2.4 Gbps) called “Super-SINET”.



Figure 4. K5 sampling/recording system with hot-ejectable Serial ATA disks

## 5. Future Plans

In 2005, TSUKUB32 went to full-scale operation of the K5 system in mid-May, following a trial operation. In 2006, all of domestic/international sessions including all of the IVS sessions will be performed using the K5 system and network data transfer.

## References

- [1] J. Fujisaku, S. Kurihara, K. Takashima: Tsukuba 32m VLBI station, IVS 2004 Annual Report, February 2004



# Nanshan VLBI Station Report for 2005

*Aili Yusup, Na Wang*

## Abstract

The Nanshan 25-meter radio telescope is operated by Urumqi Observatory. This report describes the activities and status of Nanshan VLBI station as an IVS network station in 2005.

## 1. Introduction

The station is located 70 km south of Urumqi, the capital city of Xinjiang Uygur Autonomous Region of China. The station is affiliated to Urumqi Observatory of National Astronomical Observatories, CAS. We contribute to IVS in geodetic VLBI observations. Urumqi also participated in domestic VLBI experiments between Urumqi and Shanghai, and successfully completed several test e-VLBI observations with Shanghai and Kashima, respectively. Urumqi Observatory is willing to continue the collaboration in international e-VLBI activities.

## 2. Telescope Status

### 2.1. Antenna

- Diameter: 25 meter
- Antenna type: Cassegrain beam wave-guide
- Seat-rack type: Azimuth-pitching ring
- Main surface precision: 0.40mm (rms)
- Pointing precision: 15" (rms)
- Rolling range: Azimuth:  $-270^{\circ}$  to  $270^{\circ}$ ; Elevation:  $5^{\circ}$  to  $88^{\circ}$
- Maximum rolling speed: Azimuth:  $1.0^{\circ}/\text{sec}$ ; Elevation:  $0.5^{\circ}/\text{sec}$

The control system of the telescope was upgraded in September 2005. The main surface of the antenna was adjusted and the precision of the main surface is 0.4mm (rms). We also finished painting the whole antenna.

### 2.2. Receiver

The basic specifications of the receivers are given in Table 1. New S/X band cryogenic receivers were installed in November 2005.

### 2.3. Recording System

Mark IV, Mark 5 and Mark II recording systems are available now at Nanshan VLBI station. The performance of the observing system has been improved over the last year. New FS computer is in use at Nanshan and the Field System has been upgraded to version 9.7.7 and it works well.

Table 1. Specifications of receivers

<b>Parameters</b>				<b>Freq. Range</b>
1.3cm	LCP	T <sub>sys</sub> =190K	DPFU=0.057	22100-24000
3.6cm	RCP	T <sub>sys</sub> =110K	DPFU=0.093	8100-8900
6cm	dual	T <sub>sys</sub> =22K	DPFU=0.105	4700-5110
13cm	RCP	T <sub>sys</sub> =75K	DPFU=0.096	2150-2320
18cm	dual	T <sub>sys</sub> =21K	DPFU=0.088	1400-1720
30cm	LCP	T <sub>sys</sub> =160K	DPFU=0.06	800-1200

A data sampling station for weather monitoring purposes was installed in September. The p-cal control system has been updated and the parameters of S/X band receivers are sampled from FS softwares.

#### 2.4. Time and Frequency Sytem

A new time and frequency system was established at Nanshan station. A new Hydrogen Maser MHM2010 has been used since October 2005 and it works well. We also upgraded the GPS time receiver.

### 3. Nanshan VLBI Observations During 2005

Table 2. Geodetic VLBI experiments observed by Urumqi Observatory during 2005.

<b>Experiment</b>	<b>Date</b>	<b>Remarks(problems)</b>
T2037	02.05	ok
T2038	04.05	ok
RDV50	04.27	canceled
APSG16	10.11	No fringes with IF error connect
T2040	10.18	ok
T2041	11.29	ok
APSG17	12.06	ok
T2043	12.20	ok

#### 4. Personnel

Table 3. The main staffs in Nanshan VLBI Station

<b>staff</b>	<b>position</b>	<b>Working area</b>	<b>e-mail</b>
Wang Na	Professor	Station chief	na.wang@ms.xjb.ac.cn
Aili Yusup	Professor	Chief engineer	aliyu@ms.xjb.ac.cn
Sun ZhengWen	Senior engineer	Microwave, Receiver	sunzw@ms.xjb.ac.cn
Liu Xiang	VLBI scientist	VLBI friend	liux@ms.xjb.ac.cn
Chen Maoheng	Senior engineer	Microwave, Receiver	mzchen@ms.xjb.ac.cn
Wang Weixia	Senior engineer	Microwave, Receiver	wangwx@ms.xjb.ac.cn
Shao Minghui	Senior engineer	Time and Freq., Terminal	shaomh@ms.xjb.ac.cn
Yang Wenjun	Engineer	Terminal	yangwj@ms.xjb.ac.cn
Wang Shiqiang	Engineer	Antenna	Wangshq@ms.xjb.ac.cn
Zhang Hua	Engineer	Terminal, Time and Freq.	zhangh@ms.xjb.ac.cn
Li Guanghui	Engineer	Network, Computer	ligh@ms.xjb.ac.cn
Ma Jun	Engineer	Microwave, Receiver	majun@ms.xjb.ac.cn
Chen Chenyu	Engineer	Antenna	chency@ms.xjb.ac.cn

#### 5. Future Plan

A new 1.3-cm dual polarization cryogenic receiver will be built in 2006. A new feed for both 92 cm and 49 cm band is also planned. We will increase to Mark IV VC for additional 1-MHz filter in 2006.

# Westford Antenna

*Mike Poirier*

## Abstract

Technical information is provided about the antenna and VLBI equipment at the Westford site of Haystack Observatory, and about changes to the systems since the 2004 IVS 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.

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 in 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. Primary 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.

Table 1. Location and addresses of 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. <a href="http://www.haystack.mit.edu">http://www.haystack.mit.edu</a>	

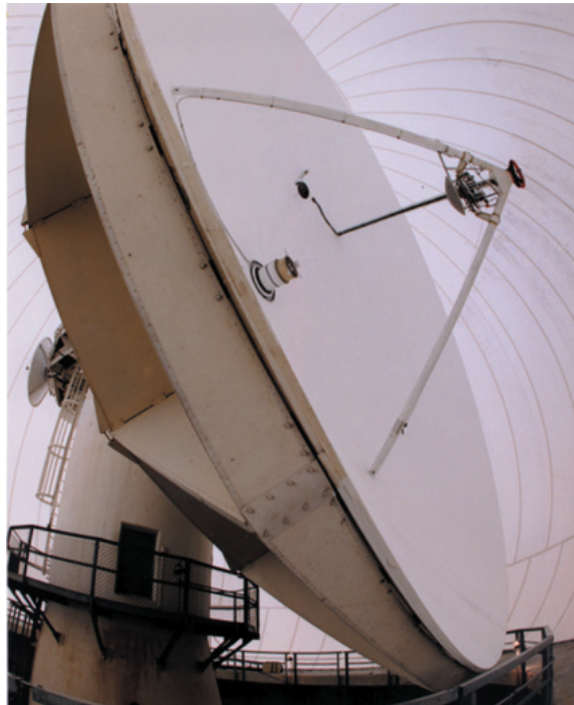


Figure 2. Wide-angle view of Westford antenna inside the radome. The VLBI S/X receiver is located at the prime focus. The subreflector in front of the receiver is installed when observing with the TAL receiver (see Section 4), which is located at the Cassegrain focus.

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 IV tape drive, which is used for recording thin tapes only, a Mark 5A recording system, and a Pentium-class PC running PC Field System version 9.7.7. The primary frequency and time standard is the NR-4 hydrogen maser. A CNS Clock GPS receiver system provides independent timing information and comparisons between GPS and the maser. Westford also hosts the WES2 GPS site of the IGS network. A Dorne-Margolin choking antenna is located on top of a tower ~60 meters from the VLBI antenna, and

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

<i>Parameter</i>	<i>Westford</i>	
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° – 470°	
elevation range	4° – 87°	
azimuth slew speed	3° s <sup>-1</sup>	
elevation slew speed	2° s <sup>-1</sup>	
	<i>X-band system</i>	<i>S-band system</i>
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

a Turbo Rogue receiver acquires the GPS data. A meteorology package provided by the NOAA Forecast Systems Laboratory continually logs meteorological data, which are downloaded daily and are available from the IGS and cignet archives.

### 3. Westford Staff

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

John Ball	pointing system software
Joe Carter	antenna controls
Dave Fields	technician, observer
Brian Corey	VLBI technical support
Glenn Millson	observer
Michael Poirier	site manager
Alan Whitney	site director

### 4. Status of the Westford Antenna

During the period 2005 January 1 - 2005 December 31, Westford participated in 57 24-hour geodetic sessions along with the 15-day CONT05 campaign in September. Westford regularly participated in the IVS-R1, IVS-R&D, and the RD-VLBA series of geodetic sessions, as well as two IVS-T2 sessions and various fringe tests and e-VLBI experiments.

During the last quarter of 2005, Westford did not participate in the IVS-R1 sessions due to

budgetary constraints. During the second half of 2005, we did however revamp and augment several of our operational systems, in order to improve reliability and reduce costs. These changes include:

- The antenna pointing software was modified to improve its robustness in the event of occasional communications problems that previously required manual intervention to restore proper pointing.
- The S/X receiver was mounted in a new frame that will allow improved access for maintenance and repairs. A new power supply package that uses fewer, and more robust, power supplies was also installed in the receiver.
- The unattended operational capability was enhanced through the addition of remote monitoring software and cameras, which together enable personnel to view the status of the equipment and the overall operation.

With these upgrades in place, Westford will be able to rejoin the IVS-R1 network, starting in January 2006.

The Mark 5A is our primary recording system on site. All geodetic sessions are now recorded on the Mark 5A. The Mark IV tape drive has been taken offline.

The only failures in the Westford antenna or VLBI systems this year were: a servo amplifier within the antenna control system, a power supply and a D/A chip within the cavity controller of the maser, and two receiver crossheads.

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. e-VLBI Development at Westford

Westford continues to play a key role in the development of e-VLBI. In 2005, Westford's participation included:

- Testbed for continued high-speed e-VLBI development over both a dedicated 10Gbps link to Haystack Observatory and a 2.5 Gbps link to the rest of the world.
- A real-time e-VLBI demonstration experiment was conducted at the SuperComputing 2005 conference in Seattle where Westford, GGAO and Onsala observatories all transmitted data to the Haystack Mark IV correlator in real-time at 512 Mbps. The correlation results were relayed in real-time for display on the showroom floor in Seattle.
- Westford continues to act as an e-VLBI testbed for the Mark 5B system, which is due for general release in Spring 2006.

## 6. Outlook

We anticipate Westford will be able to participate in the 68 24-hour geodetic sessions along with many e-VLBI experiments.

# Fundamentalstation Wettzell - 20m Radiotelescope

*Richard Kilger*

## Abstract

2005 was a very successful year for the 20m-Radiotelescope in Wettzell/Germany contributing strongly to the IVS observing program. Technical changes, improvements and upgrades have been done to increase the reliability of the entire VLBI observing system.

## 1. General Information

The 20m-Radiotelescope in Wettzell (RTW) was designed in the years 1980-81 as a project of the former "Sonderforschungsbereich 78 Satellitengeodäsie" hosted at the Technical University of Munich. RTW is an essential component of Fundamentalstation Wettzell (FSW) and is jointly operated by Bundesamt für Kartographie und Geodäsie (BKG) and Forschungseinrichtung Satellitengeodäsie (FESG) of Technical University of Munich.

At the Fundamentalstation Wettzell (FSW) the following geodetic space technique systems are operated using the same Time and Frequency system (T&F):

- the laser ranging system WLRs (Wettzell Laser Ranging System) designed for Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) being integrated in ILRS; presently a new laser Satellite Observing System (SOS) is designed to be added to WLRs,
- several GPS receivers, integrated in the global IGS, the European GPS, in the national GPS network and in time transfer experiments,
- a ringlaser "G" dedicated to the monitoring of daily variations of Earth rotation with a relative accuracy of better than  $10^{-8}$  and
- 20m-RTW being integrated into geodetic observing programs within IVS.

The Time and Frequency system (T&F) is established for the generation of timescales (UTC(IfAG)) and for the provision of very precise frequencies needed for VLBI, SLR/LLR and GPS observations, employing Cs-clocks, H-Masers and GPS time receivers. The time scale UTC(IfAG) is published in the monthly Bulletin T of BIPM.

Additional in situ observations were carried out, such as gravity observations with a superconducting gravity meter, earthquake observations with a seismometer, meteorological observations to monitor pressure, temperature and humidity including wind speed, wind direction and rain fall, water vapour observations with radiometer(s) and comparisons of its results with local radio sondes in April 2005 and during CONT05 in September, conventional geodetic control measurements to tie the reference points of the space geodetic systems RTW and SLR to the local terrestrial coordinate system and to investigate the local stability.

## 2. Technical Parameters of RTW

Figure 1 shows the Fundamentalstation Wettzell with the GPS antenna in front, to the left the WLRs, the RTW (center) and to the right the building for the new Satellite Laser Ranging System (SOS\_W) which is currently built at Wettzell to house the highly automated SLR.





Figure 1. Fundamental Station Wettzell

The technical parameters of RTW are shortly summarized below.

Geometry:

- General Concept: “Turning Head”, Cassegrain geometry with coaxial adjusted main- and subreflector,
- Main reflector: mathematical rotational paraboloid with 20m diameter, 314 m<sup>2</sup> orthogonal aperture area and 9 m focal length
- Sub reflector: mathematical rotational hyperboloid with 2.7m diameter

Kinematic Data:

- Azimuth axis (angle of movement 251.5°....831°, velocity  $\pm 3^\circ/\text{sec}$ , acceleration  $\pm 1.5^\circ/\text{sec}^2$ )
- Elevation axis (angle of movement 1°.... 90°, velocity  $\pm 1.5^\circ/\text{sec}$ , acceleration  $\pm 1.5^\circ/\text{sec}^2$ )

Surface Tolerances:

- total error of main reflector  $\pm 0.35$  mm rms
- total error of sub reflector  $\pm 0.02$  mm rms

### 3. Staff

The staff of the Fundamentalstation Wettzell consists in total of 34 members for operating, maintaining and improving all devices and developing new systems. Within the responsibility of the Fundamentalstation Wettzell are also the

- TIGO systems (see station report in this volume), operated in Concepción, Chile jointly with a Chilean partner consortium with 3 experts from Wettzell and
- O’Higgins station (see station report in this volume) in the Antarctic jointly operated with the German Space Center (DLR) and the Institute for Antarctic Research Chile (INACH).

The staff operating RTW are summarized in Table 1.

Table 1. Staff - members of RTW

Name	Affiliation	Function	Working for
Wolfgang Schlüter	BKG	head of the FSW	RTW, TIGO, O'Higgins, T&F,...
Richard Kilger	FESG	group leader RTW	RTW
Erhard Bauernfeind	FESG	mechanical engineer	RTW
Ewald Bielmaier	FESG	technician	RTW
Gerhard Kronschnabl	BKG	electronic engineer	RTW, TIGO and O'Higgins (partly)
Christian Plötz	BKG/FESG	electronic engineer	O'Higgins, RTW (partly)
Raimund Schatz	FESG	software engineer	RTW
Walter Schwarz	BKG	electronic engineer	RTW, O'Higgins and WVR (partly)
Reinhard Zeitlhöfler	FESG	electronic engineer	RTW
Daniel Helmbrecht	FESG/BKG	student	RTW
Christian Hupf	FESG/BKG	student	RTW

#### 4. Observations in 2005

Table 2 shows the scheduled and successfully observed sessions of the year 2005. It was the highest amount of observations ever performed in one year at RTW. Meanwhile RTW is the antenna with by far the most geodetic 24h-sessions in the last 20 years [CRUSTAL DYNAMICS, POLARIS, IRIS, NEOS, CORE, IVS(R1,R4, T2, R&D)].

The same is valid for the daily one hour Intensive sessions to determine  $\Delta$  [UT1-UTC]. INT1 is the Intensive session performed together with Kokee (Hawaii, USA) — formerly done with Greenbank (WV, USA) and Westford (MA, USA)—on weekdays. INT2 is a supplementary East-West-Interferometer to determine  $\Delta$  [UT1-UTC] by RT-Tsukuba and RTW observed on Saturday and Sunday, when INT1 (Kk-RTW) is not observed.

INT1 and INT2 are recorded in Mark 5 on single fixed discs. The recorded data are sent via Internet to the correlator in Tsukuba and now - since beginning of 2006 - to the Washington correlator as well. So Intensives are also progressive projects testing the new techniques to come in the near future.

Table 2. RTW participation in the IVS 24h- and 1h-observing programs

program	number of 24h-sessions
CONT05	15
IVS R1	49
IVS R4	50
IVS T2	6
IVS R&D	10
RDV/VLBA	6
EUROPE	4
MPI/EVN	1
<b>in total</b>	<b>141</b>

program	number of 1h-sessions
INT1	241
INT2	86
<b>in total</b>	<b>327</b>

#### 5. Technical Improvements and Notes

By now all VLBI measurements at RTW are recorded on Mark 5: the last session recorded on magnetic tape was the RDV session RDV53 on September 28, 2005 correlated in Socorro. The

Intensive sessions with Tsukuba (Japan) and Kokee (Hawaii, USA) are recorded on a single disc with 120 Mbyte in a special crate with Mark 5; the data are transferred after the session to the correlators in Tsukuba and Washington via e-VLBI. RTW has a connection with 34 Mbit/sec for this purpose. No physical shipments of disks are carried out for Intensives. Mark 5 recording and e-VLBI have proven to be reliable in practical day-to-day operation.

Reliability of operation was a main issue at RTW in 2005. It was increased, among other things, by implementing a new software in the antenna control unit (ACU). With correctly adjusted azimuth limits (CW- and CCW) the antenna runs now according to the guidelines set by the Field System. One additional advantage is that the antenna no longer runs “long ways” in azimuth and loses one or — worst case — two scans. This is especially important in Intensives sessions that only have about 20 scheduled scans.

Due to a vast quantity of VLBI measurements — 141 24h-session days in 2005 — the DC-motors of the azimuth axis were heavily loaded (and suffered during some R&D sessions. During the summer time R&Ds of up to 800 scans over 24 hours caused the measured temperatures on the outer surface of the azimuth motors and gearings to climb to 70°C!) In September 2005 before CONT05 we got warnings (over-current) for one of our azimuth motors. The collector area of this motor was worn out and the coal contacts caught fire. This azimuth motor has been replaced. Four identical azimuth motors were ordered. It turned out that it is difficult to impossible to adjust the four azimuth motors perfectly, if the motors have — even only small — different electric characteristics. With 4 new azimuth motors as spare RTW can maintain the high operability of the antenna in periods with many observations such as CONT05.

Another place to see the heavy loading are the parallel keys of the motor shafts of the azimuth motors; meanwhile they have to be replaced after one year of operation (Figure 2).

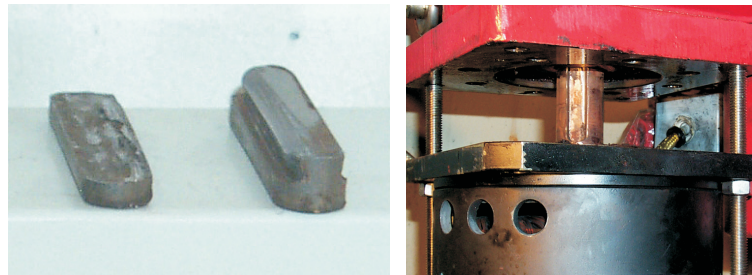


Figure 2. Destroyed keys and motor shafts

## 6. Upgrade Plans for 2006

During 2006 RTW plans to keep up its standard in observing quality and quantity. Some special points will be to upgrade its 34 Mbit/s Internet connection to about 155 Mbit/s, to integrate digital baseband converters (if already available), to start plans for a new VLBI-system/VLBI2010 in Wettzell.

## Observatorio Astronómico Nacional – Yebes

*Francisco Colomer, Pablo de Vicente, María J. Rioja*

### Abstract

This report updates the description of the OAN facilities as an IVS network station. The construction of the new 40-meter radiotelescope is nearly completed. The new S/X receiver will be installed in 2006. The co-location of geodetic techniques available at Yebes, with the VLBI antenna, the GPS receiver (IGS station), and the new installation of a gravimeter, will allow to become a Fundamental Geodetic Station. The institute staff is also involved in technical developments, and scientific research in geodesy, astrometry and astrophysics.



Figure 1. The new 40-m radiotelescope of OAN at Yebes, for geodetic and astronomical VLBI.

### 1. General Information: The OAN Facilities

The Observatorio Astronómico Nacional (OAN) of Spain, which is a department of the Instituto Geográfico Nacional (IGN, Ministerio de Fomento), operates a 14 meter radiotelescope at Yebes (Guadalajara, Spain). This facility has been a network station of the IVS until 2003, and has participated regularly in the geodetic VLBI campaigns to study the tectonic plate motions in Europe, Earth rotation, and pole motion.

The construction of a new 40 meter radiotelescope is nearly completed in Yebes (see Fig. 1). A new S/X receiver will be installed in 2006, in order to resume geodetic VLBI observations. The VLBI equipment has been constantly upgraded (including Mark 5A) and is fully operational.

## 2. OAN Staff Working in VLBI Projects

Table 1 lists the OAN staff who are involved in VLBI studies, some of which can be found at the telescope (CAY) address. The Associated Members of IVS are indicated with an asterisk. The VLBI activities are also supported by other staff like receiver engineers, computer managers, secretaries and students.

Table 1. Staff in the OAN VLBI group (Email: [vlbitech@oan.es](mailto:vlbitech@oan.es)).

Name	Background	Role	Address
Francisco Colomer*	Astronomer	VLBI Project coordinator	OAN
Jean-Francois Desmurs	Astronomer	Scientist (Astrophysics)	OAN
Jesús Gómez-González*	Astronomer	General Subdirector for Astronomy, Geodesy and Geophysics	IGN
Maria Rioja*	Astronomer	Scientist (Astrometry)	OAN
Pablo de Vicente*	Astronomer	VLBI Technical coordinator	CAY

## 3. Status of the Geodetic VLBI Activities at OAN

### 3.1. VLBI

The main contribution of OAN to IVS is the realization of geodetic VLBI observations: the OAN 14-m radio telescope at Yebes has however not participated in any VLBI campaigns since December 2003 due to the failure of the very old telescope control computer (HP1000).

Nowadays most of the activities are focused on the construction of the new 40-m radiotelescope. The system consists of several mirrors that direct the beam from the Nasmyth mirrors to the receivers. Up to seven frequency bands can be supported: S, X, C, Ku, 22 GHz and 30 GHz. This configuration allows simultaneous observations with at least two receivers. The new S/X band receivers will be ready in the laboratory in the summer of 2006.

The Mark 5A system has been inserted on a new rack which also contains a transformer for the Data Acquisition Rack. The VLBA recorder has been deprecated and for the time being is stored apart. The station is now Mark 5-only.

The hydrogen source of the Kvarz CH1-75 maser has been replaced, which should allow optimum performance during the next years.

The weather station has been replaced by a new one with better resolution and which also provides wind speed and wind direction. This station is better placed since it is far from any building.

Table 2. Number of geodetic VLBI sessions in which Yebes has observed (1995-2003),

Experiment type	CORE-B	EUROPE	IVS-T2
Number of Sessions	13	21	5

### 3.2. GPS

The GPS station at Yebes, established in 1999 and run by IGN, is the reference point of the Spanish fiducial network since 2002. In 2004, it was integrated in IGS with code ‘YEBE’.

In 2001, a new analysis center for EUREF was set up by IGN in Madrid (‘IGE’). It processes 30 stations from Spain, Portugal, Morocco, France, UK, among others. This is one of 15 EUREF LACs.

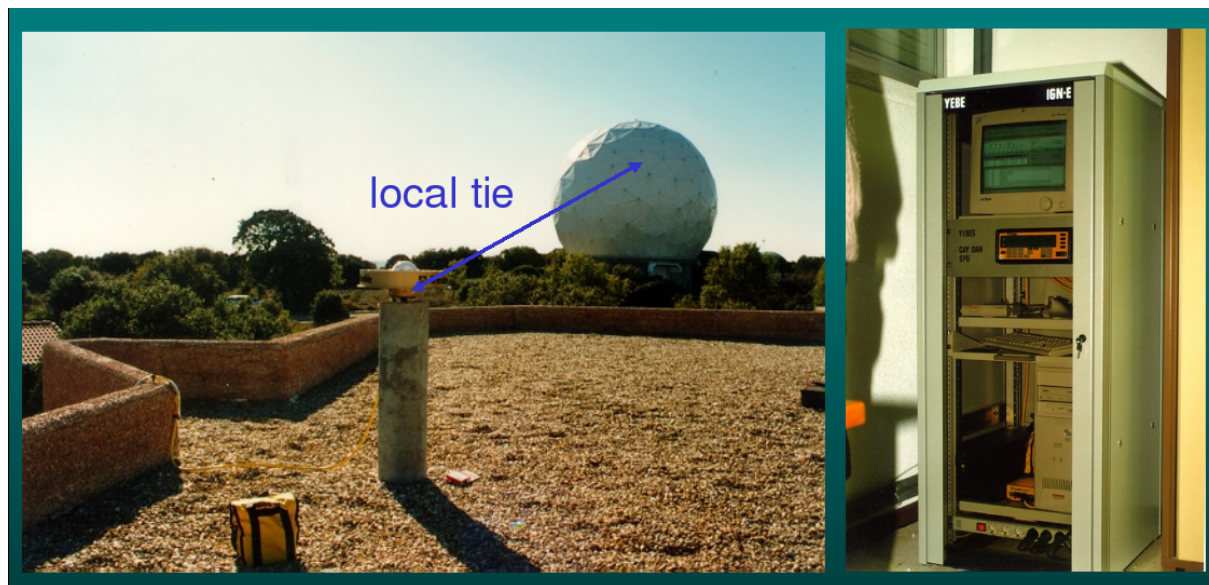


Figure 2. The IGS station “YEBE”.

### 3.3. Research

The OAN group performs high precision astrophysical VLBI studies of maser emission towards late-type stars, which will not be discussed here. However we point out that we have modified the Astronomical Image Processing System (*AIPS*) to allow the processing of full polarization data on antennas with Nasmyth optics. Similar developments will be needed if full polarization is to be used in geodetic VLBI, following the VLBI2010 project.

The OAN group is working on a new method, *Source/Frequency phase referencing*, to measure frequency-dependent position shifts of source cores with high accuracy. The first successful application to measure the core shift of the quasar 1038+528 A at S and X-bands has been reported, and the results have been validated by comparison with those from standard phase referencing techniques (Rioja et al. 2005). The method is an extension of the technique developed and demonstrated by Middelberg et al. (2005), that uses fast frequency switching observations and relies on the transfer of calibration from the lower to the higher frequency. Our new proposed method endows it with astrometric applications by adding a strategy to calibrate the ionospheric contribution. We foresee that it holds a big potential at high frequencies, in particular when applied to observations of molecular line emission. In geodesy too, the unaccounted source core shifts introduce errors in the estimated ionospheric-free observables, and hence on the astrometric/geodetic

products from the analysis.

#### 4. Future Plans

We expect first-light on the new 40 meter radiotelescope at Yebes in 2006, after the construction and commissioning are finished. The telescope is expected to be operational at S/X bands by the end of 2006 or early 2007. Other frequencies of operation will be 4-7 GHz, 10-15 GHz, 21-24 GHz (first light receiver), 30-32 GHz, 40-50 GHz, and 72-116 GHz. Connection of this telescope to GEANT (1 Gbps fiber optics link) is progressing within the frame of the EXPreS EU project. The measurement of the 40-m phase-center and local-tie to the 14-m telescope and the GPS antenna will also be performed in 2006.

On the other hand, measurements of absolute gravimetry at the 14-m telescope building have already been performed. A project of construction of a building is being finalized, which will allow the installation of permanent equipment for constant gravity monitoring.

Collocation of geodetic techniques (40-m VLBI radiotelescope, GPS receiver in IGS station, and gravimeters) will allow Yebes to become a Fundamental Geodetic Station in the coming years.



Figure 3. Artistic impression of the gravimeter building in Yebes (center), with sketch of the possible location (right) of the gravimeters (left).

#### References

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- [2] Middelberg, E., Roy, A. L., Walker, R. C., Falcke, H. “VLBI observations of weak sources using fast frequency switching”. *Astronomy & Astrophysics* **433**, p. 897-909 (2005)
- [3] Rioja, M.J., Dodson, R., Porcas, R.W., Suda, H., Colomer, F. “Measurement of core shifts with astrometric multi-frequency calibration”. *Proceedings of the 17th Working Meeting on European VLBI for Geodesy and Astrometry, Noto (Sicily, Italy)*, p. 125-130 (2005)

# Yellowknife Observatory

*Mario Bérubé, Anthony Searle*

## Abstract

The Yellowknife VLBI antenna is a 9 meter diameter antenna which was formerly the “MV-1” mobile antenna. The MV-1 was a proof-of-concept for mobile VLBI and in 1991 NASA and NOAA offered the system for use at Yellowknife.

The antenna is located at the Yellowknife Geophysical Observatory and is operated by the Geodetic Survey Division, Natural Resources Canada as part of the active control of the Canadian Spatial Reference System. This report gives an update on recent activities.



Figure 1. The Yellowknife Geophysical Observatory 9m antenna.

## 1. Overview

Formerly the “MV-1” mobile antenna, the Yellowknife antenna was used as a proof of concept for mobile VLBI under the ARIES (Astronomical Radio Interferometric Earth Surveying) program.

Following the successful proof of concept, the MV-2 and MV-3 mobile antennas were built and used extensively during NASA’s Crustal Dynamics project. The MV-1 antenna was then stationed at Vandenberg Air Force Base. In 1991 NASA and NOAA offered the system to Energy, Mines and Resources, Canada, for use at Yellowknife. With support of the Crustal Dynamics Project the Yellowknife VLBI observatory came on the air in the summer of 1991.



The antenna is located at the Yellowknife Geophysical Observatory and is the responsibility of the Geodetic Survey Division, Natural Resources Canada. The Yellowknife Geophysical Observatory is operated by the Geological Survey of Canada, Pacific Division, Natural Resources Canada. It serves to provide a second VLBI point for the Canadian Spatial Reference System (CSRS) in Canada.

## 2. General Specifications

- Latitude : 62.48 North
- Longitude : 114.48 West
- Elevation : 181.0 m
- Reflector : 9m
- Receiver : S and X cryogenic
- Azimuth speed : 40 degrees per minute
- Elevation speed : 40 degrees per minute
- PCFS version : 9.7.6
- VLBI equipment : Mark III and thick tape drive. S2 data acquisition and recording terminal.
- Time standard : NR Maser
- GPS receiver : BenchMark

## 3. Antenna Improvements

Since being installed in Yellowknife, the MV-1 has not required any major upgrades. The antenna is parked every winter because the antenna is unable to operate in low temperatures (November till March). Once spring arrives, the Yellowknife team prepares the antenna for the upcoming season.

Mechanical maintenance was performed in 1998 and the antenna has performed reasonably reliably since that time. Repairs were performed prior to the start of the observing season to correct some damage that occurred late in 2004, a new PCFS computer was installed at the same time. It is hoped a Mark 5 recorder will be installed in 2006.

## 4. Antenna Survey

The Yellowknife antenna is surrounded by a high precision survey network which has been measured three times since 1990. This network has been precisely measured to obtain the geodetic tie between the VLBI, the GPS and the DORIS reference points with a precision of a few mm.

## 5. Operations January 2005 - December 2005

In 2005, Yellowknife was involved in 2 IVS-T2 (Terrestrial Reference Frame sessions), and in 5 IVS-E3 sessions.

# Zelenchujskaya Radio Astronomical Observatory

*Andrei Dyakov, Sergey Smolentsev*

## Abstract

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

## 1. General Information

Zelenchujskaya Radio Astronomical Observatory was founded by Institute of Applied Astronomy (IAA) as one of the three stations of Russian VLBI network QUASAR [1]. Sponsoring organization of the project is Russian Academy of Sciences (RAS). The Zelenchujskaya Radio Astronomical Observatory is situated in Republic Karachaevo-Cherkessiya (Northern Caucasia) about 70 km south of Cherkessk, close by the Zelenchujskaya site (not far from Radiotelescope RATAN-600). The geographic location of the observatory is shown on the web site of IAA RAS ([http://www.ipa.nw.ru/PAGE/koi8-r/DEPOBSERV/rus\\_zel.htm](http://www.ipa.nw.ru/PAGE/koi8-r/DEPOBSERV/rus_zel.htm)). The basic instruments of the observatory are 32-m radio telescope and technical systems provided realization of VLBI observations.



Figure 1. Zelenchujskaya Observatory.

Table 1. Zelenchujskaya Observatory location and address.

Longitude	41°34'
Latitude	43°47'
Zelenchujskaya Observatory	
Republic Karachaevo-Cherkessia	
357140, Russia	
ipazel@mail.svkchr.ru	

## 2. Technical and Scientific Information

The Zelenchukskaya station equipment includes the following main components: 32 m radio telescope, equipped with low noise receivers, frequency and time keeping system with H-masers, local geodetic network, GPS Rogue SNR-8000 receiver (geodetic) and GPS/GLONASS K161 receiver (synchronization of time keeping system), data acquisition system VLBA, recording terminals Mark 5A and S2, control computers, local computer network and technical service systems. DAS VLBA was installed and completed by BBC-modules in 2005. Automatic meteo station has been installed at Zelenchukskaya in 2001. Local geodetic network (Fig. 2) is adjusted with accuracy of 2–3 mm. Characteristics of the radio telescope and other main components of the station are presented in Tables 2–4.

The time and frequency system is composed of four hydrogen standard CH1-80 and GPS/GLO-NASS receivers for the preliminary time synchronization with an accuracy of not more than 100 ns. Frequency stability of H-masers is presented in Table 4. Local VHF oscillators are locked by reference 5 MHz signal and provide 10–20 mW power output signals at frequencies 1.26, 2.02, 8.08, 4.5, 22.12 GHz. A pulse calibration system includes pulse generator with duration of pulses about 50 ps.

Table 2. Technical parameters of the radio telescope.

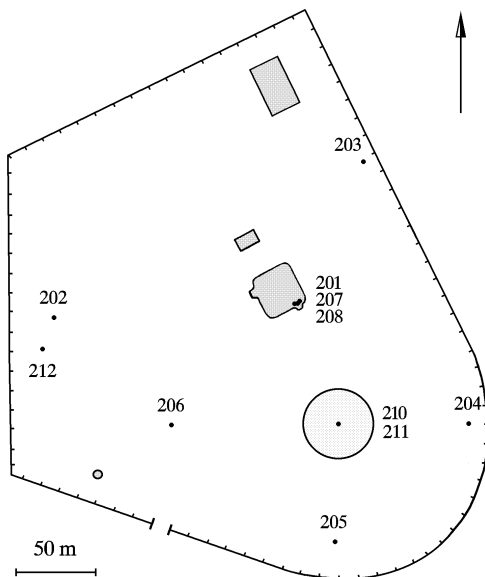
Year of construction	2000
Mount	AZEL
Azimuth range	$\pm 270$ (from south)
Elevation range	from $-5^\circ$ to $95^\circ$
Maximum azimuth - velocity - tracking velocity - acceleration	1.5 $^\circ/s$ , 1.5 $'/s$ , 0.2 $^\circ/s^2$
Maximum elevation - velocity - tracking velocity - acceleration	0.8 $^\circ/s$ , 1.0 $'/s$ , 0.2 $^\circ/s^2$
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
Surface tolerance of main reflector	$\pm 0.5$ mm
Frequency capability	1.4–22 GHz
Axis offset	$-11.5$ mm

Table 3. Parameters of receivers.

Wave band	Frequency range	Input noise temperature
18–21 cm	1.38–1.72 GHz	12 K
13 cm	2.15–2.5 GHz	12 K
6 cm	4.6–5.1 GHz	10 K
3.5 cm	8.2–8.9 GHz	15 K
1.35 cm	22.2–22.7 GHz	20 K

Table 4. Frequency stability of the CH1-80 H-maser.

Sample time interval	(Allan variance) <sup>1/2</sup>
1 second	$3 \cdot 10^{-13}$
10 seconds	$3 \cdot 10^{-14}$
100 seconds	$1 \cdot 10^{-14}$
1000 seconds	$3 - 5 \cdot 10^{-15}$



Local geodetic network includes 11 reference points (Figure 2): 202–206, 212 are ground marks, 201, 207, 208 are located at the roof of laboratory building and intended for installation of GPS/GLONASS receivers, 210 is the intersection of radiotelescope axes and 211 is intermediate mark on azimuthal platform of radiotelescope.

Figure 2. Local geodetic network at Zelenchukskaya Observatory.

### 3. Technical Staff

Andrey Dyakov — Observatory chief,  
Dmitry Dzuba — FS, pointing system controls,  
Anatoly Mishurinsky — front end and receivers support,  
Alexey Bosov — electrical power system support,  
Viktor Sherstukov — mechanical facilities support.

### 4. Outlook

Our plans for the coming year are the following:

- Final adjustment of all radio telescope systems from point of view of VLBI requirements.
- Connection of observatory with optical fiber lines.
- Participation in IVS R4, R1, EURO, T2 and RDV observing sessions during 2006 year.

### References

- [1] Finkelstein A., Ipatov A., Smolentsev S. Radio Astronomy Observatories Svetloe, Zelenchukskaya and Badary of VLBI Network QUASAR. In: IVS 2004 General Meeting Proc., eds. N. R. Vandenberg, K. D. Baver, NASA/CP-2004-212255, 2004. P. 161–165.



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# Operation Centers

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# The Bonn Geodetic VLBI Operation Center

*A. Nothnagel, D. Fischer, A. Müskens*

## Abstract

In 2005 the GIUB Operation Center has continued to carry out similar tasks of organizing and scheduling various observing series as in 2004.

## 1. Center Activities

The GIUB VLBI Operation Center is located at the Geodetic Institute 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 2005 are the same as in 2004.

As of December 31, 2005, Mrs. Dorothee Fischer had to leave us due to German university regulations. She has done a very good job for the IVS in scheduling the INT2 (Wettzell – Tsukuba) sessions for a long time putting a lot of efforts into designing optimized schedules. We wish her success in completing her Ph.D. and any further opportunities which lie ahead.



Figure 1. Building of the Geodetic Institute in a new coat (for comparison see IVS Annual Report 2003)

- **Tsukuba - Wettzell UT1-UTC K4 Intensive Series (INT2)**

The Tsukuba - Wettzell Intensive series for monitoring UT1-UTC has been continued and expanded as a joint project of the Bundesamt für Kartographie und Geodäsie (BKG, Germany), the Geographical Survey Institute (GSI, Japan) and the Geodetic Institute of the University of Bonn (GIUB, Germany).

Regular one hour sessions have been observed almost every Saturday and Sunday in 2005. All sessions are now routinely observed as eVLBI (electronic transfer) sessions reducing the time between observations and correlation considerably.

In fall 2005 the routine operation and scheduling of the INT2 sessions was handed over to the VLBI group at BKG Leipzig.

- **IVS-T2 series**

This series is being observed roughly every second month (6 sessions in 2005) primarily for maintenance and stabilisation 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 participates several times per year in the T2 sessions. In 2005 the IVS Observing Program Committee (OPC) decided to enlarge the T2 sessions from 8 or 9 stations to 14 to 16 for a stronger and more robust determination of the TRF. The scheduling of these sessions has to take into account that a sufficient number of observations is planned for each baseline of these global networks.

- **Measurement of Vertical Crustal Motion in Europe by VLBI (EUROPE)**

Four sessions with Ny-Ålesund, Onsala, Wettzell, Simeiz, Madrid (DSS65), Yebes, Medicina, Matera, Noto, Svetloe, and Effelsberg (participated twice) have been scheduled for precise station coordinate determination and long term stability tests. MPIfR is now operating a Water Vapor Radiometer at Effelsberg on a routine basis.

- **Southern Hemisphere and Antarctica Series (OHIG):**

Six sessions with the Antarctic stations Syowa (Japanese) and O'Higgins (German) plus Fortaleza, Hobart, Kokee, HartRAO and DSS45 have been organized for maintenance of the VLBI TRF and Earth rotation monitoring. OHIGGINS is also included in the T2 sessions.

## 2. Staff

Table 1. Personnel at GIUB Operation Center

Dorothee Fischer (until Dec 31, 2005)	++49-228-732623	dorothee.fischer@uni-bonn.de
Arno Müskens	++49-228-525264	mueskens@mpifr-bonn.mpg.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 2005 to December 2005. The report forecasts activities planned for the year 2006.

## 1. Changes to the CORE Operation Center's Program

The Earth orientation parameter goal of the IVS program is to attain precision at least as good as  $3.5 \mu\text{s}$  for UT1 and  $100 \mu\text{as}$  in pole position.

The IVS program was started in 2002 and used the Mark IV recording mode for each session. The IVS program began using the Mark 5 recording mode in mid 2003. Most stations were using the Mark 5 recording mode by the end of 2004. This change resulted in the 2004 sessions being processed more efficiently and freeing up correlator time. As a result, the program became station and media dependent rather than correlator dependent. The following are the network configurations for the sessions for which the CORE Operation Center was responsible:

CONT-05: 15 sessions, scheduled consecutively, 11 station network

IVS-R1: 52 sessions, scheduled weekly on Mondays, seven station network

RDV: 6 sessions, scheduled evenly throughout the year, 18 to 20 station network

IVS-R&D: 10 sessions, scheduled monthly, seven station networks

## 2. IVS Sessions January 2005 to December 2005

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

- CONT-05: The CONT05 Campaign was a continuous 15 day session with 11 stations which was observed during September 2005. The CONT05 sessions are the follow-on to the spectacularly successful CONT94 observed in January 1994 and the follow-up CONT95 (August 1995), CONT96 (fall 1996), and CONT02 (October 2002). Tsukuba recorded with e-vlbi and the other participating stations recorded with Mark 5.
- IVS-R1: In 2005, the IVS-R1s were scheduled weekly with a seven station network. There was a core network for each day plus three other stations until early September. Westford did not participate after September 7 due to budget problems. Fortunately, Matera became operational in July 2005 after being down for 1.5 years. Fortaleza was scheduled to join the IVS-R1 sessions in July 2005 after receiving their Mark 5. Fortaleza did receive their Mark 5 in 2005 but Fortaleza only participated in two IVS-R1 sessions.

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 the time delay from the end of recording to results as short as possible. The time delay goal

is a maximum of 15 days. Participating stations are requested to ship discs to the correlator as rapidly as possible. The “1” indicates that the sessions are on Mondays.

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

These sessions are being coordinated by the geodetic VLBI programs of three agencies: 1. USNO will perform repeated imaging and correction for source structure; 2. NASA will analyze this data to determine a high accuracy terrestrial reference frame; and 3. NRAO will use 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 10 R&D sessions in 2005, as decided by the IVS Program Committee, was to record at 1 Gbit/s data rate to evaluate the geodetic results. Those experiments also tested the entire data flow from scheduling through analysis for the higher data rate. There were seven regular stations that participating in the R&D sessions during 2005.

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

Table 1 gives the average formal errors for the R1, R4, RDV and CONT05 sessions from 2005. The R4 and T2 sessions have significantly better formal uncertainties in 2005 compared with 2004. The CONT05 formal errors are better than for previous CONT series by 20-30%. R1 and RDV formal uncertainties are worse than in 2004. For R1s this is probably due to problems with Gilcreek. We are currently investigating the cause of the degradation in RDV uncertainties in the last 2-3 years.

Table 2 shows the EOP differences relative to IGS for the different series. The level of agreement in 2005 is about the same for the R1 and R4s as in 2004. WRMS differences for the RDVs are significantly less in 2005, but with only 5 sessions it is not clear that one can make statistically significant conclusions. One of the 4 T2 sessions is dominating the large differences seen for 2005, but it is not obvious why this session is a large outlier. The CONT05 sessions have significantly better agreement with IGS than the R1 and R4s. This is likely due to the larger size and better global distribution of sites of the CONT05 network.

Table 1. Average EOP Formal Uncertainties for 2005

Session Type	Num	X-pole ( $\mu$ as)	Y-pole ( $\mu$ as)	UT1 ( $\mu$ s)	DPSI ( $\mu$ as)	DEPS ( $\mu$ as)
R1	50	73(61)	72(62)	3.0(2.4)	157(138)	62(56)
R4	49	68(90)	65(78)	2.5(3.2)	149(177)	60(71)
CONT05	15	37	37	1.5	76	28
T2	5	70(98)	68(85)	3.1(3.9)	165(215)	66(79)
RDV	5	44(37)	51(40)	2.6(1.9)	89(76)	35(30)

Values for 2004 are shown in parenthesis

Table 2. Offset and WRMS Differences (2005) Relative to the IGS Combined Series

Session Type	Num	X-pole		Y-pole		LOD	
		Offset ( $\mu$ as)	WRMS ( $\mu$ as)	Offset ( $\mu$ as)	WRMS ( $\mu$ as)	Offset ( $\mu$ s/d)	WRMS ( $\mu$ s/d)
R1	50	27(2)	101(94)	-192(-246)	103(101)	-3(-1)	17(16)
R4	49	-71(-130)	101(104)	-262(-273)	101(104)	0(3)	19(21)
C0NT05	15	1	57	-236	40	17	17
T2	4	251(-9)	413(176)	-330(-224)	154(129)	14(-2)	29(20)
T2	3	34	191	-226	35	0	29
RDV	5	-27(30)	32(101)	-153(192)	43(103)	5(-3)	20(17)

Values for 2004 are shown in parenthesis

#### 4. The CORE Operations Staff

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

Table 3. Key Technical Staff of the CORE Operations Center

Name	Responsibility	Agency
Dirk Behrend	Organizer of CORE program	NVI, Inc./GSFC
Steve Bailey	Procurement of materials necessary for CORE operations	GSFC/NASA
Brian Corey	Analysis	Haystack
Irv Diegel	Maser maintenance	Honeywell
John Gipson	SKED program support and development	NVI, Inc./GSFC
Frank Gomez	Software engineer for the Web site	Raytheon/GSFC
David Gordon	Analysis	Raytheon/GSFC
Ed Himwich	Network Coordinator	NVI, Inc./GSFC
Chuck Kodak	Receiver maintenance	Honeywell
Dan MacMillan	Analysis	NVI, Inc./GSFC
Leonid Petrov	Analysis	NVI, Inc./GSFC
Dan Smythe	Tape recorder maintenance	Haystack
Cynthia Thomas	Coordinate master observing schedule and prepare observing schedules	NVI, Inc./GSFC

#### 5. Planned Activities during 2006

The CORE Operation Center will continue to be responsible for the following IVS sessions during 2006.

- The IVS-R1 sessions will be observed weekly and recorded in a Mark IV mode.
- The IVS-R&D sessions will be observed 10 times during the year. The purpose of the R&D sessions in 2006 as determined by the IVS Observing Program Committee is to continue studying how to use Gb/s data rate for geodesy. Phase delay will be attempted and the SNRs will be set high.
- The RDV sessions will be observed 6 times during the year.

# NEOS Operation Center

*Kerry Kingham, M.S. Carter*

## Abstract

This report covers the activities of the NEOS Operation Center at USNO for 2005. The Operation Center schedules IVS-R4 and the 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. The operational IVS-R4 network has included VLBI stations at Gilmore Creek (Alaska), Kokee Park (Hawaii), Wettzell (Germany), Fortaleza (Brazil), Ny-Ålesund (Norway), Algonquin Park (Canada), TIGO (Chile), Svetloe and Zelenchukskaya (Russia), Hobart (Australia), Onsala (Sweden), and Matera and Medicina (Italy). A typical R4 consisted of 7 to 8 stations.

The regular stations for the IVS-Intensives were Kokee Park and Wettzell. During the second half of the year a set of sessions including Kokee Park, Wettzell and Svetloe was observed twice per month in order to characterize the Kokee Park – Svetloe baseline so that Svetloe can be used as an alternate for Wettzell should it be needed.

All sessions are correlated at the Washington Correlator, which is located at USNO and is run by NEOS.

## 2. Staff

K. A. Kingham and M. S. Carter are the only staff members of the NEOS Operation Center. Kingham is responsible for the overall management and Carter makes the schedules. M. S. Carter is located at the USNO Flagstaff Station (NOFS).





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# Correlators

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# The Bonn Astro/Geo Mark IV Correlator

*Alessandra Bertarini, Arno Müssens, Walter Alef*

## Abstract

The Bonn Mark IV VLBI correlator is operated jointly by the MPIfR and the GIUB in Bonn and the BKG in Frankfurt. In 2005 the Bonn correlator was used to demonstrate phase correction during the 3mm-VLBI session using data from the Effelsberg Water Vapour Radiometer (WVR)<sup>1</sup>.

## 1. Introduction

The Bonn Mark IV correlator is hosted at the Max-Planck-Institut für Radioastronomie (MPIfR)<sup>2</sup> Bonn, Germany. It is operated jointly by the MPIfR and by the Bundesamt für Kartographie und Geodäsie (BKG)<sup>3</sup> in cooperation with the Geodätisches Institut der Universität Bonn (GIUB)<sup>4</sup>. It is a major correlator for geodetic observations and MPIfR's astronomical projects, for instance those involving millimetre wavelengths and astrometry.

## 2. Present Status and Capabilities



Figure 1. Left: Correlator rack in 2 crates. Middle: two station units with two rack-mounted Mark 5A playback units. Right: four Mark 5B units mounted in two racks.

The Bonn correlator (Fig 1) is one of the four Mark IV VLBI data processors in the world. It has been operational since 2000. A summary of the Bonn correlator capabilities is presented in Table 1.

<sup>1</sup><http://www.mpifr-bonn.mpg.de/staff/aroy/wvr.html>

<sup>2</sup><http://www.mpifr-bonn.mpg.de/div/vlbicor/>

<sup>3</sup><http://www.ifag.de/>

<sup>4</sup><http://www.gib.uni-bonn.de>

Table 1. Correlator Capabilities

## Playback Units

Number available:	9 Mark IV tape drives, 8 Mark 5A systems (interchangeable)
Tape types:	Thick, thin
Playback speeds:	80 ips, 160 ips (thin tapes); 135 ips, 270 ips (thick tapes) up to 1024 Mbit/s (Mark 5A)
Formats:	Mark III/Mark IV/VLBA (Mark IV/VLBA w/wo barrel roll, data demod.)
Sampling:	One bit; two bit
Fan-out:	1:1 1:2 1:4
Fan-in:	Not supported
No. channels:	$\leq 16$ USB and/or LSB
Bandwidth/channel:	(2, 4, 8, 16) MHz
Signal:	Mono, dual frequency; dual polarization
Modes:	128-16-1 128-16-2 128-8-1 128-8-2 128-4-1 128-4-2 128-2-2 256-16-1 256-16-2 256-8-1 256-8-2 256-4-2 512-16-2 512-8-2 1024-16-2

## Correlation

Geometric Model:	CALC 8
Number of boards:	16
Phase cal:	Single tone extraction at selectable frequency
Pre-average times:	0.2 s to 5 s
Lags per channel:	32 minimum, 2048 maximum; 1024 tested and used
Maximum output:	9 stations: 36 baselines, 16 channels, 32 lags with autocorrelation function (ACF) without circular polarization (CP); 8 stations: 28 baselines, 16 channels, 32 lags with ACF with CP
Fringe-fit:	Off-line FOURFIT run
Export:	Data base, MK4IN to AIPS

The correlator is controlled from a dedicated workstation. Correlation setup, data inspection, fringe-fitting, and data export are done with a separate workstation. Per year about 300 to 400 Gbytes of correlated data are generated. The total disk space available for data handling at the correlator is more than 1000 Gbytes. Data security is guaranteed by using a file system with redundancy (RAID level 5) and by daily back-up of the data on a 120 Gbyte disk of a low-end Linux PC.

### 3. Staff

The people in the geodetic group at the Bonn correlator are

- Arno Müskens: group leader, overall experiment supervision, scheduling of T2, OHIG and EURO series.
- Alessandra Bertarini: experiment setup and evaluation of correlated data, media shipping.
- Alexandra Höfer: experiment setup and evaluation of correlated data, media shipping.
- 5 student operators for the night shifts and the weekends.

MPIfR staff supports IVS correlation with

- Walter Alef: correlator manager, correlator software maintenance and upgrades, and computer system administration.
- David Graham: technical development, consultant.
- Heinz Fuchs: correlator operator, responsible for the correlator operator schedule, daily operations, and media shipping.
- Hermann Sturm: correlator operator, correlator support software, media shipping.
- Michael Wunderlich: engineer, correlator, playback drives, Mark 5 support.
- Rolf Märtens: technician, playback drive maintenance, Mark 5 support.

### 4. Status

In the course of 2005 the majority of the observations became disk-only. As a result the efficiency and throughput of the correlator could be increased by nearly a factor of two. The Bonn group correlated and released about 50 geodetic experiments: three T2, 39 R1, four EURO, five CONT05, and a Zelenchukskaya fringe test. No OHIG sessions were correlated in 2005 due to late arrival of the media from the Antarctic station Syowa.

The CONT05 sessions were an overall success, and after some analysis carried out at Bonn, IVS decided that the complete campaign should be fringe-fitted in one run with fixed parameters.

The new Water Vapour Radiometer (WVR) at Effelsberg was operated in parallel with two EURO sessions (EURO75 in March and EURO78 in December). The WVR data from EURO75 were compared with zenith wet delays estimated from VLBI: the offsets were found to have an RMS of about 9 mm.

The fringe-fitting program *fourfit* was modified to accept phase corrections obtained using the Effelsberg WVR to improve the phase coherence of astronomical millimetre VLBI observations. Further validation tests are in progress.

All astronomical projects correlated at Bonn including the two millimetre sessions have been disk-only since the beginning of 2005. This was partially possible with a huge investment by MPIfR in disks which helped to supply the VLBA antennas for those observations.

### 5. Outlook for 2006

MPIfR and BKG bought four Mark 5B units and four upgrades for the existing Mark 5A units. The aim is to upgrade the correlator to 12 stations by adding 4 Mark 5Bs to the system; at the

same time 2 tape units will be removed. Later the eight existing Mark 5As will be upgraded to Mark 5B depending on the number of Mark 5B recorders in the field. Bonn and Haystack are collaborating on Mark 5B hard- and software development required for the upgrade.

The tape drives and station units will still be maintained for some time because not all IVS and VLBA stations have been upgraded to Mark 5. But it is expected that tape-based correlation will cease towards the end of 2006.

The Bonn group is involved in the development of a digital Baseband Converter (dBBC) for the European VLBI Network (EVN). This unit is designed as a full replacement for the existing analog BBCs.

In spring of 2006 it is expected that the correlator will have Gbit connectivity to the Internet. The aim is to have an optically switched connection to the European Academic Network (Géant).

# Haystack Observatory VLBI Correlator

*Mike Titus, Roger Cappallo, Brian Corey, Arthur Niell, Alan Whitney*

## Abstract

The Haystack correlator reports on its activities for the year. Mark 5B is in the final stages of development, and integration into the correlator is imminent. e-VLBI demonstrations linked to conferences were a major effort. Non-real-time e-VLBI transfers continue. Various other testing and development projects continue. An increased focus on R&D related activities rather than routine production will shape next year's correlator activities. Efforts to move operations to Linux-based systems continue.



Figure 1. Partial view of the Haystack Mark IV correlator, showing 2 racks containing 7 Mark 5A units and a decoder, correlator rack, 1 tape unit, and 1 rack containing 4 Station Units.

## 1. Introduction

The Mark IV VLBI correlator of the MIT Haystack Observatory, located in Westford, Massachusetts, is supported by the NASA Space Geodesy Program and by the National Science Foundation. The available correlator time is dedicated mainly to the pursuits of the IVS, with a small portion of time allocated to processing radio astronomy observations for the Ultra High Sensitivity VLBI (u-VLBI) project. The Haystack Correlator serves as a development system for testing new correlation modes, for e-VLBI, for hardware improvements such as the Mark 5B system, and for diagnosing correlator problems encountered at Haystack or at one of the identical correlators at the U.S. Naval Observatory and the Max Planck Institute for Radioastronomy. This flexibility is made possible by the presence on-site of the team that designed the correlator hardware and software. Additionally, some production correlator time is dedicated to processing geodetic VLBI observations for the IVS.

## 2. Summary of Activities

Once again, a variety of activities characterize the work for this past year.

On the technical side, e-VLBI and Mark 5B testing continued, with the Mark 5B system nearing implementation. Fringe products of e-VLBI real time correlations from Onsala, Westford, and GGAO at a data rate of 512 Mbps were displayed in real time at two major conferences: iGRID in September and Super Computing 2005 in November. Tangentially related to both of the above, Mark 5A testing, debugging, and repair continued in order to improve the stability of operations. In a continuing effort, non-real-time e-VLBI transfers of station data were copied onto disk packs at Haystack and shipped to the appropriate correlator; 26 experiments were transferred in 2005. The data sessions transferred came mostly from Tsukuba and Kashima, with a few sessions of Syowa data also transferred. Tests to measure directly the timing offset between the K5 and Mark IV systems were performed (see IVS NICT-TDC Newsletter No. 26, Sept. 2005). WACO and Bonn correlator support activities continued, with both hardware and software issues resolved (e.g. fixing the tgen program to support larger schedules, and replacing and repairing a failed station unit DMM at the Washington correlator). A major hardware improvement was the installation of heat sinks on the correlator input board's FIFO controller chips at Haystack and Washington. This modification has greatly reduced the failure rate of these chips, which has been an operations problem for years. Another item worthy of mention is investigation into a problem with station unit startup data creating spurious fringes in experiments without early-start recording. Also related to this was some re-investigation into the station unit's SUIM generation of valid zeros, a problem which dates back to the station unit's design.

On the organizational side, in July of last year correlator operations were partially melded with the Westford antenna in order to reduce costs. This joint operation involves remotely monitoring Westford observations while running correlator operations locally. Along with this change came a reduction in production correlator support from 30 to 24 hours per week. The focus of this support also changed, with an increased emphasis on R&D experiments and related work, and a reduction of routine production correlation.

### 3. Experiments Done

In 2005, 48 geodetic-VLBI experiments were processed at the Haystack correlator. This total consists of 9 R1s, 14 R&Ds, 2 CONTS, 1 APSG, and 22 test experiments. The test experiments covered an assortment of e-VLBI, Mark 5B, record format, and various station and equipment tests.

### 4. Current/Future Hardware and Capabilities

Currently, functional hardware installed on the system includes 6 tape units, 7 Mark 5A units, 7 station units, 16 operational correlator boards, 2 crates, and miscellaneous other support hardware. This represents an increase of 2 Mark 5A units from 2004. A minor rearrangement of correlator hardware took place mid-year, with one tape drive moved to an outer position. Its previous position was occupied by a new rack of three Mark 5As, with a keyboard/monitor integrated (see Figure 1). In order to reduce noise and save electricity, only three tape drives are kept powered up; even they have rarely been used in the past year. We have the capacity to process all baselines for 7 stations simultaneously in the standard geodetic modes, given that the aggregate recordings match the above hardware matrix. By early 2006, implementation of the Mark 5B may allow the correlation of more than 7 stations, due to the Mark 5B's independence from an accompanying



station unit. We expect to remove more tape drives from the system as more stations move to recording exclusively on a Mark 5.

## 5. Staff

The addition of Chester Ruszczyk in support of e-VLBI is the one change in staff over the past year. Staff who participated in aspects of Mark IV, Mark 5, and e-VLBI development and operations include:

### 5.1. Software Development Team

- John Ball - operator interface; playback; Mark 5A/5B; e-VLBI
- Roger Cappallo - correlation software leader; system integration; post processing; Mark 5B
- Kevin Dudevoir - correlation; maintenance/support; Mark 5A/5B; e-VLBI
- Chester Ruszczyk - e-VLBI
- Jason SooHoo - e-VLBI
- Alan Whitney - system architecture; Mark 5/e-VLBI development

### 5.2. Operations Team

- Peter Bolis - correlator maintenance
- Brian Corey - experiment correlation oversight; station evaluation; technique development
- Dave Fields - playback drive maintenance; Mark 5 installation and maintenance; general technical support
- 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 & hardware testing
- Ken Wilson - correlator maintenance; playback drive maintenance; general technical support

## 6. Conclusion/Outlook

The integration of Mark 5B into the correlator will increase capabilities, as each Mark 5B that is integrated will allow either the retirement of a station unit or an increase in the number of stations that can be simultaneously correlated. Retirement of station units should increase efficiency and throughput due to a reduction in the need for reprocessing, due to routine use of a 32 MHz playback clock, and due to the smaller setup time required by Mark 5B. Upgrade of other correlators and stations to Mark 5B will follow. e-VLBI tests and experiments will expand to include more stations and will be more extensive. Non-real-time e-VLBI transfers will continue, possibly including more stations in the near future. Correlator operations will focus more on R&D and development work

than on routine production. The effort to move operational correlator production tasks to more modern Linux-based systems over the next year will continue, possibly including the correlator run time software and control computer. Development in support of VLBI2010 is anticipated to increase next year. All the above work should result in a greatly improved data processing system as well as provide greater capability and a higher quality end-product to the IVS community.

## IAA Correlator Center

*Igor Surkis, Alexey Melnikov, Yuriy Rusinov, Violet Shantir, Vladimir Zimovsky*

### Abstract

The MicroPARSEC correlator was tested, and its hardware and software were improved. Now MicroPARSEC became the main correlator at IAA RAS. A set of experiments was processed by it. Also the old TISS-1M correlator was used.

### 1. Introduction

The MicroPARSEC and TISS-1M correlators are located and staffed by the Institute of Applied Astronomy in Saint-Petersburg, Russia. The correlators are sponsored and funded by the Russian Academy of Sciences, by the Russian Foundations of Basic Research and by the Russian Ministry of Science and Education. Dedicated to processing geodetic, astrometric and astrophysical observations, the general role of correlators is as an operational processor for VLBI observations in Russia.

### 2. General Information

The MicroPARSEC correlator and the TISS-1M correlator are used in IAA Correlation Center.

The old correlator TISS-1M was developed in 1985-1995. It consists of the 3-station correlator and tape devices S2-PT. The Mark III data stream format is processed.

The TISS-1M has two disadvantages. The bandwidth of the frequency channel is limited to 2 MHz, and only 1-bit sampling condition can be processed.

The new correlator MicroPARSEC was developed in recent years. It is based on the Altera program logical integral scheme (PLIS) technology. MicroPARSEC was developed using a standard PCI plate, which is inserted to the usual IBM PC computer. MicroPARSEC is directly connected to the S2-PT tape drive. One MicroPARSEC board can process 2 frequency channels with maximum bandwidth of 16 MHz and 1-bit or 2-bit sampling condition. VSI data stream format is used. The correlator with single MicroPARSEC board and single S2-PT unit was developed in 2003–2004.

### 3. Summary of Activities

The main focus of our activities was to test MicroPARSEC and improve its characteristics. Many experiments have been performed. Many changes of the MicroPARSEC software and some changes of hardware (PLIS reprogramming) have been done.

A bug in the hardware algorithm of the PC correlation was found. PLIS were reprogrammed.

Early for the first experiments the low precision ephemerides model was used in MicroPARSEC hardware. Now the high precision ephemerides are used.

The automatic processing of the experiments was reached. Now the full 8-hour tape can be processed automatically.

The post processing software was expanded by the observation quality control and multiband synthesis algorithm.

As result correlator with single MicroPARSEC board became fully operational.

The next goal in the MicroPARSEC correlator development is to expand number of the simultaneously processed channels and bases. It can be achieved by using a set of MicroPARSEC boards. The first multi board correlator was developed at the end of 2005. It consists of 4 MicroPARSEC boards, one S2-PT unit, special commutation unit and one IBM PC computer (Figure 1). This correlator can process up to 8 frequency channels on 1 base. The development is in its final stage. We hope to begin testing this correlator by the end of February 2006.

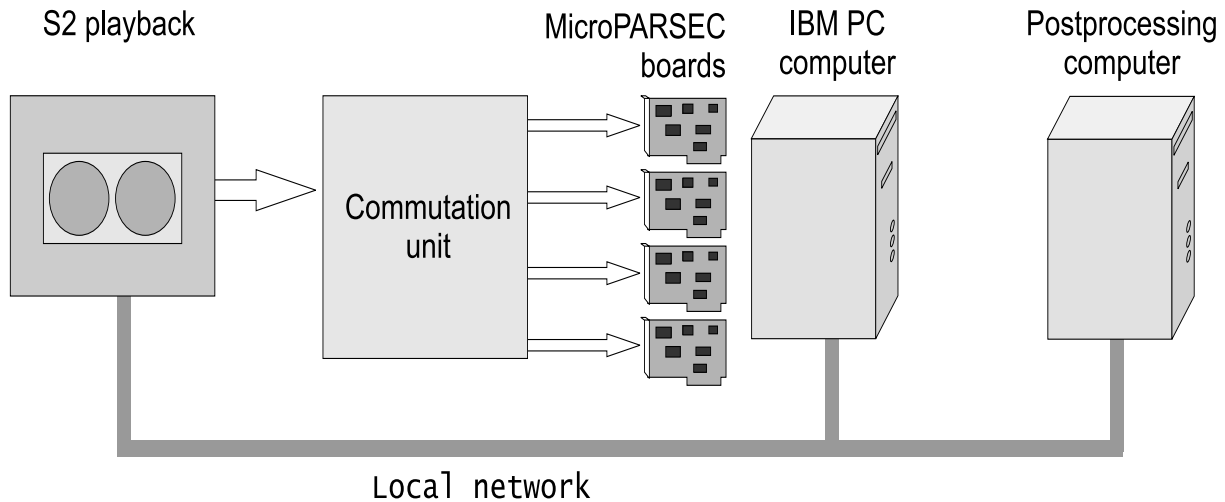


Figure 1. The 4 MicroPARSEC board correlator.

The next multibase multichannel MicroPARSEC correlator will consist of 12 MicroPARSEC boards and 2 S2-PT devices. We plan to begin testing in the middle of 2006.

Also we hope to use modern RadioAstronDigital (RDR) compatible playback units with the MicroPARSEC correlator.

#### 4. Experiments Done

Since January 2005, 14 experiments have been observed at the Russian VLBI network QUASAR at the stations Svetloe, Zelechukskaya, and Badary. They have been processed at the IAA Correlator Center with the MicroPARSEC correlator.

The new VLBI station Badary did its first observation in August 2005. The correlation response was achieved at both X-band and S-band.

The MicroPARSEC correlator software was tested and improved in these experiments.

The post processing software of multiband synthesis also was tested.

The MicroPARSEC correlator was the main device to process these experiments. Also TISS-1M correlator was used.

Also one of the MicroPARSEC boards was used as mobile correlator for testing hardware of the stations. The board was connected to the sampling unit, before formatting and recording systems. The autocorrelation functions and spectra were obtained in real time. Some defects of the station apparatus were found and eliminated.

## 5. Staff

- Alexey Melnikov — software development, correlator operator
- Yuriy Rusinov — software development, correlator operator
- Violet Shantir — software development, post processing
- Igor Surkis — principle investigator, system integration, software development
- Vladimir Zimovsky — hardware development, system integration, correlator operator

## 6. Conclusion

The new correlator MicroPARSEC was successfully used to process geodetic VLBI observations in 2005. The main efforts in 2006 will focus on expanding the number of simultaneously processed frequency channels and bases.

# VLBI Correlators in Kashima

*Mamoru Sekido, Yasuhiro Koyama, Moritaka Kimura, Hiroshi Takeuchi*

## Abstract

Correlators at Kashima were used for processing of experimental VLBI observations. Software correlators are being developed for specific purposes. Activities of NICT's group related with correlators are reported.

## 1. General Information

Kashima Space Research Center of National Institute of Information and Communications Technology (NICT: former Communications Research Laboratory) has been contributing to VLBI community by development of VLBI technologies. Environment of VLBI technology is changing owing to rapid growth of technologies in three points: computational power of personal computer (PC), miniaturization and boosting in recording capacity on hard disk drive (HDD), and availability of high speed network. It is making differences in some view points: data transportation, turn around time, flexibility of processing technique, and spreading VLBI education to universities.

Software correlators, using clusters of general purpose PCs, have the potential to reach and to overcome the performance of hardware correlators. The VLBI group at NICT is working for development of software correlator and for their application to geodesy and spacecraft observation as an engineering application. Figure 1 shows a view of observation room of the 34m station. The cluster of PCs, which are used for VLBI data acquisition, are also used for correlation processing. Data observed at other stations are transferred through the Internet or by usual mail and stored on HDD of other PCs. The distributed correlation processing is performed by sharing these data via Local Area Network.

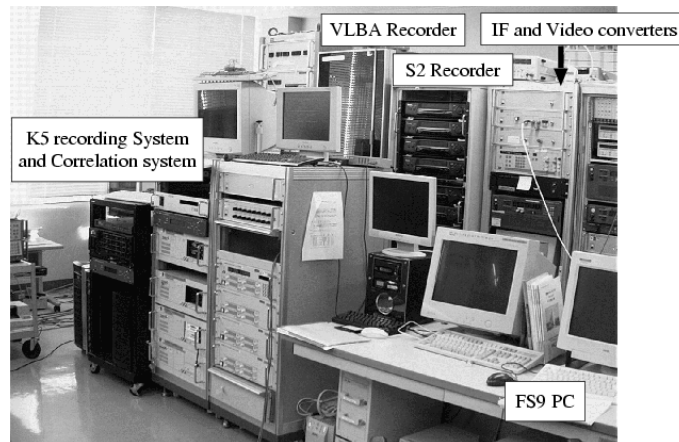


Figure 1. A K5 system located in observation room of 34m station. Since the K5 system is composed of a cluster of PCs, these PCs are used for both observation and correlation processing.

## 2. Component Description

### 2.1. Data Processing for Geodesy

Continuous VLBI campaign 2005 was organized in September 2005. Kashima 34m station did not officially participate in the observation, although VLBI observations were performed with the same schedule during a part of the campaign period. The data was recorded with 16Msps-1bit-16ch mode. Observed data at Tsukuba 32m station, which fully participated in the campaign, was transferred to Kashima and correlation processing was performed for Kashima-Tsukuba one baseline with software correlator.

GEX-13 (Giga-bit series VLBI experiment) was performed between Kashima 11m and Koganei 11m baseline with ADS-2000 in 32Msps-2bit-16ch mode [1]. The observation data were stored on HDD of PC through VSI-interface card. The data were converted to K5 format data files, then they were processed via software correlator.

### 2.2. Data Processing of Spacecraft Observation

A series of VLBI experiments for spacecraft HAYABUSA were organized with domestic VLBI stations in Japan. HAYABUSA, launched by Japanese space agency (JAXA/ISAS), is an exploration mission of asteroid (ITOKAWA). Basic observation strategy is measuring geometrical delay for spacecraft with differential VLBI technique by observing nearby quasars. Delay data of quasar have been derived by bandwidth-synthesis technique in the same way as with geodetic VLBI. Regarding the delay measurement for the spacecraft, two sorts of delay observables—group delay and phase delay—are under investigation. Since the bandwidth of the spacecraft's signal is not so wide as quasar, the precision of group delay observable is not always enough depending on the signal types. Thus phase delay is thought as alternative choice to get higher delay resolution, even the ambiguity of phase is an issue to be solved. Data reduction of group delay is performed with software correlator *fx\_cor* as the same with geodetic VLBI. Phase delay observables are extracted with a special correlation software for the signal of spectral line. The flexibility in this kind of special data processing is an advantage of software correlator.

### 2.3. Data Processing of Wide-band and Real Time VLBI

Two sorts of VLBI experiments with wide bandwidth in single channel were performed with Kashima 34m and Kashima 11m antennas. One experiment is performed in 4 Gbps (2Gsps-2bit) data rate. Observed signal was sampled with ADS-3000 [2] and recorded with 2 set of PCs through VSI-interface cards at each station. Software correlator developed by Takeuchi was used for processing. The result of first fringe with the ADS-3000 is reported in IVS-GM 2006[2].

Another VLBI experiment was real-time VLBI with ADS-1000 sampler [3]. Observation data rate was 1 Gbps (512Msps-2bit), although a quarter of the data rate was taken for real-time correlation processing and other part of data was discarded. Then real-time correlation processing in the data rate 256 Mbps (128Msps-2bit) was achieved via a software correlator, which is developed by M. Kimura. This processing was performed with Optiron Dual core 1.6GHz CPU. The reason for discarding three quarters of data rate was the limited hardware resources at that time. Real-time Giga-bit rate processing should be available with some more PC resources with high performance CPUs. Further information on the technology development will be found in NICT Technology

Development Center report in this issue [4].

## 2.4. KSP Correlation System

KSP correlation system[5, 6] was operational (Figure 2), although data processing with hardware correlator was not performed in this year. Geodetic VLBI experiments of Antarctica, which are organized by National Institute of Polar Research (NIPR), have been recorded with K4 and S2 system so far. Now K5 VLBI system is installed and used for VLBI observation in Syowa station in Antarctica; still some VLBI data recorded in S2 and K4 system are not completely processed yet. Thus the use of our KSP correlation system for the data processing of those VLBI experiments is being consulted now.



Figure 2. KSP Correlator room. The KSP hardware-correlation system, which has capability of 4 stations and 6 baselines of tape-based VLBI data processing.

## 3. Staff

- Tetsuro Kondo is working for development of software correlators, which is mainly used for geodetic VLBI.
- Yasuhiro Koyama is in charge of overall activity in our group. He is intensively working on e-VLBI on intercontinental baseline.
- Mamoru Sekido is in charge of KSP correlation system and is working on VLBI applications for spacecraft navigation.
- Moritaka Kimura is working on the development of a high speed Giga bit software correlator. He is in charge of development of next generation software correlators for VERA project of National Astronomical Observatory in Japan.
- Hiroshi Takeuchi is working on the next generation high speed sampler (ADS-3000), which has programmable data processing (digital BBC) capability, and software correlator for it.



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- [5] Hitoshi Kiuchi, Tetsuro Kondo, and Mamoru Sekido: KSP VLBI System; Correlation Processing System, J. Commun. Res. Lab., Vol. 46, No. 1, pp.47-53, March 1999
- [6] Mamoru Sekido, Tetsuro Kondo, and Hitoshi Kiuchi: KSP VLBI System; Real-Time Correlation Processing Control Software, J. Commun. Res. Lab., Vol. 46, No. 1, pp.91-96, March 1999

# Tsukuba VLBI Correlator

*Morito Machida, Masayoshi Ishimoto, Kazuhiro Takashima*

## Abstract

This is a report of the activities at the Tsukuba VLBI Correlator in 2005.

## 1. General Information

The Tsukuba VLBI Correlator, located in Tsukuba, Ibaraki, is a part of VLBI components operated by the Geographical Survey Institute (GSI), as well as the Tsukuba 32-m VLBI station (TSUKUB32). Intensive sessions (IVS-INT02) performed on Saturday and Sunday with TSUKUB32 - WETTZELL baseline for monitoring UT1-UTC have been correlated by K5 correlation system at the Tsukuba VLBI Correlator. Processing of JADE series (geodetic sessions with domestic VLBI network of GSI, run for 24-hour) is also a major task for the Tsukuba VLBI Correlator.

## 2. Component Description

The Tsukuba VLBI Correlator fully switched to K5/VSSP correlation processing in April 2005, while efforts to shift correlations system from K4 to K5/VSSP had started in autumn of 2004. K5/VSSP enables us to process data on K5/VSSP software correlator for K5 acquisition system and to put raw data from every four channels per scan into Linux files which are stored in removable disk cartridges as formatted binary files.

Equipment for K5/VSSP software correlation system at the correlator currently consists of 24 Linux computers as the data servers—each of which can share a couple of disk cartridges at once through a drive unit with 16 drive slots, eight rack mount Linux computers with 3GHz Intel Xeon dual CPUs as the correlation servers and one Linux computer for file handling and management (Figure 2). Each disk cartridge from stations is connected to a data server in an external mounting mode. Accessing raw data and auxiliary files such as schedule, session log and a priori are transparent to the operator because directories are shared among computers by Network file system (NFS).

To make software correlation from raw data within the equipment, the most essential elements are four kernel programs: “apri\_calc”, “cor”, “sdelay” and “komb”. They were originally designed and developed by National Institute of Information and Communications Technology (NICT). Based on an agreement of research cooperation between GSI and NICT, the Tsukuba VLBI Correlator is allowed to take advantage of these products which are licensed under NICT. “apri\_calc” calculates a priori delay and rate for each scan per single baseline. “cor” executes software correlation. “sdelay” makes rough fringe directly from correlator output. “komb” is a bandwidth synthesis program to obtain multi-band delay.

The kernel programs have coverage to process only one scan data of single baseline. There was an increase in the number of sessions to process at the Tsukuba VLBI Correlator. The use of the four kernel programs alone in the software correlation was too simple to meet the demands for processing many scans for multi-baselines. As a solution, we have developed an intelligent

application software, “PARNASSUS” (Processing Application in Reference to NICT’s Advanced Set of Softwares Usuable for Synchronization), to handle sessions of multi-baselines, which gives the operator a tool at hand that provides a graphical user interface and facilitates multi-task control. The application succeeds in optimizing operator’s input into kernel program and comprehensively handling distributed correlation.

CALC/SOLVE developed by NASA/GSFC is installed on HP workstation to produce primary solution.

One problem with introducing K5/VSSP was that many computers together in a machinery room made a continuously low frequency audio noise, which could affect the operators working in close proximity. Therefore, we prepared operator’s room in another room.

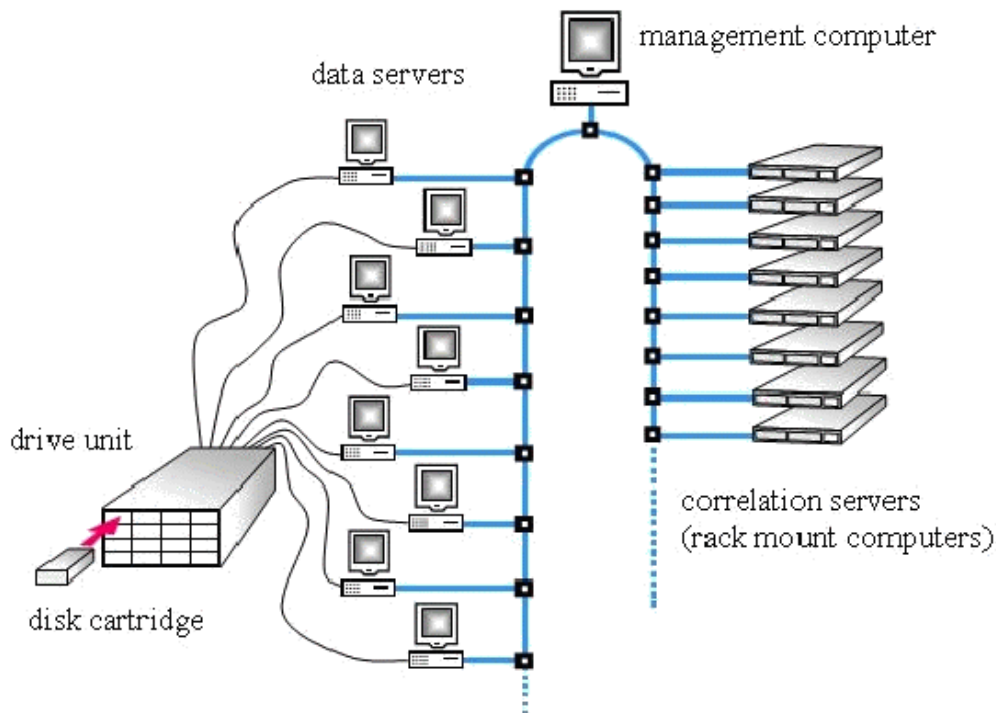


Figure 1. Equipment of K5/VSSP correlation system

### 3. Staff

List of the staff at the Tsukuba VLBI Correlator in 2005 is as follows. Staff in the field of observation team are listed in the table on the page of Tsukuba 32-m VLBI station in Network Stations section of this volume. S. Kurihara, skilled operator at Tsukuba 32-m, technical staff at the Tsukuba VLBI Correlator and VLBI analyst for six years in VLBI group of GSI, has left for a new career. In his stead, K. Kokado took over the responsibility of VLBI analysis with support from K. Takashima([1]). Routine operations were mainly performed under contract with Advanced

Engineering Services Co.,Ltd (AES) over 200 days in this year. AES was asked for 24 additional days of routine operations which were funded by National Astronomical Observatory of Japan.

- K. Takashima : Operation manager (GSI)
- M. Ishimoto : technical staff, Intensive set-up & e-VLBI, technical development (GSI)
- M. Machida : technical staff, correlation chief, evaluation of correlated data (GSI)
- K. Nozawa : main operator in routine correlation processing (Advanced Engineering Services Co., Ltd)
- K. Takano : sub operator in routine correlation processing, software engineer for “PARNASSUS” (Advanced Engineering Services Co., Ltd)



Figure 2. (from left) K. Takashima, M. Ishimoto, M. Machida, K. Takano, K. Nozawa

#### 4. Current Status and Activities

During 2005, 80 Intensive sessions (IVS-INT02) with TSUKUB32-WETTZELL single baseline for UT1, two Intensive sessions (IVS-INT02) with TSUKUB32-ONSALA60 single baseline for UT1, one Intensive session (IVS-INT02) with TSUKUB32-ONSALA60-WETTZELL baselines for UT1, 12 geodetic sessions by domestic network for 24-hour (JADE series) were processed at the Tsukuba VLBI Correlator. Y. Fukuzaki (GSI) processed three Syowa VLBI experiment (SYW sessions) using K4 correlator: SYW027, SYW031 and SYW032.

As mentioned, it was one of the major issues at the Tsukuba VLBI Correlator in 2005 to shift toward K5/VSSP correlation processing. Before the switch was accomplished in April, 24 Intensive and three JADE sessions were processed on K4 correlator. Remaining 59 intensive and nine JADE sessions were processed with K5/VSSP correlation system.

There were some steps toward a full combination of “PARNASSUS”, just referred to as “K5 utility software” in the previous annual report. The idea of developing application to aid operator’s input came to us in autumn of 2004. To start with, we divided its general function into calculating apriori delay & rate, executing correlation, bandwidth synthesis and creating databases. As a private advisory group, K. Takashima, M. Ishimoto and M. Machida were in charge of planning, primary design, requirements definition and functional specification to the application. K. Takano took control of structural design, coding, programming, testing and installation as a developer. The development is still ongoing.

- March 2005, PARNASSUS 1.0 covered calculating apriori delay & rate
- September 2005, PARNASSUS 1.1 covered executing correlation

- December 2005, PARNASSUS 1.2 covered bandwidth synthesis

K5/VSSP got along with e-VLBI in processing Intensive sessions. Data were recorded on K5/VSSP at TSUKUB32 and on Mark 5 at WETTZELL. Shortly after observation, recorded data at WETTZELL were transferred to GSI through internet. After converting Mark 5 to K5 in one or two hours, correlation was processed on K5/VSSP in distributed computing at the Tsukuba VLBI Correlator. Processing and making primary solution of Saturday and Sunday Intensives were usually completed in a day. Emphasis of processing Sunday and Saturday Intensive sessions by K5/VSSP with data transfer via e-VLBI was getting database submission to IVS within one or two days after observation. K5/VSSP correlation system, performing more efficiently in processing data, and e-VLBI, being one of next generation VLBI technique, was a close association which led to convenience not only for the correlator staff, but also users expecting UT1 as soon as possible for navigation, spacecraft control mission or land survey. Especially, “Deep Impact” in July was a sort of challenge even for us to assist with processing VLBI data of Intensive sessions for UT1. The success of the mission brought an encouragement to us since rapidly processing data came from our usual practice with distributed computing of K5/VSSP and transferring data via e-VLBI.

The Tsukuba VLBI Correlator has presented its detailed current status and activities at the VLBI community in Japan ([2]).

## 5. Plan for 2006

- It is planned to process the TSUKUB32/WETTZELL Intensive sessions (IVS-INT02) with the K5 system. The sessions are to be performed on both Saturday and Sunday with K5 (TSUKUB32) and Mark 5 (WETTZELL) systems. The Tsukuba VLBI Correlator is also expected to be responsible for processing 12 geodetic sessions (JADE) of domestic VLBI network of GSI.
- One of our aim to speed up processing is to work on expansion of our K5 correlation system. We will add eight correlation servers and eight data servers to existing K5/VSSP correlation system.
- Development and test of interactive “PARNASSUS 1.3”, having coverage from calculating a priori to making up database is one of the priorities in the first half of 2006. Some implementation plans for “PARNASSUS 2”, run in batch mode will be discussed in the advisory group of VLBI team of GSI.
- Former K4 correlator equipment will be removed by March 2006.
- We have a plan for estimating antenna thermal deformation from antenna elements, expansion coefficients, elastic stiffness constant, measured body temperature of antenna mounting frame, with taking approach of finite element method.

## References

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# Washington Correlator

*Kerry A. Kingham, Brian J. Luzum*

## Abstract

This report summarizes the activities of the Washington Correlator for the year 2005. The Washington Correlator provides up to 80 hours of processing per week, primarily supporting Earth Orientation and astrometric observations. In 2005 the major programs supported include the IVS-R4, IVS-INT, IVS-R1, IVS-T, CONT05 and CRF and CRFD experiments.

## 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 experiments. All of the weekly IVS-R4 sessions, all of the daily intensives, and several IVS-R1 sessions and 8 out of 15 CONT05 days were processed at WACO. The remaining time was spent on terrestrial reference frame and astrometry sessions. The facility houses a Mark IV Correlator.

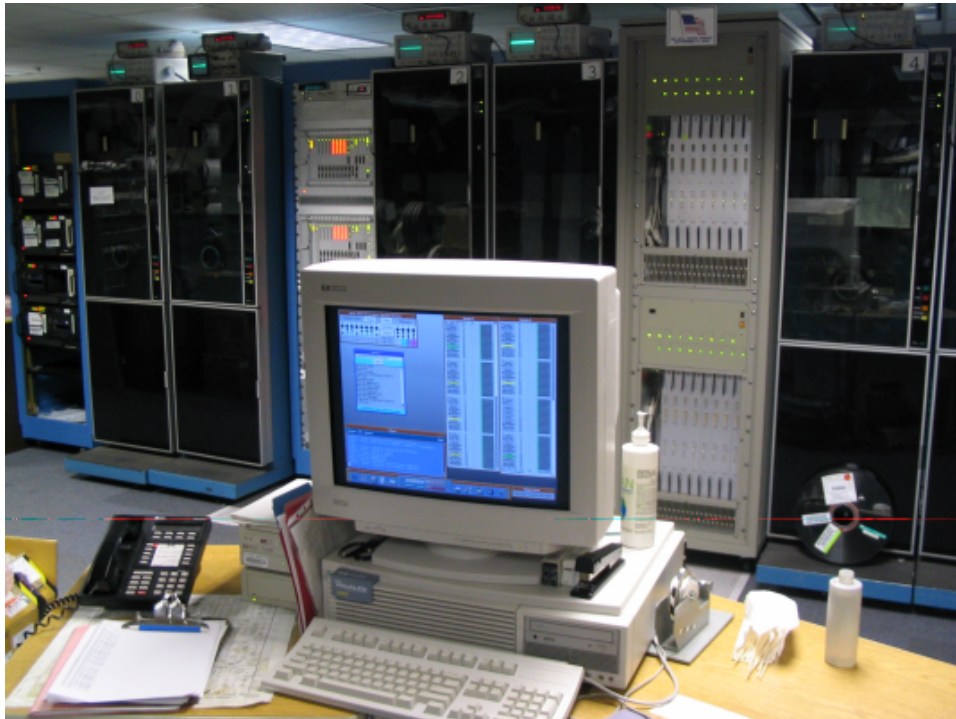


Figure 1. The left half of WACO showing 4 Mark 5A units (left), tape drives, the operator's console, and the central processor (right).

## 2. Correlator Operations

The Washington Correlator sent a Mark 5A unit to Fortaleza Station to upgrade that R4 station to Mark 5 operation. This upgrade allowed the R4s to be all Mark 5A which lowered the processing factor from 1.25 to under 1.0. Thus, the R4s take less time to process at the correlator than they do to observe. This increase in efficiency allowed the correlator hours to be reduced from 136 hours per week to 80 hours per week and still keep up with IVS processing.

The Washington Correlator processed 8 of the 15 CONT05 days, processing 5 of them twice in order to make the processing of the 15 days uniform at all correlators. The processing was still completed by the end of 2005 despite the extra processing and the fact that 3 passes were required for complete processing. Normal rapid processing of the R4s and INTs were not disrupted during this process.

Starting in July, 2005, 2 Intensives per month included Svetloe as well as Wettzell and Kokee in order to characterize the Kk-Sv baseline as a planned alternate to Kk-Wz should Wz not be able to observe. Work continues to find an alternate for Kk should Kk be unable to observe.

The Intensive observations from Wettzell were electronically transferred to the Washington area and transported to the correlator. This operation saved 1 to 2 days in shipping time.

Table 1 lists the experiments processed during 2005.

Table 1. Experiments processed during 2005

50	IVS-R4 experiments + 2 CONT days as Rapids
10	CRF (Celestial Reference Frame)
2	IVS-R1
2	APSG (Asia Pacific)
2	IVS-T (Terrestrial Reference Frame)
8	CONT05 days
226	Intensives
11	Kk-Sv-Wz Intensives

## 3. Staff

The Washington Correlator is under the management and scientific direction of the Earth Orientation Department of the U.S. Naval Observatory. USNO personnel continue to be responsible for overseeing the scheduling and processing. During the period covered by this report, a private contractor, NVI, Inc., supplied a contract manager and correlator operators. An addition to the staffing this year is Dr. Brian Luzum who is assisting with the review of experiment processing.

Table 2 lists staff and their duties.

## 4. Outlook

The Washington Correlator plans to upgrade the Mark 5A playbacks to Mark 5B coordinated with the installation of Mark 5Bs at the Network Stations. It is expected that the number of

playbacks available will increase to 10 with the addition of 2 Mark 5B units.

Table 2. Staff

<b>Staff</b>	<b>Duties</b>
Dr. Kerry Kingham (USNO)	VLBI Correlator Project Scientist
Dr. Brian Luzum (USNO)	VLBI Correlator Scientist
Bruce Thornton (NVI)	Operations Manager
Harvis Macon (NVI)	Lead Correlator operator,
Roxanne Inniss(NVI)	Media Librarian
Joseph Granderson (NVI)	Correlator Operator
Kenneth Potts (NVI)	Correlator Operator
Firew Waktole (NVI)	Correlator Operator



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# Data Centers

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# BKG Data Center

*Volkmar Thorandt, Reiner Wojdziak*

## Abstract

This report summarizes the activities and background information of the IVS Data Center for the year 2005. Included are 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 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 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 the users need to obtain username and password to get access (please contact the Data Center staff).

An incoming script is watching this incoming area and checking the syntax of the files sent by IVS components. If it is o.k. 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 Data Center by sending e-mails about its activities. The incoming script is part of a technological unit which is responsible for managing the IVS and the Operational Data Center and to carry out first analysis steps in an automatic manner. All activities are monitored to

guarantee data consistency and to control all analysis steps from data incoming to delivering of analysis products to IVS.

Public access to the BKG Data Center is available through FTP:

```
ftp.leipzig.ifag.de
uid: anonymous
pw: e-mail address
cd vlbi
```

respectively

WWW: <http://www.leipzig.ifag.de/VLBI>

Structure of BKG IVS Data Center:

```
vlbi/           : root directory
ivs-iers/       : VLBI products for IERS
ivs-pilot2000/  : directory for special investigations
ivs-pilot2001/  : directory for special investigations
ivs-pilotbl/    : directory for baseline time series
ivs-pilottro/   : directory for tropospheric time series
ivs-special/    : special CRF investigations
ivscontrol/     : controlfiles for the data center
ivsdata/        : VLBI observation files
ivsdocuments/   : IVS documents
ivsproducts/    : analysis products
                 (earth orientation, terrestrial and celestial frames,
                 troposphere, daily sinex files)
raw/            : raw files
```

## 2. Technical Equipment

HP Workstation (HP UX B11.23 U ia 64 operating system)  
disk space: 190 GBytes (Raid system)  
internet rate: 34 MBit/sec  
backup: automatic tape library

## 3. Staff Members

Volkmar Thorandt (coordination, data analysis, data center, volkmar.thorandt@bkg.bund.de)  
Reiner Wojdziak (data center, web design, reiner.wojdziaak@bkg.bund.de)  
Dieter Ullrich (data analysis, data center, dieter.ullrich@bkg.bund.de)  
Gerald Engelhardt (data analysis, gerald.engelhardt@bkg.bund.de)

# CDDIS Data Center Summary for the 2005 IVS Annual Report

*Carey Noll*

## Abstract

This report summarizes activities during the year 2005 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, staffing 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 archive and distribution of Very Long Baseline Interferometry (VLBI) data since its inception in 1982. The CDDIS is a central facility providing users access to raw and analyzed data to facilitate scientific investigation. A large portion of the CDDIS holdings of GPS, GLONASS, laser ranging, VLBI, and DORIS data are stored on-line for remote access. Information about the system is available via the WWW at the URL <http://cddis.gsfc.nasa.gov>. 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 are accessible to the public via anonymous ftp access.

### 2.1. Computer Architecture

A new Linux server, [cddis.gsfc.nasa.gov](http://cddis.gsfc.nasa.gov), became operational in early 2005, replacing the UNIX server [cddisa.gsfc.nasa.gov](http://cddisa.gsfc.nasa.gov). This dedicated server has over 3.5 Tbytes of on-line magnetic disk storage; approximately 310 Gbytes are devoted to VLBI activities. A dedicated DLT tape system is utilized for system backups. The CDDIS is located at NASA GSFC and is accessible to users 24 hours per day, seven days per week.

### 2.2. Staffing

Currently, a staff consisting of one NASA civil service employee and 2.5 contractor employees supports all CDDIS activities (see Table 1 below).

## 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 below (a figure illustrating the flow of information, data, and products between the various IVS components was presented in the

Table 1. CDDIS Staff

Name	Position
Ms. Carey Noll	CDDIS Manager
Dr. Maurice Dube	Head, CDDIS contractor staff and senior programmer
Ms. Ruth Labelle	Request coordinator
Ms. Laurie Batchelor	Senior technical specialist (part-time)

CDDIS submission for the 2000 IVS annual report). In brief, an incoming data area has been established on the CDDIS host computer, [cddis.gsfc.nasa.gov](http://cddis.gsfc.nasa.gov). Operations and analysis centers deposit data files and analyzed results using specified file names to appropriate directories within this filesystem. Automated archiving routines, developed by GSFC VLBI staff, peruse the directories and migrate 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 subdirectories 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 data base 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 2005, over 130 user organizations accessed the CDDIS on a regular basis to retrieve VLBI related files. Nearly 25K VLBI-related files were downloaded per month from the archive.

#### 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.

Table 2. IVS Data and Product Directory Structure

Directory	Description
<b>Data Directories</b>	
vlbi/ivsdata/db/yyyy	VLBI data base files for year <i>yyyy</i>
vlbi/ivsdata/ngs/yyyy	VLBI data files in NGS card image format for year <i>yyyy</i>
vlbi/ivsdata/aux/yyyy/sssss	Auxillary files for year <i>yyyy</i> and session <i>sssss</i> ; these files include: log files, wx files, cable files, schedule files, correlator notes
<b>Product Directories</b>	
vlbi/ivsproducts/crf	CRF solutions
vlbi/ivsproducts/eopi	EOP-I solutions
vlbi/ivsproducts/eops	EOP-S solutions
vlbi/ivsproducts/icr	CRF solutions
vlbi/ivsproducts/trf	TRF solutions
vlbi/ivsproducts/trop	Troposphere solutions
<b>Project Directories</b>	
vlbi/ivs-iers	IVS contributions to the IERS
vlbi/ivs-pilot2000	IVS Analysis Center pilot project (2000)
vlbi/ivs-pilot2001	IVS Analysis Center pilot project (2001)
vlbi/ivs-pilotbl	IVS Analysis Center pilot project (baseline)
vlbi/ivsproducts/ivs-pilottro	IVS Analysis Center pilot project (troposphere)
vlbi/ivs-special	IVS special analysis solutions
<b>Other Directories</b>	
vlbi/ivscontrol	IVS control files (master schedule, etc.)
vlbi/ivsdocuments	IVS document files (solution descriptions, etc.)

# Italy INAF Data Center Report

*M. Negusini, P. Sarti, S. Montaguti*

## Abstract

This report summarizes the activities of the Italy INAF VLBI Data Center. We also report about some major changes that occurred during 2004: we have changed the affiliation of our Institute and the location of the DC, officially starting from 1st January 2005. Modification of names and codes necessary for the IVS affiliation will be requested and performed during 2006. A new contact person for the IVS DC will be indicated, soon.

## 1. Introduction

Our Geodesy section and its Data Center moved to the Bologna headquarter during the year 2004, leaving the former location at the Center of Space Geodesy, Matera. This decision was partly due to the reorganization process that was started by the Italian Government in June 2003, and integrated the Institute of Radioastronomy (IRA) into INAF (Italian National Institute for Astrophysics; <http://www.inaf.it>). Therefore, as of 1st January 2005, IRA is not part of the Council of National Research (CNR) anymore. The structure of IRA, as well as its territorial organization, has changed: it is now a section of INAF, the latter being the main institute. In its constitution act, INAF is explicitly indicated as the national institute in charge of promoting, both at national and international levels, the activities related to astronomy, astrophysics and radioastronomy. The geodetic activities of IRA are continued within the new institute, but the Geodetic Division changed location and structure. At the moment, the main analysis activity and storage is concentrated in Bologna, where we store and analyze single databases, using CALC/SOLVE software. We are using f-solve regularly updated.

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 antennas. However we also store all the databases with the Ny-Ålesund antenna observations. Since 2002, we store all the databases available on the IVS data centers, starting from 1999. All the databases have been processed and saved with the best selection of the 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 (at present only for EUROPE experiments for the years 1998 and 1999), as if they were produced by a WVR. Also these databases are available and stored with a different code from the original databases. For this we have produced a modified version of DBCAL, available to external users.

## 2. Computer Availability and Routing Access

The main computer is an HP 785/B2600 workstation. The Internet address of this computer is [boira3.ira.inaf.it](mailto:boira3.ira.inaf.it) and the databases are stored in different directories and on different disks as well. The complete list of directories where databases are stored is the following:

- 1 = /data1/mk3/data1
- 2 = /data1/mk3/data2



4 = /data6/dbase6  
6 = /data5/dbase5  
5 = /data4/dbase4  
7 = /data7/dbase7  
8 = /data8/dbase8  
9 = /data9/dbase9  
10 = /geo/data  
11 = /geo/1999  
12 = /geo/2000

The username for accessing the database at the moment is geo. The password can be requested by sending an e-mail to negusini@ira.inaf.it.

The main computer that was formerly located in Matera, and that was moved to Bologna, is an HP282 computer with Internet address hp-j.ira.inaf.it. The databases are stored in the following directories:

7 = /data8/dbase8  
8 = /data10/dbase10

The superfiles are stored in different directories:

/data2/super  
/data10/super10  
/data9/super9  
/data8/super8

The list of superfiles is stored in the file /data6/solve\_files/SUPCAT. The area for data storage has a capacity up to 366 gigabytes with the installation of an external server. The data can be accessed using the username geo, and the password can be requested by writing to negusini@ira.inaf.it.

# Data Center at NICT

*Yasuhiro Koyama*

## Abstract

The Data Center at National Institute of Information and Communications Technology (NICT) archives and releases the databases and analysis results processed at the Correlation Center and the Analysis Center at NICT. Regular VLBI sessions with the Key Stone Project VLBI Network were the primary objects 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

In April 2004, the Communications Research Laboratory was integrated with the Telecommunications Advanced Organization of Japan (TAO) to establish the National Institute of Information and Communications Technology (NICT) as a new institute. The IVS Data Center at NICT archives and releases the databases and analysis results processed by the Correlation Center and 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. Since routine observations of the KSP network terminated at the end of November 2001, there were no additional data for the KSP regular sessions since 2002. In 2005, two geodetic VLBI sessions were carried out and processed. The analysis results in the SINEX (Solution Independent Exchange) file format as well as other formats are available on the WWW server. Database files generated with the Mark III database file format are available upon request and will be sent to the users in DDS tape cartridges. 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 Data Center at NICT. In the past, an FTP server was used to provide data files, but it was decided to terminate the FTP service because of security risks of maintaining an anonymous FTP server. Instead, [www3.nict.go.jp](http://www3.nict.go.jp) WWW server was prepared to place large size data files.

Table 1. URL of the WWW server systems.

Service	URL
KSP WWW pages	<a href="http://ksp.nict.go.jp/">http://ksp.nict.go.jp/</a>
IVS WWW mirror pages	<a href="http://ivs.nict.go.jp/mirror/">http://ivs.nict.go.jp/mirror/</a>
Data server	<a href="http://www3.nict.go.jp/dk/c256/ivs/">http://www3.nict.go.jp/dk/c256/ivs/</a>

The maintenance of these server machines was moved from the VLBI research group of NICT to the common division for the institutional network service of the laboratory in 2001 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 (once every two days) basis until May 1999. The duration of each session was about 23.5 hours. Within that period, daily observations were performed from March 1 to April 1, 1999 to obtain continuous VLBI data series for various investigations such as studies about the atmospheric delay models and for the improvements of the data analysis technique. The high-speed ATM (Asynchronous Transfer Mode) network line to the Miura station became unavailable in May 1999 and the real-time VLBI observations with the Miura station became impossible. Thereafter, the real-time VLBI sessions were performed with three stations only— Kashima, Koganei, and Tateyama. 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 three stations except for 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 Kashima, Miura, and Tateyama stations to Koganei station for tape-based correlation processing of the full 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 since July 22, 2000. The daily sessions were continued until November 11, 2000, and the site motion of the Tateyama and Miura stations were monitored in detail. During the period, it was found that Tateyama station moved about 5 cm to the northeast direction. 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 addition to the KSP regular VLBI sessions, domestic and international geodetic VLBI sessions were conducted by NICT in cooperation with Geographical Survey Institute (GSI) and other organizations. These sessions are listed in Table 2. The observed data of these sessions were correlated by using the K-4 correlator and the K5 software correlator at NICT either at Koganei or at Kashima.

In 2005, two geodetic VLBI sessions were performed. The GEX13 session was carried out with the baseline between 11m VLBI stations at Kashima and at Koganei. The purpose of this session was to demonstrate the capability of the newly developed multi-channel Giga-bit A/D sampler unit ADS2000 [2]. At both stations, the ADS2000 sampler unit was used to sample 10 X-band channels and 6 S-band channels at the sampling data rate of 32MSPS for each channel and the digitizing

Table 2. Geodetic VLBI sessions conducted by NICT (since 2003)

Year	exp. names	sessions
2003	CUTE	CUTE04
	K5 Test	U03031, JD0306
	e-VLBI	evlbi4, tsev6
	Nozomi	34 sessions
	Hayabusa	10 sessions
2004	e-VLBI	tsev7, tsev8
	Geodetic	U04306
	Hayabusa	5 sessions
	Huygens	2 sessions
2005	Geodetic	c0505 (CONT05, partial participation), GEX13
	Hayabusa	14 sessions

level of 2 bits/sample. The data observed at Koganei site were transferred to Kashima over the high speed network, and processed with the K5 software correlator. As the results from the session, the baseline length between two sites was estimated with an RMS uncertainty of 1.3 mm, and the performance of the ADS2000 sampler unit was demonstrated. Another geodetic VLBI session, c0505, was performed for 24 hours from 17:30 UT on September 16. The session was one of the 15 continuous global sessions of CONT05, and 34m VLBI station at Kashima was used to record data according to the c0505 observation schedule. Only the KASHIM34-TSUKUB32 baseline was processed for correlation processing by using the K5 software correlator. The main purpose of this partial participation of the 34m VLBI station at Kashima was to evaluate the performance of the extended X-band receiver. After the session, fringes were detected on all channels observed during the c0505 session and the performance of the extended X-band receiver was evaluated. The receiver noise temperature is worse in the upper edge of the extended X-band receiver, and we plan to improve the receiver noise characteristics in the upper edge.

Hayabusa spacecraft was launched on May 9, 2003 by JAXA to investigate the asteroid Itokawa. The X-band telemetry signal from the spacecraft was used to demonstrate precise orbit determination by means of VLBI observations. Since a precise orbit determination of Hayabusa was required to efficiently navigate the spacecraft on its approach to the asteroid Itokawa, many VLBI stations in Japan including the 34-m and 11-m VLBI stations at Kashima and 11-m VLBI station at Koganei participated in the observations. Hayabusa finally approached Itokawa in September 2005 and test VLBI experiments of the spacecraft were performed before and after the arrival of the spacecraft at the asteroid.

Figure 1 shows the number of geodetic VLBI sessions and number of valid observed delays used in the data analysis for each year up to the year 2005.

### 3. Staff Members

The data center at NICT is operated and maintained by the Radio Astronomy Applications Group at Kashima Space Research Center, NICT. The staff members are listed in Table 3.

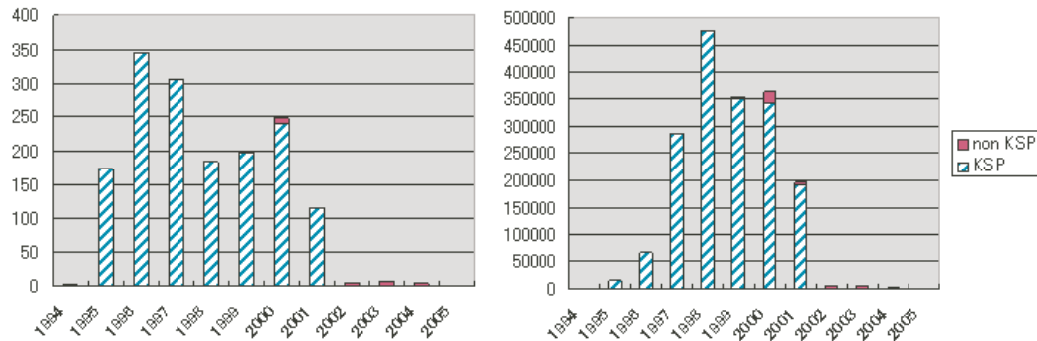


Figure 1. Number of sessions (left) and observed delays (right) used in the data analysis.

Table 3. Staff members of Radio Astronomy Applications Group, KSRC, NICT

Name	Main Responsibilities
Tetsuro KONDO	Research Center Supervisor / Software Correlator
Yasuhiro KOYAMA	Group Leader / International e-VLBI
Eiji KAWAI	Antenna system
Ryuichi ICHIKAWA	Spacecraft VLBI
Junichi NAKAJIMA	VLBI System Developments
Mamoru SEKIDO	Spacecraft VLBI
Hiroshi TAKEUCHI	VLBI System Developments
Moritaka KIMURA	VLBI System Developments
Hiromitsu KUBOKI	Antenna System
Masanori TSUTSUMI	System Engineer
Atsutoshi ISHII	Developments for Small Antenna System

#### 4. Future Plans

Although the regular VLBI sessions with the KSP VLBI network finished in 2001, the IVS Data Center at NICT will continue its service and will archive and release the analysis results accumulated by the Correlation Center and Analysis Center at NICT. In addition, a number of VLBI sessions will be conducted for the purposes of various technology developments.

#### References

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# Paris Observatory (OPAR) Data Center

*Christophe Barache*

## Abstract

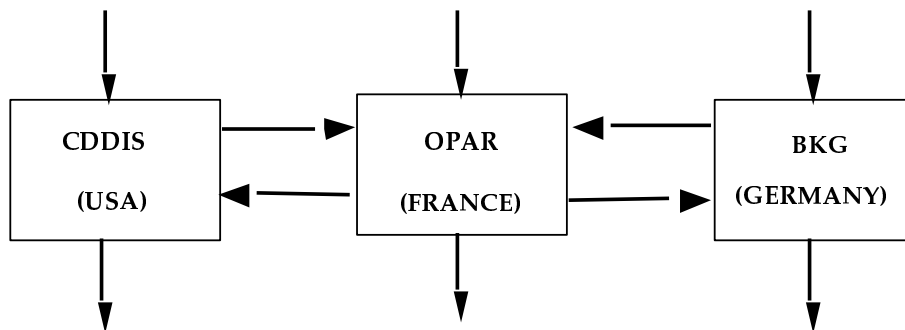
This report summarizes the OPAR Data Center activities in 2005. Included is information about functions, architecture, status, future plans and staff members of OPAR Data Center.

## 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 (auxilliary, database, products, documents),
- mirrors the other ones every three hours,
- gives free FTP access to the files.



This protocol gives the IVS community a transparent access to a data center through the same directory, and a permanent access to files in case of a data center breakdown.

## 2. Architecture

To be able to put a file in a Data Center, operation and analysis centers have to be registered by the IVS Coordinating Center. The file names have to conform to the name conventions. A script checks the file and puts it in the right directory. The script undergoes permanent improvement and takes into account the IVS components' requests.

The structure of IVS Data Centers has evolved since 2004, the raw data and specific studies has been added:

```

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/          : auxilliary files (schedule, log...)
  db/           : observation files in data-base 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
  trop/         : Tropospheric time series (starting july 2003)
raw/            : original data (not writable actually at OPAR Data Center)
ivs-iers/       : provides products for IERS Annual Report
ivs-pilot2000/  : provides products of 2000 for special investigations
ivs-pilot2001/  : provides products of 2001 for special investigations
ivs-pilottro/   : provides tropospheric time series for Pilot Project
                  (until june 2003)
ivs-pilotbl/    : provides baselines files
ivs-special/    : specific studies

```

### 3. Current Status

The OPAR Data Center is operated actually on a PC located at Paris Observatory, and running the Debian 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 more than 120 GB disc storage for VLBI activities.

The OPAR server is accessible 24 hours per day, seven days per week through Internet connection with 2Mbit/s rate. Users can get the IVS products by using the FTP protocol. Access to this server is free for users.

FTP access:

```

ivsopar.obsmp.fr
username : anonymous
password : your e-mail
cd vlbi (IVS directory)

```

#### 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 ensure better access and get the possibility to make available raw data in the OPAR Data Center, we ordered a new PC (PowerEdge 2800 - Xeron 3.0 Ghz), including a RAID 600Gb disk system extensible up to 4.7 Tb.

#### 5. Staff Members

Staff members who are contributing to OPAR Data Center and Analysis Center for IVS are listed below :

- Christophe Barache, Data Center manager and Data Analysis.
- Anne-Marie Gontier, responsible for GLORIA Analysis Software.
- Martine Feissel, scientific developments.
- Daniel Gambis, interface with IERS activities.

To obtain information about the OPAR data center please contact: [ivs.opa@obspm.fr](mailto:ivs.opa@obspm.fr)



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# Analysis Centers

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# Analysis Center of Saint-Petersburg University

*Maria Kudryashova, Veniamin Vityazev*

## Abstract

This report includes information about the activity of the Analysis Center of Saint-Petersburg University for the year 2005, staff members and background information. This year we focused our efforts on the study of polar motion in diurnal frequency band. Some results are presented here.

## 1. Introduction

Sobolev Astronomical Institute is located in Petrodvorets, near St. Petersburg. It is a research institute of the Saint Petersburg State University. In 1998 Analysis Center of Saint Petersburg University was established in the Institute. The main activity of AC SPU for International VLBI Service consists in routine processing of 24-hours and 1-hour observational sessions for obtaining Earth Orientation Parameters (EOP) and rapid UT1-UTC values respectively. During the year 2005 activity of AC SPU was supported by Ministry of Education and Science of Russian Federation (in frame of grant 37847).

## 2. Staff

The staff members who are involved in the activities of the Analysis Center are listed below:

- Veniamin Vityazev – Director of Astronomical Institute of Saint-Petersburg University, PhD., Prof. General coordination and support of activity at the Astronomical Institute.
- Maria Kudryashova – Research assistant of Astronomical Institute of Saint-Petersburg University. Processing of VLBI data.

## 3. Activities in 2005

As in the previous years we continued to provide the series of five EOPs (spu0003i.eops) and rapid estimations of UT1-UTC (spu00002.eopi) values on a regular basis. Detailed description of the solutions obtaining strategy have been given in our previous reports (see for instance [1], [2]). This year we add sessions from Int2 observational program in the process of obtaining our intensive solution spu00002.eopi. During the year 2005 our main efforts have been focused on the analysis of sub-diurnal variations of Polar Motion (PM).

### 3.1. Derivation of Sub-Diurnal Polar Motion

In our analysis we used observations from 24-hour geodetic VLBI sessions from January 1989 till April 2004. Whole amount of the processed experiments was 987. The time span covered by these data was longer than 15 years.

In order to obtain a time series of Polar Motion (PM) with sub-diurnal resolution we applied the least-square collocation method (LSQM) as it is implemented in OCCAM 6.0 software. In frame of this method, a model with 3 types of parameters is realized (see [5]). These three groups of parameters are the following:

1. global parameters under which radiSOURCE positions are usually comprehended;
2. “daily” parameters which are supposed to be constant during each 24-hour session (among these parameters were corrections to station coordinates, offsets of the Celestial Ephemeris Pole as well as the statistical expectations of stochastic parameters);
3. stochastic parameters (as such parameters we treated  $x, y$  coordinates of the pole,  $UT1 - UTC$ , clock rates and offsets, zenith delays and tropospheric gradients).

In this study an improvement of the existing Celestial Reference Frame (CRF) was not of our interest, therefore we just fixed the CRF to a priory catalogue ICRF-Ext.1. Thus we assumed that we know the radiSOURCE coordinates quite exactly. In this case model with three groups of parameters could be reduced to the model with two groups of them:

$$Bv + Cw + \xi = l, \quad (1)$$

where  $l$  is the vector of differences between the observed and calculated values (O-C);  $\xi$  is the vector of measurement errors;  $B, C$  are the matrices of partial derivatives;  $v$  is the vector of ‘daily’ parameters and  $w$  – stochastic ones. Formulas for estimating these parameters and more details concerning this procedure can be found in [3],[4], [5].

As a result of applying the LSQM we derive unevenly sampled time series of the PM and UT1-UTC. Note that in this series the model of the diurnal and sub-diurnal variations in polar motion and UT1 due to oceanic tides has already been taken into account. The model contains 71 diurnal and sub-diurnal terms and was calculated by R. Eanes based on the paper by Ray et al. (1994). The time resolution of the output ERP series is three to ten minutes during one session and two to seven days-long gaps between the sessions. As a result, it is needed to apply special methods of analysis.

### 3.2. Analysis of Polar Motion

Hereafter we will consider polar motion as complex value  $f = x - iy$ . In order to extract signals in the diurnal frequency band we used the method of complex demodulation. This method has been described in detail for instance in [6]. Here we only outline the main ideas of the method. After applying the demodulation transformation, frequencies  $\omega$  are transformed into  $\omega' = \omega - \sigma_0$ , where  $\sigma_0$  is the so-called demodulation frequency which could be chosen arbitrarily. In this work we used  $\sigma_0 = \Omega$  in order to extract prograde diurnal motion, where  $\Omega$  is a diurnal sidereal frequency equal to 1 cycle per sidereal day. In the frequency domain, due to the Fourier transform property, such transformation just shifts spectrum of the initial series by the value  $\sigma_0$  such a way that  $\omega = \sigma_0$  becomes 0.

The advantage of the transformation is that variations with frequencies from the vicinity of  $\sigma_0$  become long-periodical, i.e. slowly varying with time. All other variations are removed by a low-pass filter (Gaussian filter has been used here) which in addition significantly reduce an amount of values in the time series under estimation.

After applying the procedure described above, we derived the amplitudes ( $A$ ) and phases ( $\phi$ ) of the most powerful tidal components as well as a constant term by least-squares fitting. In the diurnal frequency band these components are  $P_1, S_1$  and  $K_1$ . First line of Table 1 contains refined estimations of  $A, \phi$  parameters of  $S_1, P_1$  terms in comparison with [3]. Amplitudes and phases of the terms have also been compared with the parameters inferred from geophysical data

(Atmosphere Angular Momentum - AAM). AAM series have been obtained from IERS Special Bureau for the Atmosphere [7].

Table 1. Amplitudes and phases of  $S_1$  and  $P_1$  components

	$S_1$		$P_1$	
	$A(\mu as)$	$\phi(deg)$	$A(\mu as)$	$\phi(deg)$
VLBI	4.8	-167.2	1.0	-66.7
AAM (mass term)	4.9	-169.7	0.8	13.0
AAMIB (mass term)	4.9	-169.7	0.8	13.0

As was expected, the most significant contribution in sub-diurnal polar motion after applying of tidal variations model [8] is due to  $S_1$  term. Parameters of this term derived from VLBI observations show very good agreement with those evaluated from AAM data in contrast to  $P_1, K_1$  components. It is due to the fact that the ocean tide contribution to the amplitude of  $S_1$  is about 4 times smaller than evaluated from VLBI data and thus this harmonic was not totally excluded by applying the Ray model. In contrast to  $S_1$  term, the amplitudes of  $P_1, K_1$  terms have already been taken into consideration in the model mentioned above.

## References

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- [5] Titov O. and Schuh H., 2000, Short periods in Earth rotation seen in VLBI data analysis by least-squares collocation methods, IERS Technical Note No 28, pp. 33-41.
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# Geoscience Australia Analysis Center

*Oleg Titov*

## Abstract

This report gives an overview about activity of the Geoscience Australia IVS Analysis Center during the year 2005.

## 1. General Information

The Geoscience Australia (GA) IVS Analysis Center is located in Canberra. After organizational changes the Geodesy group became part of the Geohazard and Earth Monitoring Division (GEMD).

## 2. Component Description

Currently the GA IVS Analysis Center contributes nutation offsets, three EOPs and their rates on regular basis for IVS-R1 and IVS-R4 networks and their predecessors (IRIS-A, NEOS-A). The EOP time series from 1983 to 2005 are available. Also the CRF catalogues using a global set of VLBI data since 1979 are regularly submitted.

## 3. Staff

- Dr. Oleg Titov - project officer

## 4. Current Status and Activities

The last global solution has been done using the new features of the OCCAM 6.1 software. VLBI data comprising 3348 daily sessions from 25-Nov-1979 till 10-Nov-2005 have been used to compute the global solution *aus2005c*. This includes 3,498,973 observational delays from 747 radiosources observed by 57 VLBI stations. Weighted root-mean-square of the solution is about 0.61 cm (about 21 picosec).

The *aus2005c* solution strategy used radiosources as close as possible to the ICRF-Ext.2 [1]. The radiosource catalogue includes 639 sources. Coordinates of 207 of the 212 defining sources [2] were treated as global and imposed by the NNR constraints. 107 'other' sources were treated as local and their positions were estimated for each VLBI session. The rest of 433 sources were treated as global without NNR constraints.

Station coordinates were also estimated using NNR and NNT constraints. The long-term time series of the station coordinates have been established to estimate the corresponding velocities for each station. Due to a limited amount of observations the velocities have been estimated for 52 stations only. Tectonic motion for Gilcreek VLBI site after the Denali earthquake is modelled using exponential function [3].

The adjustment has been done by least squares collocation method, which considers the clock offsets, wet troposphere delays and troposphere gradients as stochastic parameters with apriori

covariance functions. The gradient covariance functions were estimated from the GPS hourly values [4].

Also the GA Analysis Center continues the regular submission of EOPs to the IVS/IERS and works on the development of long-term time series for the EOP, station coordinates and comparison of techniques (VLBI, SLR, GPS) for EOP and ITRF adjustment.

## 5. Geodetic Activity of the Australian Radiotelescopes

During 2005 two Australian radiotelescopes (Hobart and Parkes) were involved in geodetic VLBI observations. Geodesy group promoted the observations in different ways.

The operations of the Hobart telescope for geodetic VLBI is supported through an Australian Research Council (ARC) grant awarded jointly to the University of Tasmania (UTAS) and GA.

The Parkes 64-meter telescope participated in three geodetic VLBI sessions in 2005. Four sessions are planned for 2006. This program is promoted in cooperation with the Australian Telescope National Facility (ATNF).

## 6. Future Plans

- update OCCAM software
- submit proposal to establish new geodetic VLBI network included 3-4 new small size fast moving telescopes around Australia
- participation in analysis of simulated VLBI data for optimization of design for the geodetic VLBI network in Australia

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# Bordeaux Observatory Analysis Center Report

*Patrick Charlot, Antoine Bellanger, Géraldine Bourda, Julio Camargo, Alain Baudry*

## Abstract

This report summarizes the activities of the Bordeaux Observatory Analysis Center during the year 2005. On the analysis side, we completed processing of seven years of NEOS-A/IVS-R4 data (1999–2005) and three years of IVS-R1 data (2003–2005) with the MODEST software. Additionally, we have been involved in testing the VLBI model of the GINS software for multi-technique combination at the raw data level. On the research side, our major achievements include the completion of observing for our ICRF densification project in the northern sky, the study of source structure index temporal variability—which led to the identification of 242 ICRF sources with potentially high astrometric quality—and a newly-developed activity aimed at monitoring the structure of the ICRF sources based on the RDV data. Plans for the year 2006 follow the same analysis and research lines.

## 1. General Information

The Observatory of Bordeaux is located in Floirac, near the city of Bordeaux, in the southwest of France. It is funded by the University of Bordeaux and the CNRS (National Center for Scientific Research). IVS analysis and research activities are attached to the M2A group (“Métrologie de l’espace, Astrodynamique, Astrophysique”) led by P. Charlot.

Our Analysis Center’s work is primarily focused on the maintenance, extension, and improvement of the celestial reference frame. In particular, we initiated an observing program on the European VLBI Network (EVN) to densify the International Celestial Reference Frame (ICRF) [1]. We also conduct routine analyses of IVS data with the aim of studying the ICRF source position stability and the physical phenomena that can affect this stability, with specific interest in studying the impact of source structures in geodetic and astrometric VLBI [2].

Our level of activity has significantly increased during the past year thanks to two new staff members (G. Bourda and J. Camargo) participating in the IVS Analysis Center work. Recent developments include VLBI analysis and testing with the GINS multi-technique software and astrophysical imaging to monitor the structural variability of the ICRF sources.

## 2. Scientific Staff

During 2005, the following five individuals contributed part or full time in IVS analysis and research activities, as described below:

- Patrick Charlot (50%): overall responsibility for Analysis Center work and data processing. His major research interests include the densification and extension of the ICRF and studies of source structure effects in geodetic VLBI data.
- Antoine Bellanger (100%): engineer with background in statistics and computer science. His main role is to conduct initial VLBI data processing and develop analysis tools as needed. He is also the web master for the M2A group.
- Géraldine Bourda (25%): postdoc fellow funded by the French space agency (CNES) since 1 September 2005. She is in charge of implementing and validating routine VLBI analyses with the GINS software for multi-technique combination.



- Julio Camargo (25%): postdoc fellow funded by the University of Bordeaux to develop astrophysical imaging of ICRF sources. His contract ended on 1 October 2005 and he has since then taken up another postdoctoral position at the Observatory of Valongo in Brazil.
- Alain Baudry (10%): radioastronomy expert. He is involved in the ICRF densification project with the EVN and has interest in radio source imaging.

### 3. Data Analysis and Software Testing

VLBI analyses are primarily conducted with the MODEST software, developed and maintained by the Jet Propulsion Laboratory [3]. It is installed on a Compaq DS20 workstation along with the AIPS and DIFMAP software which are used for astrophysical imaging (see below). During the past year, we completed initial processing for all NEOS-A and IVS-R4 sessions conducted between 1999 and 2005 along with all IVS-R1 sessions conducted since 2003. Based on this data set, we expect soon to produce a so-called “arc solution” estimating monthly ICRF source positions. The data processed also comprise the two-week-long CONT05 session conducted in September 2005.

In parallel, we also began experimenting VLBI data analysis with the GINS multi-technique software. This software, originally developed by the GRGS (“Groupe de Recherches de Géodésie Spatiale”) in Toulouse (France) for analyzing satellite geodetic data (SLR, GPS, DORIS) has been extended with a VLBI module for processing both Earth-based and space VLBI data [4]. Preliminary results for the Earth Orientation Parameters (EOP) have been obtained for all IVS-R1 and IVS-R4 sessions in 2005 and these results are being compared to those reported by the IERS. Additional testing is being carried out by carefully comparing the calculated VLBI delays in GINS with those from MODEST in order to ensure millimeter accuracy in modeling.

The developments using GINS are part of a research project aimed at combining all VLBI and space geodetic data in a consistent way to unify the reference frames and the EOP estimation. In this framework, the VLBI data are analyzed in Bordeaux, while the other space geodetic data are analyzed at the GRGS in Toulouse (for GPS and DORIS) and at the OCA (“Observatoire de la Côte d’Azur”) in Grasse (for SLR), with the final combination produced at Paris Observatory.

### 4. Celestial Frame Activities

On the observational side, we obtained EVN observing time for an additional 24-hour experiment to complete our ICRF densification project in the northern sky (see [5, 6, 7] for a description of the previous experiments). All sources that had  $> 1$  mas position errors were re-observed during this experiment, using the same EVN+ network as used previously, in order to improve their coordinates [1]. The network includes eight EVN telescopes along with three non-EVN geodetic telescopes, as listed in Table 1. A preliminary analysis comprising all data acquired so far indicates that more than 90% of the 150 sources observed for this project have now sub-milliarcsecond position errors with the addition of this new experiment. Our analysis will be finalized shortly and a paper presenting the source position results based on all such EVN+ data will be written.

Another major achievement was the study of the structure index variability by deriving time series of structure indices for all ICRF sources that have been imaged at multiple epochs. A total of 1768 X-band maps and 1544 S-band maps from the USNO data base (with up to 20 epochs for some intensively-observed sources) have been used for this investigation. Overall, our study shows that the structure index generally varies smoothly with time or is stable. By categorizing

Table 1. Network used in ICRF densification experiment conducted on 2005 February 22.

EVN telescopes	Non-EVN telescopes
Effelsberg	Algonquin Park
Medicina	Goldstone (DSS 13)
Noto	Ny-Ålesund
Onsala	
Wetzell	
Hartebeestock	
Urumqi	
Shanghai	

the sources using the maximum value of the structure index over all epochs, we also identified a subset of 242 sources (from a total of 557 sources that have been characterized in this way) with “permanently” good (i.e. either 1 or 2) structure indices. Such sources are potential candidates to serve as defining sources in the next realization of the ICRF. Further details about the results of this investigation will be given in the Proceedings of the 4th IVS General Meeting.

As mentioned above, we also initiated a new activity aimed at imaging the ICRF sources observed during the RDV experiments. This project is conducted in close cooperation with the USNO group in order to extend the time base of the current image data base. Our work so far has focused on establishing an appropriate way to calibrate and edit the RDV data, and to test semi-automatic procedures to map the sources. We have also began imaging the sources observed in the RDV36 experiment (conducted on 2002 December 11). Examples of the X-band images derived for 1308+326 and 0234+285 from these data are shown in Fig. 1. 1308+326 is an ICRF defining source while 0234+285 is categorized as a candidate source. The two sources show maximum structure indices of 4 and 3, respectively, in the structure index time series analysis described above.

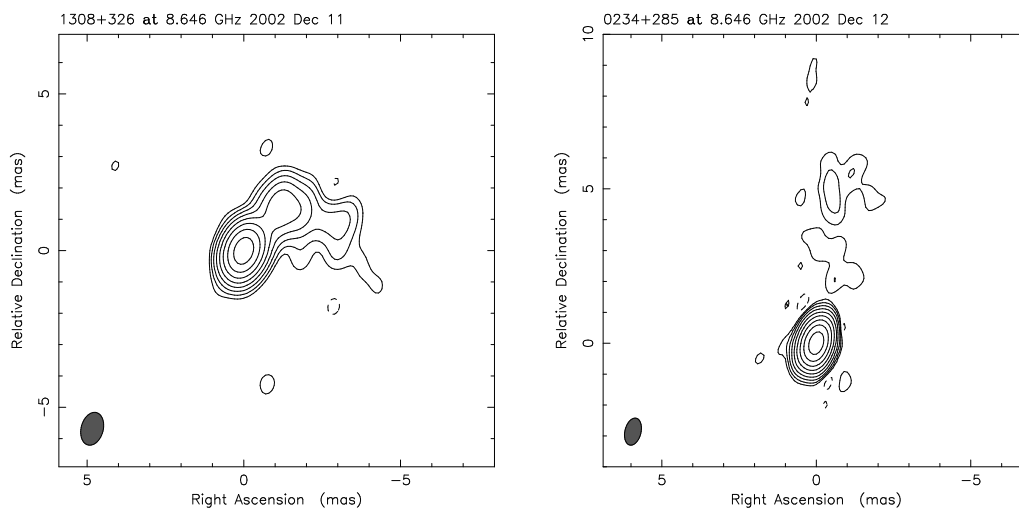


Figure 1. VLBI images at X band for two ICRF sources (1308+326 and 0234+285) as derived from the data of the RDV36 experiment.

## 5. Outlook

For the year 2006, our plans include the following:

- Keep on analyzing the new IVS-R1 and IVS-R4 sessions as they become available and set up an operational “arc position” solution to monitor the temporal evolution of the source coordinates.
- Pursue further the testing of the GINS software and implement operational procedures for VLBI analysis as part of the effort to integrate VLBI, GPS, DORIS and SLR data in a multi-technique combination at the observation level.
- Obtain final results for the astrometric coordinates of the 150 sources observed in our four ICRF densification experiments, and compare these with the VLBA Calibrator Survey positions for the common sources.
- Continue to evaluate the astrometric suitability of the ICRF sources as new maps become available at S, X, K and Q bands, and make the corresponding structure indices and structure correction images publicly available.
- Continue the processing of the RDV experiments in cooperation with the USNO team to monitor the X- and S-band structural evolution of the ICRF sources and extend the time coverage of the current image data base.

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# Matera CGS VLBI Analysis Center

*Roberto Lanotte, Mauro Pirri, Giuseppe Bianco, Cecilia Sciarretta*

## Abstract

This paper reports the VLBI data analysis activities at the Space Geodesy Center (CGS) at Matera from January 2005 through December 2005 and the contributions that the CGS intends to provide for the future as an IVS Data 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 is active in the framework of the most important international programs. VLBI data analysis activities are performed at CGS for a better understanding of the tectonic motions with specific regards to the European area. The CGS, operated by Telespazio 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. Cecilia Sciarretta, Responsible for scientific activities, Telespazio.
- Dr. Roberto Lanotte, Geodynamics data analyst, Telespazio.
- Dr. Mauro Pirri, Geodynamics data analyst, Telespazio.

## 3. Current Status and Activities

### 3.1. Global VLBI Solution cgs2005a

The main VLBI data analysis activities at the CGS in the year 2005 were directed towards the realization of a global VLBI analysis, named cgs2005a, using the CALC/SOLVE software (developed at the GSFC). The cgs2005a will be included in the IVS solutions “pool” and its main characteristics are:

- Data span:  
1980.04.11 - 2004.12.31
- Estimated Parameters:
  - Celestial Frame:  
right ascension and declination as global parameters for 537 sources and as local parameters for 7 sources.
  - Terrestrial Frame:  
Coordinates and velocities for 83 stations as global parameters and as local parameters for 30 stations.

- Earth Orientation:  
Unconstrained X pole, Y pole, UT1, Xp rate, Yp rate, UT1 rate, dpsl and deps.

### 3.2. IVS Tropospheric Products

Regular submission of tropospheric parameters (wet and total zenith path delays, east and north horizontal gradients) for all VLBI stations observing in the IVS R1 and R4 sessions was continued during 2005. At present 292 sessions have been analysed and submitted covering the period from 2002 to 2005.

### 3.3. IVS Pilot Project “Time Series of Baseline Lengths”

Regular submission of station coordinate estimates, in SINEX files, was continued during 2005 for the IVS pilot project “Time Series of Baseline Lengths”. At present 660 sessions have been analysed and submitted covering the period from 2000 to 2005.

### 3.4. Analysis of the 2004 Matera Survey and VLBI Invariant Point Determination

The role played by CGS as geodetic fundamental station, hosting the main space geodetic technique systems SLR, VLBI, and GPS, makes the whole survey theme (measurements, related corrections and processing) of great importance for the CGS activities.

The latest survey at CGS was performed in February/March 2004 and involved measurements connecting seven IERS geodetic reference points and 14 additional reference points of the local network. A technical report on the measurement procedure, with details on the local network is available at GeoDAF (Geodetic Data Archiving Facility) at the URL

[http://geodaf.mt.asi.it/html\\_old/surv\\_rep.html](http://geodaf.mt.asi.it/html_old/surv_rep.html).

During July 2005, a measurement campaign was carried out to estimate the VLBI IVP from the geometrical surface described by four optical retro reflectors mounted on the antenna structure.

A new software (GSMAT) for the analysis of the survey raw measurements was developed. The main characteristics of this software are:

- atmospheric effects removed using continuously measured values of local temperature, pressure and humidity provided by the meteorological sensors operating at ASI CGS and disseminated as RINEX meteorological file in the GeoDAF database;
- rigorous network adjustment (weighted least squares method) with minimal inner constraints (via SVD), using the whole covariance matrix at each step of the computation;
- outlier detection;
- designed to keep the human intervention on the data processing at a minimum;
- The VLBI invariant point can be estimated modeling the geometrical figure described by a retro-reflector located on the antenna. Using a least squares method the following three models and parameters can be estimated:
  - sphere: centre coordinates + radius
  - torus: centre coordinates + 2 radii

– inclined torus: centre coordinates + 2 radii + 2 rotation angles

- production of the SINEX file with coordinates of the IERS reference points and VLBI IVP.

#### **4. Future Plans**

- Continue and improve the realization of global VLBI analysis.
- Continue to participate in IVS analysis projects.

# DGFI Analysis Center Annual Report 2005

*Volker Tesmer, Hermann Drewes, Manuela Krügel*

## Abstract

This report summarizes the activities of the DGFI Analysis Center in 2005 and outlines the planned activities for the year 2006.

## 1. Introduction

The German Geodetic Research Institute (Deutsches Geodätisches Forschungsinstitut, DGFI) is an autonomous and independent research institution located in Munich. It is run by the German Geodetic Commission (Deutsche Geodätische Kommission, DGK) at the Bavarian Academy of Sciences. The research covers all fields of geodesy and includes the participation in national and international projects as well as functions in international bodies (see also <http://www.dgfi.badw.de>).

## 2. Activities in 2005

### 1. Consistent Reference Frames

The parameters of a celestial reference frame (namely spherical coordinates of radio sources) in VLBI solutions are, to a certain extent, always dependent on other parameters such as station positions and velocities (TRF) and the Earth orientation parameters (EOP). This is why much effort was spent on computing a solution, in which VLBI observations are analyzed with all the unknown parameters estimated simultaneously. As a consequence, the TRF, CRF as well as the EOP determined in such a way will be fully consistent with each other. Both, the homogeneity between the frames and the EOP and the homogeneity of all parameters in time are not ensured by today's products of the IERS.

The actual DGFI VLBI solution 05R02 comprises 2699 sessions between 1984 and 2005, each about 24 h long, including a total of 49 telescopes (of which 46 are part of ITRF2000) observing 1954 sources (of which 562 are part of ICRF-Ext1). Session-wise datum free normal equations were set up with the VLBI software OCCAM 6.0 (modified for estimating source positions) and accumulated to one common equation system with the DGFI software DOGS-CS (see also Tesmer et al. 2004). This equation system can be solved either by fixing station positions and velocities as well as source positions to the values given in ITRF2000 and ICRF-Ext1 (with the EOP estimated), or by applying a non-biasing datum, namely NNR and NNT, e.g. for 25 stable stations w.r.t. ITRF2000 and NNR, e.g. for 199 stable sources w.r.t. ICRF-Ext1. Comparisons between the results of such different approaches confirm the necessity of a solution where TRF, CRF and the EOP are estimated simultaneously:

- IERS EOP C04 is not consistent to ICRF-Ext1 and the VLBI-part of ITRF2000,
- ITRF2000 and ICRF-Ext1. were not computed using the same modelling, which can influence the parameters of the respectively other frame systematically,
- in VLBI solutions, station and source positions can depend significantly on each other, especially in case of weakly determined objects.

## 2. Combination of space geodetic techniques using CONT02 data

GPS derived rates of daily terrestrial pole, dUT1 and nutation angles are highly precise. However, the long-term information in dUT1 and nutation series determined with satellite techniques is strongly dependent on the estimation strategy and/or the mathematical formulation of the orbits. Because of its direct link to the CRF, VLBI is capable to determine low frequencies in dUT1 and nutation uniquely stable, whereas the higher frequencies of VLBI-derived EOP (especially of the terrestrial pole) are of lower precision due to technical reasons: Firstly, VLBI observes networks consisting of few stations only, which can easily lead to weakly determined rate-parameters; secondly, VLBI telescopes cannot cover the whole sky by observations in arbitrary high time resolution, thus limiting the separability of topocentric parameters in high temporal resolution such as those necessary to model the influences of the troposphere and the station clocks. Therefore, adequately combined GPS and VLBI observations will give the best EOP results in the whole frequency domain and provide optimal precision, stability and interpretability for the whole set of parameters.

The benefit of a rigorous combination approach was demonstrated by a combination of VLBI data from 15 days of VLBI observations in October 2002 (CONT02) and the corresponding GPS data, carried out in close cooperation with the Research Establishment Satellite Geodesy (FESG) at the Technical University of Munich. As an example for the effect, Figure 1 compares station repeatabilities of the combined and uncombined VLBI and GPS solutions (see also Thaller et al. 2006). For this, the VLBI and the GPS softwares were prepared in very close cooperation to have identical a priori models and parameterizations.

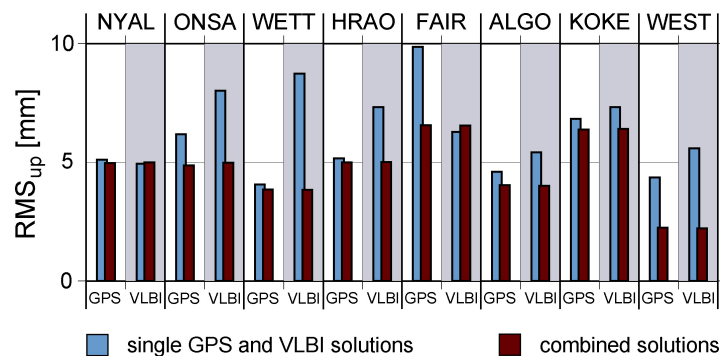


Figure 1. Comparison of the repeatabilities of daily GPS and VLBI height estimates using the data of the CONT02 campaign, estimated in single solutions as well as in a combined solution. It reflects the potential of the combined solution approach to stabilize VLBI as well as GPS.

## 3. DGFI VLBI SINEX files as a contribution to the IERS Combination Pilot Project

Another attempt to promote combination efforts is the participation in the IERS Combination Pilot Project, which was started in the beginning of 2004 as a major step towards more consistent, routinely generated IERS products. The corresponding DGFI VLBI contribution were SINEX files of 2666 daily sessions between 1984 and 2005, submitted to the IVS on a quasi operational basis. These files contain the Earth orientation parameters and station positions for each 24-hour session as decomposed normal equations in the SINEX format. The IVS-combined normal equations, compiled from contributions of up to seven IVS Analysis



Centers each, is the VLBI input to the IERS Combination Project, and to the upcoming realization of the International Terrestrial Reference Frame ITRF2005.

#### 4. Towards a new realization of the International Celestial Reference Frame (ICRF)

The International Celestial Reference System (ICRS) is realized by the coordinates of several hundred radio sources observed by VLBI. The IERS as well as the IVS aims for a new realization of the ICRS in the coming years, which shall, if feasible, be generated by combining several VLBI solutions. The first comparisons of radio source catalog test solutions of several IVS Analysis Centers were presented during the 6th IVS Analysis Workshop, held in Noto, Italy in April 2005. DGFI contributions to these efforts were a CRF solution computed with OCCAM as well as investigations concerning the homogeneity of catalogues computed with different solution setups.

#### 5. Interim VLBI terrestrial reference frame VTRF2005

Since the ITRF2000 was based only on observation data until the end of 2000, the quality of this TRF deteriorated for the time since then. In order to provide a terrestrial reference frame for operational VLBI determinations of EOP and atmospheric water vapour content, in 2005, TRF realizations of five Analysis Centers were combined by the IVS Analysis Coordinator to the terrestrial VLBI reference frame VTRF2005 (Nothnagel, 2005). One of these contributions was computed by DGFI, using the VLBI software package OCCAM.

#### 6. IVS OCCAM Working Group

As all work at DGFI related to VLBI is done with the VLBI software OCCAM, the collaboration in the IVS OCCAM Working Group is of particular importance for the DGFI IVS Analysis Center. The general task of the OCCAM Working Group is to regularly improve the OCCAM software. It is chaired by Oleg Titov from Geoscience Australia (Canberra, Australia). Active members are scientists of the Vienna University of Technology (Vienna, Austria), the St. Petersburg University, the Institute of Applied Astronomy (both St. Petersburg, Russia) and DGFI. The current version 6.0 of the software was officially released in February 2004 during the IVS General Meeting in Ottawa, Canada (Titov et al. 2004). Since then, the software was upgraded in many parts, especially the code that solves the equation systems with the least squares approach, which now allows also to estimate source positions. This was done in very close cooperation with the Vienna University of Technology, during several small working meetings, the latest in February and September 2005. An updated, official version of OCCAM will be available soon.

### 3. Staff

In 2006, members of the DGFI IVS Analysis Center were Manuela Krügel, Hermann Drewes and Volker Tesmer.

### 4. Plans for 2006

Main research goals of the DGFI IVS Analysis Center will be:

- to further improve the VLBI software OCCAM,

- to support IVS TRF and CRF preparation activities, including submission of appropriate solutions computed at DGFI as well as analysis of different contributions,
- to submit SINEX files for forthcoming 24-h sessions to the IVS on a quasi operational basis,
- to intensify the work related to a combined estimation of geodetic target parameters from VLBI and observations of other space geodetic techniques.

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# FFI Analysis Center

*Per Helge Andersen*

## Abstract

FFI's contribution to the IVS as an analysis center focuses primarily on a combined analysis at the observation level of data from VLBI, GPS and SLR using the GEOSAT software. This report shortly summarizes the current status of analyses performed with the GEOSAT software. FFI is currently Analysis Center for IVS and ILRS, Technology Development Center for IVS, and Combination Research Center for IERS.

## 1. Introduction

Recently, a number of co-located 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 site. In addition, a constant eccentricity vector from the reference point of the co-located station to each of the individual phase center of the co-located antennas 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 independent of water vapour, gives new information which will help in the de-correlation of atmospheric and other solve-for parameters and 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 accounted for with the GEOSAT software developed by FFI during the last 23 years.

## 2. Staff

Dr. Per Helge Andersen - Research Professor of Forsvarets forskningsinstitutt (FFI) and Institute of Theoretical Astrophysics, University of Oslo.

## 3. Combination of VLBI, GPS, and SLR Observations at the Observation Level

The GEOSAT software was recently upgraded to use numerical weather models (ECMWF) and 3D raytracing for the calculation of signal delays due to the troposphere. Twelve years of VLBI data have been analyzed with this feature and the improvement of the results is remarkable. A lot of experimentation must be performed before final conclusions can be drawn, but it seems that the ECMWF model needs to be scaled by one or more estimated parameters in the VLBI analyses. The raytracing procedure can also be used to detect periods with rapidly changing atmospheric conditions which cannot be modeled with sufficient accuracy. This information can be used to identify and neglect such data leading to more stable values for the atmospheric scaling parameters. This strategy is expected to be especially valuable for the analysis of GPS and future

Galileo tracking data due to the great redundancy of datasets provided by the two satellite systems.

Plots of these estimates and spectral analyses of the results reveal interesting results. The general trend is that the ECMWF model seems to perform better at low latitudes than at higher latitudes. There is a clear seasonal signal especially for the higher latitudes. The noise level of the estimated Earth orientation parameters is typically at the level of 50 microarcseconds for the angles and 2-3 microtimeseconds for UT1. The results suggest that the applied procedure can be used to investigate how well the ECMWF model is able to describe climatic changes. Of course, many more years of data must be analyzed for such applications.

The GEOSAT software is presently undergoing extensive developments. Some of these are explained in the FFI Technology Development Center report in this volume.

## The BKG/GIUB VLBI Analysis Center

*Volkmar Thorandt, Axel Nothnagel, Gerald Engelhardt, Markus Vennebusch,  
Dorothee Fischer, Dieter Ullrich*

### Abstract

In 2005 the activities at the BKG/GIUB VLBI Analysis Center, as in previous years, consisted of routine computations of Earth orientation parameter (EOP) time series and 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 were 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. At BKG a set of antenna axis offsets was estimated as a prerequisite for issuing the official list of VLBI antenna axis offsets by the IVS Analysis Coordinator. At the same time first steps to investigate the long-term stability of radio sources in the VLBI analysis were done. At GIUB the emphasis was placed on individual research topics.

### 1. General Information

The BKG/GIUB VLBI Analysis Center has been established jointly by the Bundesamt für Kartographie und Geodäsie (BKG), Leipzig, and the Geodetic Institute of the University of Bonn (GIUB). Both institutions maintain their own analysis groups in Leipzig and Bonn but cooperate intensively in the field of geodetic VLBI. The responsibilities include data analysis for generating of the IVS products and special investigations with the goal of increasing the accuracy and reliability. BKG is responsible for the computation of time series of EOP and tropospheric parameters, the generation of daily SINEX files, and quarterly updated global solutions for TRF and CRF realizations. In fall 2005 the BKG group took over responsibility for the scheduling of the Tsukuba - Wettzell INT2 UT1 - UTC observing sessions. Details of the research topics of BKG/GIUB are listed in section 3.

### 2. Data Analysis

At BKG the Mark 5 VLBI data analysis software system Calc/Solve, release of March 18, 2004 (ref. [3]), is currently still used for VLBI data processing. Work was started to install the update to release of August 16, 2005 (ref. [4]) and the LINUX test version of Calc/Solve. In addition, an independent technological software environment for the Calc/Solve software is available. The latter is used for linking up the Data Center management with the pre- and post-interactive part of the EOP series production and to monitor all Analysis and Data Center activities (Data Center topics are described in the BKG Data Center report in this issue). The Mark 5 software is running under Fortran 90 on a HP workstation with an HP-UX11.00 operating system.

- **Processing of correlator output**

The BKG group continued the generation of calibrated databases for the sessions correlated at the MPIfR/BKG Mark 5 Astro/Geo Correlator at Bonn (e.g. R1, T2, OHIG, EURO) and submitted them to the IVS Data Centers.

- **Creating of schedule files**

BKG has taken over a new task with regard to VLBI session scheduling. The schedule files for the Intensive observation sessions of the baseline TSUKUBA-WETTZELL have been created since August 2005.

- **IVS EOP time series**

The new EOP time series bkg00007 differs from the previous bkg00006 by the implementation of the official list of the VLBI antenna axis offsets (ref. [2]). Bkg00007 was extracted from a global solution with 24 hour VLBI sessions since 1984. Altogether 3213 sessions were processed. The main parameter types in this solution are globally estimated station coordinates and velocities together with radio source positions. Minimal constraints for the datum definition were applied to get zero net rotation and net translation for 26 selected station positions and velocities with respect to the VTRF2003 (ref. [7]) and zero net rotation for 212 defining sources with respect to ICRF-Ext.1 (ref. [5]). The station coordinates of the stations TIGOCONC (Chile), SVETLOE (Russia), CTVASTJ (Canada), and METSAHOV (Finland) were estimated as local parameters in each session.

The UT1 time series bkgint03 was replaced by bkgint04. Again the official list of the VLBI antenna axis offsets (ref. [2]) was used. The observations of both baselines KOKEE-WETTZELL and TSUKUBA-WETTZELL each with a duration of about 1-hour were processed regularly. Series bkgint04 was generated with fixed TRF (VTRF2003) and fixed CRF derived from the global BKG solution for EOP determination. The estimated parameter types were only UT1, station clock, and zenith troposphere. A total of 1723 UT1 Intensive sessions were analyzed for the period between 1999.01.01 and 2006.01.15.

- **Quarterly updated solutions for submission to IVS**

For the IVS products TRF and CRF quarterly updated solutions were computed. There are no differences in the solution strategy compared to the continuously computed EOP time series bkg00007. 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, but now with station coordinates, 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, horizontal gradients) for all VLBI sessions since 1984. The tropospheric parameters are directly extracted and transformed into SINEX for tropospheric estimates from the results of the standard global solution for the EOP time series bkg00007.

- **Daily SINEX files**

The VLBI group of BKG also continued the regular submissions of daily SINEX files for all available 24 hours sessions as base solutions for the IVS time series of baseline lengths and for combination techniques. In addition to the global solutions independent session solutions were computed for the parameter types station coordinates, EOP, and nutation parameters. The a priori datum for TRF is defined by the VTRF2003 and the fixed CRF derived from the global complete BKG solution for EOP determination is used for the a priori CRF information.

### 3. Research Topics

- **Estimation of VLBI antenna axis offsets**

The BKG group participated in the coordinated effort to generate reliable VLBI antenna axis offsets. A complete set of axis offsets was estimated from all available geodetic VLBI data to verify and update the values used so far. This data set was used as one of the input series to create an official list of VLBI antenna axis offsets by the IVS Analysis Coordinator.

- **Radio source stability**

First steps to investigate long-term stability of radio sources in the VLBI analysis were made at BKG. So time series for all radio sources were computed with nearly no change in datum definition. The a priori datum for CRF is defined by zero net rotation of 199 stable sources detected by M. FEISSEL-VERNIER (ref. [1]) with respect to ICRF (ref. [5]). Based on these time series of radio source positions residuals to the weighted mean of a radio source component can be tested for normal distribution for the purpose of uncovering systematic errors. Presently the normal distribution was not rejected for 121 radio sources in both components (right ascension, declination).

- **Analysis of the Tsukuba - Wettzell INT2 Series**

At GIUB a detailed analysis of the Tsukuba - Wettzell INT2 series for the determination of UT1 - UTC is being completed for a consistent integration into the results of the R1 and R4 network sessions as well as the INT1 (Wettzell - Kokee Park) series. The results will be published in a Ph.D. thesis in 2006.

- **Analysis of water vapour radiometer data**

Investigations in the use of water vapour radiometer data (WVR) in VLBI data analysis were continued. A comparison campaign for atmospheric sensors at Wettzell was analyzed leading to the detection of severe deficits of the ETHZ radiometer.

- **IERS Combination Pilot Project and ITRF2005 input generation**

Within the IERS Combination Pilot Project and the ITRF2005 initiative SINEX files from seven IVS Analysis Centers have been combined into the official IVS submission to the IERS. A number of consistency issues had to be solved before a rigorous combination could be achieved. Final tasks are still being completed.

- **Phase and cable cal investigations**

Motivated by the investigations of MacMillan (ref. [6]) in the azimuth dependence of the phase calibration at Onsala a project was launched searching for azimuth and/or elevation dependencies also at other telescopes. The results will be published in 2006.

- **Simulations of cluster-to-cluster VLBI sessions**

A setup of several radio telescopes at individual sites observing in different directions at the same time can be used for cluster-to-cluster observing sessions. Observation schedules were generated for a few test setups of multi-station network sessions and single baseline UT1 - UTC intensive sessions using the SKED program. In simulation studies the schedules were analyzed with the Calc/Solve program and the results intercompared. The results of these investigations will be published in 2006.

## 4. Personnel

Table 1. Personnel at BKG/GIUB Analysis Center

Thomas Artz (from Jan 1, 2006)	GIUB	++49-228-733570	thomas.artz@uni-bonn.de
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## GSFC VLBI Analysis Center

*David Gordon, Chopo Ma, Dan MacMillan, Leonid Petrov, John Gipson, Karen Bayer*

### Abstract

This report presents the activities of the GSFC VLBI Analysis Center during 2005. The GSFC 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 aimed at improving the VLBI technique.

## 2. Activities

### 2.1. Analysis Activities

The GSFC analysis group routinely analyzes all Mark IV/5 IVS sessions using the Calc/Solve system, and performs the AIPS 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, CONT05, APSG, and NEOS Intensive INT01 sessions. During 2005, the group processed and analyzed 164 24-hr (51 R1, 51 R4, 15 CONT05, 6 RDV, 11 R&D, 7 T2, 7 CRF, 8 CRDS, 2 CRFS, 4 EURO, and 2 APSG) sessions and 309 1-hr UT1 (226 NEOS INT01, and 83 INT02) sessions. We also submitted updated EOP files and daily Sinex solution files for all IVS sessions to the IVS Data Centers immediately after analysis. The group also generated and submitted two TRF solutions to the IVS Data Centers using all suitable VLBI sessions. The Analysis Center maintains a web site (<http://lupus.gsfc.nasa.gov/>) which underwent major revisions during 2005.

### 2.2. Support Activities

Over the years, the GSFC Analysis Center has directly or indirectly supported numerous missions and projects of other groups and agencies. For instance, our rapid Intensive session UT1 turnaround has played crucial roles in determining precise maneuvers required for various planetary spacecraft, such as Cassini and others. We have also provided valuable support for the Gravity Probe B mission for several years. This has included generating and calibrating databases of the guide star and phase reference sources from VLBA astrometry sessions, and determination of the precise position of the phase reference sources from our own RDV observations. This is allowing GP-B scientists to accurately measure the proper motion of the guide star, a prerequisite for accurate measurement of the satellite's precession. We also have provided a source position service as part of the RDV program since 1997. Observations of 18 requested sources were made for members of the astronomical community in 2005, and precise positions were obtained where possible.

### 2.3. Research Activities

The GSFC analysis center performs research aimed at improving the VLBI technique. The primary research activities undertaken during 2005 include the following:

- Hydrology loading: The effect of hydrology loading was further investigated. Model site displacements calculated from the most recent version of the Milly et al. (J. Hydrometeorology, 3, 283-299, 2002) model were applied in analysis. For most baselines the observed variance reduction ( $1-8 \text{ mm}^2$ ) was greater than the model variance ( $1-5 \text{ mm}^2$ ) because the hydrology signal is seasonal and correlated with other unmodeled seasonal effects (even after removing antenna thermal deformation and using the IMF mapping function). This can also be seen from estimates of hydrology loading site vertical admittances that are mostly larger than 1.5.
- CONT05 analysis: A preliminary analysis of the 15 CONT05 sessions was made. Initial conclusions are: 1) RMS differences between CONT05 and IGS are 55 and 36  $\mu\text{as}$  for X-pole and Y-pole, which are  $\sim 50\%$  of the R1/R4 IGS differences, and are likely a result of the larger CONT05 network, 2) Subdaily EOP residuals to the JMG96 high frequency EOP tidal model have RMS  $\sim 180 \mu\text{as}$ , which is somewhat greater than the formal uncertainties ( $\sim 120 \mu\text{as}$ ) and similar to the level of residuals from previous CONT series, 3) Baseline length repeatabilities are  $\sim 0.8-1 \text{ ppb}$ .
- Unstable sources: Analysis of source position time series shows that a significant number of geodetic sources show unstable behavior. EOP estimates are improved if the apparent motions of unstable sources are estimated as multinode splines (rather than treating them as fixed). This is seen by reduced polar motion and nutation differences in the simultaneous CORE-A/NEOS-A sessions (1997-2000). Future work will include identifying all unstable sources that should be removed from the geodetic catalog, identifying other stable sources that should be added, and determining the best analysis strategy for treating unstable sources.
- Source Monitoring: 2005 marked the second year of our source monitoring program. Our goal is to systematically monitor all sources in regular use 1) in the geodetic catalog; 2) in the ICRF; and 3) that Martine Feissel classified as potentially stable. The total number of sources in this combined list is 302. The observational target is inclusion in at least 12 sessions per year for geodetic sources, and at least 2 sessions per year for other sources. Most geodetic sources meet these targets automatically in the regular scheduling of experiments. But for those sources that do not, a certain amount of observing is scheduled using the R1 sessions, where each R1 can include up to 10 sources from the monitoring list. The monitoring program has been very successful. At its start, there were  $\sim 160$  sources not observed during the previous 2 years, and  $\sim 70$  sources observed only once. By the end of 2005, only 1 source had not been observed and only 16 had been observed less than twice during the prior year. Based on the above success, we are expanding the program to include imaging this same set of sources using the RDVs. The goal will be to image each geodetic source at least 3 times per year and other sources at least once every two years.
- Correlation between VLBI observations: A key assumption in VLBI parameter estimation has been that all observations can be treated as independent. There is anecdotal evidence though that this is not the case. For example, analysts have noticed that within a scan, all of the residuals involving a common station appear to be correlated. We examined several

RDV sessions to verify if this was indeed the case. It was found that, on average, station dependent residuals ranged from about 5 to 15 ps in an RMS sense. This is much larger than would be expected by chance, indicating that there is real station dependent noise which is correlated. The parameter estimation strategy in program SOLVE needs to be modified to correctly account for this noise. We expect that this will result in two effects—the parameter estimates will change and the formal errors will get larger.

- VCS4/5: A fourth and fifth set of VLBA calibrator sessions were observed and processed by GSFC and NRAO personnel in order to fill the remaining holes in the current geodetic/astrometric catalog north of -40 degrees declination. Positions were obtained for 836 new sources in three VCS4 and three VCS5 sessions, and 580 of these were found to be suitable as calibrators. The geodetic/astrometric catalog now contains 3481 detected sources, with 2892 suitable as calibrators. This work will be published in the *Astronomical Journal* in 2006. For more details see <http://vlbi.gsfc.nasa.gov/vcs/>.
- Higher frequency CRF: Members of the analysis group are working with associates at JPL, USNO, NRAO and elsewhere, to extend the celestial reference frame to higher frequencies by using the VLBA at K and Q bands ( $\sim 24$  and  $\sim 43$  GHz). The primary goals are to build up a reference frame for use in planetary spacecraft navigation at Ka band ( $\sim 33$  GHz), and to build a reference frame less affected by source structure and apparent proper motion and potentially more precise than the current X/S frame. A K band session and a K/X/S VLBA session were observed and analyzed in 2005. To date, the group has conducted 8 VLBA sessions and developed a catalog of 259 sources at K-band and 132 sources at Q-band, with sub-mas positions. Future work will concentrate on observing weaker sources, and densifying the catalog along the ecliptic and in the regions needed for several upcoming Mars missions.

## 2.4. Software Development

The GSFC group develops and maintains the Calc/Solve analysis system. Several updates were released during 2005. Calc/Solve development work was concentrated on the development of a Linux/HP-UX compatible version. At year's end, it was in use at GSFC and several other Analysis Centers. The next release of Calc, version 10, is in final testing and will be released early in 2006. It is updated for compliance with the IERS Conventions (2003), and uses the non-rotating origin system. Further work was done on program GEODYN to develop algorithms and software for computation of path delays for near zone objects for processing VLBI observations of the Cassini/Huygens lander.

## 3. Staff

Members of the analysis group and their areas of activity include: Dr. Chopo Ma (CRF, TRF, EOP, K/Q reference frame development, IVS representative to the IERS, and current chairman of the IERS directing board), Dr. Dan MacMillan (CRF, TRF, EOP, mass loading, antenna deformation, apparent proper motion, and post-seismic studies), Dr. David Gordon (database analysis, RDV processing and analysis, K/Q reference frame development, VLBA calibrator surveys, Calc development), Dr. Leonid Petrov (CRF, TRF, EOP, mass loading analysis, VLBA calibrator surveys, Calc/Solve development, Linux migration, GEODYN development), Dr. John Gipson (source monitoring and improved parameter estimation), and Ms. Karen Baver (R4 and Intensives analysis,

software development, Linux migration, web site development and maintenance).

#### **4. Future Plans**

Plans for the next year include: release the Calc10/Solve Linux/HP-UX version; oversee the re-Calcing of all data bases in the IVS Data Centers; incorporate correlations between observations in standard VLBI processing; participate in development of the next VLBI ICRF; participate in additional K/Q observations and reference frame development; continue development of GEODYN for analysis of spacecraft VLBI observables; and perform further research aimed at improving the VLBI technique.

#### **5. Publications**

“The Third VLBA Calibrator Survey”, L. Petrov, Y.Y. Kovalev, E. Fomalont, D. Gordon, *Astronomical Journal*, vol. 129, 1163-1170, 2005.

# MIT Haystack Observatory Analysis Center

*Arthur Niell, Brian Corey*

## Abstract

The contributions of Haystack Observatory to the analysis of geodetic VLBI data focus on improvement in the accuracy of the estimation of atmospheric delays and on the reduction of instrumental errors through analysis. In the past year progress was made in two areas: 1) understanding the value of Numerical Weather Models for troposphere correction and 2) evaluating the contribution of polarization impurity to uncalibrated post-fit delay residuals.

## 1. Geodetic Research at the Haystack Observatory

The MIT Haystack Observatory is located approximately 50 km northwest of Boston, Massachusetts. Geodetic analysis activities are directed primarily towards improving the accuracy of geodetic VLBI results, especially through the reduction of errors due to the atmosphere and to instrumentation. This work, along with operation of the geodetic VLBI correlator and with support of operations at the Westford, GGAO, Gilmore Creek, Fortaleza, and Kokee Park VLBI sites, is supported by NASA through a contract from the Goddard Space Flight Center.

## 2. High Resolution Numerical Weather Model for Atmosphere Anisotropy

A numerical weather model provides the most information about the atmospheric conditions over a large volume. Sequential twelve hour forecasts with three kilometer horizontal resolution are being generated using the MM5 numerical weather model (NWM) for the eight sites of CONT02 to see if the high resolution can be used to improve the treatment of inhomogeneities in the atmosphere. However, the usefulness of the information is dependent on the accuracy of the calculated parameters. Lacking any better measurements, and by tradition, the standard of accuracy is the radiosonde.

Comparisons have been made at the positions of radiosondes in the fields of three of the sites, Westford, Kokee, and Hartebeesthoek, for the zenith delays and for the delay at  $5^\circ$  for the CONT02 period. The values from the NWM were calculated at the surface heights of the NWM, then corrected to the height of the lowest radiosonde level. As an example, the means of the differences of the delays at  $5^\circ$  are shown in Figure 1.

The height of the surface at the grid points nearest to the radiosonde launch site varies with horizontal resolution. After correction to the height of the lowest radiosonde vertical level, the agreement among the different resolutions improves. The largest mean difference for the 3-km grid is 4 mm, corresponding to approximately 1 mm of height error. Note that this is for a forecast of six hours.

## 3. Impact of Mapping Function Error on Choice of Minimum Elevation

Two effects compete for determining the minimum elevation of data that should be included in a geodetic VLBI solution. The geometric precision of the vertical coordinate (formal UP error) improves as lower data are included, but any atmosphere errors, such as mapping function, are

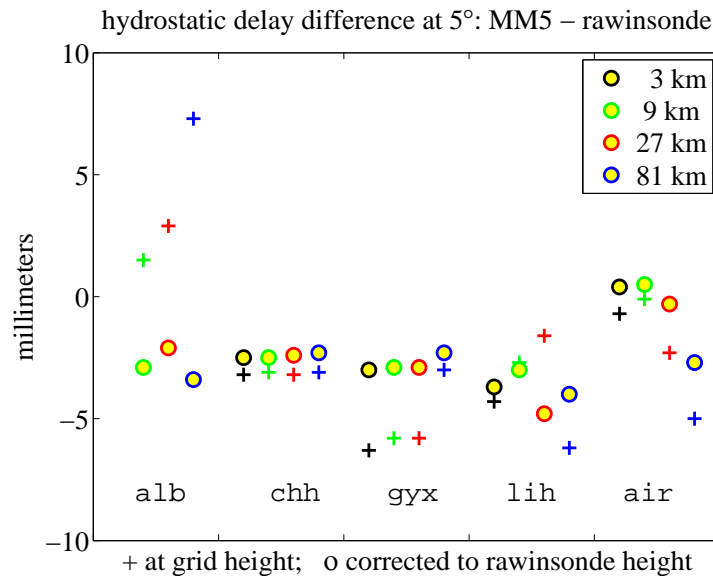


Figure 1. Mean difference of hydrostatic delays at 5° between MM5 numerical weather forecast and rawinsonde for three radiosonde sites near Westford and one each near Kokee (LIH) and Hartebeesthoek (AIR). For each horizontal resolution the profiles of temperature and humidity at the four nearest grid points of the MM5 forecast are interpolated to the position of the radiosonde.

increased. Four mapping functions are available for VLBI analysis, and the contribution of each to the long-term scatter is shown as a function of latitude in Figure 2.

The magnitude of the RMS scatter decreases rapidly with increasing latitude, being reduced by a factor of almost two even by 7.5°.

As an example of the difference in strategy that should be used depending on the choice of mapping function, consider Gilcreek and Kokee in the CONT94 sessions. The formal height errors for Gilcreek and Kokee are, respectively, approximately 3 mm and 7 mm at 5° and rise to 5 mm and 11 mm at 12.5°. The combined uncertainties due to mapping function and geometry are shown in Figure 3 for Kokee and Gilcreek. Because the geometric error dominates for Kokee, data should be kept to the lowest possible elevation, regardless of mapping function. For Gilcreek, on the other hand, the mapping function error will dominate below about 10° if NMF or GMF is used, but the UP error can be reduced by using VMF1 and retaining (or scheduling) data down to 5°.

This type of analysis should be conducted for every session to determine the minimum elevation, which might be different for each antenna, and which may also vary between sessions for a given antenna.

#### 4. Cross Polarization as a Source of Instrumental Error

A significant source of instrumental error in geodetic VLBI is imperfect polarization response of the antenna feeds, which are nominally right circularly polarized (RCP). If the feeds at two stations have some left circular (LCP) contamination, the LCP signals will correlate and thereby

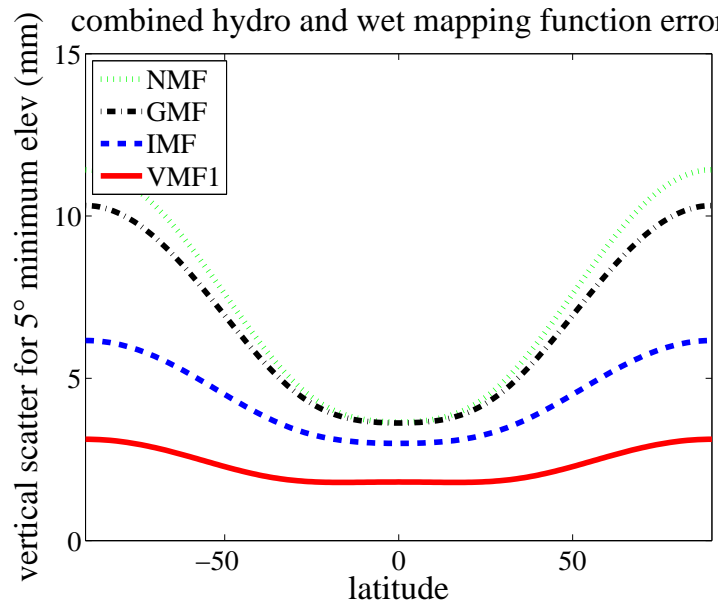


Figure 2. Contribution of mapping functions to long-term RMS of vertical component of site position as a function of site latitude for minimum elevation of  $5^\circ$ . The effects of the hydrostatic and wet mapping functions have been added quadratically. NMF - [3]; GMF - [1]; IMF - [4]; VMF1 - [2]

bias the estimated delay. In the worst case of fringe phase frequency dependence, two antennas that are  $-14$  dB cross-polarized can have their multiband delays biased by 18 ps for wideband (720 MHz) X-band observations.

In order to set limits on the magnitude of such errors, data were analyzed from a July 1996 R&D polarization experiment (RDPLR1), which was carried out concurrently with two normal geodetic sessions (GTRF11 and NAPS2). In RDPLR1, six VLBA antennas observing with both polarizations at both S and X tracked three calibration sources for 8 hours; they then tagged along with the two geodetic sessions. From the correlator output for the 8 hours, one can estimate the cross-polarization responses of the VLBA antennas. With the VLBA characteristics known, one may then estimate, or at least set limits on, the LCP contamination in the geodetic RCP feeds.

The analysis to date has been based only on fringe amplitudes, without regard to fringe phases, and only baseline-based estimates of cross-polarization are available. Station-based limits on LCP contamination can be inferred in only a few cases. Even with that limitation, it is possible to draw some preliminary conclusions. Typical cross-hands amplitudes on VLBA-only baselines are 2–4% and 3–8% as strong as parallel-hands at X and S, respectively, which implies cross-polarization power responses at each antenna of  $<-28$  dB and  $<-22$  dB, respectively. The LCP contamination of the geodetic RCP feeds is generally much higher, with values ranging from  $-20$  dB to  $-12$  dB at X, depending on frequency, for Algonquin, Fortaleza, Gilcreek, Hobart, Westford, and Yellowknife; at S-band, the cross-polarization exceeds  $-10$  dB at Yellowknife at some frequencies.

The analysis is currently being extended to include the fringe phase information and to produce a complete set of station-based estimates of the LCP response at the geodetic stations.

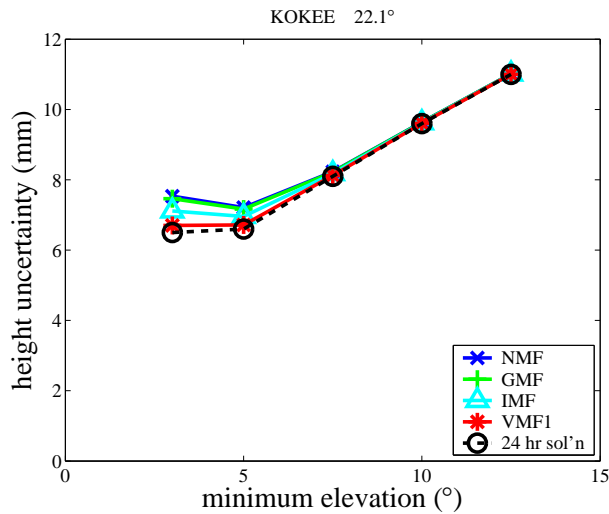


Fig 3a.

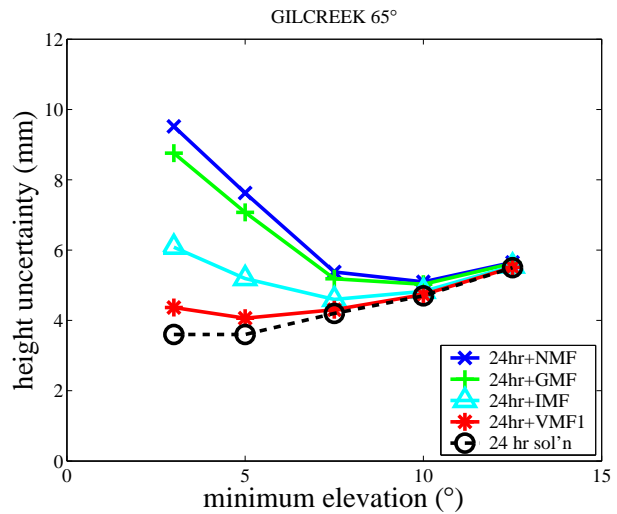


Fig 3b.

Figure 3. Height uncertainty for 3a) Kokee and 3b) Gilcreek for CONT94, as a function of minimum elevation, formed by combining the formal UP error (24 hour solution) with the total mapping function error, adjusted for each minimum elevation, for four different mapping functions.

## 5. Outlook

For the high-resolution NWM studies the goal is to complete the forecasts for the remaining five sites and to investigate the impact of the inhomogeneities seen in the 3 km grids on the horizontal and vertical coordinates of the stations in CONT02.

On completion of the analysis of the cross-polarization impurity, the results will be applied to a subset of the geodetic data to evaluate the change introduced by the correction.

An objective of both studies is to understand the magnitude of the errors that should be added to the parameter estimates, but which have not yet been considered.

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## IAA VLBI Analysis Center Report 2005

*Zinovy Malkin, Elena Skurikhina, Julia Sokolova, Vadim Gubanov, Sergey Kurdubov,  
George Krasinsky*

### Abstract

The report contains a brief overview of IAA VLBI analysis activities in 2005 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. Several groups are involved in VLBI data analysis and related studies. Their activities in 2005 are described below. The IAA AC web page [http://www.ipa.nw.ru/PAGE/DEPFUND/GEO/ac\\_vlbi/](http://www.ipa.nw.ru/PAGE/DEPFUND/GEO/ac_vlbi/) is supported.

### 2. Organization and Staff

IAA groups that contributed to the IAA AC activities are:

1. Lab of Space Geodesy and Earth Rotation (LSGER): Dr. Zinovy Malkin (Head, 30%), Prof. Vadim Gubanov, Dr. Elena Skurikhina, Sergey Kurdubov, Julia Sokolova (all 100%). The main tasks of the lab are EOP service, computation and investigation of operational and long-term series of EOP, station and radio source coordinates, tropospheric parameters, comparison and combination of space geodesy products. For most products and studies the group makes use of OCCAM/GROSS software. Vadim Gubanov and Sergey Kurdubov continued development of the QUASAR software which is intended to provide complete processing of VLBI observations including global analysis and investigation of the stochastic geophysical signals.

2. Lab of Ephemeris Astronomy (LEA): Prof. George Krasinsky (Head, 80%). The main activity was directed to processing VLBI-based EOP for fitting the parameters of new precession-nutation theory (as well as that of UT1 variations) ERA-2005 constructed by numerical integration of refined differential equations of the Earth rotation.

### 3. Analysis Activities

#### 3.1. LSGER Group

The activities of the LSGER group in 2005 were as follows:

- Development of the OCCAM/GROSS software was continued. Main improvements made in 2005 were:
  - Implementation of the Vienna Mapping Function VMF1;
  - Using VMF1 data for correction of erroneous station meteorological data;
  - Modification of the software to provide processing of the large sessions (continuous CONT05 data set consisting of almost 100,000 observations was successfully processed).

Many other changes with no significant influence on the results were made.

- Operational processing of the “24h” and intensive VLBI sessions, and submitting the results to the IERS and IVS was performed on a regular basis. Processing of the intensive sessions is fully automated. New EOP series `iaa2005a.eops` and `iaa2005a.eopi`, along with new series of the session station coordinates `iaa2005a.bl` and troposphere parameters `iaa2005a.trl` were started. The main difference of the `iaa2005a` solution with respect to the previous one is using the VTRF2005 catalog of station positions and velocities, except SVETLOE and GILCREEK stations for which alternate models are used. At the moment, the EOPS series contains 3195 estimates of pole coordinates, UT1, and celestial pole offsets, and the EOPI series contains 5165 estimates of UT1.
- New 26-year long-time series of station coordinates, baseline lengths, and tropospheric parameters (ZTD, gradients) were computed. Analysis of the results is in progress.
- Investigations in the framework of the IVS Pilot Project “Next ICRF” were started. Main directions of this activity are computation of source catalogs, their comparison and combination. In 2005 several tools in Fortran and MATLAB were developed for investigations of systematic differences between catalogs. The first catalog with QUASAR software was obtained and is now under investigation.
- Special processing of about 100 sessions with participation of the IAA SVETLOE station was performed with the goal to improve the station position and velocity, in particular to provide accurate computation of UT1 from the Intensives series observed in the sessions involving SVETLOE. It was found that accounting for the seasonal variations of the station coordinates substantially affects the velocity estimate. More details can be found in [1].
- Operational computation of the NGS cards was continued. NGS cards are computed in automated mode. To reduce the delay in delivering NGS cards to the users, IVS data archive is now checked for new observations every 6 hours.
- IAA archive of VLBI observations and products was supported. At present, all available X and S databases and NGS cards have been stored. The total volume of the data storage has reached 55 GB.

In 2005 the first global solution using the QUASAR software was obtained. All available data for 1979–2005 were processed by means of the least-squares collocation technique. The radio source coordinates, and station coordinates and velocities, along with antenna axis offsets for all stations were estimated as global parameters. EOP, WZD (linear trend plus stochastic signal), troposphere gradients, station clocks (quadratic trend plus stochastic signal) were estimated as arc parameters for each session. For testing of the results, some investigation was carried out. In particular, EOP from R1/R4 and Intensive sessions were computed with OCCAM and QUASAR software using various source and station catalogs. Results of this test are shown in (Table 1). One can see that the bias of the EOP series obtained with the QUASAR catalogs is larger than the one for the EOP series obtained with VTRF/ICRF systems. This problem is now under study.

### 3.2. LEA Group

The current VLBI-based offsets of the Celestial Pole positions provided by Analysis Centers GSFC, USNO, BKG, IAA (OCCAM and QUASAR series), MAO, AUS (time interval 1984, Jan 1 –

Table 1. WRMS residuals of the EOP series w.r.t. EOP(IERS)C04 after removing linear trend.

TRF/CRF		Xp $\mu\text{as}$	Yp $\mu\text{as}$	UT1 $0.1\mu\text{s}$	Xc $\mu\text{as}$	Yc $\mu\text{as}$	UT1(Int) $0.1\mu\text{s}$
OCCAM							
VTRF05/ICRF-Ext.2	wrms	113	110	51	68	70	152
	bias	$-215\pm 6$	$405\pm 6$	$-14\pm 3$	$20\pm 4$	$6\pm 4$	$-102\pm 6$
QUASAR TRF/CRF	wrms	112	104	51	67	71	156
	bias	$-638\pm 6$	$603\pm 5$	$-112\pm 3$	$-18\pm 3$	$-36\pm 4$	$-177\pm 6$
QUASAR							
VTRF05/ICRF-Ext.2	wrms	139	159	77	88	100	161
	bias	$-245\pm 7$	$447\pm 8$	$-10\pm 4$	$2\pm 5$	$46\pm 5$	$-108\pm 6$
QUASAR TRF/CRF	wrms	115	122	55	86	100	170
	bias	$-631\pm 6$	$614\pm 6$	$-127\pm 3$	$-35\pm 4$	$1\pm 5$	$-177\pm 6$

2005, Oct 20) were discussed applying the Earth's rotation theory ERA-2005 constructed by numerical integration of differential equations of rotation of the deformable Earth with the two-layer fluid core [2, 3]. As a result, it appeared possible to estimate objectively quality of all the analyzed series: see Table 2 in which the entries are arranged in accordance with the values of the WRMS errors of the residuals  $\sigma(d\phi \sin \theta)$  and  $\sigma(d\theta)$  with the ERA-2005 ( $\theta$ ,  $\phi$  being the Euler's angles of nutation and precession). Smallness of these errors characterizes quality of the corresponding series. The columns  $N_{obs}$  and  $N_{del}$  of Table 2 provide numbers of the data used and rejected, respectively.

 Table 2. Numerical model: statistics  $\sigma_{d\theta}$ , and  $\sigma_{d\phi}$  (mas), Dec 1983 – Oct 2005

Series	$\sigma(d\theta)$	$N_{obs}$	$N_{del}$	$\sigma(d\phi) \sin \theta$	$N_{obs}$	$N_{del}$	Package
GSFC	0.136	3546	42	0.129	3545	43	Calc/Solve
USNO	0.138	3260	29	0.131	3255	34	Calc/Solve
IAA	0.138	3041	55	0.131	3041	55	OCCAM/GROSS
IAA1	0.139	3074	79	0.132	3056	97	QUASAR
BKG	0.140	2916	56	0.133	2922	50	Calc/Solve
AUS	0.170	1466	2	0.171	1455	13	OCCAM
MAO	0.179	2852	2	0.198	2849	4	SteelBreeze

Considering the best series of the offsets, the corresponding WRMS values are significantly less than those for the adopted model IAU2000. For instance, the GSFC values  $\sigma(d\theta)$ ,  $\sigma(d\phi) \sin \theta$  are 0.136 mas and 0.129 mas, while for the IAU2000 model they are 0.172 mas and 0.165 mas, respectively. Intercomparison of the Earth's rotation theories ERA-2005 and IAU2000 (in the sense ERA-2005 minus IAU2000) is illustrated by Figure 1 for the time span 2000–2010. Figure 1 also shows the residuals of the GSFC series with the IAU2000 theory for the time span for which VLBI data are available (Jan 1, 2000 – Dec 27, 2005). The solid smooth curves present the differences ERA-2005 minus IAU2000. One can see that by 2009 the discrepancy in the precessional angle  $\phi$  will reach  $-2$  mas and its absolute value will increase after that epoch. Because the residuals of IAU2000 with the VLBI data for the recent years demonstrate their deterioration (unlike those of ERA-2005 model) we believe that these discrepancies have to be attributed to errors of IAU2000,

but not to those of the numerical theory ERA-2005. The WRMS error of differences between the observed UT1 (GSFC series) and the ERA-2005 model is equal to 18 ms for the period 1984–2005. More details are given in [4].

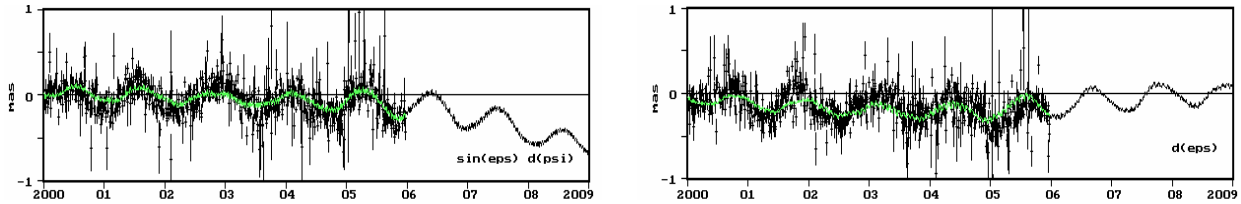


Figure 1. Observed and predicted corrections to IAU2000, GSFC series.

#### 4. Outlook

Plans for the coming year include:

- Further improve algorithms and software for processing of the VLBI observations.
- Continue regular computation of operational and long-time EOP, station coordinates, and troposphere parameters series with OCCAM software. Submit the results to IVS and IERS.
- Perform global analysis of the VLBI data with QUASAR OCCAM 6.1 software [6]; comparison of the results.
- Continue investigations of VLBI estimation of EOP, station coordinates, and troposphere parameters, and comparison with satellite techniques.
- Advance a model for seasonal variations of WZD [5].
- Continue investigation in comparison and combination of source catalogs; participate in the IVS Pilot Project “Next ICRF”.

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## Vienna IGG Special Analysis Center Annual Report 2005

*Harald Schuh, Johannes Boehm, Robert Heinkelmann, Thomas Hobiger, Sonja Todorova,  
Joerg Wresnik*

### Abstract

In 2005 the Institute of Geodesy and Geophysics (IGG) at the Vienna University of Technology continued its investigations in atmospheric research for geodetic VLBI: Among other topics, it was dealing with the neutral atmosphere in terms of long time series of tropospheric parameters and with the ionosphere in particular by determining ionospheric parameters from VLBI observations. Furthermore, it started simulation studies which are dedicated to the new VLBI2010 observing system.

### 1. General Information

The Institute of Geodesy and Geophysics (IGG) is part of the Faculty of Mathematics and Geoinformation of the Vienna University of Technology. It is divided into three research units, one of them focusing on advanced geodesy (mathematical and physical geodesy, space geodesy). Within this research unit, one group (out of four) is dealing with geodetic VLBI.

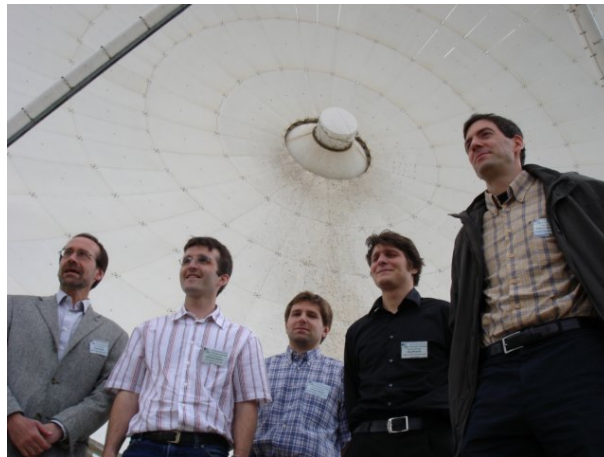


Figure 1. Members of the IVS AC at IGG, Vienna, in front of the Noto telescope at the European VLBI meeting in 2005 . From left: Harald Schuh, Johannes Boehm, Thomas Hobiger, Joerg Wresnik, and Robert Heinkelmann. Sonja Todorova is missing on this picture.

### 2. Staff

Personnel at IGG associated with the IVS Special Analysis Center in Vienna are Harald Schuh (Head of IGG, member of IVS Directing Board), and the scientific staff members Johannes Boehm, Robert Heinkelmann, Thomas Hobiger (until April 2005 at Kashima Space Research Center / NICT, Japan), Sonja Todorova, and Joerg Wresnik. While Johannes Boehm and Robert Heinkelmann are mainly concentrating on tropospheric research, Thomas Hobiger and Sonja Todorova focus on the ionosphere. Joerg Wresnik is taking care of the simulation studies.

### 3. Current Status and Activities

- **Modification of the VLBI software package OCCAM**

Together with Oleg Titov (Geoscience Australia), chairman of the 'OCCAM Group', and Volker Tesmer (Deutsches Geodätisches Forschungsinstitut, Germany), IGG is involved in the development of the OCCAM software. In 2005, the VMF1 (Boehm et al., 2006) and GMF (Boehm et al., 2006a) have been implemented in OCCAM.

- **Troposphere Mapping Functions**

The Vienna Mapping Functions VMF have been updated with the VMF1 (Boehm et al., 2006 [1]). Furthermore, the purely empirical Global Mapping Functions GMF have been developed (Boehm et al., 2006a) to be consistent with VMF1. They are based on spherical harmonic expansions and only account for seasonal variations.

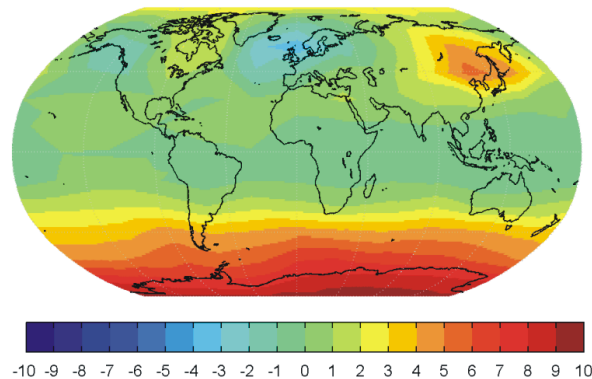


Figure 2. Station height change in mm for January when using GMF instead of NMF.

- **IVS Tropospheric Combination and Long Time Series of Tropospheric Parameters**

In 2005 the IGG combined weekly solutions of wet and total zenith delays from eight IVS Analysis Centers. The combined solution undergoes several quality checks before it is provided to the user community via the webpage <http://mars.hg.tuwien.ac.at/~ivstrop/>, maintained at IGG (Heinkelmann et al., 2005). Combination reports are available as tables; the most recent ten combinations and statistics are also provided graphically. The IVS combined tropospheric parameters are used for comparison by individuals and institutions. Since May 2005 north-south and east-west gradients are compared, too, showing systematic differences in the range of a few millimetres between individual ACs. The long time series of tropospheric parameters provided by six Analysis Centers have been combined using the BIBER estimator for outlier elimination and variance component estimation to determine the weights for the combination process on the level of results.

- **IVS-MET: Meteorological Surface Instrumentation and Data**

During 2005 several efforts to get the missing meta-data about the IVS meteorological surface instrumentation were launched, but with low success. Important information necessary

for a reliable climate analysis is still missing. The time series of surface pressure measurements of all VLBI sites were homogenized statistically using the SNHT (Heinkelmann et al., 2005a) method. The analysis revealed jumps ranging from 1hPa to about 17hPa in almost every time series significantly distorting the determination of wet zenith delays, if ignored. The role of meteorological data for the VLBI analysis was assessed comparing long time series of tropospheric parameters using surface pressure and temperature data from surface instrumentation and from the European Centre of Medium-Range Weather Forecast (ECMWF). For the exchange of knowledge and up-to-date data the IVS-MET web page <http://mars.hg.tuwien.ac.at/~ivstrop/ivsmet.html> was set up.

- **VLBI as a tool to probe the ionosphere**

Within project VLBIonos at the IGG, Vienna a method has been developed which enables estimation of vertical total electron content values from VLBI measurements (Hobiger et al., 2006). As VLBI observations cover more than two complete solar cycles, longer than all other space geodetic techniques using radio signals, the relation to space weather indices on long time scales can be demonstrated. Additionally, the results obtained from VLBI can be cross-validated against GPS, satellite altimetry data, and theoretical models like IRI. It can be stated that the overall agreement between VLBI and GPS is within the formal error of each technique and that both systems detect the same periods of ionospheric variations. But only VLBI is able to reveal long period signals like the (~11 year) solar cycle, since it covers a sufficiently long time span. Systematic biases of the techniques can be investigated and deficiencies of theoretical models can be revealed.

- **Detection of short period ionosphere variations by VLBI**

The usage of fringe phase information from VLBI measurements is a new and challenging field of research, which can be applied for the detection of short period variations (scintillations) of the ionosphere. Short period ionosphere variations can be detected very precisely, if the signal-to-noise ratio of the VLBI data is high enough. A method for the extraction of such disturbances was developed and dispersive influences could be separated from intra-scan delay variations. Possible physical origins of the disturbances were investigated and the results obtained from VLBI were validated against GPS measurements to verify the outcomes.

- **Simulation studies**

Simulations for VLBI2010 were started to propose new observing strategies and schedules, to improve troposphere and clock modeling, to find the best antenna configuration and to optimize the network geometry. The simulation studies are realized by a sequence of three software programs. After scheduling the observations with SKED, the fake observations (Monte Carlo simulation) are transformed to NGS format. These files are the input for the VLBI analysis software package OCCAM, which will be adapted for the simulations. The covariance and correlation matrices from OCCAM will be available in SINEX format and will be the input for a Matlab program called VV-SIM (Vienna VLBI-Simulation), which allows the interpretation of the results with distinct numbers and figures to deliver objective criteria for comparison.

## 4. Future Plans

For the year 2006 the plans of the IVS Special Analysis Center at IGG include:

- Further development of OCCAM, e.g., the implementation of high resolution, a priori gradients from numerical weather models
- Homogeneous recombination of the weekly combined tropospheric parameters
- Combination of tropospheric parameters on the level of normal equations
- Further investigations of the influence of various meteorological data on the global and local parameters of the VLBI analysis
- Investigations of the ionosphere by means of VLBI
- Development of a multi-technique global ionosphere model
- Further development of a software correlator based on Matlab (Hobiger and Kondo, 2005)
- Further simulation studies for VLBI2010

## 5. Acknowledgements

We are very grateful to the Austrian Science Fund (FWF) for supporting our work by research projects P16136-N06 ('VLBIONOS'), P16992-N10 ('VLBI for climate studies'), and P18404-N10 ('VLBI2010'). The authors want to thank the Japanese Society for the Promotion of Science, JSPS (project PE 04023) and Kashima Space Research Center, NICT for supporting the research stay of Thomas Hobiger in Japan.

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# Italy INAF Analysis Center Report

*M. Negusini, P. Sarti, S. Montaguti*

## Abstract

This report summarizes the activity of the Italy INAF VLBI Analysis Center. We also report about some major changes that occurred during year 2004 and have changed the affiliation of our Institute and the location of the AC, officially starting from 1st January 2005. Modification of names and codes necessary for the IVS affiliation will be requested and performed during 2006. A new contact person for the IVS AC will be indicated, soon. The structure and the activities of the Analysis Center remain unchanged.

## 1. General Information

Our geodesy section and its Analysis Center moved to the Bologna headquarter during 2004, leaving its former location situated at the Center of Space Geodesy, Matera. This decision partly originated by the reorganization process that was started by the Italian Government in June 2003, and in which the Institute of Radioastronomy (IRA) was integrated into INAF (the Italian National Institute for Astrophysics; <http://www.inaf.it>). Therefore, since 1st January 2005, IRA is not part of the Council of National Researches (CNR) anymore. The structure of IRA, as well as its territorial organization, changed: it is now part of INAF, a much larger institute. In its constitution act, INAF is explicitly indicated as the national institute in charge of promoting, both at national and international levels, the activities related to astronomy, astrophysics and radioastronomy. The geodetic activity of IRA has been maintained within the new institute but the Geodetic Division has changed location and structure. Though the reorganization process is not complete yet, new opportunities are foreseen in the process. The Geodetic Division within INAF has increased, joining the former IRA division with the former geodetic division of the Cagliari Astronomical Observatory. Within this new group, the coordination of geodetic activities involving Medicina and Noto telescopes seems to be very promising, also optimizing the efforts required for organizing and planning geodetic activities that are relevant for SRT (Sardinia Radio Telescope; <http://www.ca.astro.it/srt/index.htm>). SRT is now a project of INAF: this new Institute is therefore managing three out of four radiotelescopes located on the Italian national territory.

## 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 the following years that software was installed on an HP360 workstation and later on an HP715/50 workstation. We analyzed mostly databases with some European baselines, generally at least three. We are also storing all the databases with the Ny-Ålesund antenna data. All hardware resources are now located at Bologna headquarters. These are two HP785/B2600 workstations and one HP282 workstation. We run CALC/SOLVE software package and f-SOLVE. During 2005, we have stored all the 1999-2005 databases available on the IVS data centers. All the databases have been processed and saved with the best selection of the parameters for the final arc solutions.

Our AC is participating in the IVS TROP Project on Tropospheric Parameters since the beginning of the activities. Submission of tropospheric parameters (wet and total zenith delay,

horizontal gradients) of all IVS-R1 and IVS-R4 24hr VLBI sessions is regularly performed in form of SINEX files. Moreover, we imported and analyzed all the other 2000-2005 databases available on the IVS data centers, in order to compute the tropospheric parameters. We are carrying out a comparison between the VLBI tropospheric estimates and the GPS-derived troposphere for the co-located sites. Long time series of troposphere parameters have been computed using all VLBI sessions available on our catalogue, in order to estimate the behaviour in time of the content of water vapour in the atmosphere. We submitted long time series of tropospheric parameters to IVS TROP Project.

### 3. Outlook

For the time being, our catalogue contains all experiments containing European stations and all sessions performed after 1998. It is our intention to upload and analyze all experiments performed in the previous years, thus completing the catalogue.

# IVS Analysis Center at Main Astronomical Observatory of National Academy of Sciences of Ukraine

*Sergei Bolotin, Yaroslav Yatskiv*

## Abstract

This report summarizes the activities of VLBI Analysis Center at Main Astronomical Observatory of National Academy of Sciences of Ukraine in 2005.

## 1. Introduction

The VLBI Analysis Center was established in 1994 by Main Astronomical Observatory (MAO) of the National Academy of Sciences of Ukraine as a working group of the Department of Space Geodynamics of MAO. In 1998 the group started its IVS membership as an IVS Analysis Center. The AC MAO is located in the Central building of the observatory in Kiev.

## 2. Technical Description

The computer of the Analysis Center is a Pentium-4 1.9 GHz CPU box with 256M RAM and a 160 GB HDD. It is running under Linux/GNU Operating System and is used for software development and VLBI data processing.

Main Astronomical Observatory has a 256 kbps link for Internet connection.

The STEELBREEZE software is written in the C++ programming language and uses Qt 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 delay) of single and multiple sets of sessions. The time delay is modeled according to the IERS Conventions (2003) [2], plus additional models (tectonic plate motion, nutation models, wet and hydrostatic zenith delays, mapping functions, etc). The software makes estimations of the following parameters: 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.

## 3. Staff

The VLBI Analysis Center at Main Astronomical Observatory consists of two members:

**Prof. Yaroslav Yatskiv:** Head of the Department of Space Geodynamics, performs general coordination and support of activity of the Center.

**Ph.D. Sergei Bolotin:** Senior research scientist of the Department of Space Geodynamics, responsible for the software development and data processing.

## 4. Current Status and Activities in 2005

In 2005 we performed regular VLBI data analysis to determine Earth rotation parameters. This “operational” solution is produced and submitted to IVS on a weekly basis. The IERS Conventions

(2003) [2] models have been applied in the analysis. In the solution coordinates of stations and Earth orientation parameters are estimated.

Also, this year our participation in the IVS Tropospheric Parameters project was continued. Estimated wet and total zenith delays for each station were submitted to IVS. The analysis procedure is similar to the previous one.

In the frame of “*Next ICRF*” project two “global” solutions were obtained, `maotst01` and `maotst02`. They were derived using the same data analysis strategy, but covering different time spans for the observations (1979–2005 and 1990–2005).

Normal equation systems for each session (1979–2005) were evaluated and submitted to IVS for further analysis.

## 5. Plans for 2006

MAO Analysis Center will continue to take part in operational EOP determination as well as updating the solutions of TRF and CRF from VLBI analysis of full dataset of observations.

The development of the software STEELBREEZE will be continued next year also.

## Acknowledgments

The work of our Analysis Center would be impossible without activities of other components of IVS. We are grateful to all contributors of the Service.

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# Analysis Center at National Institute of Information and Communications Technology

*Ryuichi Ichikawa, Mamoru Sekido, Hiroshi Takeuchi, Yasuhiro Koyama, Tetsuro Kondo*

## Abstract

This report summarizes the activities of the Analysis Center at National Institute of Information and Communications Technology (NICT) for the year 2005.

## 1. General Information

The NICT analysis center is located in Kashima, Ibaraki, Japan. It is operated by the Radio Astronomy Applications Group, Kashima Space Research Center of NICT. VLBI analyses at NICT are mainly concentrated on experimental campaigns for developing new techniques such as e-VLBI measurements for the real-time EOP determination and differential VLBI (DVLBI) for spacecraft orbit determination. In addition we carried out monthly IVS-T2 sessions. On September 12, 2005 Kashima 34 m station participated in the CONT05 campaign. WVR measurements were carried out at Kashima and Tsukuba during the campaign. We are also developing an automatic GPS analysis system named “APPS (Advanced Precise Positioning System)” to provide precise positioning for non-geodesist users.

## 2. Staff

The staff members who are contributing to the Analysis Center at the NICT are listed below (in alphabetical order):

- ICHIKAWA R., Spacecraft Orbit Determination and Atmospheric Modeling.
- KONDO T., Research Center Supervisor/Software Correlator
- KOYAMA Y., Group Leader/International e-VLBI
- SEKIDO M., Spacecraft Orbit Determination
- TAKEUCHI H., VLBI System Developments

## 3. Current Status and Activities

### 3.1. EOP Measurements

In September 2005, the Continuous VLBI 2005 (CONT05) campaign was carried out. On September 16, 2005 Kashima 34 m station participated in the CONT05 campaign. This measurement could be achieved by expanding the frequency coverage of X-band receiver system [1]. Preliminary results based on analysis between Kashima and Tsukuba baseline indicate that the system improvement worked well. To demonstrate the intercontinental e-VLBI technique Kashima 34 m station participated in two experiments on September 28-29, 2005 (iGrid 2005) and on November 12-18, 2005 (the annual Supercomputing Conference 2005).

### 3.2. Differential VLBI for Spacecraft Tracking

We performed 16 VLBI experiments for tracking HAYABUSA spacecraft during 2005. HAYABUSA, which means “Falcon” in Japanese, was launched on May 9, 2003, landed on asteroid “Itokawa” and tried to execute sampling from the asteroid on November 20 and 26, 2005. Unfortunately, as of the end of 2005, it was not confirmed whether HAYABUSA succeeded in sampling or not. Six VLBI sessions were observed during the HAYABUSA descending phase on Itokawa from November 4 to 26, 2005. In these measurements Kashima, Tsukuba and Chichijima of GSI, Usuda and Uchinoura of ISAS/JAXA, Mizusawa of NAOJ participated. The main purpose of these measurements was to evaluate the accuracy of spacecraft position determination using the differential VLBI technique. In addition the data from the measurements is also used to evaluate an internal time delay in the backend system.



Figure 1. Two WVRs at the Tsukuba 32 m station of GSI. Both Kashima and Tsukuba were equipped with WVRs during the CONT05 campaign.

### 3.3. APPS

We are developing an automatic GPS analysis system named “APPS (Advanced Precise Positioning System)”. APPS enables everybody to obtain accurate GPS solutions without requiring geodetic understanding, the operation of sophisticated GPS software, or complicated data handling. Users can submit static single point or multi-station network GPS data to the APPS analysis

server by e-mail and receive the analyzed results back by e-mail after a few minutes. At present we provide the mail-based APPS analysis service to a limited number of users in order to help to revise the system. We are also developing a web service for APPS.

### 3.4. Evaluation of Atmospheric Model

Both Tsukuba of GSI and Kashima VLBI stations performed atmospheric delay measurements using water vapor radiometer (WVR) during the CONT05 campaign. The data of co-located GPS stations were also obtained. At Tsukuba the radiosonde station of Japan Meteorological Agency (JMA) is located about 9 km south from GSI VLBI station. After the campaign our two WVRs were simultaneously operated at Tsukuba for the comparison with the radiosonde data sets (see Fig 1). Since Tsukuba and Kashima are located in the Asian monsoon region and the campaign was performed in the summer season of Japan, water vapor content was highly variable during the campaign. The maximum value of zenith wet delay (ZWD) is up to 30 cm. We show that the ZWD from GPS is in good agreement at less than 10 mm level. The ZWD derived by VLBI measurements is under investigation. In addition we will compare them also with operational pressure level data from the JMA numerical weather model.

## 4. Future Plans

For the year 2006 the plans of the Analysis Center at NICT include:

- Several international and domestic VLBI experiments for the real-time EOP determinations using e-VLBI and the K5 system (both VSSP system and PC/VSI system).
- Differential VLBI experiments for spacecraft tracking and its analysis
- Development of the analysis software for spacecraft positioning using phase delay observables
- Improvement of processing speed and efficiency for the VLBI data correlation using multi-processor and high speed network
- Evaluation of simulated positioning errors due to the tropospheric parameters (VLBI, GPS, WVR and the numerical weather prediction model)

In addition KSP data sets are still available at the URL <http://ksp.nict.go.jp/index.html>. General information about VLBI activities at NICT is provided at:

<http://www2.nict.go.jp/ka/radioastro/index.html>

(Please note that these URLs were changed from those given in the 2003 annual report).

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# Paris Observatory Analysis Center OPAR: Report on Activities, January - December 2005

*A.-M. Gontier, M. Feissel-Vernier, C. Barache*

## Abstract

The stability of extragalactic radio sources were further studied in 2005. Extending the Feissel-Vernier [1] study, three lists of reference sources based on progressively larger tolerances, are proposed. They include 181, 225, and 247 sources, respectively. Studies of the VLBI stations' stability were initiated. Using a new station stability analysis method [4], the noise spectrum and level of the non-linear signal in time series of station positions was characterized. We show that the non-linear signal has a white noise spectrum. The stability at one-year sampling time is better than 2 mm in the North and East directions, and 5 mm in the Up direction. The amplitude of the annual component is smaller than 1 mm in the North and East directions, and 5 mm in the Up direction.

## 1. Revision and Extension of the List of Stable Sources

Feissel-Vernier [1] proposed a list of 199 well observed radio sources considered stable, and 163 sources considered unstable, based on the statistical analysis of time series of source directions. An extension of the analyses was performed [2], leading to downgrading some of the sources initially considered as stable on the one hand, and to extending the list with additional sources.

A first extension concerns the sources with a relatively poor observation history. The Feissel-Vernier [1] stability detection, referred to MFV hereafter, was based on time series statistics of yearly averaged source coordinates. It has therefore the limitation of requiring time-density of observation. Over the 1990-2002 time span, 358 sources, i.e. about half of the total, were considered too sparsely observed to be submitted to the scheme. In order to learn more about their possible stability, a simplified selection scheme was applied to those sources. For sources observed in more than three sessions over more than two years, we assume that, in both  $\alpha \cos\delta$  and  $\delta$ , a standard deviation of the weighted mean position smaller than  $0.5 \mu\text{as}$  and a linear drift smaller than  $50 \mu\text{as}/\text{year}$  are an indication that the source might be stable. We thus select a set of 22 additional sources.

The second extension is based on a re-iterated computation of time series of coordinates provided by C. Ma. The MFV scheme was applied to time series of source coordinates that were derived taking subsets of the ICRF *defining* sources as the background reference. As a sizeable part of those were detected as unstable, one could not rule out the possibility that the intrinsic instability of the set of reference sources create spurious instabilities in the sources under study. A slightly modified scheme was therefore applied to time series of source coordinates derived from a global analysis where the original 199 stable sources were held fixed relative to the ICRF through a No-Net-Rotation (NNR) condition, using the CALC-SOLVE software package. The modified selection scheme includes the following rejection condition. Apparent drifts in  $\alpha \cos\delta$  or  $\delta$  larger than  $10 \mu\text{as}/\text{year}$ , at a  $5\text{-}\sigma$  significance. A set of 44 sources were detected as stable by this modified scheme.

Moreover, when the additional stability condition is applied to the time series used by Feissel-Vernier [1], the following 18 sources are found to be unstable. 0059+581, 0202+149, 0229+131, 0234+285, 0602+673, 0738+313, 0745+241, 0749+540, 1045-188, 1053+704, 1404+286 (OQ208),



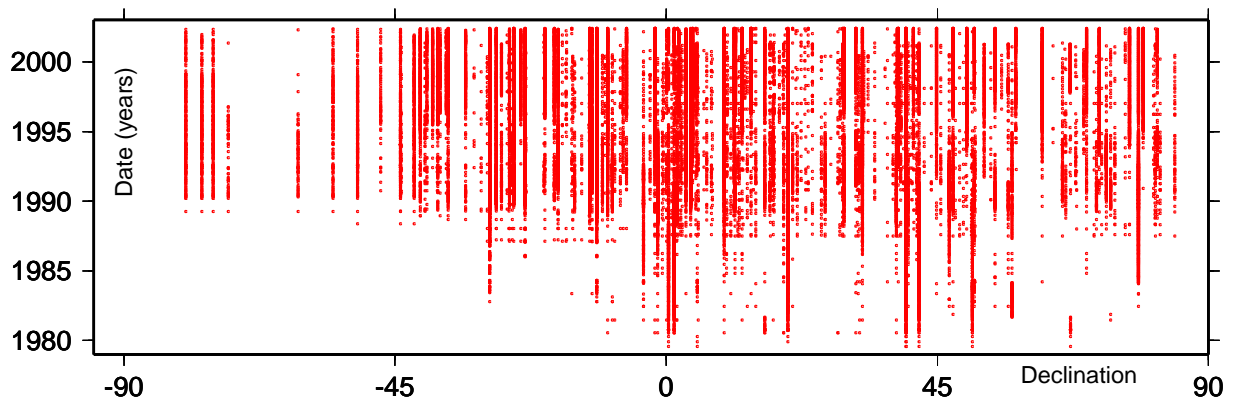


Figure 1. 1979-2002 observations of the 247 most stable sources. Each dot represents a session in which the source was observed.

1502+106, 1606+106, 1611+343, 1638+398 (NRAO512), 1642+690, 1726+455, 1738+476. The source names used here are the IERS source designations (see <http://hpiers.obspm.fr/icrs-pc/icrf/icrfdico.html>). The names used by the IVS are given in brackets when different. This modified scheme reduces the original set of 199 stable sources to only 181. This is the third change in the source selection.

In summary, a list of 247 sources considered stable, and thus considered suitable for the maintenance of the ICRF axes were obtained as follows.

- Adding to the MFV stability scheme the exclusion of sources with apparent drifts in  $\alpha \cos \delta$  or  $\delta$  larger than  $10 \mu\text{as}/\text{year}$ , at a  $5\text{-}\sigma$  significance and applying it to the data set used by Feissel-Vernier [1] provides a first list of 181 proposed reference sources.
- Selecting sources with low position scatter in the sparsely observed sources over 1990-2002 adds another 22 objects to the proposed reference sources.
- Applying the modified stability scheme to time series of source coordinates derived from a global analysis where the original 199 stable sources were held fixed provides 44 additional proposed reference sources.

The 247 sources are available at URL [http://hpiers.obspm.fr/icrs-pc/icrf/stable\\_2006.txt](http://hpiers.obspm.fr/icrs-pc/icrf/stable_2006.txt). Their observation history is illustrated in Figure 1.

## 2. Stability of VLBI Station Positions

We summarize hereafter a set of statistical tests and diagnostics concerning the spectral content of time series of coordinates of IVS stations, using time series of station coordinates provided by C. Ma. The major signature in time series of station coordinates is usually modelled as a tri-dimensional linear drift. The horizontal component is mostly related to the tectonic plate motion, while the Up component is assumed to reflect uplift or subsidence. The remaining component (“non-linear motion”) may be interpreted as noise related to local geophysical phenomena, instrumentation, or to the analysis strategies and modelling. Our analysis method is focusing on time series of residual coordinates relative to linear motion of the stations. The analysis is based on the combined use of Principal Components in the time domain (PCT) and Allan variance analysis [4].

Table 1. Stability estimators for 37 VLBI stations, 1990.0-2004.2

DOMES No	Stn	Start	End	Y	%Ms	PCT1		1-yr	All_StDv, Noise			Mult	Stb
						%Var	ASdv Sp		East	North	Up		
						mm		mm	mm	mm			
40424S001	1311	90.1	94.1	4	7	99%	3.5 Wh	0.7 Wh	0.1 Wh	3.5 Wh	2.42	1.8	
41705S006	1404	91.9	96.9	5	11	81%	5.5 Wh	2.7 Wh	0.9 Wh	4.9 Wh	1.11	2.0	
50103S010	1545	90.3	03.8	13	56*	63%	4.4 Wh	1.9 Wh	2.8 Wh	4.4 Wh	0.54	2.2	
13407S010	1565	90.1	03.3	13	53*	73%	3.6 Wh	1.5 Wh	2.1 Wh	3.6 Wh	1.30	1.6	
21701S001	1856	90.1	02.2	12	41	93%	10.4 Wh	1.5 Wh	2.6 Wh	10.1 Wh	2.84	3.9	
21701S004	1857	90.3	03.9	13	69*	73%	14.7 Wh	2.7 Wh	11.3 Wh	13.2 Wh	1.88	6.1	
40451M125	7108	93.4	03.5	10	60*	99%	19.7 Wh	1.5 Wh	4.3 Wh	19.4 Wh	0.01	7.8	
40441S007	7208	95.1	00.5	5	9	93%	2.9 Fl	0.8 Wh	0.6 Wh	2.8 Wh	3.77	1.6	
40440S003	7209	90.1	04.2	14	1	80%	3.1 Wh	0.7 Wh	0.6 Wh	3.1 Wh	3.31	1.1	
10402S002	7213	90.1	04.2	14	21	91%	3.8 Wh	0.5 Wh	1.2 Wh	3.8 Wh	2.52	1.5	
40441S004	7214	90.1	96.6	6	3	81%	1.5 Wh	1.7 Fl	0.7 Wh	1.2 Wh	1.22	0.7	
14201S004	7224	90.1	04.2	14	0	85%	1.7 Wh	0.6 Wh	0.5 Wh	1.7 Wh	2.32	0.7	
40408S002	7225	90.1	02.8	12	1	86%	2.5 Fl	0.8 Wh	1.0 Wh	2.5 Fl	2.99	1.5	
21605S009	7227	90.3	04.2	14	49*	64%	6.3 Wh	3.8 Wh	3.2 Wh	6.3 Wh	1.11	2.8	
12711S001	7230	90.1	04.2	14	38*	92%	3.2 Wh	0.8 Wh	0.8 Wh	3.2 Wh	2.03	1.5	
30302S001	7232	90.1	04.2	14	2	81%	3.9 Wh	1.2 Wh	1.5 Wh	3.9 Wh	1.07	1.8	
40456S001	7234	90.1	03.7	13	41	88%	4.9 Wh	0.8 Wh	1.3 Wh	4.9 Wh	4.92	2.0	
50116S002	7242	90.2	04.2	14	12	71%	4.7 Wh	1.8 Wh	1.9 Wh	4.6 Wh	1.04	1.9	
12734S005	7243	90.8	03.9	13	11	90%	1.8 Wh	0.5 Wh	0.8 Wh	1.7 Wh	1.06	0.7	
66008S001	7245	93.1	04.1	11	81*	83%	13.6 Wh	6.7 Wh	4.2 Wh	13.6 Wh	1.03	5.4	
40104S001	7282	90.5	04.2	13	17*	93%	3.1 Wh	0.8 Wh	0.7 Wh	3.1 Wh	1.98	1.2	
40127M004	7296	91.5	03.4	11	74*	89%	8.4 Wh	1.8 Wh	2.6 Wh	8.0 Wh	1.62	3.1	
41602S001	7297	93.4	04.2	10	7*	88%	4.2 Wh	1.0 Wh	1.1 Wh	4.1 Wh	2.25	1.8	
40424S007	7298	93.5	04.2	10	0	73%	1.3 Wh	0.8 Wh	0.4 Wh	1.3 Wh	1.25	0.6	
10317S003	7331	94.8	04.2	9	2	95%	2.7 Wh	0.6 Wh	0.6 Wh	2.6 Fl	3.48	1.5	
12337S008	7332	94.5	03.2	8	61*	90%	9.2 Wh	2.6 Wh	5.1 Wh	8.8 Wh	0.94	3.6	
21730S007	7345	98.5	04.1	5	14	66%	3.1 Wh	1.5 Wh	2.9 Wh	1.0 Wh	2.26	1.1	
12717S001	7547	90.1	03.9	13	58*	90%	2.7 Wh	0.7 Wh	1.7 Wh	2.7 Wh	0.88	1.1	
40466S001	7610	92.7	03.7	11	44*	84%	2.5 Wh	0.6 Wh	0.8 Wh	2.5 Wh	2.69	0.9	
40463S001	7611	91.4	03.7	12	29	93%	3.4 Wh	0.6 Wh	0.6 Wh	3.4 Wh	4.49	1.3	
40465S001	7612	92.7	03.5	11	40	90%	3.7 Wh	0.6 Wh	1.0 Wh	3.6 Wh	4.03	1.7	
40442S017	7613	92.1	03.7	11	33	75%	1.9 Wh	0.4 Wh	0.9 Wh	2.0 Wh	2.10	0.8	
40473S001	7614	93.4	03.5	10	36	95%	3.6 Wh	0.7 Wh	0.6 Wh	3.6 Wh	4.17	1.4	
43201S001	7615	93.5	03.7	10	37	94%	4.3 Wh	1.0 Wh	1.2 Wh	4.2 Wh	2.23	1.9	
40439S006	7616	92.7	03.7	11	43*	93%	3.1 Wh	0.8 Wh	0.9 Wh	3.1 Wh	3.40	1.6	
40477S001	7617	93.6	03.8	10	36	84%	3.2 Wh	1.6 Wh	0.9 Wh	2.8 Wh	1.87	1.2	
40471S001	7618	92.7	03.7	11	40*	60%	1.7 Wh	1.1 Wh	1.0 Wh	1.7 Wh	1.18	0.9	

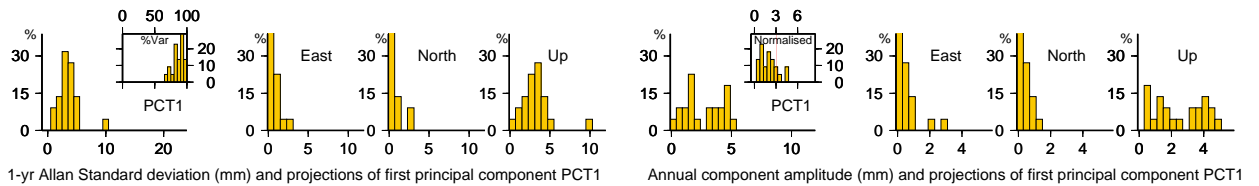


Figure 2. Distribution of the medium term stability (1-yr Allan standard deviation) and of the amplitude of the annual component in the 1990-2004 motion of 22 well observed IVS stations. The normalized amplitude is the ratio of the amplitude estimated by least squares analysis to its formal uncertainty.

The statistical quantities thus derived include medium term stability and annual signatures, scaling factors of the original coordinates uncertainties, stability indices, and various flags and criteria [3]. Table 1 gives details of the stability results found for 37 IVS stations. The meaning of the headings is as follows.

- DOMES No; Stn; Start; End; Y: DOMES Number and CDP name of the station; start and end dates of the data span, in years (first two digits of year omitted), and number of yearly averages.
- %Ms: Percentage of missing points in the time series, considering 35-d averages. The 15 stations flagged by \* have data gaps longer than 200 days.
- PCT1: Percentage of signal variance that it explains (%Var), Allan standard deviation for a one-year sampling time in millimetres (ASdv) - see the distribution of these quantities in Figure 2 - and noise spectrum (Sp). “Wh” stands for white noise, “F1” for flicker noise.
- 1-yr All\_StDv, Sp (East, North, Up): Allan standard deviation for the one-year sampling time of the series in the local coordinate system, in millimetres, and noise spectrum.
- Mult fact: Scale factor of the original coordinates uncertainties based on the Allan variance for the one-year sampling time. Large scale factors indicate larger underestimation of the formal uncertainties.
- Stb ind: Stability index. The most stable series have the lowest stability index.

The distributions of PCT1 Allan standard deviations and of their projections onto the East, North, Up directions are shown on Figure 2. The left part concerns the Allan variance of the non-linear signal for a one-year sampling time (independent of the annual signature, by construction) and the right part concerns the annual signature. In both cases, most of the signal is in the Up direction, with clear splitting in two populations in the case of the annual component. As indicated by the insert of the PCT1 histogram, a number of these seasonal amplitudes are significant at the  $1\text{-}\sigma$  level, and a few are significant at the  $3\text{-}\sigma$  level.

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# The IVS Analysis Center at the Onsala Space Observatory

*Rüdiger Haas, Hans-Georg Scherneck*

## Abstract

This report briefly summarizes the activities of the IVS Analysis Center at the Onsala Space Observatory during 2005. Some examples of achieved results and ongoing analyses are presented.

## 1. Introduction

The IVS Analysis Center at the Onsala Space Observatory focuses on a number of research topics that are relevant for space geodesy and geosciences. We address these research topics in connection to data observed with geodetic VLBI and complementing techniques. In the year 2005 the main focus was on thermal deformation of radio telescopes, loading phenomena, the European geodetic VLBI data, and sensing of atmospheric water vapor content with space geodetic and complementing techniques. Some results are briefly presented in the following.

## 2. Modeling of Thermal Deformation of Radio Telescopes

During 2005 we continued to model thermal deformations of radio telescopes. Our aim was to develop a model that allows to relate the air temperature measurements that are recorded in the VLBI log-files to vertical height changes of the radio telescopes. The model is based on previous work described in [1]. The work was done as part of a Sokrates-Erasmus student exchange project between Chalmers University of Technology and Vienna Technical University. Vertical height changes observed with the invar measurement systems at Onsala and Wettzell and the corresponding local temperature observations were used as input parameters for the model [2].

## 3. Ocean Tide and Atmospheric Loading

The service provided by the automatic ocean tide loading provider [3] has been maintained and extended during 2005 and the two new models TPXO.7.0 [4] and FES2004 [5] were added. The time series of atmospheric loading predictions [6] were updated to cover the year 2005.

## 4. Analysis of European Geodetic VLBI Data

We continued to analyze the data observed in the European geodetic VLBI network. Figure 1 shows the baseline length results through 2005 on all European baselines connecting to Onsala. For most of the baselines the weighted root-mean square (WRMS) scatter is on the order of 4–5 mm.

## 5. Contribution to the IVS TROP Project

Also during 2005 we continued to submit on a regular basis tropospheric parameters for all VLBI stations observing in the IVS R1 and R4 networks [7].

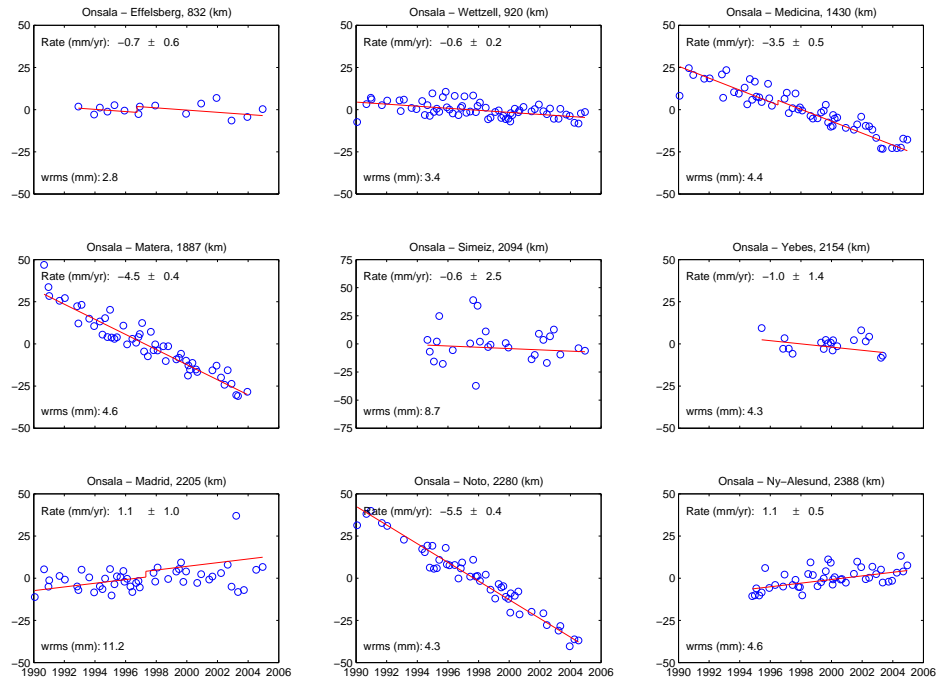


Figure 1. Baseline length observations in the European geodetic VLBI network. Shown are all European baselines connecting to Onsala.

## 6. IPWV Trends in Europe

We investigated trends in atmospheric water vapor for six European space geodetic stations that are equipped with both VLBI and GPS equipment and also have a radiosonde launch site relatively close by [8]. The zenith wet delay (ZWD) results obtained from VLBI and GPS were converted to Integrated Precipitable Water Vapor (IPWV) and combined with corresponding results from radio sondes (RS) by using a variance-covariance estimation strategy. Figure 2 shows the corresponding IPWV time series. The combined results were also compared to estimated IPWV trends from the ERA40 model [9]. Both groups of trends did only agree well for 2 out of the six sites. Furthermore, we detected a dependency of the GPS IPWV trends on the chosen elevation cutoff angle.

## 7. Atmospheric Gradients During CONT02

We continued to analyze the atmospheric parameters at Onsala during CONT02 [10], [11]. The radiometer data were reprocessed and the rain radar observations were used to identify and exclude radiometer measurements that were affected by rain. Results for zenith wet delays (ZWD) were presented in [12]. Scatter plots of gradient results from VLBI, GPS and the two microwave radiometers Astrid and Konrad that were operated at Onsala during CONT02 are shown in Figure 3 and reported in [13]. While the VLBI and GPS results agree reasonably well, there are small biases between the radiometer results and between radiometer and space geodesy results. The correlation coefficients are generally below 0.5 for all comparison pairs.

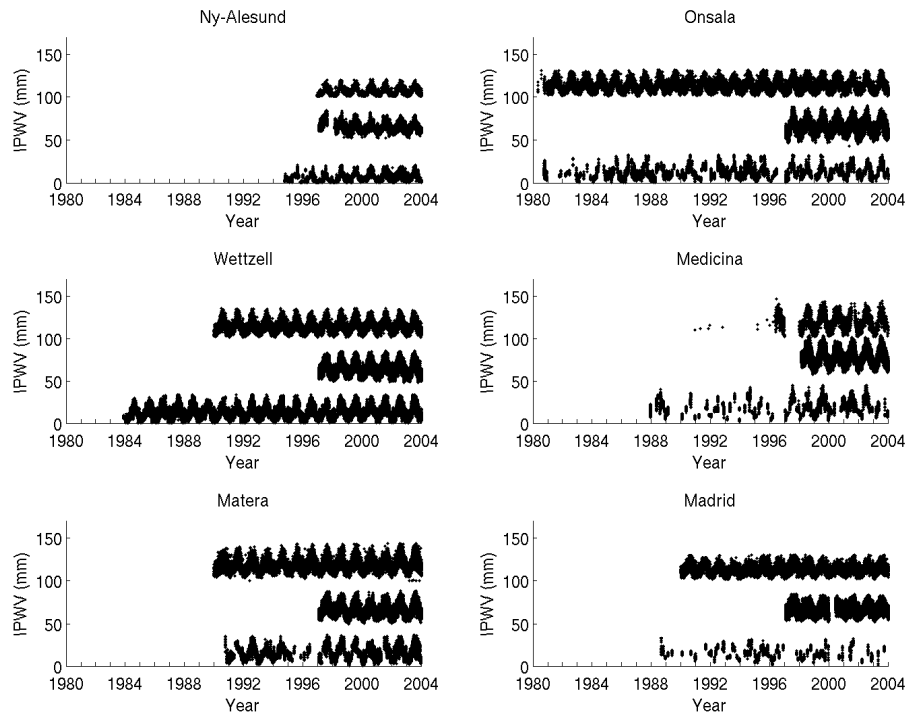


Figure 2. Time series of IPWV for six space geodetic stations in Europe. In each picture the displayed data show from the bottom to the top IPWV results for VLBI, GPS, and RS, respectively. Offsets of 50 mm and 100 mm are added for GPS and RS, respectively, in order to improve readability of the graphs.

## 8. Outlook

The IVS Analysis Center at the Onsala Space Observatory will continue its work on specific topics relevant for space geodesy and geosciences.

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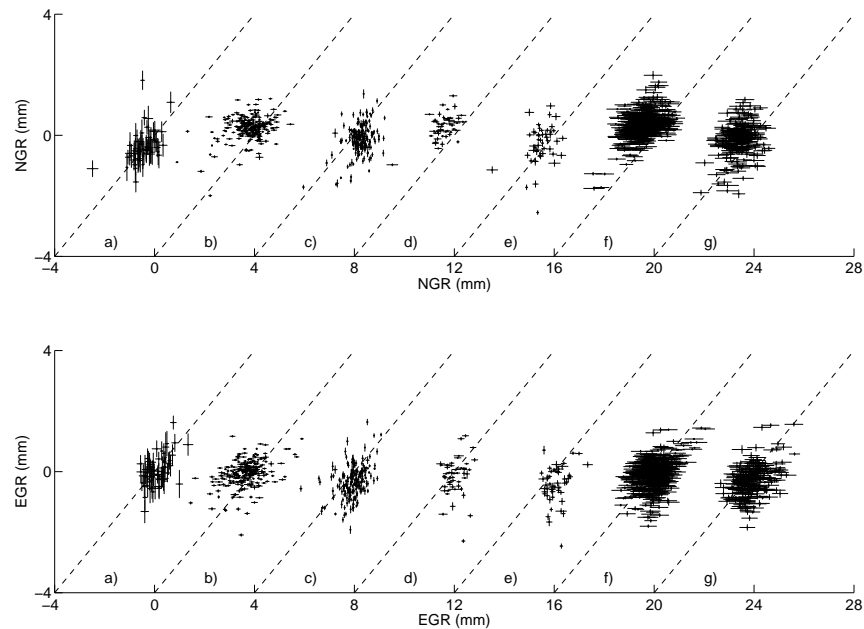


Figure 3. Scatter plots of north gradient (NGR, top) and east gradient (EGR, bottom) results: a) GPS vs. VLBI, b) Astrid vs. Konrad, c) Konrad vs. Astrid, d) Astrid vs. VLBI, e) Konrad vs. VLBI, f) Astrid vs. GPS, g) Konrad vs. GPS. From left to right the scatter plots are offset in steps of 4 mm along the x-axis. The dashed lines indicate lines of perfect agreement.

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# SHAO Analysis Center 2005 Annual Report

*Jinling Li*

## Abstract

Our research activities in 2005 were mainly focused on satellite positioning and orbit determination by VLBI. We were also involved in the coordination of VLBI experiments, data archives, reduction and application studies of the Asia-Pacific Space Geodynamics program. Our contribution to the next realization of the International Terrestrial Reference Frame (ITRF2005) proved to be of good quality covering the complete period of VLBI observations. The plan for the next year is to continue our efforts in the application studies of VLBI. We are also planning to contribute to IVS the extension solutions of Earth Orientation Parameters, to analyze the position stability of astrometric/geodetic radio sources, to apply differential VLBI in satellite positioning, and to discuss regional cooperations of astrometric/geodetic VLBI.

## 1. General Information

As one of the research groups of Shanghai Astronomical Observatory (SHAO), we focus our activities on the studies of Radio Astrometry and Celestial Reference Frames. We use the CALC/SOLVE software package for the routine VLBI data processing. We are now developing softwares in FORTRAN code to deal with satellite VLBI observations. The related members involved in the IVS activities are Jinling Li, Guangli Wang, Bo Zhang, Li Guo, Jing Wang, Ming Zhao, and Zhihan Qian.

## 2. Activities in 2005

### 2.1. Observations and Data Reduction

In October and December of 2005 two new 24hour VLBI sessions of the Asia Pacific Space Geodynamics program (APSG) were carried out. As shown in Table 1, up to now there are in total 17 APSG sessions with a single solution *wrms* of about 40ps. Shanghai participated in several IERS/IVS campaigns aimed at comparisons of reference frames and/or Earth Rotation Parameters (EOP); for instance, the contribution to the next realization of the International Terrestrial Reference Frame (ITRF2005), which proved to be of good quality covering the complete period of high quality VLBI observations. We also give some effort in the preparation of the EOP extension solutions.

### 2.2. The Ionosphere Delay Correction of the Satellite VLBI Observations

In astrometric/geodetic VLBI dual-frequency observations at S/X bands are used to correct the ionosphere delay. However, in the Chinese lunar mission Chang'E, the S/X dual-band observations could not be always guaranteed during the satellite positioning and trajectory determination by range, Doppler and VLBI. It was therefore necessary to make the ionosphere delay corrections by using other means besides the dual-band technique, for instance using GPS data. In addition, it should be checked whether the dual-band technique is still valid to the ionosphere delay correction of the satellite VLBI tracking data or not.



Table 1. VLBI observations of APSG

Code	Session	Stations	Duration	Delays	<i>wrms</i>
APSG01	97OCT06XA	GC,HB,KK,SE,UR	24h01m57s	858	46ps
APSG02	97OCT20XA	GC,HB,KA,KK,SE,UR	24h02m48s	1533	50ps
APSG03	98NOV05XA	GC,KK,SE,TS,UR	24h58m04s	1404	40ps
APSG04	98NOV12XA	GC,HB,KK,SE,TS,UR	23h56m49s	1700	43ps
APSG05	99NOV01XA	GC,HB,KA,KK,SE,UR	23h58m04s	931	56ps
APSG06	99NOV04XA	GC,HB,KA,KK,SE,UR	23h55m02s	1443	47ps
APSG07	00OCT02XA	GC,HB,KK,SE,TS,UR	23h42m26s	950	41ps
APSG08	01OCT10XA	HB,KK,SE	23h51m29s	274	51ps
APSG09	01OCT15XA	HB,KK,SE,TS,UR	23h57m39s	1143	42ps
APSG10	02OCT08XA	GC,HB,KK,SE,TS,UR	23h49m19s	1516	37ps
APSG11	02NOV05XA	GC,HB,KK,SE,TS,UR	23h56m41s	1961	38ps
APSG12	03OCT08XA	GC,HB,KK,SE,TS,UR	23h26m21s	2120	35ps
APSG13	03OCT21XA	KK,SE,TS,UR,HB	23h24m15s	1296	43ps
APSG14	04SEP15XA	GC,HB,KK,SE,TS	23h48m42s	1050	35ps
APSG15	04SEP29XA	GC,HB,KK,SE,TS	24h00m00s	1508	37ps
APSG16	05OCT11XA	GC,HO,KK,SH,TS	23h53m37s	1359	34ps
APSG17	05DEC06XA	GC,HO,KK,PA,SH,TS,UR	23h50m30s	2690	36ps

The Total Electron Content (TEC) along the ray path measured by VLBI and predicted by GPS for Seshan25 — Urumqi baseline and baselines of CONT02, a two-week campaign of continuous VLBI sessions in 2002, were compared. The comparisons indicated that ionosphere information from GPS observations could be applied to correct the VLBI observations of satellite, but there may exist significant systematic difference between the two techniques. Further analysis showed that this systematic difference is mainly related to the phase-calibration during the VLBI observation. In the reduction of astrometric and geodetic VLBI observations this systematic behavior is parameterized as the quasi clock bias leaving no effects on the solutions of source positions, station coordinates and EOP. In the data reduction of satellite VLBI tracking, however, practice shows that the quasi clock bias could not be solved simultaneously with the positions or the orbit elements of satellite. In order to determine this systematic behavior we therefore need to observe extragalactic radio sources during the satellite tracking, even though the dual band technique is being applied.

When the observation elevation is low there may be quadratic trend in the systematic difference, whose determination also requires observations of extragalactic radio sources at low elevation. In consideration of the time-space variation of the ionospheric ion density it is helpful to observe radio sources close to the tracking pass. There is a large scatter in the difference of TEC obtained by the two techniques at low elevation. The increase in GPS sampling rate and those observations from GPS local network are therefore beneficial to the improvement both in the time-space coverage of ionosphere and in the prediction precision of TEC by GPS observations, especially at low elevation.

### 2.3. The Reduction of the Satellite VLBI Observations

For the satellite positioning and orbit determination by VLBI during the Chang'E mission, the software is still under development and is partly examined by geo-satellite VLBI tracking data. There is still a long way to go to apply the software to the mission. Issues that still need some effort include (1) synthesis reduction of range and Doppler as well as VLBI observations of satellite, (2) synthesis reduction of observations of satellite as well as quasars, (3) setting of constraint of geocentric or lunar centric distance of satellite and so on.

### 2.4. Other Astrometric Activities

The Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) was primarily proposed by Chinese scientists Shouguan Wang and Dingqiang Su, members of the Chinese Academy of Sciences. This telescope is characterized by important creative ideas in several aspects and the tracking mode is special too. Usually the tracking motion of telescopes is accomplished by setting the velocity to be in accordance with the diurnal motion and then adjusted by, for instance, the optical-electronic tracking device, which maintains the image of a guiding star staying at the center of the field of view (FOV). However, for LAMOST no object image at the FOV center could be available. In addition, all the fibers are required to precisely capture and track their corresponding objects. Due to the diurnal motion, the atmospheric refraction, and the aberration, the coordinates of images on the focal plane are changing with time. The tracking of images can be done by machinery driving systems only if the image positions could be precisely predicted, or equivalently, the tracking parameters of LAMOST could be precisely calculated. The precise vectorial expressions of tracking parameters of LAMOST are deduced by taking into consideration the real observation conditions, including the effects of atmospheric refraction, the diurnal and annual aberration, as well as the variation of the refraction coefficient with the altitude of the observation station and the air temperature and pressure at the observation epoch. Comparisons and analysis show that on the level of arc second a comprehensive consideration of all the effects is necessary to the precise tracking of objects by LAMOST fibers.

We are also working on the CCD observations and data reduction of stars and satellite.

## 3. Plans for 2006

We will continue to focus our efforts on the application studies of VLBI to satellite positioning and orbit determination, mainly concerning the post-correlation stage. We will try our best to be closely involved in the IERS/IVS activities. We intend to provide to the IVS the extension EOP solutions, to analyze the position stability of astrometric/geodetic radio sources, to think about the application of differential VLBI in the satellite positioning and to discuss regional cooperations of astrometric/geodetic VLBI. The analysis of the high frequency variation of EOP will be continued.

# U.S. Naval Observatory VLBI Analysis Center

*David A. Boboltz, Alan L. Fey, David M. Hall, Kerry A. Kingham*

## Abstract

This report summarizes the activities of the VLBI Analysis Center at the United States Naval Observatory for calendar year 2005. Over the course of the year, Analysis Center personnel analyzed biweekly diurnal experiments with designations IVS-R1 and IVS-R4 for use in-house and continued timely submission of IVS-R4 databases for distribution to the IVS. During the 2005 calendar year, the USNO Analysis Center produced three periodic global Terrestrial Reference Frame (TRF) solutions with designations usn2005a, usn2005b, and usn2005c. Earth orientation parameters based on these solutions, updated by the diurnal (IVS-R1 and IVS-R4) experiments, were submitted to the IVS. Beginning in November of 2005, Analysis Center personnel began IVS submission of an EOP-I series based on the intensive experiments.

Other activities in the 2005 calendar year included the continued generation of files in the SINEX format based on new 24-hr experiments and submission to the IVS. With regards to the Celestial Reference Frame (CRF), Analysis Center personnel continued a program designed to increase the sky density of ICRF sources especially in the southern hemisphere. Activities included scheduling, analyzing and submitting databases for IVS-CRF experiments and the production of global CRF solutions designated crf2005a, crf2005b, and crf2005c. This report also describes activities planned for the 2006 calendar year.

## 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, the production of periodic global Terrestrial Reference Frame (TRF) and Celestial Reference Frame (CRF) solutions, and the submission to the IVS of intensive (EOP-I) and session-based (EOP-S) Earth orientation parameters based on USNO global TRF 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, USNO personnel engage in research aimed at developing the next generation ICRF. Information on USNO VLBI analysis activities may be obtained at:

<http://rorf.usno.navy.mil/vlbi/>.

## 2. Current Analysis Center Activities

### 2.1. Experiment Analysis and Database Submission

During the 2005 calendar year, personnel at the USNO VLBI Analysis Center continued processing of diurnal (IVS-R1 and IVS-R4) experiments for use in internal USNO global TRF and CRF solutions. USNO is also responsible for the timely analysis of the IVS-R4, and the resulting databases are submitted within 24 hours of correlation for dissemination by the IVS. In addition, Analysis Center personnel continue to be responsible for the analysis and database submission for the periodic IVS-CRF experiments. The primary goal of these experiments is the densification of ICRF sources in the southern hemisphere. In 2005, USNO scheduled and analyzed 19 CRF experiments including IVS-CRF31 through IVS-CRF36, CRF-S4 through CRF-S7, and IVS-CRDS16

through IVS-CRDS24. The analyzed databases were submitted to the IVS. In the 2005 calendar year, Analysis Center personnel also continued analyzing IVS intensive experiments for use in a USNO EOP-I time series.

## 2.2. Global TRF Solutions, EOP and SINEX Submission

USNO VLBI Analysis Center personnel continued to produce periodic global TRF solutions (usn2005a, usn2005b and usn2005c) over the course of the 2005 calendar year. All USNO global TRF solutions including the most recent solution may be found at:

<http://rorf.usno.navy.mil/solutions/>.

Session-based Earth orientation parameters derived from these TRF solutions were compared to those derived from GSFC periodic TRF solutions and with the IERS-C04 time series prior to

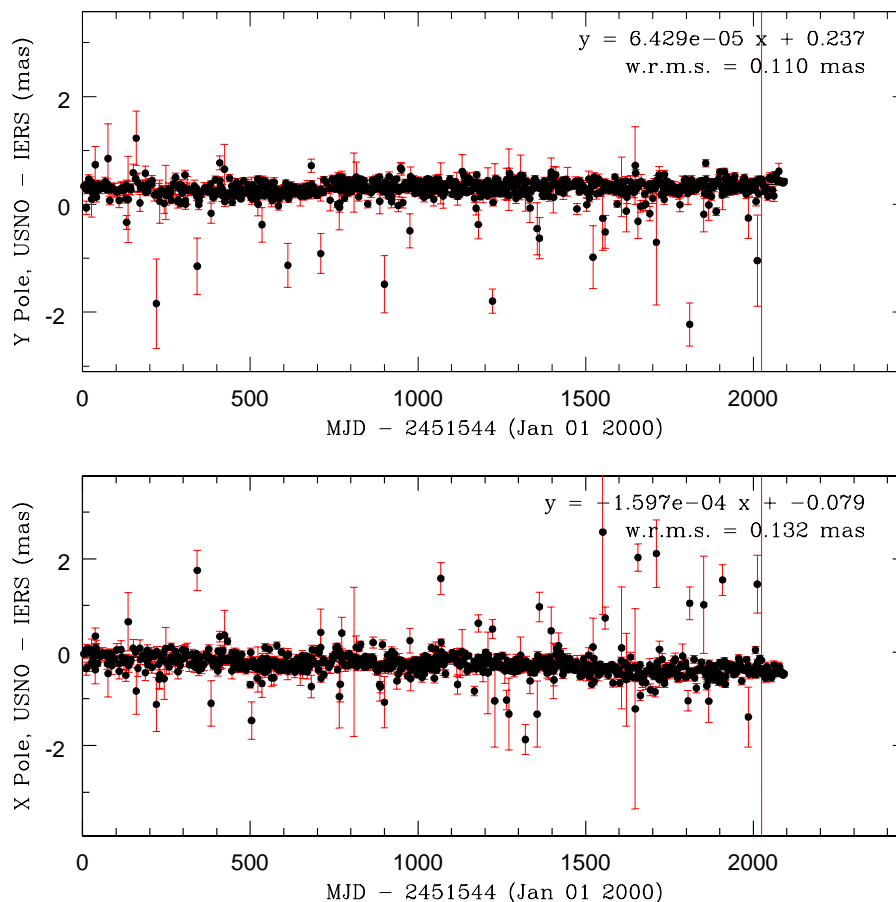


Figure 1. Differences between pole positions estimated from the usn2005c TRF solution and the IERS-C04 time series from January 2000 through September 2005. A weighted least squares linear fit to the data and the weighted RMS are shown in the upper right corner of each plot.

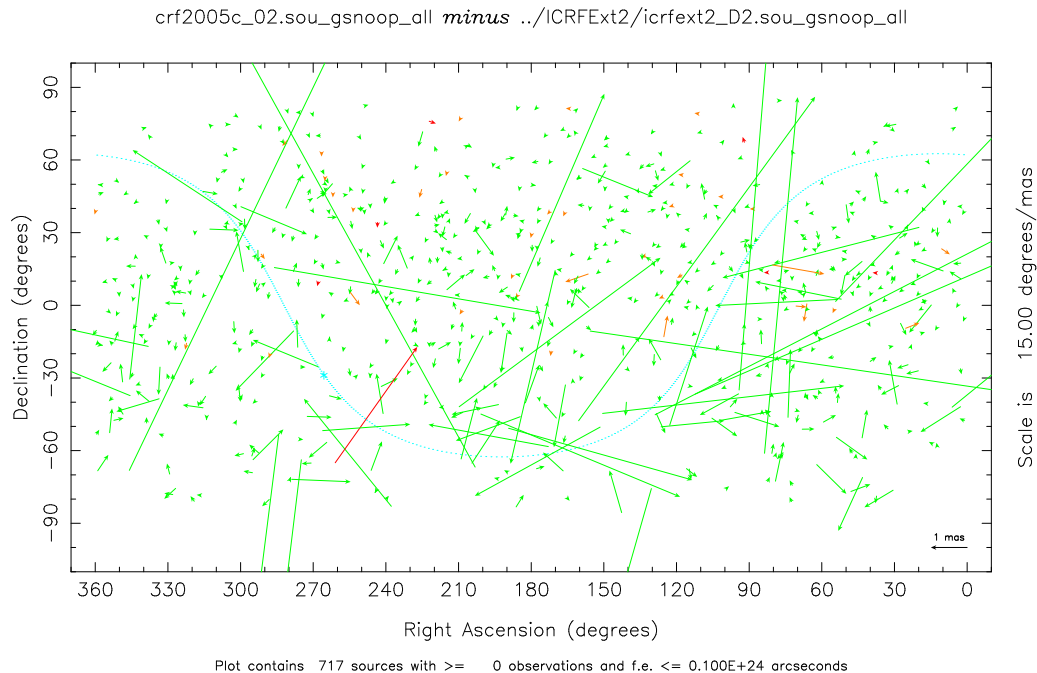
submission to the IVS. Figure 1 shows an example of the comparison information available at the web site mentioned above. In this figure, differences in pole position estimates derived from the usn2005c solution and the IERS-C04 time series are plotted.

Analysis Center personnel continued to produce an EOP-S series based on the global TRF solutions and continuously updated by new data from the IVS-R1/R4 experiments since the most recent global solution. This updated EOP-S 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 to produce suitable SINEX format files based on new 24-hr experiments and the resulting files submitted to the IVS.

In addition to EOP-S and SINEX series, USNO Analysis Center personnel continued to produce an EOP-I series based on the IVS intensive experiments. USNO personnel began submitting this EOP-I series to the IVS in November 2005.

### 2.3. Celestial Reference Frame

During the 2005 calendar year, Analysis Center personnel continued work on the production of global CRF solutions for dissemination by the IVS including crf2005a, crf2005b, and crf2005c. These solutions are routinely compared to the current ICRF and are available through the previously mentioned web site: <http://rorf.usno.navy.mil/solutions/>. As an example, Figure 2 shows the differences between USNO crf2005c source positions and the corresponding ICRF-Ext.2 positions for 717 sources.



afey 12-Oct-2005 12:31

Figure 2. Differences in the source positions as derived from the most recent CRF solution (crf2005c) and ICRF-Ext.2 solution. Plotted are 717 sources in the ICRF. The dotted line represents the galactic equator.

During 2005, Analysis Center personnel also continued research into the densification of the ICRF in the southern hemisphere through IVS-CRF and ATNF/USNO observations was continued in 2005. New images of 48 southern hemisphere extragalactic sources were published by Ojha, et al. (2005, AJ, 130, 3609), bringing the number of observed southern hemisphere sources to 111. From these images, approximately one-third of the sources were judged to be compact enough to be used in astrometric/geodetic VLBI experiments.

### 3. Staff

The staff of the VLBI Analysis Center is drawn from individuals who work at the USNO. The staff and their responsibilities are:

<b>Name</b>	<b>Responsibilities</b>
David A. Boboltz	Periodic global TRF solutions and comparisons, Sinex generation and submission, web page administration, VLBI data analysis.
Alan L. Fey	Periodic global CRF solutions and comparisons, CRF densification research, web page administration, VLBI data analysis.
David M. Hall	VLBI data analysis and database submission, IVS EOP-S submission.
Kerry A. Kingham	Correlator interface, VLBI data analysis

### 4. Future Activities

For the upcoming year January 2006–December 2006, USNO VLBI Analysis Center personnel plan to accomplish the following activities:

- Continue the processing of biweekly IVS-R1/R4 experiments for use in internal TRF and CRF global solutions and continue submission of IVS-R4 databases for dissemination by the IVS.
- Continue the production of periodic global TRF solutions and the submission of EOP-S estimates to the IVS updated by the IVS-R1/R4 experiments.
- Submit a series of SINEX format files retroactive to 1979 based on all available USNO databases.
- Continue the analysis of intensive experiments and submission of EOP-I estimates to the IVS.
- Continue the analysis and database submission for all IVS-CRF experiments.
- Continue ATNF/USNO astrometric observations and research regarding the densification of the ICRF in the southern hemisphere.
- Continue the production of periodic global CRF solutions.

# USNO Analysis Center for Source Structure Report

*Alan L. Fey, David A. Boboltz, Ralph A. Gaume, Kerry A. Kingham*

## Abstract

This report summarizes the activities of the United States Naval Observatory Analysis Center for Source Structure for calendar year 2005. VLBA high frequency experiments BL115C, BL122A and BL122B were calibrated and imaged. A Southern Hemisphere imaging and astrometry program for maintenance of the ICRF continued. Imaging of an additional 42 southern hemisphere ICRF sources at 8.4 GHz was completed. Activities planned for the year 2006 include continued imaging of ICRF sources at standard and higher frequencies and continued analysis of source structure and its variation.

## 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 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/](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 3450 Very Long Baseline Array (VLBA) images of 497 sources at radio frequencies of 2.3 GHz and 8.4 GHz. Additionally, the RRFID contains 976 images of 255 sources at frequencies of 24 GHz and 43 GHz. The RRFID can be accessed from the Analysis Center web page or directly at

<http://www.usno.navy.mil/RRFID/>

A recent addition to the RRFID are Australian Long Baseline Array (LBA) images of 69 southern hemisphere ICRF sources at a radio frequency of 8.4 GHz.

## 2. Current Activities

### 2.1. RDV Imaging

During calendar year 2005, the USNO did not produce images for any of the VLBA RDV experiments. Collaborations are underway with Glenn Piner at Whitier College and Patrick Charlot of Bordeaux Observatory to calibrate and image several of the RDV experiments.

### 2.2. VLBA High Frequency Imaging

VLBA observations to extend the ICRF to 24 and 43 GHz continued in 2005. These observations are part of a joint program between the National Aeronautics and Space Administration, the

USNO, the National Radio Astronomy Observatory (NRAO) and Bordeaux Observatory. During the calendar year 2005, three VLBA high frequency experiments (BL115C, BL122A and BL122B) were calibrated and imaged adding 65 images at 2.3 GHz, 100 images at 8.4 GHz and 193 images at 24 GHz to the Radio Reference Frame Image Database.

### 2.3. ICRF Maintenance in the Southern Hemisphere

The USNO and the Australia Telescope National Facility (ATNF) are collaborating in a continuing VLBI research program in Southern Hemisphere source imaging and astrometry using USNO, ATNF and ATNF-accessible facilities. These observations are aimed specifically toward improvement of the ICRF in the Southern Hemisphere by a) increasing the reference source density with additional bandwidth-synthesis astrometric VLBI observations, and b) VLBI imaging at 8.4 GHz of ICRF sources south of  $\delta = -20^\circ$ .

VLBI images for a total of 69 Southern Hemisphere ICRF sources at a frequency of 8.4 GHz using the Australian Long Baseline Array were published by Ojha, et al. (2004, AJ, 127, 3609). Additional images of 48 southern hemisphere extragalactic sources were published by Ojha, et al. (2005, AJ, 130, 2529) bringing the total number of observed sources to 111. These data were used to calculate a “structure index” for the sources; the structure index yields an estimate of their astrometric quality. Approximately 35% of sources in this sample were found to have a structure index indicative of compact or very compact structures. The remaining two-thirds of the sources were found to be less compact and should probably be avoided in astrometric and geodetic VLBI experiments requiring the highest accuracy unless intrinsic source structure can be accounted for in the astrometric/geodetic analysis. Images for an additional  $\sim 50$  sources have been made and are being prepared for publication.

### 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, Ralph A. Gaume and Kerry A. Kingham.

### 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 2006 are planned:

- Continue imaging and analysis of VLBA 2.3/8.4/24/43 GHz experiments
- Make additional astrometric and imaging observations in the Southern Hemisphere in collaboration with ATNF partners
- Fey et al. (2004, AAS, 205, 9112) developed an algorithm to use images from the RRFID to classify sources in terms of their suitability for astrometric use based on their spatial compactness. Initially applied to the high frequency (24/43 GHz) data, the method will be applied to the study of ICRF sources at the standard frequencies (2.3/8.4 GHz).



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# Technology Development Centers

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# Canadian VLBI Technology Development Center

*Bill Petrachenko, Mario Bérubé, Anthony Searle*

## Abstract

The Canadian Technology Development Center has developed an “end-to-end” geodetic VLBI system built on S2 equipment. The development of this system has led to an operational IVS network. Development work continues to streamline operations and improve S2 instrumentation. The Technology Development Center is actively preparing to engage in the development of the VLBI2010 systems.

## 1. Introduction

The Canadian VLBI Technology Development Center 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 Herzberg Institute for Astrophysics of the National Research Council of Canada, (DRAO/HIA/NRC).

## 2. S2 VLBI Geodesy

The S2 VLBI observation program continued in 2005 as the operational “E3” IVS observing network. The “E3” Network consists of Algonquin, Yellowknife, the Canadian Transportable VLBI Antenna (CTVA), Kokee Observatory, Svetloe Observatory, and the Transportable Integrated Geodetic Observatory (TIGO) located in Concepcion, Chile. The Gilmore Creek antenna in Fairbanks, Alaska participated in the E3 network during the winter months of 2005, when Yellowknife was not operational.

## 3. S2 VLBI System

The S2-DAS is designed to accommodate up to four VLBA/Mark IV-type single sideband baseband converters (BBCs), each with a local oscillator (LO) independently frequency switchable under computer control. The recording system uses 8 modified super-VHS recorders.

The Canadian Correlator is a six station correlator (expandable to ten stations) using S2 playback terminals and is designed to handle S2 frequency-switched bandwidth synthesis data.

## 4. Canadian Transportable VLBI Antenna (CTVA)

The CTVA is a 3.6m radio telescope acquired to facilitate densification of the VLBI measurements of the Canadian Spatial Reference System (CSRS). The antenna will be co-located with GPS elements of the Canadian Active Control System (CACS), part of the CSRS, to provide fiducial station positions. The Canadian Technology Development Center is responsible for CTVA system development.

The CTVA spent all of 2005 in St. John’s, Newfoundland. CTVA uses a group of local university and college students for all observing operations.

The CTVA communication system was upgraded in late 2004 allowing for high-speed Internet, web-based cameras, and automated site monitoring in 2005, improving site reliability and safety. In December of 2005 XM radio began broadcasting in Canada, unfortunately, a local terrestrial repeater saturated the S-band receiver. A study is currently underway to determine an optimum solution to the problem, which will require either new on site hardware or relocation of the CTVA.



Figure 1. Local visitor examines the tie between IGS station STJO and CTVASTJ

## 5. S2 Geodetic Experiment Scheduling, Operations and Analysis

The “E3” network continues to contribute with monthly EOP sessions using 6 stations. The EOP results are comparable to R4 sessions but have slightly greater uncertainty due to network configuration and sensitivity.

## 6. VLBI2010

Following the release of the VLBI2010 report, Bill Petrachenko was appointed to chair the VLBI2010 committee, which is tasked with continuing the work outlined in the report. NRC has also presented a concept for a low cost 12-metre carbon fibre antenna, and has established a small laboratory for concept testing.

# FFI Technology Development Center - Software Development

*Per Helge Andersen*

## Abstract

FFI's contribution to the IVS as a Technology Development Center focuses primarily on the development and validation of the GEOSAT software for a combined analysis at the observation level of data from VLBI, GPS and SLR. This report shortly summarizes the latest improvements of the GEOSAT software. FFI is currently Analysis Center for IVS and ILRS, Technology Development Center for IVS, and Combination Research Center for IERS.

## 1. The GEOSAT Software

The advantages of the combination of independent and complementary space geodetic data at the observation level is discussed in Andersen ([1]). The models of GEOSAT are listed in Andersen ([2]). The most important changes implemented in 2005 are described in the following.

The GEOSAT software is presently undergoing extensive development. The validation of GEOSAT with VLBI and SLR tracking data is completed with very promising results. Right now the GPS part of GEOSAT is in the validation phase.

Regarding SLR: The use of a detector-dependent center of mass correction, 3D raytracing, and taking into account a signal strength dependent range bias for some stations, led to a slight change in the value of GM as determined from SLR data. The use of multicolor laser data has been implemented and gives excellent post-fit residuals. This will be further investigated in 2006. Also the GNSS part of GEOSAT has undergone extensive changes, for instance with the inclusion of a second and third order ionospheric correction, absolute phase center corrections for all antennas etc.

The new version of GEOSAT is expected to be ready for routine processing within 1.5 years. The new version of GEOSAT will have two additional very useful features: 1) It can simultaneously combine data from virtually any number of VLBI, SLR, and GPS instruments at a co-located site either observing simultaneously or in different time windows. All information will contribute to the estimation of the migration of an automatically selected master reference point at each station. 2) The station-related solve-for model parameters in a combined processing of the VLBI + SLR + GNSS can either be instrument-dependent, technique-dependent, microwave-dependent, optical-dependent, site-dependent, satellite/spacecraft-dependent, or radio source-dependent. The switching between the different types is extremely simple. A typical application would be to, in a first run, treat the zenith wet delay parameters as instrument-dependent parameters. This means that, for example, a station with two GPS receivers and one VLBI instrument will have three estimates of these parameters. If the results look consistent, all these parameters can be estimated as one single parameter represented by a microwave-dependent parameter in a second run. The same can be tested for clock parameters for co-located clocks etc. Since the raytracing starts at the position of the phase center for each instrument/antenna, the effect of different antenna heights will automatically be accounted for to the level of accuracy of the numerical weather model rescaled by the in-situ observed pressure values from the surfmet data.

The GEOSAT software has recently been used for the calibration of the GLOBUS-II radar north in Norway. This radar is one of the most accurate radars available today. After calibration

using GEOSAT the performance in precision improved by one to two orders of magnitude!

## 2. Staff

Dr. Per Helge Andersen - Research Professor of Forsvarets forskningsinstitutt (FFI) and Institute of Theoretical Astrophysics, University of Oslo.

## References

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# GSFC Technology Development Center Report

*Ed Himwich, John Gipson*

## Abstract

This report summarizes the activities of the GSFC Technology Development Center (TDC) for 2005, and forecasts planned activities for 2006. The GSFC TDC develops station software including the Field System, scheduling software (SKED), hardware including tools for station timing and meteorology, scheduling algorithms, operational procedures, and 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, employed by NVI, Inc, and Chuck Kodak, employed by Honeywell.

The remainder of this report covers the status of the main areas of development that are currently being pursued.

## 2. Field System

The GSFC TDC center 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 file (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 all the IVS network stations (over 30) and also at many stations that do VLBI only for astronomical observations. The only major observatories not using it are the VLBA and VERA.

During this period some of the new features that were released in FS version 9.8 were:

1. "systests" system test utilities developed and released
2. Mark IV decoder garbled response and time-out problems fixed
3. PFMED able to handle long procedure lines
4. numerous small bug fixes and improvements were added

In the next year, several other improvements are expected, among these are: (1) a complete update to the documentation and in a more modern format that will be easier to use; (2) conversion of the FORTRAN source to use the g77 compiler, this will enable use of the source level debugger, *gdb* for development and field debugging; (3) use of *fsvue* or Real VNC for network operation; (4) *chekr* support for Mark 5A systems; (5) use of the Mark IV decoder for phase-cal extraction in the field; and (6) support for periodic firing of the noise diode during observations.

### 3. DRUDG and SKED

The GSFC TDC is responsible for the development, maintenance, and documentation of SKED and DRUDG. These two programs are very closely related, and 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 as input to DRUDG for making the control files and procedures for their station. During 2005 many changes were made to both SKED and DRUDG.

#### 3.1. SKED

SKED is the program used to generate geodetic VLBI schedules. Several major enhancements were made to SKED this year.

1. SKED was ported to run under Linux. For the most part this work was done by Alexey Melnikov (see his report in this volume). J. Gipson assisted in verification and debugging. There is now a single unified source code for both HP and Linux. The Linux version of SKED typically runs several times faster than the HP-UX version. We aided many centers in successfully installing the Linux version of SKED.
2. Covariance optimization was a feature that was introduced in SKED in the mid-1990s, but had not been used in many years. This was resurrected and improved with numerous bugs fixed. Solve simulation studies involving schedules generated using covariance optimization indicate improvement of up to 20% in EOP.
3. The interface used to select stations, sources and observing modes was drastically re-written, simplified and unified. The same source code is now used in displaying and selecting all of these items. You can now use the cursor keys to move around, instead of instead of “j-k-l-m”. For stations which have several different kinds of equipment you can choose which kind you want to use.
4. Previously if you changed stations in any way, you had to reselect the frequency because SKED did not know what frequency sequence you were using. SKED was made smarter so that in most cases it can determine this by comparing the information in the schedule file with that in the catalogs. If it can determine the correct mode unambiguously, you no longer need to select the frequencies. If it cannot determine the mode, it prompts the user to reselect it.
5. A graphical user interface was written using the open source and freely available Tcl/Tk scripting program. This interface is still under internal testing, but will be released next year.
6. Both SKED and DRUDG were made Mark 5 aware. Mark 5 is now a valid recorder type in SKED. The primary advantage of generating the schedule using Mark 5 is that you do not have to budget for tape changes or rewinds.
7. SKED was modified so that you can exclude stations for part of the schedule. This feature is useful because some stations, particular Kokee and Wettzell, will be unavailable for part of the experiment because they are participating in Intensives. Previously the scheduler had



to manually exclude the stations. Now all they need to do is specify when the stations are unavailable, and SKED will do the rest.

### **3.2. DRUDG**

Several minor changes were made to DRUDG.

1. DRUDG continued to be changed as the Mark 5 specifications evolved. For example, an FTP option was introduced in the “disk2file” command.
2. DRUDG is now Mark 5 aware. If a schedule is generated using the Mark 5 recorder in SKED, DRUDG will handle this correctly.
3. DRUDG will now print Mark 5 labels using the log file.
4. DRUDG now supports Dymo printers.

# Haystack Observatory Technology Development Center

*Alan Whitney*

## Abstract

Work at MIT Haystack Observatory is currently focusing on three areas:

1. Mark 5B VLBI data system
2. e-VLBI
3. Digital Backend

We will describe each of these areas.

## 1. Mark 5B VLBI Data System

The Mark 5B VLBI data system, developed at MIT Haystack Observatory, is nearing readiness for deployment. It is based on the same physical platform, uses the same disk-modules as the Mark 5A, and supports the same maximum data rate of 1024 Mbps. However, the Mark 5B incorporates a VSI standard interface.

In order to use the Mark 5B system with an existing Mark IV or VLBA data-acquisition system, the installation of an adapter is required to create a VSI output. For an existing VLBA system, a Metsahovi-designed VSI-C board is used to create a standard VSI interface; the VLBA formatter is not used. For a Mark IV system, the existing Mark IV formatter is modified to create two VSI interfaces, allowing data from all 14 BBC's to be recorded to two Mark 5B's for a total aggregate data rate of 1792 Mbps.

An engineering upgrade is being designed for the Mark 5A playback system to allow disks recorded on the Mark 5B system to be replayed on a Mark 5A system with the output in VLBA tape-track format; this upgrade to the Mark 5A is dubbed 'Mark 5A+' and will allow existing Mark IV correlators to process Mark 5B data on Mark 5A+ playback systems.

In addition, the Mark 5B supports all critical functionality of the Mark IV Station Unit, so that the Mark 5B may be directly connected to a Mark IV correlator through a simple interface without the use of a Mark IV Station Unit. This will allow existing Mark IV correlators to inexpensively expand the number of stations they support. We expect that the Mark 5B will be fully (hardware and software) interfaced to the Mark IV correlator system in early 2006.

Prototype Mark 5B systems are expected to be available in mid-2006. A 2Gbps version of the Mark 5B, operating at a maximum data-clock rate of 64MHz, is under development.

## 2. e-VLBI Development

In Spring 2005 Haystack Observatory hired Dr. Chester Ruzsczyk, an expert in high-speed networking, to replace Dr. David Lapsley. We welcome Chet to our staff.

Haystack Observatory continues to develop the e-VLBI technique with a broad spectrum of efforts, including:

## 2.1. Super Computing 2005 e-VLBI Demonstration

In November 2005, Haystack worked in conjunction with the DRAGON project to set up dedicated light paths from three telescopes in the U.S. and Europe for a high-speed real-time e-VLBI demonstration at the SC05 meeting in Seattle, WA. Data from the Westford, GGAO and Onsala antennas were streamed to the Mark IV VLBI correlator at Haystack Observatory at 512Mbps/station and correlated in real-time (no disk recording at either station or correlator). The data flows were successfully sustained for hours, showing that real-time e-VLBI is very viable provided good communication paths from the antennas to the correlators are available. The results of the correlation were streamed back to the Seattle conference floor in real-time (see Figure 1). We also attempted to bring Kashima, Jodrell and Westerbork into the experiment, but were hampered by various problems, indicating that high-speed real-time e-VLBI is still not quite ready for prime time!



Figure 1. Schematic diagram of real-time 512Mbps e-VLBI demo at SC05

## 2.2. VSI-E Testing

Haystack Observatory is working with Kashima to test the prototype VSI-E implementation. This is a particularly good testbed as Kashima uses K5 data systems and Haystack uses Mark 5 data systems, which is an excellent test of VSI-E between heterogeneous data platforms. Once VSI-E is fully tested and functional, attention will be turned to tuning it for higher speeds, followed by broader deployment.

## 2.3. Regular e-VLBI Data Transfers

Routine use of e-VLBI at Haystack continues to grow. All data recorded on K5 systems at Tsukuba and Kashima are currently transferred via e-VLBI to Haystack Observatory, where it is transferred to Mark 5 disk modules and sent to target correlators at Haystack, USNO or MPI; approximately 100TB have been transferred over the last year, including all Tsukuba data from the CONT05 experiment. Daily UT1 Intensive data from Wettzell are transferred via e-VLBI to a site near USNO in Washington, D.C., where it is picked up and taken to USNO for correlation. Additionally, monthly UT1 Intensive data are transferred from Tsukuba to MPI for correlation.

Regular e-VLBI data transfers from Ny-Ålesund to Haystack are expected to begin in early 2006.

## 2.4. Automated Data Transfers

As routine e-VLBI becomes more prevalent, it is extremely important that the data-transfer process be automated to the fullest extent possible. As part of an ongoing effort, work is continuing on the development of toolkits for helping to automate the transfer of VLBI data across Wide Area Networks. As a result, most e-VLBI data transfers are now mostly ‘hands-off’, including recovery from a variety of common problems.

## 2.5. DRAGON

Researchers at Haystack are participating in a project called “Dynamic Resource Allocation through GMPLS over Optical Networks” (DRAGON) in collaboration with the University of Maryland Mid-Atlantic Crossroads (MAX), Univ. of S. California Information Sciences Institute, George Mason Univ., NASA/GSFC and USNO, and industry partner Movaz Networks. This project has e-VLBI as one of its premier applications and provides advanced optical switching infrastructure for supporting e-VLBI experiments.

## 2.6. Measurement and Protocol Testing

Network performance characterization and protocol testing between various e-VLBI sites around the world continues. Tests within the United States, Japan, South America and Europe are ongoing. Recent results have demonstrated up to 900Mbps international data rates using advanced transfer protocols between servers located in Tokyo, Japan and at Haystack.

## 2.7. EGAE

Researchers at Haystack continue to work on the Experiment Guided Adaptive Endpoint (EGAE). EGAE provides the interface between a VSI data acquisition system and the network and implements the RTP-based VSI-E protocol. Current experiments include looking at the suitability of various transport protocols (e.g. TCP, High speed TCP, SABUL, TSUNAMI, etc.) for use within this framework and how best to integrate these protocols into the EGAE.

## 3. Digital Back Ends

Based on an NSF-funded astronomy VLBI project, and in collaboration with the Space Science Laboratory at UC Berkeley, Haystack Observatory is designing and testing an inexpensive Digital Backend (DBE) module which will initially be used for radio astronomy, but which we plan to adapt for geodetic VLBI as well.

DBEs have a number of distinct advantages, including absolute predictability and repeatability, sharp filter cutoffs, and low cost. We estimate that the complete back of 14 analog BBCs in a current geodetic VLBI system can be replaced with a couple of DBEs at a cost <\$10,000, compared to at least \$250,000 for the inferior and obsolete analog BBCs.

A prototype FPGA-based DBE under test is shown in Figure 2. The DBE accepts a 500MHz bandwidth IF which is sampled at 1024Msamples/sec. The sampler is followed by a Polyphase

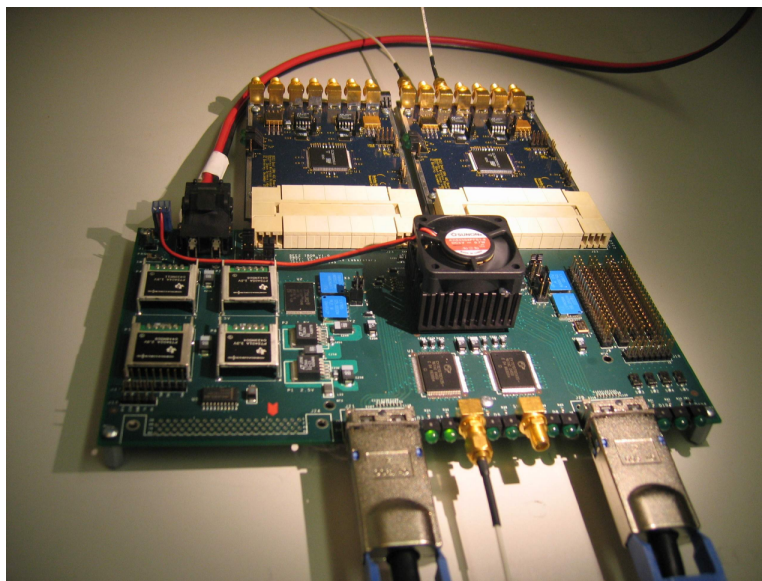


Figure 2. Prototype DBE under test

Filter Bank which divides the 500MHz IF into sixteen 32MHz bandwidth channels spanning the 500MHz IF input. With 2-bit sampling, the output data rate is 2048Mbps, which will interface to the next-generation Mark 5B data system.

## Institute of Applied Astronomy Technology Development Center

*Leonid Fedotov, Alexander Ipatov, Anton Berdnikov, Dmitry Marshalov, Alexey Melnikov,  
Mikhail Kharinov, Andrey Mikhailov*

### Abstract

The domain of IAA TDC includes the development of software and hardware for Russian VLBI network QUASAR. This report describes IAA activities in this direction.

## 1. General

Technology Development Center is responsible for all parts of the Russian VLBI network and consists of separate laboratories developing hardware and software for this project. Now the 32 m radio telescope in Svetloe is participating in international VLBI network observations and in domestic radioastronomical and VLBI observations. Radio telescope in Zelenchukskaya is participating in domestic radioastronomical and VLBI observations and since December 2005 in international VLBI observations as well. The Badary station was equipped with VLBI registration terminal produced in IAA and first testing VLBI observations on the three base QUASAR network were carried out.

## 2. Technical/Scientific

### 2.1. VLBI Data Acquisition and Recorder Equipment

A new VLBI Data Acquisition System was installed at Zelenchukskaya observatory (Figure 1). The system consists of VLBA4 Terminal with 14 BBC, Mark IV Formatter and Decoder (Figure 2) and Mark 5A recorder. The station was already equipped with an S2-RT recorder. By now all equipment installation work is completed for this observatory.

The usage of the VLBA4 Terminal in geodetic VLBI observations requires an additional frequency converter because the frequency range of the VLBA BBCs is limited to 480–1020 MHz. The converter was developed and assembled in the laboratory of Signals Conversion and Registration Systems IAA RAS together with RELTA company.

The converter transfers signal of intermediate frequency range from 100–500 MHz to working frequency range of VLBA4 system. It consists of two identical channels working in terms of frequencies addition and LO with fixed frequency 479.9 MHz. Every channel has two outputs. Non-converted IF signal passes to first output which is used in the IF range 480–1000 MHz. Converted signal appears on second output which is used in the IF range 100–479 MHz.

Investigations showed that the frequency converter allows the usage of the VLBA4 terminal in the frequency range 100–1000 MHz except for the range 460–480 MHz where the operation is complicated by the existence of moire components.

The frequency converter consists of two identical conversion channels, a local oscillator plate (Figure 3) and an LO power divider.

The main parameters of the frequency converter are shown in Table 1.



Figure 1. VLBI Data Acquisition and Recorder Equipment at Zelenchukskaya observatory

Table 1. The main parameters of frequency converter

Number of channels		2
Working frequency range		100–1000 MHz
Frequency range with converting		100–479 MHz
Frequency range without converting		479–1000 MHz
Dynamic range		more than 35 dB
Minimum level of signal		–50 dBm
Level of moire components		no more 20 dB
Gain		–4 dB
AFC unevenness in range:	100–479 MHz	no more 2 dB
	479–1000 MHz	no more 3 dB
AFC unevenness in 16 MHz bandwidth in range:	100–479 MHz	no more 0.4 dB
	479–1000 MHz	no more 0.3 dB
LO frequency		479.9 MHz
Signal level of LO		+5 dBm
Phase noise's level of LO (relative)	1 MHz	–85 dBc/Hz
	100 kHz	–75 dBc/Hz
under tune-out for:	10 kHz	–55 dBc/Hz

## 2.2. SKED Software

Operation Centers use SKED as the main tool in geodetic scheduling to make the .skd file that contains observing schedule. These centers had to maintain a Hewlett-Packard workstation because SKED was restricted to using this platform with HP-UX operating system.

Since the price of personal computers has dropped, while their power increased, there has been much interest in porting applications that once ran only on workstations to run on personal

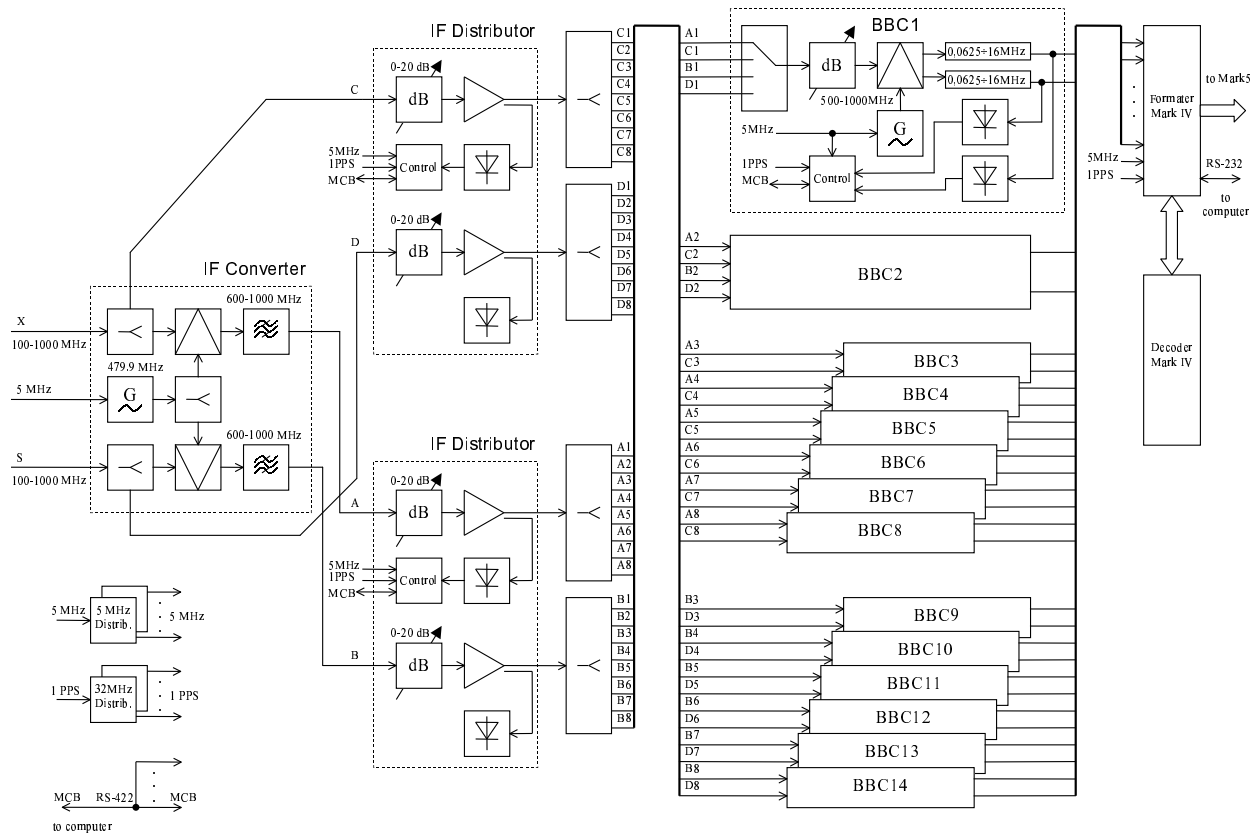


Figure 2. VLBI Data Acquisition System VLBA4

computers, often under the Linux environment.

In late 2004, IAA RAS volunteered to help modify the SKED software to run on personal computers under Linux.

In early 2005 Alexey Melnikov with the assistance of John Gipson (GSFC) completed porting SKED to Linux and then some testing has been done. Several bugs were fixed.

Now SKED has the unified source code that can be compiled under both Linux and HP-UX and it is 2–3 times faster under Linux than under HP-UX.

The Linux version of SKED was used at IAA to make several schedules using the three stations Svetloe, Zelenchukskaya, and Badary. Altogether 13 sessions were observed since July, 2005.

### 2.3. Monitoring of Geodetical Sources

Observation methodics were developed for radiometric monitoring of the flux density of the sources from the four lists, which are used in the following IVS programs: 1) Intensives INT1 and INT2, 2) CRF, 3) ICRF and 4) Geodesy (R1, R4, T2).

The program of monitoring was started in July 2005. The complete list of sources consist of 128 sources. The observations are carried out every month on X-band. Currently 22 daily observations have been carried out. Each time from 30 up to 50 sources are being observed. The results of the processing come to GSFC. The software developed at IAA is used for processing.



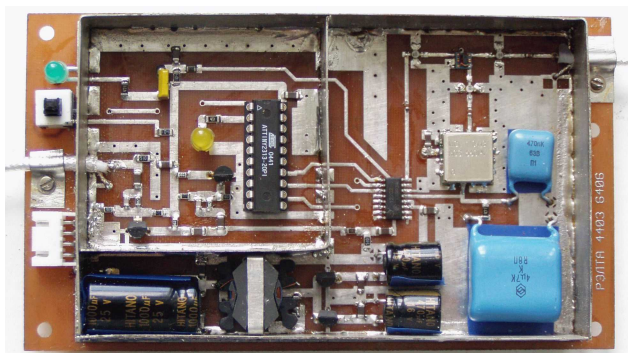


Figure 3. The LO plate of the frequency converter

### 3. Technical Staff

For all staff the IAA address (8, Zhdanovskaya st., St. Petersburg, 197110, Institute of Applied Astronomy (IAA) RAS, Russia, Director Andrey Finkelstein, FAX +7-812-230-7413) is valid.

Table 2. Technical Staff

Prof. Nikolay Koltsov	Main Scientific Researcher	VLBI and radiometric registration system	+7-812-235-3316	nec@ipa.rssi.ru
Dr. Sergey Smolentsev	Vice Director	Time keeping Frequency standard	+7-812-275-4415	smolen@ipa.rssi.ru
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## Technology Development Center at NICT

*Tetsuro Kondo, Yasuhiro Koyama, Hiroshi Takeuchi, Ryuichi Ichikawa*

### Abstract

National Institute of Information and Communications Technology (NICT) has led the development of VLBI technique and has been keeping high activities in both observations and technical developments. This report gives a review of the Technology Development Center (TDC) at NICT and summarizes recent activities.

### 1. TDC at NICT

National Institute of Information and Communications Technology (NICT) publishes the newsletter “IVS NICT-TDC News (former IVS CRL-TDC News)” twice a year in order to inform about the development of VLBI related technology as an IVS technology development center. The newsletter is available through the Internet at the URL <http://www2.nict.go.jp/ka/radioastro/tdc/index.html>.

### 2. Staff Members of NICT TDC

Table 1 lists the staff members at NICT who are involved in the VLBI technology development center at NICT.

Table 1. Staff Members of NICT TDC as of December, 2005 (alphabetical).

Name	Works
ICHIKAWA, Ryuichi	Delta VLBI, 2.4m Antenna system
ISHII, Atsutoshi	2.4m Antenna system
KAWAI, Eiji	34m Antenna system
KIMURA, Moritaka	e-VLBI, Giga-bit system, PC-VSI, Software correlator
KONDO, Tetsuro	e-VLBI, K5/VSSP32, Software correlator
KOYAMA, Yasuhiro	e-VLBI, ADS2000
KUBOKI, Hiromitsu	Antenna system, CARAVAN* system
NAKAJIMA, Junichi	Giga-bit system, CARAVAN system
SEKIDO, Mamoru	Delta VLBI, PCAL system
TAKEUCHI, Hiroshi	e-VLBI, VLBI@home, ADS3000
TSUTSUMI, Masanori	e-VLBI

\* CARAVAN: Compact Antenna of Radio Astronomy for VLBI Adapted Network system

### 3. Development of New Samplers

Samplers developed by NICT are categorized into two series: 1) ADS series sampler equipped with a VSI-H interface; 2) VSSP series sampler not equipped with a VSI-H but directly connectable to a host PC.

### 3.1. ADS Series Sampler



Figure 1. ADS2000 (left) and ADS3000 (right).

Table 2. Specifications of the ADS series sampler.

	ADS1000	ADS2000	ADS3000
Reference Signals	10 MHz, 1 PPS	10 MHz, 1 PPS	10 MHz, 1 PPS
Number of Input Ch.	1	16	1
A/D bits	1, 2	2	8
Sampling Freq.	512 MHz, 1024 MHz	2, 4, 8, 16, 32, 64 MHz	2048 MHz
Output Interface	VSI-H	VSI-H	VSI-H $\times$ 2
Function	—	PCAL detection	DBBC etc.

Table 2 summarizes the specifications of the ADS series. ADS2000 and ADS3000 (Figure 1) are new developments in the ADS series.

ADS2000 is a 16-ch sampler dedicated to geodetic VLBI observation and was developed to replace the DFC2000. ADS2000 was used for the actual geodetic VLBI experiment on March 11, 2005 at the data rate of 1024 Mbps. Results indicate that the performance of the system is fine[1].

ADS3000 is the successor to the ADS1000 but it is equipped with two VSI-H ports and is greatly improved in performance. By use of a high-performance FPGA it is possible to output in a variety of modes shown in Table 3. Furthermore, FPGA code is rewritable so that it can be used for multiple applications such as digital baseband converter (DBBC) for multi-channel geodetic VLBI, software demodulator for spacecraft downlink signal in spacecraft VLBI or satellite communications, or spectrometer for broadband astronomical observations. A test observation using ADS3000 was carried out on Nov. 25, 2005 at the data rate of 4096 Mbps and we got the first ever 4 Gbps fringes successfully.

### 3.2. VSSP Series Sampler

K5/VSSP32 was developed (Figure 2) in the VSSP series. K5/VSSP32 is a successor to the K5/VSSP. It uses a USB 2.0 as an interface with a host PC. Maximum sampling frequency per channel was increased to 64 MHz. As a K5/VSSP32 unit has 4 channel analog inputs, 4 units can

Table 3. Selectable output modes of ADS3000.

Total rate	Sampling rate	# of AD bits	VSI-H clock rate	Output port
1 Gbps	128 MSps	8	32 MHz	VSI-H port1
2 Gbps	1024 MSps	2	32 MHz	VSI-H port1 + VSI-H port2
2 Gbps	512 MSps	4	32 MHz	VSI-H port1 + VSI-H port2
2 Gbps	256 MSps	8	32 MHz	VSI-H port1 + VSI-H port2
2 Gbps	256 MSps	8	64 MHz	VSI-H port1
4 Gbps	2048 MSps	2	64 MHz	VSI-H port1 + VSI-H port2
4 Gbps	1024 MSps	4	64 MHz	VSI-H port1 + VSI-H port2
4 Gbps	512 MSps	8	64 MHz	VSI-H port1 + VSI-H port2

cover 16 channels which is a sufficient number of channels for geodetic VLBI. In the meantime, a K5/VSSP32 can connect to a notebook PC or a laptop PC through USB 2.0 interface. First observations using the K5/VSSP32 and a notebook were taken on Nov. 10, 2005, and soon the first fringes were successfully found by the software correlator. Table 4 summarizes the specifications of the VSSP series.



Figure 2. K5/VSSP32 unit (left) and 16 ch module (right).

#### 4. Development of 2.4m Antenna System

We have been developing a 2.4 m antenna system (Figure 3) with an X band receiver[2], which is an extended version of the CARAVAN (Compact Antenna of Radio Astronomy for VLBI Adapted Network) system, for a VLBI observation using our giga-bit VLBI system. The first fringe was successfully detected on Dec. 7, 2005. We will continue the development of the system with the goal of monitoring Earth rotation and spacecraft tracking.

Table 4. Specifications of the VSSP series sampler.

	K5/VSSP	K5/VSSP32
Reference Signals	10 MHz, 1 PPS	10/5 MHz, 1 PPS
Number of Input Ch/unit	4	4
A/D bits	1, 2, 4, 8	1, 2, 4, 8
Sampling Freq.	0.04, 0.1, 0.2, 0.5, 1, 2, 4, 8, 16 MHz	0.04, 0.1, 0.2, 0.5, 1, 2, 4, 8, 16, 32, 64 MHz
Maximum Data Rate	64 Mbps/unit 256 Mbps/4units	256 Mbps/unit 1024 Mbps/4units
Interface with PC	PCI-bus	USB2.0
Function	—	digital LPF



Figure 3. 2.4m antenna at Kashima.

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# The IVS Technology Development Center at the Onsala Space Observatory

*Tobias Nilsson, Rüdiger Haas, Gunnar Elgered*

## Abstract

In last year's report we presented a method for assessing the instrumental noise of a water vapor radiometer by using theory of atmospheric turbulence in order to separate the observed variability due to instrumental noise and atmospheric variability. We have applied this to the radiometer data observed with the two co-located radiometers, Astrid and Konrad, at the Onsala Space Observatory during CONT02 and CONT05.

## 1. Introduction

In last year's report [1] and in [2] we showed how atmospheric turbulence models can be used together with slant wet delays inferred from microwave radiometer observations in order to assess the atmospheric variability as well as the radiometer noise level. This is done by modeling the squared difference between two observed slant wet delays in different directions ( $i$  and  $j$ ) as:

$$\left\langle \left( \frac{\hat{l}_i}{m_i} - \frac{\hat{l}_j}{m_j} \right)^2 \right\rangle = k^2 \left\langle \left( \frac{l_i}{m_i} - \frac{l_j}{m_j} \right)^2 \right\rangle_0 + (m_i^{-2} + m_j^{-2}) \cdot Var[B] \quad (1)$$

where  $\langle \dots \rangle$  denotes expectation value;  $\hat{l}_i$  is the slant wet delay measured by the radiometer in the direction  $i$ ;  $m_i$  is the mapping function in the direction  $i$ ;  $\left\langle \left( \frac{l_i}{m_i} - \frac{l_j}{m_j} \right)^2 \right\rangle_0$  is the expectation value for the squared difference between the slant wet delays (mapped to zenith) from turbulence models [5];  $k^2$  is a constant describing the atmospheric variability; and  $Var[B]$  is the variance of the radiometer noise. The constant  $k^2$  is needed because the coefficients used in the turbulence model, from which  $\left\langle \left( \frac{l_i}{m_i} - \frac{l_j}{m_j} \right)^2 \right\rangle_0$  is calculated (i.e. the turbulence constant  $C_n$  and the effective tropospheric height of turbulence  $h$  [5]), might vary. By using slant wet delay data from a radiometer,  $k^2$  and  $Var[B]$  can be estimated [2]. Using two co-located radiometers provides an opportunity to apply the method to both radiometers and to compare the results, in order to assess the accuracy of the method.

## 2. Results

During CONT02 (15–31 October 2002) and CONT05 (12–27 September 2005) two radiometers, Astrid [3] and Konrad [4], were operated simultaneously at the Onsala Space Observatory. The Konrad radiometer was slaved to the VLBI schedule, while the Astrid radiometer operated in a continuous sky-mapping mode. During CONT05 the azimuth drive of Astrid was broken so it was only scanning in elevation, while during CONT02 it moved both in azimuth and elevation. The retrieved values of  $k^2$  and  $Var[B]$  are shown in Figure 1 (CONT02) and Figure 2 (CONT05).

From the figures we note that for both CONT02 and CONT05 the noise level is lower for Konrad than for Astrid. One reason for this is the longer integration time used by Konrad ( $\sim 10$  s compared

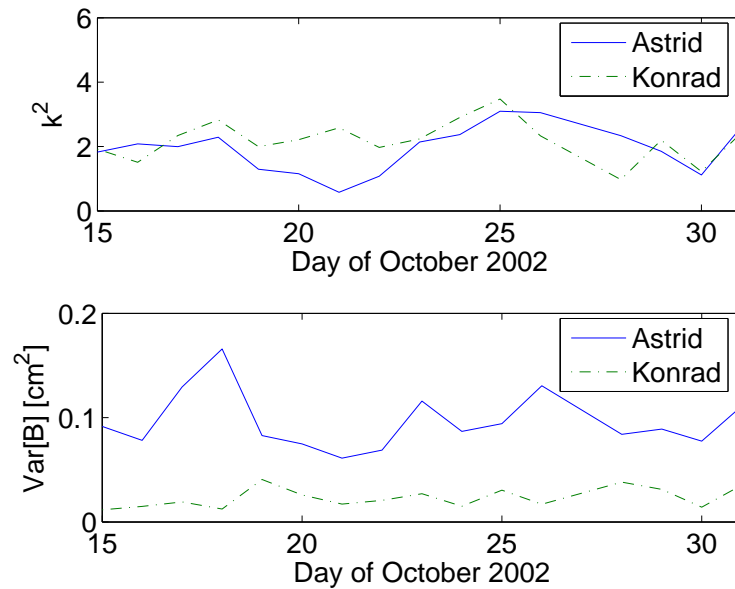


Figure 1. Plots of  $k^2$  and the radiometer noise variance (see Equation 1) during CONT02, estimated from Astrid and Konrad radiometer data.

to  $\sim 1$  s for Astrid). Another explanation is that Konrad is a newer radiometer, with a more stable and accurate data acquisition system. The data acquisition system of Astrid was upgraded in 2003 resulting in a lower noise level in CONT05 —  $0.066 \text{ cm}^2$  compared to  $0.098 \text{ cm}^2$  during CONT02 (the variance of the noise was on average  $0.025 \text{ cm}^2$  for Konrad in both experiments).

The  $k^2$  parameter describes how variable the atmosphere is. We expect that days with very variable sky conditions would have a high  $k^2$  value, and days with stable sky conditions a low value of  $k^2$ . During CONT05 the sky conditions at Onsala Space Observatory were observed with a web-camera, hence we could test how  $k^2$  correlated with sky conditions. Figure 3 shows snap-shot pictures of the sky at different times during September 20, a day with a high  $k^2$  value. As can be seen, the sky conditions vary between clear sky and very cloudy. September 23 was a day with a low  $k^2$  value, and snap-shot pictures of the sky during this day are shown in Figure 4. It appears that the sky was clear during the entire day.

### 3. Future plans

We will continue to evaluate the turbulence models and the instrumental noise of the radiometers by continuing to acquire simultaneous observations with the two co-located radiometers. We will investigate how the integration time of the radiometer affects the instrumental noise. Other instrumental effects, so far neglected in our investigations, will be studied. For example, the impact of the antenna beam-width of the two radiometers on the results ( $6^\circ$  for Astrid and  $\sim 3^\circ$  for Konrad). The correlation between the  $k^2$  parameter and the variability of the sky conditions will also be studied. We plan to install a zenith-looking camera close to the two radiometers that will continuously monitor the sky.

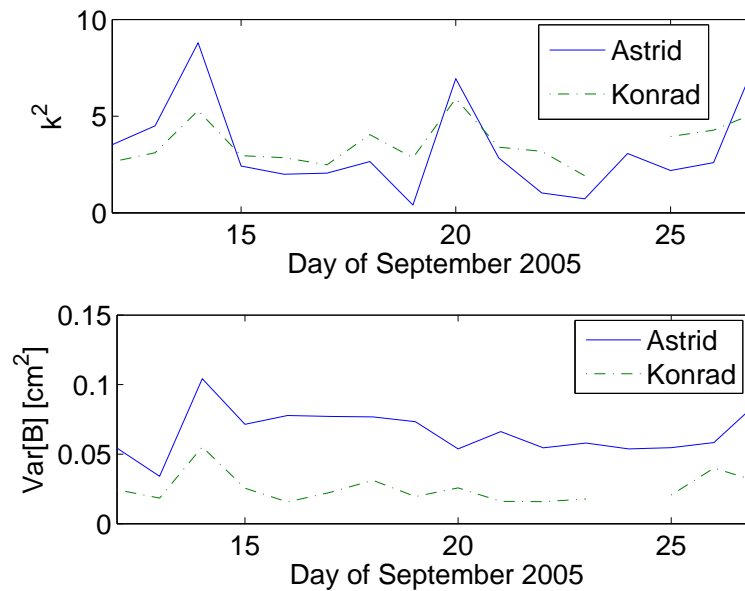


Figure 2. Plots of  $k^2$  and the radiometer noise variance (see Equation 1) during CONT05, estimated from Astrid and Konrad radiometer data.

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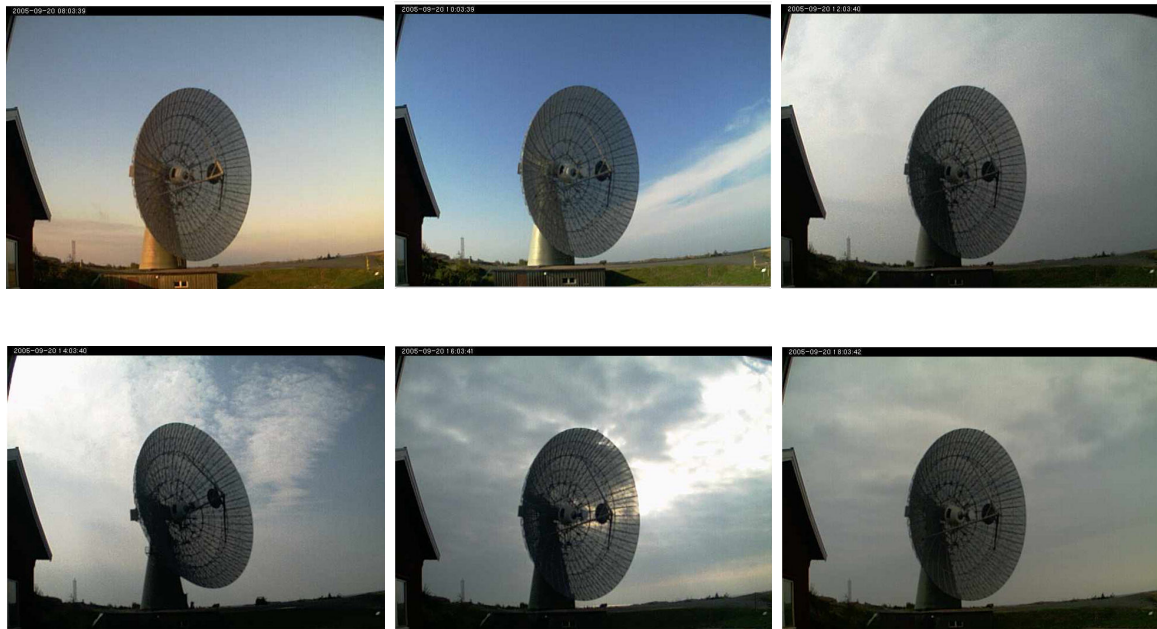


Figure 3. Snap-shot pictures of the sky at Onsala Space Observatory, during September 20 2005, at 8:00, 10:00, 12:00, 14:00, 16:00, and 18:00 local time (UTC+2 hr).

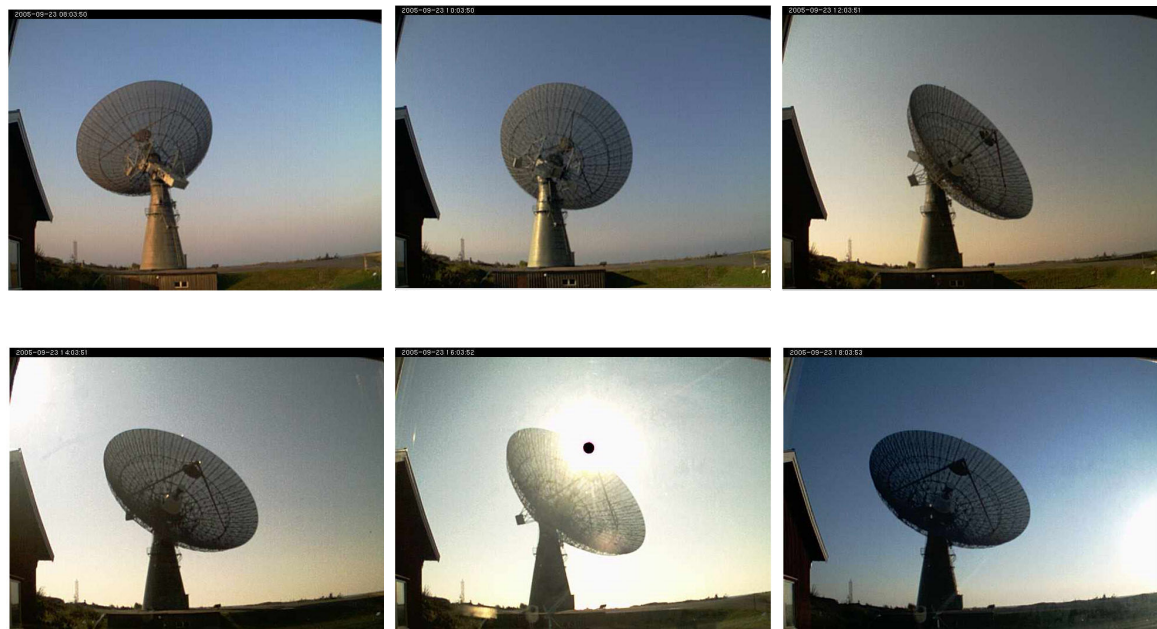


Figure 4. Snap-shot pictures of the sky at Onsala Space Observatory, during September 23 2005, at 8:00, 10:00, 12:00, 14:00, 16:00, and 18:00 local time (UTC+2 hr).



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# Bibliography

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## Bibliography

### 1. Introduction

The following bibliography compiles papers that were published in the field of geodetic and astrometric VLBI during the year 2005. There is no distinction between peer-reviewed, reviewed or proceedings publications. This list is by no means exhaustive.

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# IVS Information

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# 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 an official Service of the International Association of Geodesy (IAG).

### 1.2. Objectives

IVS fulfills its charter through the following objectives. The primary objective of IVS is to foster VLBI programs as a joint service. This is accomplished through close coordination to provide high-quality VLBI data and products.

The second objective of IVS is to promote research and development activities in all aspects of the geodetic and astrometric VLBI technique. This objective also supports the integration of new components into IVS. The further education and training of VLBI participants is supported through workshops, reports, electronic network connections, and other means.

The third objective of IVS is to interact with the community of users of VLBI products and to integrate VLBI into a global Earth observing system. IVS interacts closely with the International Earth Rotation Service (IERS) which is tasked by the IAU and IUGG with maintaining the international celestial and terrestrial reference frames and with monitoring Earth rotation.

To meet 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 closely coordinates its activities with the astronomical community because of the dual use of many VLBI facilities and technologies for both astronomy and astrometry/geodesy.

IVS accepts observing proposals for research and operational programs that conform to the IVS objectives.

### 1.3. Data Products

VLBI data products contribute uniquely to these important determinations:

- definition and maintenance of the celestial reference frame
- monitoring universal time (UT1) and length of day (LOD)
- monitoring the coordinates of the celestial pole (nutations and precession)

These results are the foundation of many scientific and practical applications requiring the use of an accurate inertial reference frame, such as high-precision navigation and positioning. IVS provides, through the collaborative efforts of its components, a variety of significant VLBI data products with differing applications, timeliness, detail, and temporal resolution, such as:

- all components of Earth orientation parameters at regular intervals
- terrestrial reference frame
- VLBI data in appropriate formats
- VLBI results in appropriate formats
- local site ties to reference points
- high-accuracy station timing data
- surface meteorology, tropospheric and ionospheric measurements

All VLBI data products are archived in IVS Data Centers and are publicly available.

#### **1.4. Research**

The VLBI data products are used for research in many related areas of geodesy, geophysics, and astrometry, such as:

- UT1 and polar motion excitation (over periods of hours to decades)
- solid Earth interior research (mantle rheology, anelasticity, libration, core modes, nutation/precession)
- 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 vertical (scale) component
- climate studies

To support these activities, there are ongoing research efforts whose purpose is to improve and extend the VLBI technique in such areas as:

- improvements in data acquisition and correlation
- refined data analysis techniques
- spacecraft tracking (Earth-orbiting and interplanetary)
- combination of VLBI data and results with other techniques

## **2. Permanent Components**

IVS acquires VLBI data, correlates the data, analyzes the data to produce geodetic, astrometric, and other results, and archives and publicizes data products. IVS accomplishes its goals through the types of permanent components described in this section. IVS will accept proposals at any time for a permanent component. Such proposals will be reviewed by the Directing Board. The seven types of IVS permanent components are:

- Network Stations
- Operation Centers
- Correlators

- Analysis Centers
- Data Centers
- Technology Development Centers
- Coordinating Center

IVS acquires VLBI data, correlates the data, analyzes the data to produce geodetic and astrometric results, and archives and publicizes data products. IVS accomplishes its goals through the operational components described below.

### **2.1. Network Stations**

The IVS observing network consists of high performance VLBI stations.

- Stations can 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 set up by the Directing Board.
- VLBI data acquisition sessions are conducted by groups of Network Stations that are distributed either globally or over a geographical region.

### **2.2. Operation Centers**

The IVS Operation Centers coordinate the routine operations of one or more networks. Operation Center activities include:

- planning network observing programs,
- establishing operating plans and procedures for the stations in the network,
- supporting the network stations in improving their performance,
- making correlator time available at an IVS Correlator,
- generating the detailed observing schedules for use in data acquisition sessions by IVS Network Stations,
- posting the observing schedule to an IVS Data Center for distribution and to the Coordinating Center for archiving.

IVS Operation Centers follow guidelines from the Coordinating Center for timeliness and schedule file formats. Operation Centers cooperate with the Coordinating Center in order to define:

- the annual master observing schedule,
- the use of antenna time,
- tape availability and shipping,
- the use of other community resources.

### 2.3. Correlators

The IVS Correlators process raw VLBI data and station log files following a data acquisition session. Their other tasks are to:

- provide immediate feedback to the Network Stations about problems that are apparent in the data,
- jointly maintain the geodetic/astrometric community's tape pool,
- make processed data available to the Analysis Centers,
- regularly compare processing techniques, models, and outputs to ensure that data from different Correlators are identical.

### 2.4. Analysis Centers

The IVS coordinates VLBI data analysis to provide high-quality products for its users. The analyses are performed by Analysis Centers and by Associate Analysis Centers.

Analysis Centers are committed to produce series of Earth Orientation Parameters (EOP) or series of individual EOP components, without interruption and at a specified time lag to meet IVS requirements. In addition, Analysis Centers produce station coordinates and source positions in regular intervals.

The 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 Analysis Center makes from IVS recommendations are properly documented. Analysis Centers provide timely feedback about station performance. In addition to these regular services, 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.

### 2.5. Data Centers

The IVS Data Centers are repositories for VLBI observing schedules, station log files, and data products. Data Centers may mirror other Data Centers to make the distribution and maintenance of data more efficient and reliable.

- Data Centers are the primary means of distributing VLBI products to users.
- Data Centers work closely with the Coordinating Center and with the Analysis Centers to ensure that all the information and data required by IVS components are quickly and reliably available.

Data Centers provide the following functions:



- receive and archive schedule files from Operation Centers,
- receive and archive log files and ancillary data files from the Network Stations,
- receive and archive data products from the Analysis Centers,
- provide access and public availability to IVS data products for all users.

## 2.6. Technology Development Centers

The IVS Technology Development Centers contribute to the development of new VLBI technology. They may be engaged in hardware and/or software technology development, or evolve new approaches that will improve the VLBI technique and enhance compatibility with different data acquisition terminals. They will:

- design new hardware,
- investigate new equipment,
- develop new software for operations, processing or analysis,
- generate new information systems,
- develop, test, and document prototypes of new equipment or software,
- assist with deployment, installation, and training for any new approved technology.
- After dissemination of the new hardware or software, the centers may continue to provide maintenance and updating functions.

## 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 all IVS activities.

The primary functions of the Coordinating Center are to:

- coordinate observing programs approved by the Directing Board,
- maintain the master schedule of observing sessions, coordinating the schedule with astronomical observing programs and with IVS networks,
- foster communications among all components of the IVS,
- define the best use of community resources,
- develop standards for IVS components,
- provide training in VLBI techniques,
- organize workshops and meetings, including an annual IVS technical meeting,
- produce and publish reports of activities of IVS components,

- maintain the IVS information system and archive all documents, standards, specifications, manuals, reports, and publications,
- provide liaison with the IERS, IAG, IAU, FAGS, and other organizations,
- provide the Secretariat of the Directing Board.

### 3. Coordinators

Specific IVS activities for technology, network data quality, and data products 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 Networks 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,

The Network Coordinator works closely with the geodetic and astronomical communities who are using the same network stations for observations. The Coordinator takes a leading role in ensuring the visibility and representation of the Networks.

#### 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 analysis software documentation,
- 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 analysis products from all Analysis Centers are archived and available for the scientific community, and
- forms the official products of IVS, as decided by the IVS Directing Board, using a suitable combination of the analysis results submitted by the Analysis Centers.

The Analysis Coordinator works closely with the geodetic and astronomical communities who are using some of the same analysis methods and software. The Analysis Coordinator plays a leadership role in the development of methods for distribution of VLBI products so that the products reach the widest possible base of users in a timely manner. The coordinator promotes the use of VLBI products to the broader scientific community and interacts with the IVS Coordinating Center and with the IERS.

### **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 is responsible for coordinating the new technology activities of IVS and for stimulating advancement of the VLBI technique. The Technology Coordinator performs the following functions:

- maintains cognizance of all current VLBI technologies and ongoing development
- coordinates development of new technology among various IVS components
- helps promulgate new technologies to the geodetic/astrometric community
- strives to ensure the highest degree of global compatibility of VLBI data acquisition systems

The Technology Coordinator works closely with the astronomical community because of the many parallels between the technology development required for both groups.

## **4. Directing Board**

### **4.1. Roles and Responsibilities**

The Directing Board determines policies, adopts standards, and approves 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.

A specific function of the Board is to set scientific goals for the IVS observing program. The Board will establish procedures for external research programs and will review any proposals thus received.

The Board may determine appropriate actions to ensure the quality of the IVS products and that the IVS components maintain the adopted standards.

### **4.2. Membership**

The Directing Board consists of appointed members who serve *ex officio*, members elected by the Directing Board, and members elected by the IVS components. The members are:

Appointed members *ex officio*:

- IAG representative
- IAU representative
- IERS representative
- FAGS representative

- Coordinating Center Director

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.

Selected by Directing Board upon review of proposals from IVS Member Organizations:

- Technology, Network, and Analysis Coordinators (3 total)

Elected by Directing Board upon recommendation from the Coordinating Center (see below):

- Members at large (3)

Elected by IVS Components (see below):

- Correlators and Operation Centers representative (1)
- Analysis and Data Centers representative (1)
- Networks representatives (2)
- Technology Development Centers representative (1)

Total number: 16

The five appointed members are considered *ex officio* and are not subject to institutional restrictions. The FAGS representative is a non-voting member in accordance with FAGS requirements.

The five members of the Directing Board who are elected by IVS Permanent Components must each be a member of a different IVS Member Organization. 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 2-year terms once renewable.

A 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 for the remainder of the original term.

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 three months notice before resigning.

### 4.3. Elections

Election of Board members by 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 Board are made by consensus or by simple majority vote of the members present. In case of a tie, the chair shall vote but otherwise does not vote. 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 change any of the members elected by the Directing Board before the normal term expires.

## **4.6. Meetings**

The 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. The reviews should be done every four years.

## **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 Correspondents.

### **5.3. Associate Members**

Individuals associated with organizations that support an IVS component may become IVS Associate Members. Associate Members are generally invited to attend non-executive sessions of the Directing Board meetings with voice but without vote. 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 on a mailing list maintained by the Coordinating Center. They do not actively participate in IVS but 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 General Secretary
- President of IAG Section II – Advanced Space Technology
- President of IAG Section V – Geodynamics
- President of IAU Division I – Fundamental Astronomy

- President of IAU Commission 19 – Rotation of the Earth
- President of IAU Commission 8 – Positional Astronomy
- President of IAU Commission 31 – Time
- President of IAU Commission 40 – Radio Astronomy
- President of URSI Commission J – Radio Astronomy

Individuals are accepted as IVS Corresponding Members upon request to the Coordinating Center.  
Last modified: 12 September, 2005

## IVS Member Organizations

(alphabetized by country)

Organization	Country
Geoscience Australia	Australia
University of Tasmania	Australia
Vienna University of Technology	Austria
Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Space Geodynamics Laboratory	Canada
Geodetic Survey Division, Natural Resources Canada	Canada
Dominion Radio Astrophysical Observatory	Canada
Canadian Space Agency	Canada
Universidad de Concepción	Chile
Universidad del Bío Bío	Chile
Universidad Católica de la Santísima Concepción	Chile
Instituto Geográfico Militar	Chile
Chinese Academy of Sciences	China
Observatoire de Paris	France
Observatoire de Bordeaux	France
Deutsches Geodätisches Forschungsinstitut	Germany
Bundesamt für Kartographie und Geodäsie	Germany
Forschungseinrichtung Satellitengeodäsie, TU-Munich	Germany
Geodetic Institute of the University of Bonn	Germany
Istituto di Radioastronomia INAF	Italy
Agenzia Spaziale Italiana	Italy
Geographical Survey Institute	Japan
National Institute of Information and Communications Technology	Japan
National Astronomical Observatory of Japan	Japan
National Institute of Polar Research	Japan
Norwegian Defence Research Establishment	Norway
Norwegian Mapping Authority	Norway
Astronomical Institute of St.-Petersburg University	Russia
Institute of Applied Astronomy	Russia
Hartebeesthoek Radio Astronomy Observatory	South Africa
Instituto Geográfico Nacional	Spain
Chalmers University of Technology	Sweden
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

Organization	Country
Australian National University	Australia
University of New Brunswick	Canada
Max-Planck-Institut für Radioastronomie	Germany
FÖMI Satellite Geodetic Observatory	Hungary
Korea Astronomy Observatory	Korea
Joint Institute for VLBI in Europe (JIVE)	Netherlands
Westerbork Observatory	Netherlands
Auckland University of Technology	New Zealand
Central (Pulkovo) Astronomical Observatory	Russia
National Radio Astronomy 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
Algonquin Radio Observatory	Geodetic Survey Division, Natural Resources Canada	Canada
Fortaleza, Radio Observatório Espacial do Nordeste (ROEN)	Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Gilmore Creek Geophysical Observatory	NASA Goddard Space Flight Center	USA
Goddard Geophysical and Astronomical Observatory	NASA Goddard Space Flight Center	USA
Hartebeesthoek Radio Astronomy Observatory	Foundation for Research and Development	South Africa
Hobart, Mt. Pleasant Radio Observatory	University of Tasmania	Australia
Kashima 34m	National Institute of Information and Communications Technology (NICT)	Japan
Key Stone Project Koganei 11m	National Institute of Information and Communications Technology (NICT)	Japan
Key Stone Project Kashima 11m	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 INAF	Italy
Mizusawa 10m	National Astronomical Observatory of Japan (NAOJ)	Japan
Noto (Sicily)	Istituto di Radioastronomia INAF	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
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), Universidad del Bío Bío (UBB), Universidad Católica de la Santísima Concepción (UCSC), Instituto Geográfico Militar (IGM), Bundesamt für Kartographie und Geodäsie (BKG)	Chile, Germany
Tsukuba VLBI Station	Geographical Survey Institute	Japan
Nanshan VLBI Station	Chinese Academy of Sciences	China
Westford Antenna, Haystack Observatory	NASA Goddard Space Flight Center	USA
Fundamentalstation Wettzell	Bundesamt für Kartographie und Geodäsie (BKG) and Forschungseinrichtung Satellitengeodäsie der Technischen Universität München (FESG)	Germany
Observatorio Astronómico Nacional - Yebes	Instituto Geográfico Nacional	Spain
Yellowknife Geophysical Observatory	Geodetic Survey Division, Natural Resources Canada	Canada
Radioastronomical Observatory Zelenchukskaya	Institute of Applied Astronomy RAS	Russia

### Operation Centers

Component Name	Sponsoring Organization	Country
Geodetic Institute Bonn (GIUB)	University of 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 and Geodätisches Institut der Universität Bonn	Germany
MIT Haystack Correlator	NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Correlator	Institute of Applied Astronomy	Russia
National Institute of Information and Communications Technology (NICT)	National Institute of Information and Communications Technology (NICT)	Japan
Tsukuba VLBI Center	Geographical Survey Institute	Japan
Washington Correlator	National Earth Orientation Service (NEOS)	USA

**Data Centers**

<b>Component Name</b>	<b>Sponsoring Organization</b>	<b>Country</b>
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**

<b>Component Name</b>	<b>Sponsoring Organization</b>	<b>Country</b>
Astronomical Institute of St.-Petersburg University	Astronomical Institute of St.-Petersburg University	Russia
Geoscience Australia	Geoscience Australia	Australia
Observatoire de Bordeaux	Observatoire de Bordeaux	France
Centro di Geodesia Spaziale (CGS)	Agenzia Spaziale Italiana	Italy
DGFI	Deutsches Geodätisches Forschungsinstitut	Germany
Forsvarets forskningsinstitutt (FFI)	Norwegian Defence Research Establishment	Norway
GIUB-BKG Analysis Center	Geodätisches Institut der Universität Bonn and Bundesamt für Kartographie und Geodäsie	Germany
Goddard Space Flight Center	NASA Goddard Space Flight Center	USA
Haystack Observatory	Haystack Observatory and NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Analysis Center	Institute of Applied Astronomy	Russia
Institute of Geodesy and Geophysics (IGG)	Institute of Geodesy and Geophysics (IGG), of the University of Technology, Vienna	Austria
Italy INAF	Istituto di Radioastronomia INAF	Italy
Jet Propulsion Laboratory	Jet Propulsion Laboratory	USA
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
Observatoire de Paris	Observatoire de Paris	France
Onsala Space Observatory	Chalmers University of Technology	Sweden
Shanghai Observatory	Shanghai Observatory, Chinese Academy of Sciences	China
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

### Technology Development Centers

<b>Component Name</b>	<b>Sponsoring Organization</b>	<b>Country</b>
Canadian VLBI Technology Development Center	CRESTech, NRCan, DRAO, CSA	Canada
Forsvarets forskningsinstitutt (FFI)	Norwegian Defence Research Establishment	Norway
Goddard Space Flight Center	NASA Goddard Space Flight Center	USA
Haystack Observatory	Haystack Observatory and NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Technology Development Center	Institute of Applied Astronomy	Russia
National Institute of Information and Communications Technology	National Institute of Information and Communications Technology	Japan
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## List of Acronyms

AAM	Atmosphere Angular Momentum
AARNet	Australia Academic and Research Network (Australia)
AAS	American Astronomical Society
AC	Analysis Center
ACF	AutoCorrelation Function
ACU	Antenna Control Unit
AD	Analog-to-Digital
AES	Advanced Engineering Services Co., Ltd (Japan)
AGU	American Geophysical Union
AIPS	Astronomical Image Processing System
APPS	Advanced Precise Positioning System
APSG	Asia-Pacific Space Geodynamics program
APT	Asia Pacific Telescope
ARIES	Astronomical Radio Interferometric Earth Surveying program
ARO	Algonquin Radio Observatory (Canada)
ASI	Agenzia Spaziale Italiana (Italian Space Agency) (Italy)
ATA	Allen Telescope Array
ATM	Asynchronous Transfer Mode
ATNF	Australia Telescope National Facility (Australia)
BBC	Base Band Converter
BIPM	Bureau International de Poids et Mesures (France)
BKG	Bundesamt für Kartographie und Geodäsie (Germany)
CACS	Canadian Active Control System
CARAVAN	Compact Antenna of Radio Astronomy for VLBI Adapted Network (Japan)
CAS	Chinese Academy of Sciences (P.R. China)
CAY	Centro Astronómico de Yebes (Spain)
CDDIS	Crustal Dynamics Data Information System (USA)
CDP	Crustal Dynamics Project
CGS	Centro di Geodesia Spaziale (Italy)
CNES	Centre National d'Etudes Spatiales (France)
CNR	Council of National Researches (Italy)
CNRS	National Center for Scientific Research (France)
CNS	Communication, Navigation and Surveillance Systems, Inc. (USA)
CORE	Continuous Observations of the Rotation of the Earth
CPP	IERS Combination Pilot Project
CRAAE	Centro de Rádio Astronomia e Aplicações Espaciais (Brazil)
CRAAM	Centro de Rádio-Astronomia e Astrofísica Mackenzie (Brazil)
CRESTech	Centre for Research in Earth and Space Technology (Canada)
CRF	Celestial Reference Frame
CRL	Communications Research Laboratory (now NICT) (Japan)
CSA	Canadian Space Agency (Canada)
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)

CSRS	Canadian Spatial Reference System
CTVA	Canadian Transportable VLBI Antenna
CUTE	CRL and University Telescopes Experiment (Japan)
CWDM	Coarse Wavelength Division Multiplexer
DAR	Data Acquisition Rack
DAS	Data Acquisition System
DAT	Digital Audio Tape
DBBC	Digital Base Band Converter
DBE	Digital BackEnd
DGFI	Deutsches Geodätisches Forschungsinstitut (Germany)
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DOMES	Directory Of MERIT Sites
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DRAGON	Dynamic Resource Allocation through GMPLS over Optical Networks
DRAO	Dominion Radio Astrophysical Observatory (Canada)
DSN	Deep Space Network
DSNA	Deep Space Network Array (USA)
DSS	Deep Space Station
DVLBI	Differential VLBI
EAN	Eastern Asia VLBI Network
ECMWF	European Center for Medium Range Weather Forecasting
EGAE	Experiment Guided Adaptive Endpoint
EGS	European Geophysical Society
ENVISAT	ENVironmental SATellite
EOP	Earth Orientation Parameters
ERP	Earth Rotation Parameters
ESA	European Space Agency
EU	European Union
EUREF	EUropean REference frame
EVLA	Expanded Very Large Array
e-VLBI	Electronic VLBI
EVN	European VLBI Network
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FESG	Forschungseinrichtung Satellitengeodäsie/Technical University of Munich (Germany)
FFI	Forsvarets Forskningsinstitutt (Norwegian Defence Research Establishment)
FFT	Fast Fourier Transform
FOV	Field Of View
FS	Field System
FTP	File Transfer Protocol
FWF	Fonds zur Förderung der wissenschaftlichen Forschung (Austrian Science Fund)
GA	Geoscience Australia (Australia)
GAPE	Great Alaska and Pacific Experiment
GARNET	GSI Advanced Radiotelescope NETwork (Japan)
GARR	Gruppo per l'Armonizzazione delle Reti della Ricerca (Italy)

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GARS	German Antarctic Receiving Station (Antarctica)
GBT	Green Bank Telescope (USA)
GCGO	Gilmore Creek Geophysical Observatory (USA)
GEMD	Geohazard and Earth Monitoring Division (Australia)
GeoDAF	Geodetical Data Archive Facility (Italy)
GEX	Giga-bit Series VLBI EXperiment
GFZ	GeoForschungsZentrum (Germany)
GGAO	Goddard Geophysical and Astronomical Observatory (USA)
GGFC	Global Geophysical Fluids Center
GGOS	Global Geodetic Observing System
GGP	Global Geodynamics Project
GIUB	Geodetic Institute of the University of Bonn (Germany)
GLONASS	GLOBAL NAVIGATION Satellite System
GLORIA	GLOBAL Radio Interferometry Analysis
GMF	Global Mapping Function
GMST	Greenwich Mean Sidereal Time
GNSS	Global Navigation Satellite System
GP-B	Gravity Probe B
GPS	Global Positioning System
GRGS	Groupe de Recherches de Géodésie Spatiale (France)
GSD	Geodetic Survey Division of Natural Resources Canada (Canada)
GSFC	Goddard Space Flight Center (USA)
GSI	Geographical Survey Institute (Japan)
HPBW	Half Power Beam Width
HTSI	Honeywell Technology Solutions Incorporated (USA)
IAA	Institute of Applied Astronomy (Russia)
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICRF	International Celestial Reference Frame
ICRS	International Celestial Reference System
IERS	International Earth Rotation and Reference Systems Service
IGFN	Italian Space Agency GPS Fiducial Network (Italy)
IGG	Institute of Geodesy and Geophysics (Austria)
IGGOS	Integrated Global Geodetic Observing System (now GGOS)
IGM	Instituto Geográfico Militar (Chile)
IGN	Instituto Geográfico Nacional (Spain)
IGS	International GNSS Service
ILRS	International Laser Ranging Service
IMF	Isobaric Mapping Function
INAF	Istituto Nazionale di AstroFisica (Italy)
INPE	Instituto Nacional de Pesquisas Espaciais (Brazil)
IPWV	Integrated Precipitable Water Vapor
IRA	Istituto di RadioAstronomia (Italy)
IRIS	International Radio Interferometric Surveying
ISAS	Institute of Space and Astronautical Science (Japan)

ITRF	International Terrestrial Reference Frame
IUGG	International Union of Geodesy and Geophysics
IVP	InVariant Point
IVS	International VLBI Service for Geodesy and Astrometry
JADE	Japanese Dynamic Earth observation by VLBI
JARE	Japanese Antarctic Research Expedition (Japan)
JAXA	Japan Aerospace Exploration Agency (Japan)
JGN	Japan Gigabit Network (Japan)
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)
KPGO	Koike Park Geophysical Observatory (USA)
KSP	KeyStone Project (Japan)
KSRC	Kashima Space Research Center (Japan)
LAMOST	Large sky Area Multi-Object fiber Spectroscopic Telescope (China)
LBA	Long Baseline Array
LEA	Lab of Ephemeris Astronomy (Russia)
LEIF	Large Equipment and Infrastructure Funding
LLR	Lunar Laser Ranging
LNA	Low Noise Amplifier
LO	Local Oscillator
LOD	Length Of Day
LSB	Lower Side Band
LSGER	Lab of Space Geodesy and Earth Rotation (Russia)
LSQM	Least Squares Method
MAO	Main Astronomical Observatory (Ukraine)
MBH	Mathews/Buffett/Herring nutation model
MIT	Massachusetts Institute of Technology (USA)
MLRO	Matera Laser Ranging Observatory (Italy)
MOBLAS	MOBile LASer
MODEST	MODEL and ESTimate
MPI	Max-Planck-Institute (Germany)
MPIfR	Max-Planck-Institute for Radioastronomy (Germany)
MTLRS	Modular Transportable Laser Ranging System
NAOJ	National Astronomical Observatory of Japan (Japan)
NASA	National Aeronautics and Space Administration (USA)
NCEP	National Centers for Environmental Prediction (USA)
NEOS	National Earth Orientation Service (USA)
NESDIS	National Environmental Satellite, Data, and Information Service (USA)
NGS	National Geodetic Survey (USA)
NICT	National Institute of Information and Communications Technology (Japan)
NIPR	National Institute of Polar Research (Japan)
NMA	Norwegian Mapping Authority (Norway)



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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)
NRAO	National Radio Astronomy Observatory (USA)
NRCan	Natural Resources Canada (Canada)
NSF	National Science Foundation (USA)
NTT	Nippon Telegraph and Telephone Corporation (Japan)
NVI	NVI, Inc. (USA)
OAN	Observatorio Astronómico Nacional (Spain)
OCA	Observatoire de la Côte d'Azur (France)
OPAR	Observatoire de PARis (France)
OPC	(IVS) Observing Program Committee
OSO	Onsala Space Observatory (Sweden)
PARNASSUS	Processing Application in Reference to NICT's Advanced Set of Softwares Usable for Synchronization
PCAL	Phase CALibration
POLARIS	POLAr motion Analysis by Radio Interferometric Surveying
PRARE	Precision RAnge and Range-rate Experiment
RAS	Russian Academy of Sciences (Russia)
RDV	Research and Development sessions using the VLBA
RFI	Radio Frequency Interference
ROEN	Rádio-Observatório Espacial do Nordeste (Brazil)
RRFID	Radio Reference Frame Image Database
RTP	Real-Time Protocol
SEFD	System Equivalent Flux Density
SETI	Search for ExtraTerrestrial Intelligence
SGL	Space Geodynamics Laboratory (Canada)
SHAO	SHanghai Astronomical Observatory (China)
SINEX	Solution INdependent EXchange format
SKA	Square Kilometer Array
SLR	Satellite Laser Ranging
SPbU	Saint-Petersburg University (Russia)
SPU	Saint-Petersburg University (Russia)
SRTM	Shuttle Radar Topography Mission
STDN	Satellite Tracking Data Network (USA)
SVD	Singular Value Decomposition
SWT	SW Technology (USA)
TAC	Totally Accurate Clock
TAO	Telecommunications Advanced Organization (Japan)
TDC	Technology Development Center
TEC	Total Electron Content
TLRS	Transportable Laser Ranging System
TOW	Technical Operations Workshop

TRF	Terrestrial Reference Frame
UBB	Universidad del Bío Bío (Chile)
URSI	International Union of Radio Science
USB	Upper Side Band
USNO	U. S. Naval Observatory (USA)
UT	Universal Time
UT1	Universal Time
UTAS	University of TASmania (Australia)
UTC	Coordinated Universal Time
VCS	VLBA Calibrator Survey
VERA	VLBI Exploration of Radio Astrometry
VLBA	Very Long Baseline Array (USA)
VLBI	Very Long Baseline Interferometry
VMF	Vienna Mapping Functions
VSI	VLBI Standard Interface
VSI-H	VLBI Standard Interface Hardware
VSOP	VLBI Space Observatory Program
VSSP	Versatile Scientific Sampling Processor
VTRF	VLBI Terrestrial Reference Frame
WACO	WAShington COrrrelator (USA)
WIDAR	Wideband Interferometric Digital ARchitecture
WVR	Water Vapor Radiometer
WWW	World Wide Web
ZTD	Zenith Total Delay
ZWD	Zenith Wet Delay



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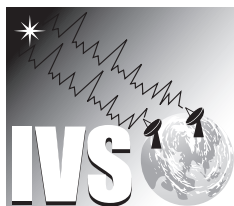
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