

1999

A R K U A I E T



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...ation Service, a
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...ight Center for VLBI

Goddard Space Flight Center
Greenbelt, MD 20771 USA

August, 1999

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PREFACE

This volume of reports is the 1999 Annual Report of the International VLBI Service for Geodesy and Astrometry — IVS. The individual reports were contributed by VLBI groups in the international geodetic community who constitute the components of IVS.

The IVS 1999 Annual Report documents the work of the IVS components for the year ending March 1, 1999, the official inauguration date of IVS. As the newest of the space technique services, IVS decided to publish this Annual Report as a reference to our organization and its components.

All of the content of this Annual Report also appears on the IVS web site at:

<http://ivscc.gsfc.nasa.gov/publications/ar1999>

This book and the web site are organized as follows:

- The first section of the Annual Report contains general information about IVS: its mission, structure, and Directing Board. The Chairman's report gives a brief history of the genesis of IVS, an overview of IVS as an organization, and a look toward the future.
- The second section comprises two brief overviews of VLBI with particular emphasis on reference frames which are fundamental to geodesy and astrometry. This material is offered with the intention of providing brief but comprehensive overviews to those readers of the Annual Report who are unfamiliar with the technique of VLBI and its applications to geodesy and geodynamics.
- The next seven sections contain the heart of the Annual Report — the reports from each IVS component: the Coordinators, Network Stations, Operation Centers, Correlators, Data Centers, Analysis Centers, and Technology Development Centers. These reports are dense with technical information, staff descriptions, photographs, and plans for the coming year. Each report documents the work of the IVS component for the year preceeding the start of IVS.
- The last section provides IVS reference material: the Terms of Reference, a list of institutions contributing to this Annual Report, the list of IVS Associate Members, a complete list of the IVS components, and a list of acronyms.

The IVS 1999 Annual Report will be a valuable reference for information about IVS and its components. This Annual Report will serve as a baseline from which we can measure the anticipated progress of IVS in coming years.

ACKNOWLEDGEMENTS

The editor would like to acknowledge the essential contributions of the following people to the preparation of the IVS 1999 Annual Report:

- Leonid Petrov and Hayo Hase convinced me to use LaTeX as the source format for these reports. This has made it possible to automate the production of both the printed version and the web version.
- Leonid Petrov provided the TeX programming to produce the appearance of the printed page and he devised the scheme for pagination of the individual reports.
- Hayo Hase provided a demonstration station report and template. His example enabled even those unfamiliar with LaTeX to produce outstanding reports.
- Karen Bayer did the programming and wrote the scripts that processed all of the LaTeX source files. Her scripts produced the tables of contents, the printed reports, the HTML versions, and the institution lists. Her scripts also paginated the entire report.
- Frank Gomez located and installed the software for the latest versions of LaTeX and LaTeX2HTML. He also provided system and web administration support throughout.
- John Hazen designed the striking cover art that captures the essence of geodetic VLBI today, and he did the layout for the color pages of the report.
- The HTML versions of the reports were generated using the LaTeX2HTML translator Version 98.1 by Nikos Drakos, Computer Based Learning Unit, University of Leeds, customized for IVS by the editor.

Finally I would like to thank all of the IVS colleagues who contributed their reports to the Annual Report. The high quality of the reports demonstrates that we have an active worldwide community with a splendid future.

Nancy Vandenberg
IVS Coordinating Center Director
Editor, 1999 Annual Report

TABLE OF CONTENTS

Preface	iii
Acknowledgements	v
About IVS	1
IVS Organization	2
IVS Component Map	4
Directing Board	6
Chairman's Report	8
Reference Frames in VLBI	11
Overview of VLBI	13
The Celestial Reference Frame	18
Coordination	23
Coordinating Center Report	25
Analysis Coordinator Report	27
Network Coordinator Report	29
Technology Coordinator Report	31
Network Stations	33
Algonquin Radio Observatory	35
Progress at ROEN - Fortaleza Geodetic Station	39
Gilmore Creek Geophysical Observatory	42
Goddard Geophysical and Astronomical Observatory	46
USNO Green Bank 20-Meter Telescope	49
Hartebeesthoek Radio Astronomy Observatory	53
Kashima 34-m Radio Telescope	57
Key Stone Project VLBI Stations (Kashima, Koganei, Miura, and Tateyama)	62
Kokee Park Geophysical Observatory	66
Matera CGS VLBI Station	70
Medicina Station Report	74
Report from the Noto VLBI Station	77
NYAL Ny-Ålesund 20-metre Antenna	80
German Antarctic Receiving Station O'Higgins	85
Onsala Space Observatory - IVS Network Station	90
Status Report of Seshan VLBI Station	94
Simeiz VLBI Station	96
Svetloe Radio Astronomical Observatory	101
JARE Syowa Station 11-m Antenna, Antarctica	105
Transportable Integrated Geodetic Observatory	110
Tsukuba 32-m VLBI Station	115
Urumqi Astronomical Observatory	119
Westford Antenna	122
20-m Radiotelescope at Wettzell	126
Observatorio Astronómico Nacional	132
Yellowknife Observatory	136
Operation Centers	139
The Bonn Geodetic VLBI Operation Center	141
CORE Operations Center	143
The U.S. Naval Observatory VLBI Program: Operations in 1998 and 1999	147

TABLE OF CONTENTS

Correlators	149
The Bonn Astro/Geo Mark IIIA Correlator	151
The Haystack Observatory VLBI Correlator	153
Key Stone Project VLBI Correlation Center	156
Tsukuba VLBI Center	160
Washington Correlator	164
Data Centers	167
BKG Data Center	169
Data Center at Communications Research Laboratory	170
CDDIS Data Center Summary	173
Matera GeoDAF Data Center	177
Italy CNR Data Center Report	179
Paris Observatory (OPAR) Data Center	181
Analysis Centers	183
Analysis Center of Saint-Petersburg University	185
The Bordeaux Observatory IVS Analysis Center	186
Matera CGS VLBI Analysis Center	189
Special Associate Analysis Center at Communications Research Laboratory	192
DGFI Analysis Center	196
Combination of Results at FFI - Data Analysis	198
The GIUB/BKG VLBI Analysis Center	200
GSFC VLBI Analysis Center Annual Report	203
Analysis and Research at the Haystack Observatory	207
IAA VLBI Analysis Center Report for 1998-1999	209
Italy CNR Analysis Center Report	213
JPL VLBI Group Report for 1998-1999	215
IVS Analysis Center at MAO UNAS	217
Paris Observatory Analysis Center OPAR: Report on Activities January 1998 - March 1999	220
The IVS Special Analysis Center at the Onsala Space Observatory	228
VLBI Research Activities for Astrometry and Geodesy at Shanghai Astronomical Observatory	232
Earth Orientation Analysis from the U.S. Naval Observatory VLBI Program	236
Technology Development Centers	241
Canadian VLBI Technology Development Center	243
Technology Development Center at CRL	248
Combination of Results at FFI - Software Development	253
Goddard Space Flight Center IVS Technology Development Center	256
IVS Technology Development Center at Haystack Observatory	259
Institute of Applied Astronomy Technology Development Center	264
Institute d'Estudis Espacials de Catalunya (IEEC)	269
The IVS Technical Development Center at the Onsala Space Observatory	272
IVS Information	277
IVS Terms of Reference	279
IVS Components	288
Contributing Institutions	292
IVS Associate Members	297
List of Acronyms	307

ABOUT IVS

IVS ORGANIZATION

Mission:

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.

Objectives:

IVS is the International VLBI Service for Geodesy and Astrometry. IVS groups geodesy and astrometry together because they use the same observations and the same analysis gives both types of results.

IVS is a service of International Association of Geodesy (IAG). IVS was originally established under IAG Commission VIII — the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG).

IVS is the third of this type of service to be established. The first was the IGS (International GPS Service) which has been highly successful as a service for GPS. The second service was the ILRS (International Laser Ranging Service) which started in late 1998.

The objectives of IVS are

- to provide a service to support geodetic, geophysical, and astrometric research and operational activities;
- to promote research and development for VLBI; and
- to interact with users of VLBI products.

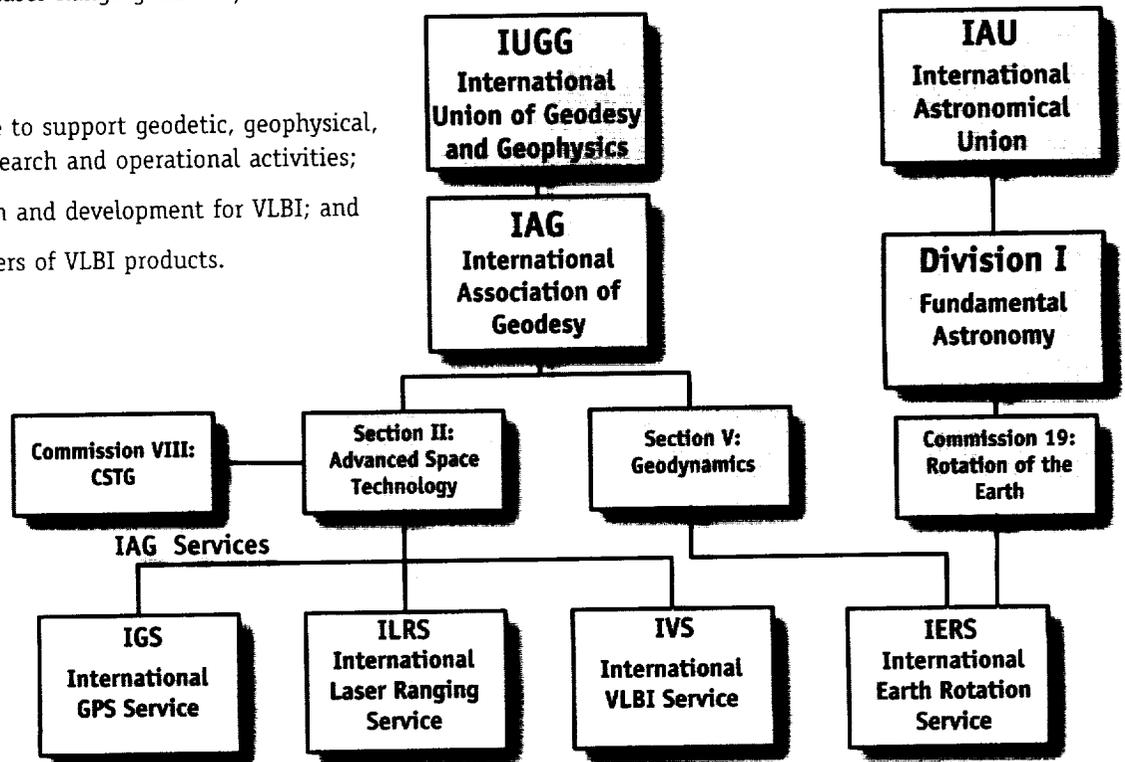
IVS provides data and products for the scientific community.

Some of the products are

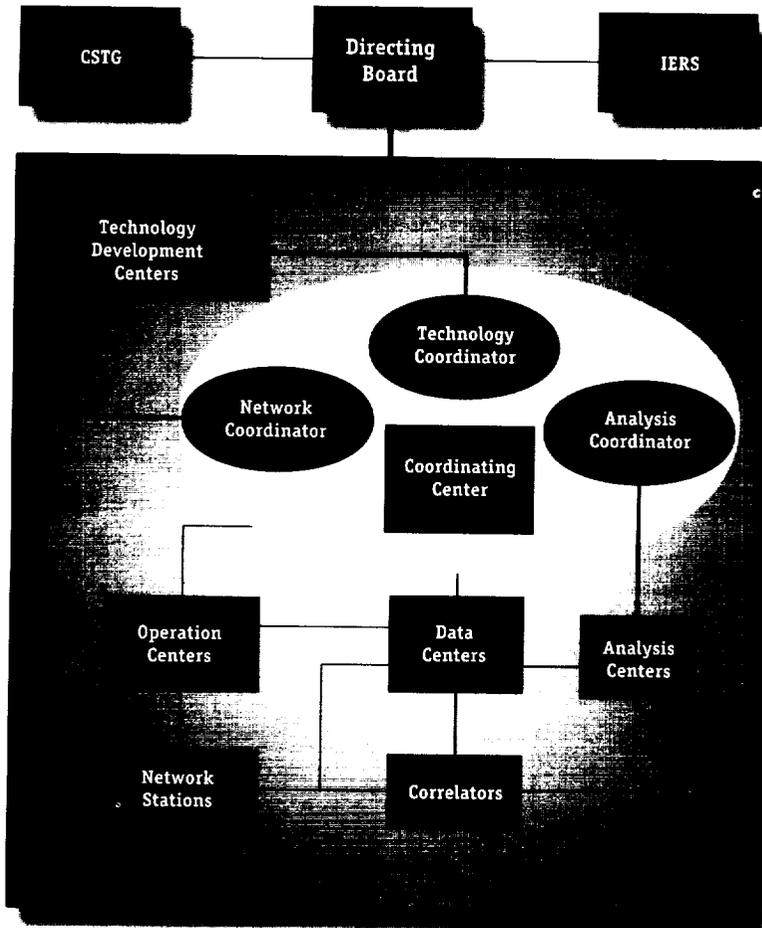
- a terrestrial reference frame (TRF),
- the international celestial reference frame (ICRF), and
- Earth orientation parameters (EOP),

All IVS data and products are archived and are publicly available.

The organizations listed on the next page contribute to IVS by supporting one or more IVS components.



Structure:



The goals of IVS are realized through seven types of components. The interaction among the various components is shown in the accompanying figure.

- Network Stations are high performance VLBI stations that acquire data.
- Operation Centers coordinate the activities of a network of Network Stations.
- Correlators process data, provide feedback to stations, and provide processed data to analysts.
- Analysis Centers analyze data and produce results and products.
- Data Centers distribute products to users, and provide storage and archive functions.
- Technology Development Centers develop new VLBI technology
- The Coordinating Center coordinates the daily and long-term activities of IVS.

In the figure, the link to the International Earth Rotation Service (IERS) indicates that the IVS is now the VLBI Coordinating Center for IERS. The Directing Board provides overall guidance. The Coordinating Center and the three Coordinators work closely together. Each Coordinator has a special relationship with the components they work with. All of the components interact with each other on a daily basis.

Organization

Organization	Country
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
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
Istituto di Radioastronomia CNR	Italy
Agenzia Spaziale Italiana	Italy
Geographical Survey Institute	Japan
Communications Research Laboratory	Japan
National Astronomical Observatory of Japan	Japan

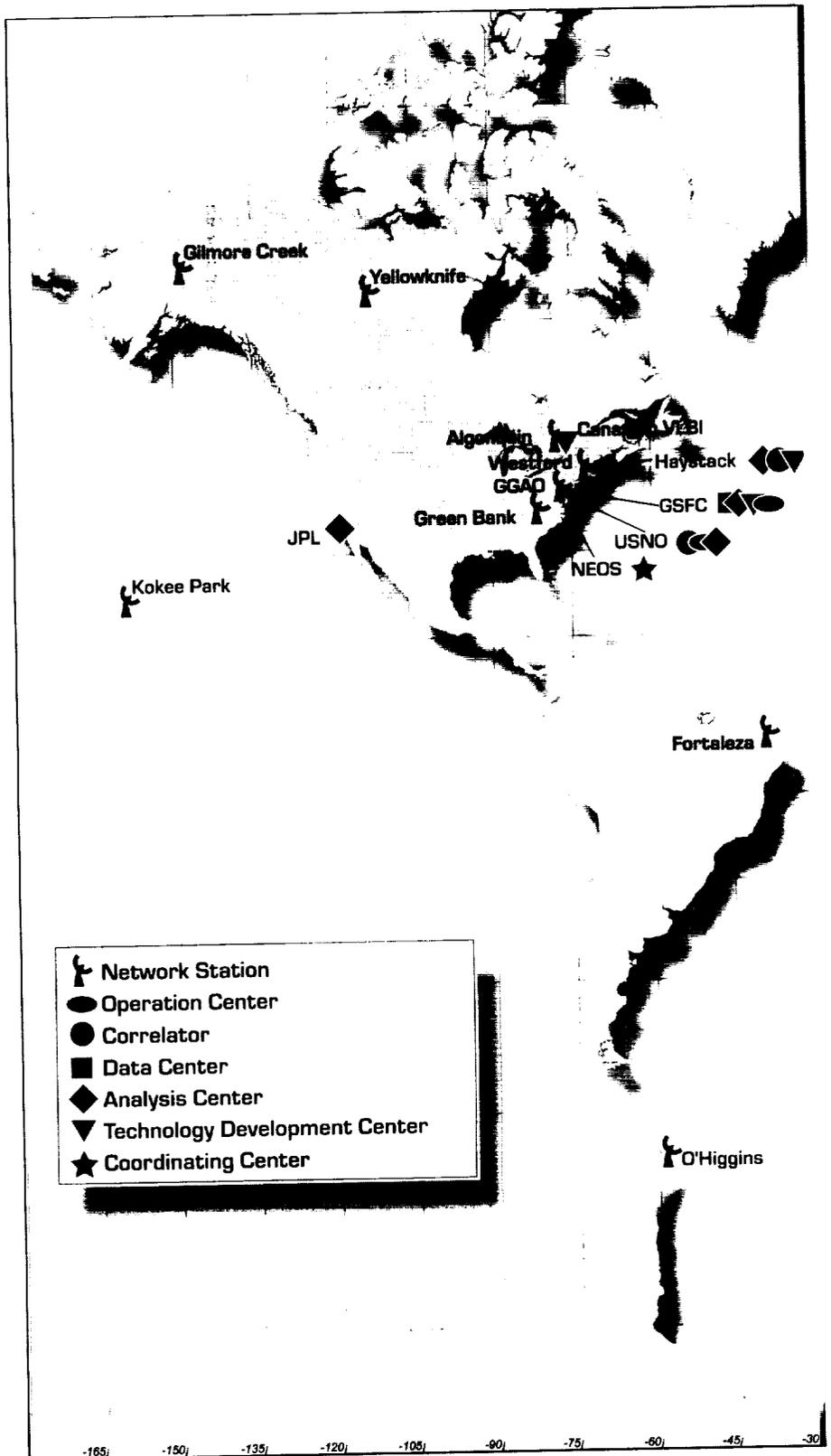
Organization

Organization	Country
National Institute of Polar Research	Japan
Joint Institute for VLBI in Europe	Netherlands
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
Institut d'Estudis Espacials de Catalunya	Spain
Observatorio Astronómico Nacional	Spain
Chalmers University of Technology	Sweden
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

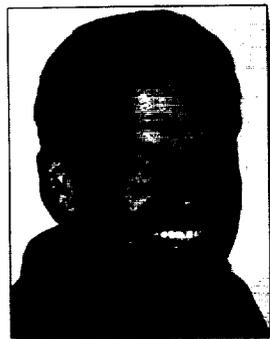
IVS COMPONENT MAP

IVS Components by Country

Brazil	1
Canada	3
China	3
France	3
Germany	8
Italy	7
Japan	14
Netherlands	2
Norway	3
Russia	5
South Africa	1
Spain	2
Sweden	3
Ukraine	2
USA	17



IVS DIRECTING BOARD



NAME: Wolfgang Schlüter
AFFILIATION: Bundsamt für Kartographie und Geodäsie, Germany
POSITION: Chairman and Networks Representative
TERM: 4 years



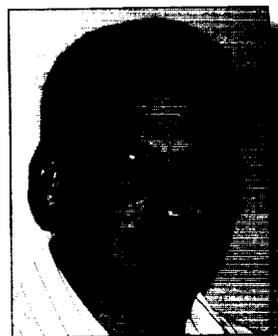
NAME: Gerhard Beutler
AFFILIATION: University of Berne, Switzerland
POSITION: IAG Representative
TERM: *ex officio*



NAME: Marshall Eubanks
AFFILIATION: U.S. Naval Observatory, USA
POSITION: Correlators and Operation Centers Representative
TERM: 4 years



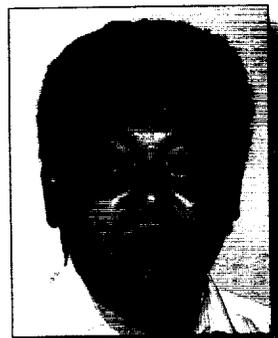
NAME: Wayne Cannon
AFFILIATION: Space Geodetic Laboratory, Canada
POSITION: At Large Member
TERM: 2 years



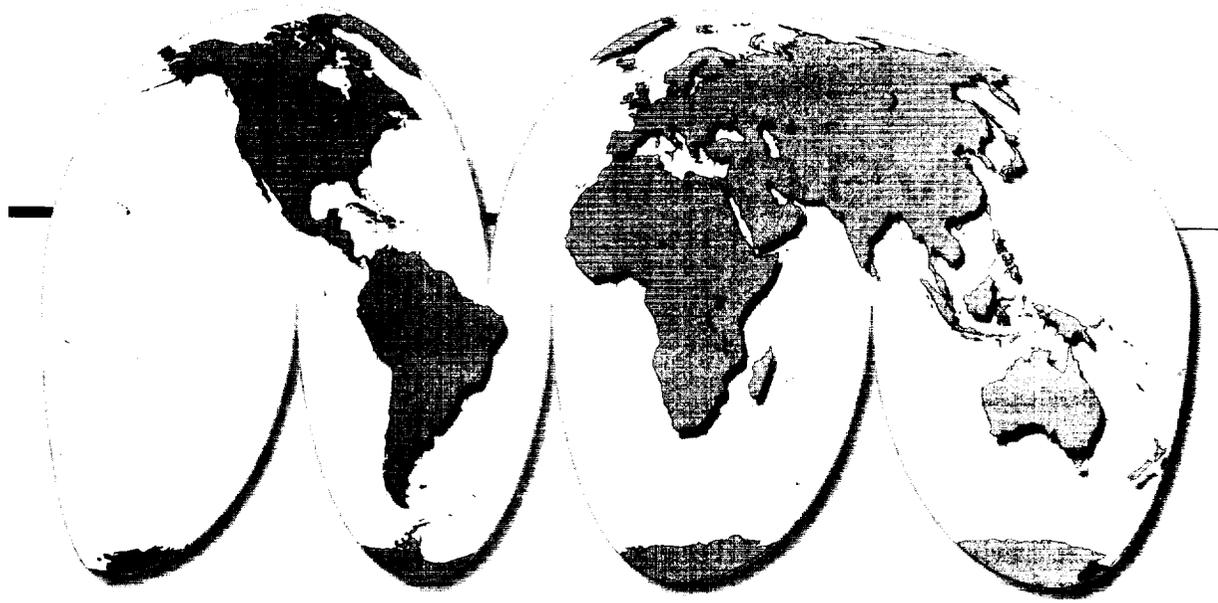
NAME: Ed Himwich
AFFILIATION: NVI, Inc./Goddard Space Flight Center, USA
POSITION: Network Coordinator
TERM: 4 years



NAME: Nicole Capitaine
AFFILIATION: Paris Observatory, France
POSITION: IAU Representative
TERM: *ex officio*



NAME: Tetsuro Kondo
AFFILIATION: Communications Research Laboratory, Japan
POSITION: Technology Development Centers Representative
TERM: 2 years



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



NAME: Paolo Tomasi
AFFILIATION: CNR Bologna, Italy
POSITION: At Large Member
TERM: 4 years



NAME: Shigeru Matsuzaka
AFFILIATION: Geographical
Survey Institute, Japan
POSITION: Networks
Representative
TERM: 4 years



NAME: Nancy Vandenberg
AFFILIATION: NVI, Inc./Goddard
Space Flight Center, USA
POSITION: Coordinating Center
Director
TERM: *ex officio*



NAME: Axel Nothnagel
AFFILIATION: University of
Bonn, Germany
POSITION: Analysis and Data
Centers Representative
TERM: 2 years



NAME: Alan Whitney
AFFILIATION: Haystack
Observatory, USA
POSITION: Technology
Coordinator
TERM: 2 years

IVS CHAIRMAN'S REPORT

Wolfgang Schlüter
Bundesamt für Kartographie und Geodäsie

1. Introduction

The inauguration date for the International VLBI Service for Geodesy and Astrometry was March 1st, 1999. A tremendous amount of work was done by individuals for preparation of the Terms of Reference, the Call for Participation and the evaluation of the proposals as well as for the initialisation of the establishment of the IVS components.

I'm aware that the success of IVS is dependent on the support of the individuals of the member institutions, which provide the technology, observations, and data handling, processing and analysis on a long term basis. It is extremely important to maintain the good cooperation, already developed over many years, between institutions and individuals. Information flow among the members and to users outside of the IVS is vital.

We are presenting now the first Annual Report of the IVS to document from the very beginning the status of the service and to demonstrate transparency to the applicants, scientists and administrators to gain or to keep their confidence. All components were asked to summarize their status and to point out their future contributions to IVS. Thanks to all for making first Annual Report a valuable document about the IVS.

2. General Remarks

Three decades ago the space techniques played only a marginal role in the understanding of the kinematics and dynamics of the Earth. The breakthrough came as a result of the MERIT [Feissel, 1986] campaign and the Crustal Dynamics Project [Smith, 1993] in the 1980s. The space techniques demonstrated their potential for the realisation of the global reference frames ICRF and ITRF and for the determination of Earth orientation parameters and crustal movements. Since that time the VLBI technique played the important and primary role for monitoring of EOP and crustal motions. VLBI is the only technique that determines the ICRF.

The requirement for continuous monitoring of EOP as well as for continuous determination of station positions and quasar positions was recognized as a result of MERIT. Regarding the VLBI technique, it has been realized by performing series of VLBI experiments. NASA/GSFC, NOAA-NGS, USNO, FGS and other agencies have organized and coordinated international

VLBI observations such as IRIS, NEOS, CORE, Intensive and more with the primary objective to monitor EOP. Several series of experiments were performed for the determination of plate tectonics such as GLOBAL, X-ATL, N-ATL, EUROPE etc. and many R&D-experiments to improve the technique and investigate its potential. The results have been continuously reported to the IERS, the International Earth Rotation Service (<http://hpiers.obspm.fr>), which was established as a consequence of the MERIT campaign.

The VLBI community was organized within the International Association of Geodesy (IAG) in Commission VIII—the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)—as the VLBI Subcommission. CSTG is also Subcommission B.2 in the Committee on Space Research (COSPAR).

Over all the years the results of the VLBI technique became basic and important products for many applications in science and in practice. The need grew for the establishment of an international service which would take over the responsibility for the delivery of the VLBI products on a long term basis and guarantee highest quality. The new service would replace the relatively loose, historically grown commitments and become an umbrella of the VLBI community.

3. Transition from the CSTG Subcommission to the IVS

Encouraged by the success of the International GPS Service (IGS), established in 1992, the president of the CSTG, Gerhard Beutler, University of Berne, proposed in May 1997 to organize the SLR/LLR and the VLBI subcommissions of the CSTG into comparable services. His vision was twofold: first, a service will guarantee much more strongly the provision of highly reliable products and second, the SLR/LLR and the VLBI techniques urgently needed more acceptance and support in the scientific community. The coordination of the activities within services of the SLR/LLR and VLBI communities will strongly concentrate resources and increase the potential to improve the techniques.

Thomas A. Clark, in his function as chairman of the CSTG VLBI Subcommission, drafted the Terms of Reference for the IVS in October 1997. The final version was worked out by a

Subcommission Steering Committee whose members were James Campbell (chairman), Yasuhiro Koyama, Chopo Ma, Arthur Niell, Axel Nothnagel, Jim Ray and Nancy Vandenberg. The Terms of References were presented and approved at both the CSTG Executive Committee and IERS Directing Board meetings in Nice/France in April 1998. The Call for Participation was jointly released by CSTG and IERS on June 1, 1998. The Steering Committee evaluated the proposals and accepted all of them in October 1998.

In summary, the IVS has

- 30 network stations (concentrated in USA, Europe, and Japan, deficit in the southern hemisphere),
- 3 operation centers (NASA-GSFC, NEOS, GIUB),
- 7 correlators (IAA/Russia, GSI/Japan, CRL/Japan, NEOS(Washington)/USA, NASA(Haystack)/USA, JIVE/Netherlands, BKG-MPI/Germany),
- 6 data centers (CNR/Italy, CRL/Japan, NASA-GSFC/USA, Observ. Paris/France, Agenzia Spaziale/Italy, BKG/Germany),
- 18 analysis centers (global AC to provide IVS core products; associate AC for investigations or other related products),
- 9 technology centers (supporting Mark III and Mark IV, K4 and S2 technologies),
- 1 coordinating center (NEOS, a cooperation of USNO and GSFC),

All together there are:

- 74 components representing 30 institutions in 15 countries
- 229 Associate Members

In November 1998, the Steering Committee, in accordance with the Terms of Reference, released the call for nominations for representative positions on the Directing Board (due to December 10, 1999) and the call for proposals for the positions of the Coordinators (Analysis, Network, Technology). The elections were carried out in the period from December 15, 1998 to January 1999 via e-mail by the Associate

Members. The Steering Committee formed the Directing Board on the basis of the elections, the proposals for Coordinators, and the nominations for the At Large members. The Directing Board held its first meeting on February 11, 1999 at Wettzell, before the 13th Working Meeting on European VLBI.

The position of the Analysis Coordinator will be filled by autumn 1999. The task presently is being performed by NEOS with a team consisting of Chopo Ma (GSFC), Marshall Eubanks (USNO) and Nancy Vandenberg (CC).

4. Summary of Activities

As a first step to provide the information on IVS, the IVS web site was set up and officially announced on March 1, 1999, the official inauguration date of IVS (<http://ivscc.gsfc.nasa.gov>). For access in Europe and in Asia, the web site is mirrored at BKG in Germany and at CRL in Japan (<http://www.leipzig.ifag.de/IVS> and <http://ivs.crl.go.jp/mirror>).

A logo contest, with entries due June 1, was announced. The decision on the official IVS logo will be made at the next Directing Board Meeting (July 19, 1999).

A solicitation for IVS data and analysis was released (due April 15) in order to obtain proposals from the Operation Centers and Analysis Centers on the provision of products as observational data products (correlation results), analysis products such as Earth Orientation Parameters (EOPs), combined analysis products to become "official" IVS products, analysis functions e.g. comparison studies or new product developments.

A call for proposals for the Analysis Coordinator was included in the solicitation.

A Coordinators meeting was held at GSFC on April 8, 1999. The purpose was to discuss the activities of each Coordinator. Particular emphasis was placed on areas where the responsibilities of the Coordinators may overlap.

Preparations for the first IVS Annual Meeting have started. The invitation and Call for Contributions is distributed separately. The 1st IVS General Meeting will be held in Kötzing, Germany, close to the Fundamentalstation Wettzell in the period from February 21 to 25, 2000.

5. Prospects

Among the services IGS, ILRS and IVS, the latter one is the youngest and was established a few months ago. Obviously a lot of work is ahead of us. The primary goal is to coordinate all the components to a highly reliable service, which guarantees high quality and timely products on a long term basis.

Emphasis has to be placed on the development of standards for the components, in order to enhance the overall data quality, quantity and reliability.

Improvements have to be considered in the network configuration. Cooperation with related communities and standardisation of the data acquisition interfaces will increase the number of network stations and will balance their distribution.

New developments in technology will accelerate data exchange and will allow improvements in the degree of automatisisation for the operation of stations, the correlation and the analysis. The implementation of the MK IV correlator will soon open up new possibilities. The Coordinators will carry an important role.

Transparency in the IVS decisions, strong cooperation and an open exchange of information will play key roles in guaranteeing the success of the service. Close cooperation with the other services—considering our common objectives—is a requirement.

Acknowledgements

On behalf of the Directing Board I appreciate the work which has been done for the establishment of IVS and I express my thanks to all who have contributed to the IVS startup and to its successful operation so far. I express explicitly my thanks to Prof. Gerhard Beutler, who initiated the transition to the IVS, Dr. Thomas Clark and Prof. James Campbell as the chairs of the CSTG VLBI Subcommission during the transition period from the Subcommission to the service, Dr. Nancy Vandenberg for the coordination of the work, and the members of the Steering Committee that was established for the transition period. Thanks also to all who have contributed to this report.

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- Feissel, Martine (ed.); MERIT-Cotes Results on Earth Rotation and Reference Systems, Bureau International de l'Heure, Section de la Rotation Terrestre, Observatoire de Paris, Paris 1986.
- Smith, David E. (ed.); Contributions of Space Geodesy to Geodynamics, Earth Dynamics, Geodynamics Series Volume 23, 24 and 25, American Geophysical Union, Washington, D.C. 1993.

REFERENCE FRAMES IN VLBI



Overview of VLBI

Wayne Cannon
Space Geodynamics Laboratory

1. The Importance of Reference Frames

Modern geodetic techniques are expected to provide the observational basis for the systematic investigation of a wide range of scientific questions including, among others:

- the motions, tectonic and otherwise, of the Earth's crust on local, regional, continental, and global scales.
- the rotational dynamics of the Earth.

In general, scientific investigations of these phenomena proceed by the precise determination of the position vectors and their time dependence of observation locations on the Earth's surface. These determinations are carried out to a high precision (often as high as parts in 10^9 to parts in 10^{10}) by a variety of geodetic techniques over many decades. In an effort to advance our understanding of many important geophysical phenomena it is often essential that high precision data sets, realized by various geodetic techniques and acquired at times that are decades (and eventually even centuries) apart, be merged, analyzed, and interpreted in a coherent and self-consistent manner. In general this sort of data analysis requires the combination of vector (and possibly tensor) quantities, directly or indirectly, derived from the geodetic measurements. In combining high precision vector and tensor quantities it is essential that the components of the vector and the elements of the tensor are **referred to a common set of fundamental basis vectors or a common fundamental reference frame lest the procedure yield mathematically illogical and physically meaningless results**. When very high precision geodetic measurements are being analyzed in this fashion it is essential to find a solution to the question of a common fundamental reference frame.

In order to serve the purpose required of it in the context of modern geodesy, such a common fundamental reference frame must:

- be realizable to a precision of the order of parts in 10^{10}
- be reproducible to a precision of the order of parts in 10^{10} over time scales of centuries or longer

2. Candidate Fundamental Reference Frames

Historically fundamental geodetic reference frames (Terrestrial Reference Frames) were attached to the surface of the Earth. Such frames of reference were of course rotating and their use in dynamical applications required a precise measurement of the rotation vector of the reference frame. This required continuous monitoring of the Earth's rotation since the rotation vector was time varying as a result of a variety of geophysical phenomena. In the modern context the rotational motion of the tectonic plates of the Earth, at rates of the order of $\pi/2$ per 10^8 years

or roughly parts in 10^8 per year, renders this frame unstable on the times scales of interest and precludes the use of the Earth's surface as a candidate for such a fundamental reference frame.

The practice of successful navigation at sea also imposed a requirement for the establishment of a fundamental reference frame on the sky. The Celestial Reference Frame was defined by the equator, ecliptic, and pole of rotation of the Earth and was realized by the estimates of the celestial coordinates of stars in the Milky Way Galaxy. In the modern context the rotation of the Milky Way Galaxy at rates of the order of 2π per 3×10^8 years or roughly parts in 10^8 per year combined with the chaotic proper motions of stars renders this frame unstable on the time scales of interest and precludes the use of the Milky Way Galaxy as a candidate for such a fundamental reference frame.

Other inadequate candidates for the definition of a fundamental reference frame include the orbital planes of passive compact satellites such as "Lageos" or "Starlette". These objects are buffeted by the solar wind, are perturbed by the tidal forces of the Sun and Moon, are subjected to the gravitational accelerations of time varying harmonics of the Earth's gravity field, and are subjected to the gravitational accelerations of unknown high order harmonics of the Earth's gravity field.

The orbital planes of active satellites such as GPS and GLONASS are even less suitable for the definition of a fundamental reference frame. Active satellites suffer from all the drawbacks of passive compact satellites and have in addition the complications of large drag effects on solar panels, orbital maneuvers imposed by ground controllers, and angular momentum dumps imposed by ground controllers.

The present-day solution to the definition of the **fundamental reference frame** has been found by retreating from the Earth to the edges of the known Universe and adopting a cosmological frame of reference defined by a large number (400 to 600) of "bright" quasars and Active Galactic Nucleii (AGNs) whose relative positions on the celestial sphere are estimated by Very Long Baseline Interferometry (VLBI) measurements with an internal precision of the order of 0.1 to 0.2 milli-arc seconds or a few parts in 10^{10} . This suite of cosmological objects define what is referred to as the International Celestial Reference Frame (ICRF). The ICRF has been adopted by both the IUGG and the IAU as constituting the **fundamental reference frame** for astronomy, astrophysics, geodesy, and geophysics. The ICRF is tied to the Equatorial or Dynamical Reference Frame defined by the Vernal Equinox and the North Celestial Pole (NCP) with high (0.2 to 1.0 milli-arc second) precision, largely as a result of the intrinsically high precision of VLBI measurements, but with low (100 to 200 milli-arc second) accuracy), limited largely by the uncertainties in the location of the Equinox and NCP within the Dynamical Frame.

3. VLBI Basics

The fundamental geodetic VLBI observable, τ_{obs} also known as the signal "delay", is the differential time-of-flight, between two VLBI antennas located on the Earth's surface, of broadband microwave "noise" signals emanating from quasars or other cosmological radio sources. This is an observable which depends only on **fundamental physics**, namely a realization of the atomic second and a clock synchronization convention.

The VLBI signal delay τ_{obs} is measured by amplifying, downconverting in frequency, and digitally sampling, the quasar signal at each antenna site with electronic signal processing devices whose time, frequency, and phase information is derived coherently from an on-site atomic fre-

quency standard, usually a hydrogen maser. Figure 1 shows the basic geometry of VLBI and the equipment used.

The digitally sampled quasar signals are recorded, along with precise station time information, by a broad bandwidth digital data recorder and the recorded tapes are subsequently delivered to a special purpose VLBI correlator facility for cross correlation processing. Cross correlation processing of VLBI data requires continual and precise compensation, before multiplication, for the changing differential time-of-flight and changing differential Doppler shift imparted to the microwave signals by the rotation of the Earth during the entire period of coherent integration. The relative delay at which the peak of the cross correlation function is found yields a value of τ_{obs} .

As in all correlation functions, the width of the central maximum of the VLBI cross correlation function is inversely related to the bandwidth of the signals being cross correlated. The precision with which the value of the signal delay τ_{obs} may be measured is given by $\delta\tau_{obs}$ and is related to the effective bandwidth B_{eff} of the cross correlated signal by

$$\delta\tau_{obs} = \frac{1}{SNR \cdot B_{eff}} \quad (1)$$

where SNR refers to the signal-to-noise ratio observed on the interference fringes and B_{eff} refers to the **effective bandwidth** of the recorded VLBI signals. In geodetic VLBI systems it is customary to increase the effective bandwidth of the recorded signals beyond the limitation imposed by simple considerations of the maximum bit rate and the Nyquist Sampling Theorem by recording a number of widely spaced, relatively narrowband, RF signal channels; separately filtered from the broadband quasar noise signal. In this way geodetic VLBI systems function by observing the microwave analog of **optical white light interference fringes** with the attendant very small tolerance on relative delay. As a typical example we shall consider $B_{eff} = 700$ MHz, $SNR = 50$, and $\delta\tau_{obs} = 28$ picoseconds which corresponds to about 8 millimetres of light travel distance. Modern VLBI systems routinely measure the signal delay τ_{obs} to a few tens of picoseconds.

The VLBI signal delay measured at the correlator, τ_{obs} , while dominated by the differential time-of-flight of the quasar microwave signal between the radio observatories, does contain other significant contributions that require attention. In general we may express the signal delay τ_{obs} as a sum of many terms

$$\tau_{obs} = \tau_g + \tau_{clock} + \tau_{inst} + \tau_{trop} + \tau_{ionos} + \tau_{rel} + \dots \quad (2)$$

where, for example

- τ_{clock} is a contribution to the signal delay arising from the mis-synchronization of the reference clocks at each observatory

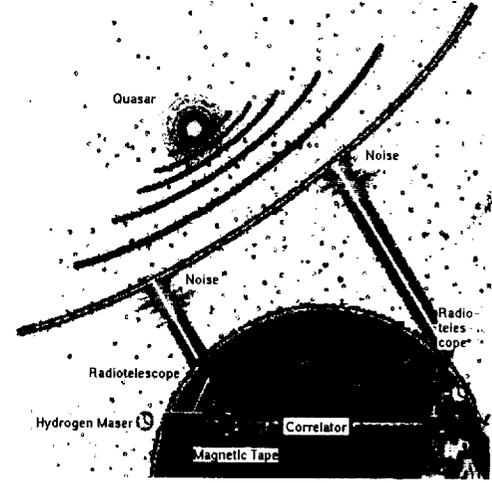


Figure 1. VLBI Concept. Original drawing by John Hazen, modified by Hayo Hase.

- τ_{inst} is a contribution to the signal delay arising from the propagation delays through on-site cable runs and other instrumentation
- τ_{trop} is a contribution to the signal delay arising from the propagation delays through the non-ionized portions of the Earth's atmosphere.
- τ_{ionos} is a contribution to the signal delay arising from the propagation delays through the ionized portions of the Earth's atmosphere.
- τ_{rel} are special and general relativistic corrections to the classical geometric delay τ_g

All of these terms, with the exception of τ_{rel} , are to be considered from a geodetic VLBI perspective to constitute small nuisance terms corrupting the classical geometric delay τ_g . The effects of all of these terms, including τ_{rel} , must be accounted for and then removed by one of several methods:

1. direct computation from known physics, (τ_{rel})
2. direct calibration (τ_{inst})
3. least squares estimation by modelling, possibly with the aid of locally measured input parameters, (τ_{atmos} , τ_{clock})
4. direct removal by physical processes (τ_{ionos})

The classical geometric delay, τ_g is defined implicitly by

$$\tau_g(t) = \frac{1}{c} \hat{s} \cdot [\vec{r}_2(t) - \vec{r}_1(t + \tau_g(t))] \quad (3)$$

where \vec{r}_1 and \vec{r}_2 are the geocentric (or solar system barycentric) position vectors of the radio observatories and \hat{s} is a unit vector in the direction of the source of radiation as seen from the origin of the geocentric (or solar system barycentric) frame. Repeated determinations of $\tau_g(t)$ by the sequential observation, in rapid succession, of many radio sources $\hat{s}_k, k = 1, 2, 3, \dots$ results in a data set sufficient to overdetermine the VLBI vector baseline $\vec{b} = \vec{r}_2 - \vec{r}_1$. This data set is analyzed by standard non-linear least squares methods to yield a high precision estimate of the VLBI vector baseline, Earth orientation parameters (precession, nutation, polar motion, UT1), station clock errors, as well as other quantities such as radio source positions etc that pertain to the VLBI observation technique. The Earth orientation parameters are referred to the non-rotating ¹ cosmological frame of the ICRF.

The ICRF is often described (erroneously) as constituting the “best definition of an inertial frame” for the purposes of physics and astronomy. While the ICRF is an essential aspect of the definition of an inertial frame, this wording suggests that the ICRF can be used to define a “global inertial frame”. This is an error and is a practice that should be discouraged. A description of the ICRF that is in accord with relativistic physics would require the recognition that global inertial frames do not exist. Local inertial frames however do exist and require for their definition a “local standard of rest” that is provided by a state of free-fall and a “standard of non-rotation” that

¹The adoption by the IUGG and IAU of the ICRF defined by VLBI and the use of the ICRF to define a standard reference frame for the geodetic application of VLBI to the measurement of Earth orientation parameters is based on an assumption that the Universe at large is non-rotating. Our present day understanding of modern physics persuades us that this is likely to be the case. Kurt Gödel has shown that if the Universe at large is rotating then there exist closed, time-like world lines and it would be possible to travel into one's past; a feat generally considered impossible.

is provided by the ICRF. The geocenter and the solar system barycenter are both in a state of free-fall and are both suitable origins for a local inertial frame and both are used in the reduction of VLBI observations. The **essential role** of the ICRF in both cases is to provide the requisite “standard of non-rotation” required to establish the inertial reference frame.

The present-day repeatability of vector baseline determinations by VLBI techniques, between radio observatories equipped with state-of-the-art VLBI systems, is of the order of a few millimetres on baselines up to several thousand kilometers. A global network of geodetic VLBI observatories carrying out routine VLBI measurements provide an **essential contribution** to the definition of the International Terrestrial Reference Frame (ITRF) defined by a number of geodetic control points, many but not all of which, are co-located with geodetic VLBI antennas, whose positions and velocities within the ITRF are continually monitored.

The Celestial Reference Frame

Chopo Ma
Goddard Space Flight Center

1. Introduction

The conceptual basis of reference frames defined by extragalactic objects is straightforward: that the universe as a whole does not rotate so very distant objects cannot have an overall rotational motion. Experimentally, the global rotation of the universe is less than 10^{-12} arcsecond/yr as inferred from the 3K microwave background radiation. At the distance of 108 parsecs, even if an object were moving transversely at the speed of light, its angular velocity would be less than 0.6×10^{-3} arcsecond/yr, while an object moving at a physically more reasonable speed comparable to the Sun would show a motion of 10^{-6} arcsecond/yr, entirely undetectable by current technology. Since neither systematic universal motion nor random motion at such great distance is measurable, it is reasonable to construct a static celestial reference frame on the basis that such objects are fixed in the sky.

2. Historical Background

The idea of using extragalactic objects to define the celestial reference frame is quite old, having been discussed by Herschel and Laplace some two hundred years ago, even before there was proof that such objects existed. The discovery of external galaxies and their distances in the early 20th century raised the possibility of their use as fiducial objects for the celestial reference frame. However, their fuzzy, faint optical images made it quite difficult, and astrometry continued to use bright stars despite the complications of significant random and systematic motions. Fortunately observations in the radio frequencies in the 1960s revealed a class of objects that has proven to be suitable for astrometry of the highest order, albeit with some limitations. These are quasars, compact radio sources which are pointlike in the optical band but with large red shifts implying cosmological distances.

3. Use of the VLBI Technique

The technique for measuring the positions of quasars and similar objects is VLBI (very long baseline interferometry). In this application, VLBI is a geometric technique that measures directions in space with great accuracy. Schematically, using a pair of distant antennas, the difference in the time of arrival at the two stations of signals emitted by a radio source is measured with a precision of a few picoseconds. For a typical baseline of 5000 km, this corresponds to a fraction of a milliarcsecond. This time difference (delay) and its first derivative (delay rate) are reconstructed by offline correlation of the signals (actually radio noise usually buried in the thermal noise of the electronics) recorded at the two ends of the baseline. A key piece of equipment at the stations is the clock used to time events. VLBI makes use of hydrogen masers with stability of a part in 10^{14} for both time and frequency, and the raw data are recorded digitally at rates up to 1 Gbit/sec.

In current practice a network of up to 20 stations observes 50–80 radio sources around the sky multiple times during a 24-hr session. Since a delay and a delay rate are generated from each pair of stations for each time a source is observed, there can be upwards of 20,000 delay/delay rate data points from one observing session. VLBI observations suitable for high precision astrometry began in the late 1970s with the development of dual-frequency receivers and the Mark III VLBI data acquisition system, and an active worldwide observing program continues.

4. Analysis

The analysis of VLBI data for astrometric and geodetic purposes requires the estimation of source positions, station positions, nutation corrections, and parameters characterizing the behavior of the clock and atmosphere at each station as well as careful modeling of all geophysical and astronomical effects. Each separate session provides the relative positions of the observed sources with some uncertainty. On different days different sets of sources are observed. It is the overlap of some common sources from one day to another that connects all the positions together.

From all the overlaps and directly measured positions come the complete set of relative positions. Repeated measurements, either directly in one day or indirectly from different days, improve the precision of the inferred positions. Having varied combinations of baselines and sets of observed sources strengthens the overall geometry and weakens the correlations between the source coordinates and the numerous phenomena modeled in the analysis. In particular, a mixture of north-south and east-west baselines is needed to determine both components of source position.

Since VLBI measurements give relative positions, the orientation of the ensemble of positions, i.e., the pole and right ascension origin, must be determined from external information. This is a necessary step in assigning the numerical position values that define the reference frame. In practice the intermediate results are manipulated as the usual right ascension and declination values, but the fundamental VLBI measurements are of the arclengths between sources, the precision of which is contained in the full covariance matrix of the set of source positions. The earliest VLBI positions in 1971 were no better than a few arcseconds, but by the mid 1980's a few milliarcseconds had been achieved.

Unlike stellar astrometry, which must rely on a conventional theory of precession and nutation to transform true of date coordinates to mean coordinates of the standard epoch, VLBI astrometry is sensitive to the errors in the standard precession/nutation model, which amount to several milliarcseconds. To achieve the full accuracy inherent in the stability of extragalactic positions, it is necessary to allow for corrections to the precession/nutation theory. This can be accomplished in two ways, either by adjusting the precession constant and various nutation coefficients or by estimating the offset between the actual pole and the modeled pole for each day of observation.

5. Genesis of the ICRF

The process of laying the conceptual foundation for the extragalactic reference frame, identifying its fiducial objects, and developing the fundamental catalog was begun at the XXth IAU General Assembly in Baltimore in 1988 by a resolution stating “The International Astronomical Union should adopt a celestial reference frame based upon a consistent set of coordinates for a sufficient number of extragalactic objects when the required observational data have been successfully obtained and appropriately analyzed. ... This reference frame is likely to be based, initially

at least, exclusively upon radio astrometry.”

The Working Group on Reference Systems headed by J. Hughes was established with subgroups for time (B. Guinot), coordinate frames and origins (J. Kovalevsky), astronomical constants (T. Fukushima), and the theory of nutation (D. McCarthy). The fundamental concepts of what is now the ICRF (International Celestial Reference Frame) were developed by the subgroups and extensively discussed at the IAU Colloquium 127 on Reference Systems held in Virginia Beach in 1990.

The General Theory of Relativity for space and time, the use of extragalactic radio objects, and the continuity between the existing stellar and the anticipated extragalactic celestial reference frames were summarized in nine recommendations adopted as a resolution by the XXIst IAU General Assembly in Buenos Aires in 1991.

A working group under C. de Vegt was formed to select the radio sources to be used with emphasis on the need to connect the radio and optical frames.

The XXIInd IAU General Assembly in Den Haag in 1994 adopted the list of some 600 sources and established a new working group under L. Morrison to define the positions. This work was done by a subgroup of VLBI and celestial reference system specialists. The resulting ICRF catalog was adopted by the XXXIIIrd IAU General Assembly in Kyoto in 1997 and came into effect on 1 January 1998, replacing the FK5.

A Working Group for the International Celestial Reference System (ICRS) under F. Mignard was formed to carry on the ICRF work, to extend the frame to other objects and frequencies, and to elucidate the consequences of the ICRF.

6. Definition of the ICRF

According to the new adopted rules, the fundamental directions of the celestial reference system will remain fixed in space; they will no longer be dependent on modeling the motion of solar system objects. The fiducial objects will be monitored. The adopted positions may be revised when improved information is available, but the coordinate axes will be maintained by implementing the statistical condition that the coordinates of selected defining sources show no global rotation from the old set of coordinates to the new realization.

The data used to determine the ICRF radio source positions included 1.6 million pairs of dual-frequency delays and rates from 1979 through the middle of 1995. The data were contributed from several geodetic and astrometric observing programs, the vast majority of the observations coming from the former but most of the sources coming from the latter. The design of the analysis was intended to provide (1995) state of the art source positions, in particular to free the results from contamination from precession/nutation errors, anomalous source behavior, geodetic noise, and systematic atmospheric effects. Simultaneous dual-frequency observations provided the calibration of ionospheric dispersion. Celestial pole offsets in obliquity and longitude were estimated for each day. Positions of sources with excessive scatter or apparent motion (as determined from test solutions) were estimated separately for each day as were station positions. An elevation limit of 6 degrees was adopted to balance the need for maximum observing geometry against the difficulty in correctly modeling the atmosphere at low elevations. Atmospheric gradients were estimated to remove a significant systematic effect. Both delays and rates were used to maximize the information available and to decrease correlations.

Because of the large number and high quality of observations, the formal errors for the positions

were exceedingly small and not a meaningful measure of uncertainty. It was necessary to consider several other effects to assign realistic errors. One was the statistical validity of the formal errors. Another was the cumulative influence of all modeling errors and editing decisions. Yet another was the magnitude of specific, identifiable errors that could have distorted the results. A consideration of all known error sources indicated that a realistic error estimate could be made by inflating the formal errors by a factor of 1.5 followed by a root-sum-square increase of 0.25 milliarcsecond. For the most frequently observed sources the 0.25 milliarcsecond was the dominant error.

The sources from the ICRF solution were divided after the fact into three categories:

- 212 defining sources that met a series of quality criteria;
- 294 candidate sources that failed one or more of the quality criteria, e.g., too few observations or observing interval too short;
- and 102 “other” sources (whose positions were estimated each day).

While the distribution over the sky of the ICRF as a whole is quite uniform (see Figure 1), the defining sources are sparser in the southern hemisphere because of a dearth of VLBI stations and limited observing programs. The “other” sources include a number with relatively bright optical counterparts that could be used to connect the radio and stellar frames.

The axes of the frame were aligned to the International Earth Rotation Service (IERS) realization of the ICRS with an error of 0.020 milliarcsecond. The Hipparcos catalog, which is the optical realization of the celestial reference frame, was aligned to the ICRF, largely through VLBI observations of radio stars. The ICRF also provides the framework for various space geodetic techniques to measure the terrestrial positions and velocities that constitute the terrestrial reference frame and to monitor variations in the rotation of the Earth.

The two chief phenomena leading to random and systematic errors in the ICRF are the atmosphere and source structure. While the propagation delay at zenith from the dry atmosphere can be accurately calibrated from local meteorological data, the dry delay in the line of sight to the observed source is subject to modeling error. The delay from water vapor cannot be calibrated accurately, and both delays are subject to random temporal and spatial fluctuations that must be estimated from the VLBI or other microwave data.

7. Source Structure

The quasars are not point radiators. Source structure can cause the position to appear slightly different depending on baseline geometry, and changes in source structure can cause apparent movement. Detailed source maps show that intrinsic variations in structure can be quite extreme, ranging from relatively compact naked-core objects, to compact double sources, to complex core-jet objects. The situation is complicated by the fact that compact extragalactic radio sources are known to have variable intensity and to have frequency- and time-dependent intrinsic structure. Consequently, unknown and unmodeled source structure effects may be introduced into the reference frame. The sources can be characterized after mapping by the degree to which the delay and

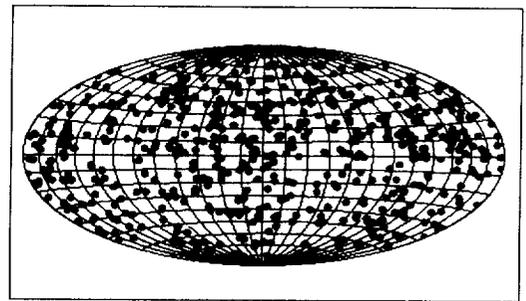


Figure 1. Distribution of ICRF sources.

delay rate are affected by the structure over the full range of possible baseline geometries, and the worst sources can be rejected for most astrometric purposes.

8. Future Work

As of the beginning of 1999, 800 000 more observations including 50 new sources had been acquired by geodetic and astrometric programs since the ICRF was constructed in 1995. These need to be integrated with the data and analysis used for the ICRF to update the original catalog. The original ICRF analysis need not be copied exactly to incorporate new data, but the new positions must be consistent with the ICRF at its stated level of accuracy, 0.25 milliarcsecond in overall source positions and 0.020 milliarcsecond in orientation.

Positions will be determined for new sources, and updated positions and errors will be found for candidate sources with additional observations. The positions and uncertainties of the defining sources will not be changed since they are the actual realization of the ICRF, and the work to include more recent data does not lead directly to the replacement of the existing ICRF. The defining sources will be used in a no-net-rotation condition relative to the ICRF to assure that positions from new analyses are aligned with the ICRF.

There are several features that distinguish the ICRF from conventional stellar catalogs that formerly defined the celestial reference frame.

1. First, the quasars are optically faint so connection to the stellar frame is complicated.
2. Second, while the positional history of the radio sources is known, the results of future observations cannot be predicted. Consequently, new sources must be observed to replenish and expand the list of candidates.
3. Third, as new observations accumulate, it should be possible to move candidate sources up or down the scale of usefulness in subsequent ICRF realizations.

The problem of position changes related to source structure variation may be solved in the future if the application of source structure information permits the identification and use of truly kinematically static points in the sky. Since the original VLBI delay and delay rates are accessible, they can always be reused in improved analysis. When models and estimation techniques are significantly improved and sufficient data are accumulated, a new ICRF can be constructed *de novo*.

A detailed reference about the ICRF may be found in Ma C, Arias E F, Eubanks T M, Fey A L, Gontier A-M, Jacobs C S, Sovers O J, Archinal B A, Charlot P 1998 The International Celestial Reference Frame Realized by Very Long Baseline Interferometry *Astron. J.* 116 516-546.

COORDINATION

From the Terms of Reference:

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 other IVS components. The Coordinating Center works closely with the Technology Coordinator, the Network Coordinator, and the Analysis Coordinator to coordinate all IVS activities.

Technology Coordinator

The Technology Coordinator is responsible for coordinating the new technology activities of IVS and for stimulating advancement of the VLBI technique.

Network Coordinator

The Network Coordinator is responsible for stimulating the maintenance of a high quality level in the station operation and data delivery.

Analysis Coordinator

The Analysis Coordinator is responsible for coordinating the analysis activities of IVS and for stimulating VLBI product development and delivery.



IVS Coordinating Center Report

Nancy Vandenberg

Abstract

This report summarizes the activities of the IVS Coordinating Center since the establishment of IVS, and forecasts the activities planned for the coming year.

1. Coordinating Center Operation

The IVS Coordinating Center 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 main mission of the Coordinating Center is to provide communications and information for the IVS community and the greater scientific community. The Coordinating Center coordinates 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. Initial Activities

During the few months before and after the official inauguration of IVS, the Coordinating Center supported the following IVS activities:

- Feb. 11 Arranged the first IVS Directing Board meeting at Wettzell, Germany. Notes from this meeting were published on the IVS web site.
- Mar. 1 Set up the IVS web site at <http://ivscc.gsfc.nasa.gov>. The web site is the primary means of providing communication and information services to the IVS community.
- Mar. 5 Set up a mail system for IVS. All mail is archived and can be read on the web site. The address ivsmail@ivscc.gsfc.nasa.gov is used for messages of general interest to the whole community.
- Mar. 8 Announced a contest for the IVS logo, and posted the logos for viewing on the web site.
- Mar. 29 Initiated mirror sites for the IVS web site at Communications Research Laboratory in Japan and Bundesamt für Kartographie und Geodäsie in Germany. The mirrors enable quicker connections for colleagues around the world.
- Apr. 8 Hosted a meeting of the IVS Chair and Coordinators. Notes from this meeting were published on the IVS web site.
- June Coordinated the receipt of contributions to the first IVS Annual Report.
- July 19 Arranged the second IVS Directing Board meeting at Birmingham, England.
- July Published the first IVS Annual Report (this volume), covering the period of the year prior to the establishment of IVS.

3. Staff

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

Name	Title	Responsibilities	Allocation
Nancy Vandenberg	Director	Web and data base design and content, Directing Board support, meeting support program, publications	50%
Cynthia Thomas	Operation Manager	Master schedule, resource management, session web pages, meetings support, special sessions support	50%
Frank Gomez	Web Manager	Web server administration, mail system maintenance, discussion system maintenance, data center support, session processing scripts, mirror site liaison	50%
Merri Sue Carter	Web Support Programmer	Web site maintenance, configuration files maintenance	10%
Karen Baver	Publication Support Programmer	Publication processing programs	10%
<i>new hire</i>	Data Technician/Programmer	Data base maintenance and programming, site catalog inputs, report production, product delivery support	100%

4. Plans

During the period until March 1, 2000, the Coordinating Center plans to do the following:

- Work with the Canadians who will manage a web site for IVS analysis functions.
- Enhance the web site with links to IVS-coordinated observing sessions.
- Establish electronic discussion groups on topics of interest to the IVS community.
- Update the site catalog maintained by GSFC.
- Establish web access to the IVS data base of information.
- Set up configuration files for all IVS components.
- Coordinate the first IVS General Meeting, to be held in Kötztig, Germany, February 21-25, 2000.
- Publish the proceedings of the first IVS General Meeting.

Analysis Coordinator Report

Marshall Eubanks, Chopo Ma, Nancy Vandenberg

Abstract

This report describes the activities of the IVS Acting Analysis Coordinator team. Activities planned for the coming year are forecast.

1. Initial Activities

The National Earth Orientation Service (NEOS) was appointed as Acting Analysis Coordinator at the first IVS Directing Board meeting because there had been no proposal received for this position. NEOS is a joint activity of the U.S. Naval Observatory and NASA's Goddard Space Flight Center for VLBI.

The authors of this report form a team that has been performing the work of Analysis Coordinator. We plan to turn over a smoothly running system when the new Analysis Coordinator is selected.

Our first activity was to write a solicitation for IVS data products and analysis products. The solicitation was announced on March 10 and proposals were received by April 15. The purpose of the solicitation was to obtain the commitment of IVS components for providing data and analysis products on an continuing, operational basis.

Next we developed a draft data and products plan that laid out a proposed disk structure and procedures. Comments were received about the plan from various members of the IVS analysis community and changes in the data structure and the procedures were made based on the suggestions received.

We worked with the primary IVS Data Centers OPAR (Paris), CDDIS (GSFC), and BKG (Leipzig) to develop a script that verifies data and analysis submissions and then moves the files into the IVS data structure. A plan was coordinated for these Data Centers to mirror each other's holdings so that all IVS data and product files will be accessible at all three Data Centers. We coordinated with the IVS Operation Centers to begin submitting data to the Data Centers operationally. The Team is monitoring the flow of data and products to ensure that this new service functions smoothly.

2. Plans

For the immediate future, we recognize that the most work needs to be done in establishing communications between IVS Analysis Centers. We will set up an electronic discussion group to discuss work in progress such as troposphere modeling, styles of parameterization, and so on.

Coordination with the other services is a very important activity. We will make contact with the IGS and ILRS Analysis Coordinators and identify topics of mutual interest such as colocation difficulties, definition of the TRF, and problems specific to each technique. We will work with the IGS and ILRS Analysis Coordinators and with the members of the IVS teams who proposed to be active in these topics. We will also work with the new IERS Analysis Coordinator.

There have been informal proposals for a new data exchange and archiving format. We plan to initiate discussions on this topic and develop a formal proposal.

We are receiving analysis products at the IVS Data Centers and several IVS Analysis Centers have begun the work of combining the individual contributions into a single product. We encourage this activity and we are monitoring the process. A consensus still needs to be reached about what constitutes the official IVS products.

We plan to hold an analysis workshop to establish coordination among the many analysis activities of IVS. The workshop will be an opportunity to exchange ideas and expertise on various aspects of analysis techniques and results.

Network Coordinator Report

Ed Himwich

Abstract

The Network Coordinator (NC) is responsible for assuring high quality data are produced by the Network Stations (NS). This report identifies the Network Coordinator and discusses some of the history of efforts to assure high quality data and some of the new initiatives that will be put into place. The NC also acts as liaison to the observational astronomical VLBI community and as an advocate for the IVS NS with the IVS organization.

1. Network Coordinator

The initial IVS Network Coordinator (NC) is Ed Himwich. He has over 17 years experience in many aspects of geodetic VLBI including: operations, control software development, experiment and logistical coordination, data analysis software development, data analysis, management, and scientific research.

Himwich works at NASA Goddard Space Flight Center. At this location he is able to work closely with the Core Operations Center, GSFC Analysis Center, GSFC Technology Development Center, and the IVS Coordinating Center. Being located at GSFC also provides access to a variety of work stations, personal computers, and peripherals. In addition, an absolutely mandatory high speed connection to the Internet is available.

2. Status of Network Coordination

There was no such position as Network Coordinator prior to March 1, 1999. However, several people, Ed Himwich among them, were carrying on many of the functions on an informal basis. They monitored the status of the experiments, correlation, and data analysis for problems. They contacted station personnel to help them resolve problems or refer them to the individuals who could help them. They visited stations to provide training, install upgrades, suggest improvements, as well as carry feedback back to the technology development centers. They worked closely with the European VLBI Network on Field System software and operations development. When necessary they would act as an advocate for stations when requirements were being developed that seemed unreasonable or problems were not getting the resources needed for their resolution.

3. Outlook

This year will be the first one of activity for the Network Coordinator (NC) as such. It is expected that most of the work existing will continue. However, now it will be a formally recognized activity. In addition there will be new initiatives that are carried out under the IVS banner.

The new initiatives will include development of performance standards, monitoring operations, Web plots, and station visits. In order to help each station achieve high quality in their data, we plan to develop performance standards for hardware, software, and operations. These will provide

a set of specifications that the stations can use to verify that their performance is nominal. If the performance is not nominal, the standards will provide a goal for improving performance.

The "ivs-ops" mail list, correlator reports, and analyst reports will be monitored for signs of problems. The NC will contact the network stations (NS) to help resolve these problems. The NC will attempt to help resolve the problem or will try to make sure the NS get in contact with people who can. This is not really a new initiative, but now is included as part of the responsibilities of the NC.

There will a Web based plotting system for display of ancillary data from the logs. In addition to providing an easily accessible historical archive, this should make it easier to isolate and identify problems.

The need for people from technology development centers to visit stations is clear. Not only does this provide an opportunity for additional training and hardware and software "tune-ups", but it provides an opportunity for more direct feedback to the technology development centers about problems that have been encountered. Unfortunately because of time and money constraints it is difficult to have all the stations visited as often as we would wish, at least once every three years. These visits are a resource to all the stations, not just the ones visited. In order to get as much advantage as possible from these visits, a Web page will be developed that will chronicle the visits. This should make it easier for other stations to benefit from new developments and insights that come out of the visits.

Coordination of station operations between geodesy and astronomy is especially important at stations that make both types of observations. A great deal of progress in this area has been made by standardizing the control software used and harmonizing the use of schedules. This work will continue. Several improvements are coming in the FS that will further unify operations and benefit both communities. In particular mode independent parity check procedures and automated Tsys measurements will benefit all users. The EVN continues to be one of the largest users of the FS. We expect the geodetic community's collaboration with them on FS development to continue.

The role of NC as an advocate for the NS is not intended to displace existing channels of communication. NS will still deal with the same people (including the NC) for schedule, operations, and maintenance issues. However, if a NS has a problem that is not being resolved or wishes to raise an issue at a higher level, the NC is an appropriate first contact for additional assistance. The NC is the one person within the IVS specifically charged with looking out for the stations' interests as a whole.

Another initiative that will be started is that each station will be asked to designate one person to be the "Friend of Geodesy". This is intended to be in the style of the EVN's "Friend of VLBI" for astronomy. The duties of this person will be explained more fully in the call for these designations, but basically this person would act as the primary contact at the station for issues dealing with geodetic VLBI.

Technology Coordinator Report

Alan Whitney

Abstract

The main initial effort of the Technology Coordinator has been participation in the development of a VLBI Standard Interface. Future plans include formation of technology study groups and compilation of an index of VLBI technology papers.

1. VLBI Standard Interface

The primary focus of efforts for the past few months has been the development of a "VLBI Standard Interface" (VSI) specification which will allow the transmission of data to and from heterogeneous VLBI Data Transmission Systems (DTS). The goal is to define the interface to be compatible with traditional recording/playback systems, network data transmission, and even direct-connect systems. In order to do this the design of the VSI must completely hide the detailed characteristics of the data-transport mechanism and deal only with the interfaces to the outside world.

The following assumptions are being made in the development of the VSI specification:

- The DTS is fundamentally a receiver and transmitter of *bit streams*.
- The *meaning* of individual bit streams is not specified; normally, a bit-stream will be a stream of sign or magnitude bits associated with particular samples, but the actual meaning is to be mutually agreed upon between the data-acquisition system and the correlator.
- The received and transmitted bit-stream clock rates may be different (e.g. the playback rate to the correlator may be speeded up or slowed down); however, all bit-stream clock rates on acquisition must be the same, and all bit-stream clock rates on transmit must be the same.
- The data-acquisition time tag of every bit in every bit stream must be fully recoverable with no ambiguity.

A committee consisting of representatives from technical development centers in North America, Europe, Japan and Australia is actively reviewing and expanding the draft proposal. The effort is being fully coordinated with the international astronomical VLBI community as well, with the goal of a unified standard interface for all VLBI activities worldwide. We hope that an agreed standard interface definition can be reached by the end of 1999.

2. Other Activities

Other planned and ongoing activities in the technology coordination area are:

1. Formation of a few small subgroups with interests in particular technology areas. The members of these subgroups will be drawn from IVS technology centers and other experts in the field. These sub-groups, interacting primarily via e-mail, will be asked to develop a list of concerns and goals and to suggest the steps needed to achieve them. The VLBI Standard Interface group serves as a prototype for this type of activity.

2. Compilation of an index of published papers and memos in all of the relevant VLBI technology areas. Ideally, this will be a Web-based index with links to electronic versions of the referenced material. The members of all IVS Technology Development Centers, as well as other experts in the field, will be invited to contribute. This activity is planned to be formally initiated in the latter half of 1999.
3. Promotion and encouragement of the inclusion of topical sessions on advanced VLBI technology at international meetings and workshops.

NETWORK STATIONS

From the Terms of Reference:

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.



Algonquin Radio Observatory

Mario Bérubé, Calvin Klatt

Abstract

This report gives an overview of the activities at the Algonquin Radio Observatory. It also summarizes the technical parameters and upgrades done to improve the antenna performance. Finally, the Algonquin VLBI team is introduced.

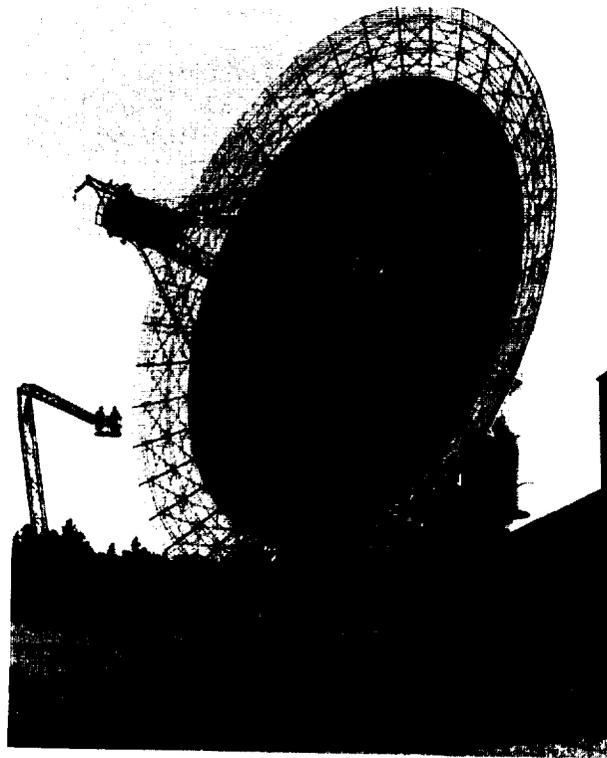


Figure 1. Algonquin Radio Observatory 46m Antenna

1. Overview

The Algonquin Radio Observatory (ARO) is situated in Algonquin provincial park, about 250 km north of Ottawa. The 46-m telescope was built and operated by the National Research Council (NRC) of Canada and began operations in May, 1966. At the current time the ARO is operated by the Geodetic Survey Division of Natural Resources Canada in partnership with the Space Geodynamics Laboratory, CRESTech.

The ARO 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 ($\sigma=20$ m). The antenna participated in the NASA CDP and DOSE programs beginning in 1984. A long term loan of a Mark III terminal from NASA in 1989 makes it possible to participate regularly in VLBI observations in support of the maintenance of the celestial and terrestrial reference frames in the CORE and NEOS series. The GSD also maintains a permanent GPS monitoring station at Algonquin which is used by all IGS Analysis Centers as a fiducial reference. Satellite laser ranging and absolute gravity observations are also available for the site which is located on the stable pre-cambrian Canadian Shield. Local site stability has been monitored regularly using a high-precision network.

The Algonquin Radio Observatory Act protects the site from radio interference. This protection extends to a few hundred kilometers, making Algonquin a very quiet site.

2. General Specifications

- Latitude : N 45 57 19.812
- Longitude : E 281 55 37.055
- Elevation : 260.42 m
- Reflector : 46 m diameter with first 36.6 m made of 0.634 cm steel plates surrounded by 4.6 m of steel mesh.
- Foci : S and X band at prime focus. Gregorian capability with 3 m elliptical subreflector.
- Focal length : 18.3 m (prime focus)
- Focal ratio : $f/D = 0.4$ for full surface and 0.5 for solid surface.
- Surface accuracy : 0.32 cm for solid portion and 0.64 for mesh.
- Beamwidth : 3.0 arcmin at 3 cm wavelength (10 Ghz)
- Azimuth speed : 24 degrees per minutes.
- Elevation speed : 10 degrees per minutes.
- Receiver : S and X cryogenic receiver.
- VLBI equipment : Mark III with thick tape drive. : S2 data acquisition and recording terminal.
- PCFS version : 9.3.7
- Time standard : NR Maser
- GPS receiver : Rogue

3. Antenna Improvements

In order to improve the operational performance of Algonquin, GSD undertook a major upgrade of the antenna control system which was completed in 1997. For high precision tracking of radio sources the original control system used a Master Equatorial (ME) system to control the 46-m antenna. In recent years this system became unreliable and had to be replaced. In the new system

the azimuth and elevation drives are directly controlled by computer. This greatly simplifies the control system and has produced a major improvement in the reliability of the Algonquin antenna.

This antenna control system still uses the original azimuth and elevation encoders to determine antenna position. In the next year, we are planning to upgrade them in a way that should not affect scheduled operations.

4. Antenna Survey

The antenna is surrounded by a high stability network made of 13 concrete piers. This network has been precisely measured four times to obtain the geodetic tie between the VLBI, the GPS and the SLR reference points with a precision of few mm. The VLBI antenna itself requires a special indirect survey since the reference point cannot be accessed directly.



Figure 2. Algonquin Antenna with co-located GPS Antenna

This year we are planning to re-measure the network. In addition to tying GPS and SLR to VLBI, we will be doing a special survey to determine the antenna deformation as a function of elevation angle.

5. Algonquin VLBI team

The Algonquin VLBI team has a very diversified background with many years of experience in VLBI. The team is based in Ottawa, 250 km from the Algonquin antenna. Using satellite communication, the team can monitor the Algonquin site from its office in Ottawa. For a VLBI experiment, three members of the team drive to the site a day in advance to check the antenna and the VLBI equipment. At the same time they perform general maintenance of the site. All members are experienced VLBI operators.

- Mario Bérubé : (50%) station programming, geodetic data analysis
- Sylvain Brazeau : (90%) electronics, cryogenic, RF, VLBI equipment
- Mike Daniels : (75%) data quality, masers, VLBI equipment, gravity
- Stephen Farley : (90%) VLBI logistics, site operations, Linux
- Calvin Klatt : (10%) VLBI data analysis, scheduling
- Jacques Lafrance : (50%) high precision survey, transportable antenna

Contractor

- Normand Servant : Site maintenance and VLBI operations

Consultants

- Doug Sparkes : Electronics engineer for antenna control system
- Don Buchan : Mechanical engineer for antenna

6. Operations 1998-1999

Algonquin Radio Observatory is involved in several international VLBI networks. We summarize below the activities in the past year.

- CORE-A 26
- NEOS 15
- CORE-B 6
- MARS 5
- CGLBI 5
- NAPS 2

Progress at ROEN - Fortaleza Geodetic Station

Pierre Kaufmann, A. Macilio Pereira de Lucena, Claudio E. Tateyama

Abstract

This report presents the works developed at ROEN: Rádio-Observatório Espacial do Nordeste, Eusébio near Fortaleza, CE, Brazil, in 1998. Activities were related to observing sessions, major maintenance items, and scientific results obtained.

1. ROEN General Information

The North-East Spatial Radio Observatory, ROEN, located at INPE facilities in Eusébio, nearly 30 km east from 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 coordinated by CRAAE, the Center for Radio Astronomy and Space Applications, which is a consortium between Brazilian institutions Mackenzie, INPE, USP and UNICAMP. Construction and activities at ROEN were sponsored at the beginning by U.S. agency NOAA and Brazilian Ministry of Science and Technology's FINEP agency. Presently the operational staff and part of infra-structure is maintained by INPE and by Mackenzie, the other costs of technical maintenance, part of infra-structure, are sponsored by US agencies NASA, USNO and NOAA.

2. Technical Parameters 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 8.27. Observations are recorded with a Mark III data acquisition system. One Sigma-Tau hydrogen maser clock standard is operated at ROEN. One dual frequency GPS Rogue receiver is operated continuously. The collected data are provided to the IGS center, as well to Brazilian IBGE center. ROEN has all basic infrastructure for mechanical, electrical and electronic maintenance of the facilities.

3. CRAAE and ROEN Staff Dedicated to Space Geodesy

The Brazilian space geodesy program, conducted by CRAAE, is coordinated by Prof. Pierre Kaufmann, from the São Paulo main office, receiving scientific assistance from Dr. Claudio E. Tateyama, and partial administrative support from Valdomiro S. Pereira and Neide Gea. Partial technical assistance might be given by Itapetinga Radio Observatory staff, near São Paulo.

The ROEN station facilities and geodetic VLBI and GPS operations are managed by Eng. A. M. P. de Lucena (CRAAE/INPE), assisted by Eng. Adeildo Sombra da Silva (CRAAE/Mackenzie), and technicians Avicena Filho (CRAAE/INPE) and Clairvânia Maria Anastácio da Silva (CRAAE/Mackenzie). Partial administrative assistance is given by Onivaldo Assunção de Freitas (CRAAE/INPE).

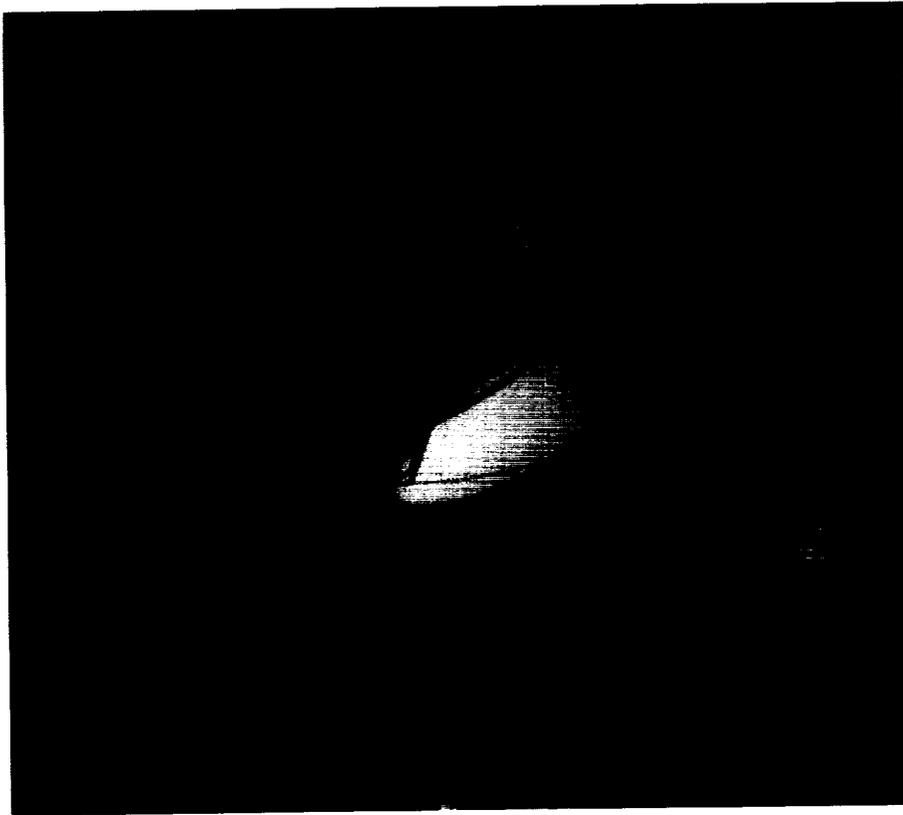


Figure 1. The 14.2-m antenna located in Eusébio near Fortaleza

4. Status for 1998/1999

- Geodetic VLBI observations. ROEN has participated in 91 VLBI observational runs until March 1999 on experiments NEOS-A (52), IRIS-S (12), CORE-B (11), CRF (3) and CORE-OHIG (3).
- Development and major maintenance. (1) Antenna positioner: replacement and repair of large elevation gear box, mechanical alignment of elevation axis, electrical alignment including controller card, high power amplifier, DC motors and tachometers for both axes, new pointing model was implemented. (2) Repairing jobs on four Mark III video converters, current monitoring of power conversion station, controller of power motor-generator group, 14 bit tracking converter card of shaft encoder, display controller of the UPS, and spectrum analyser unit. (3) Installed internet connection, with server, router, 64 kbs radio link via INPE at Natal. (4) New thermal dissipation system done, in order to prevent corrosion in the inductosyns.
- Scientific papers using ROEN:
 1. Tateyama, C.E., Kingham, K.A., Kaufmann, P., Piner, B.G., de Lucena, A.M.P., Botti, L.C.L., "Observations of BL Lacertae from the Geodetic VLBI Archive of the Washington Correlator", ApJ 500, 810, 1998.

2. Tateyama, C.E., Kingham, K.A., Kaufmann, P., Piner, B.G., Botti, L.C.L., de Lucena, A.M.P., "Observations of OJ287 from the Geodetic-VLBI Archive of the Washington Correlator", ApJ 520, scheduled for August 1, 1999.
3. Almeida, A.A., Vilas-Boas, J.E.S., Lucena, A.M.P., Huebner, W.F., "On an Upper Limit to the Continuum Microwave Radiation from Comet C/Hale-Bopp(1995 O1)", Icarus, submitted, 1999.

5. Plans for 1999/2000

Plans are for keeping ROEN regular operations along the following year, with a number of essential improvements needed. Prospects for obtaining funds to upgrade data acquisition system to Mark IV are expected to improve.

Gilmore Creek Geophysical Observatory

Rich Strand

Abstract

The following report provides a general technical description and operational overview of the Gilmore Creek Geophysical Observatory located near 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. The GCGO telescope can be seen in Figure 1 as the last antenna on the right in the valley. GCGO was instrumented by NASA's Crustal Dynamics Project in the mid 1980s for the Alaskan mobile VLBI campaign and used as the base station for those geodetic measurements [1]. The GCGO is part of the NASA Space Geodesy program in cooperation with the U.S. Naval Observatory.



Figure 1. NOAA/NASA Data Acquisition and Geophysical Observatory. Fairbanks, Alaska

Table 1. Address of GCGO near Fairbanks.

Gilmore Creek Geophysical Observatory NOAA/NESDIS FCDAS 1300 Eisele Road Fairbanks, AK 99712 http://www.fcdas.noaa.gov
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2. Technical Parameters of GCGO

The 26 meter telescope is hydraulic operated and controlled by a Modcomp computer system (see Table 2). The DAT rack is a VLBA terminal and recorder (thin tape). The X/S band

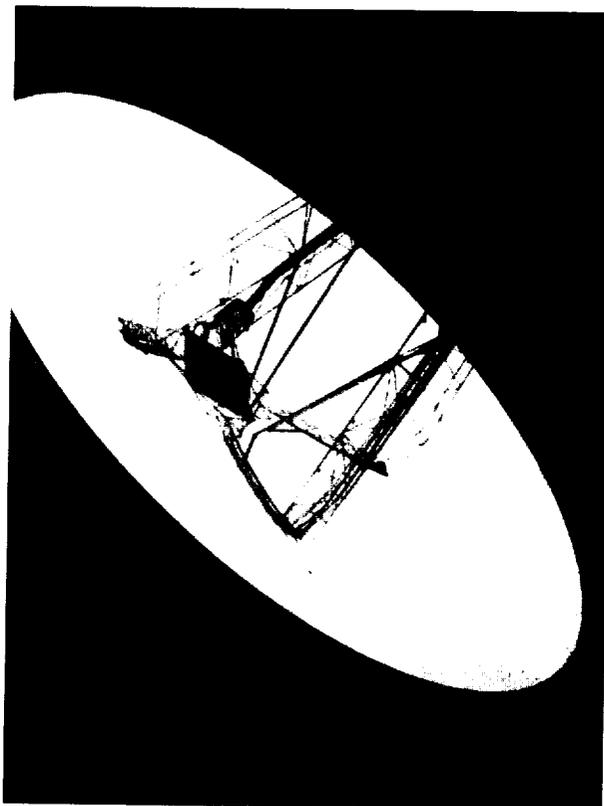


Figure 2. GCGO 26-meter radio telescope, Fairbanks, Alaska. Monument number 4047. X-East Y-North. Latitude N 64° 58' 43.81288" and Longitude E 147° 29' 42.18552" Height 306.418 meters

microwave receiver has a cryogenic low noise front end. VLBI Field System version 9.3.25 is used with a PC. Hydrogen Maser NR5 is the time standard with a HP Cesium for the telescope computer. A TAC receiver is used with a HP 5334 counter for GPS offset measurements. The station also runs NASA/JPL Rogue receiver 8100 running software v. 3.2.32.8. UCLA maintains the HIPAS system located in the GCGO and currently is operating an ionosonde. The Institut Geographique National in France operates the DORIS beacon that is located near the NOAA transmitter area.

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

GCGO is a major NOAA data collection facility and does not have a science staff. The NOAA Manager is Jim Budd. The site is operated by the Lockheed Technology Services Group with Doug Ooms as Lockheed Project Manager and Mike Simmons as Lockheed Operational Manager.

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

R. Strand and S. Caskey are assigned to GCGO technical staff with T. Knuutila, Z. Padilla, H. Grotsema, and D. Eubanks assisting. The telescope hydraulic system is maintained by M. Meindl, A. Sanders and W. Powell.

4. Status of Gilmore Creek Geophysical Observatory

Gilmore Creek continues to observe in the CORE, NEOS, and RDV experiments. Yasuhiro Koyama arrived on site Jan/Mar to install the K4 DFC2100 for K4TIE observing. GCGO was used for Mars Pathfinder and USNO intensive as well as fringe sessions for equipment verification checks for other stations. The NASA/JPL Rogue receiver was replaced in June. It is now running Y2K compliant software. The Doris beacon was reprogrammed by station staff to continue support of precision satellite-based orbit determination. The VLBI receiver was pulled from the telescope several times this year for dewar repair. D. Rhine, Allied-Signal, arrived on site in September for maser preventive maintenance. PRARE satellite tracking instrument failed in June and has been shipped to Germany for repair. Field system software development continues by Ed Himwich, NVI, using the station's DAT racks for testing. The majority of Gilmore Creek's data loss has been due to telescope hydraulic failures.

Table 3. VLBI observing at Gilmore Creek between 03/01/98 and 03/01/99.

Experiments assigned to GCGO - 101
Observations scheduled - 27757
Observations recorded - 27078
Efficiency - 97.55%

5. Outlook

Increased observing in CORE program is scheduled. RFI studies are being completed due to full time operation of a gold mine near the station. Plans are being made to move this observatory to the NOAA operations building and installing a new 20 meter electric drive telescope.

References

- [1] C.Ma, J.Sauber, L.Bell, T.Clark, D.Gordon, W.Himwich, and J.Ryan Measurement of Horizontal Motion in Alaska Using VLBI 1990, In: Journal of Geophysical Research, vol 95, No.B13, Pg 21991-22011, December 10,1990

Goddard Geophysical and Astronomical Observatory

Rawland Covey, Charles Kodak

Abstract

This report summarizes the technical parameters and the technical staff of the VLBI system at GGAO. It also gives an overview of VLBI activities during the previous year. The outlook lists the tasks planned for 1999.

1. GGAO at Goddard

The Goddard Geophysical and Astronomical Observatory consists of a radio telescope for VLBI, several SLR sites including a 48" telescope for developmental Satellite Ranging, a GPS timing and development lab, meteorological sensors and a H-maser clock. In addition, we are a fiducial IGS site with several IGS receivers.

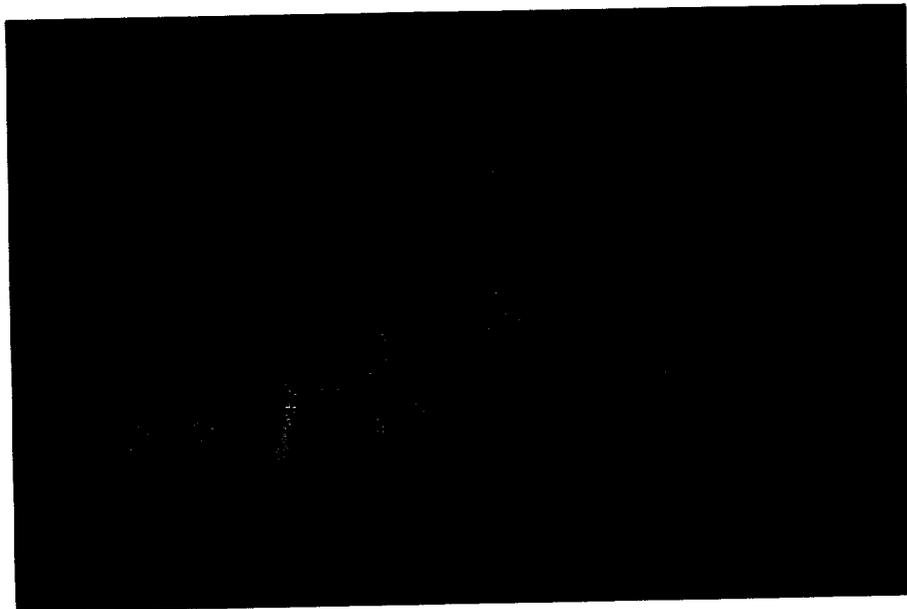


Figure 1. MV-3 VLBI antenna at GGAO.

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.

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. The design criteria were

Table 1. Location and addresses of GGAO at Goddard.

Longitude	76.8265° W
Latitude	39.0219° N
MV3 Code 299.0 Goddard Space Flight Center, (GSFC) Greenbelt, Maryland 20771	
http://www.gsfc.nasa.gov	

- 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).

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 ²
elevation range	0...90°
elevation velocity	3°/s
elevation acceleration	1°/s ²
X-band	8.18 – 8.98 GHz
<i>receiving feed</i>	<i>Cassegrain focus</i>
T_{sys}	24 K
<i>Bandwidth</i>	800 MHz, -2dB
G/T	32.1 dB/K
S-band	2.21 – 2.45 GHz
<i>receiving feed</i>	<i>primary focus</i>
T_{sys}	19 K
<i>Bandwidth</i>	240 MHz, -2dB
G/T	21.2 dB/K
VLBI terminal type	Mark IV
recording media	thin-tape only
Field System version	9.3.25

3. Technical Staff at GGAO

The GGAO VLBI facility gains from the experiences of the Goddard VLBI group. GGAO is a NASA R&D and facility, operated under contract by AlliedSignal Technical Services Corporation (ATSC).

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	Company
Rawland Covey	engineering technician	100%	ATSC
Jay Redmond	engineering technician	20%	ATSC

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 the table 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, 1998 to March 1, 1999.

Date	Experiment
1998-02-09	RDV07
1998-04-15	RDV08
1998-06-24	RDV09
1998-08-10	RDV10
1998-09-01	NA279
1998-10-01	RDV11
1998-10-06	NA284
1999-02-02	NA301

5. Outlook

GGAO will continue to support both scheduled experiments and developmental activities. Our scheduled experiments have been shifted from the RDV's to the NEOS-A throughout 1999.

The plan for 1999 consists of:

1. Continuing testing of PC-FS version 9.3.25 based on Linux kernel 2.0.
2. Testing of the Mark IV decoder prototype.
3. Continuing with research on Mark IV development.
4. Continually striving to improve the performance of the entire receive system.

USNO Green Bank 20-Meter Telescope

Frank Ghigo

Abstract

NRAO-Green Bank has been operating a 20-meter telescope for the USNO Earth orientation program since 1995. This report summarizes the characteristics of the system and its activities from 1995 to the present. One may also find information in the NRAO-Green Bank web page: <http://www.gb.nrao.edu/fgdocs/20m/GB20m.html>

1. Introduction

The NRAO-Green Bank 20-meter telescope is operated by the National Radio Astronomy Observatory (NRAO) under contract with the U.S. Naval Observatory (USNO), in support of USNO and NASA Earth Orientation, geodetic, and astrometric VLBI programs.

The 20-meter was built by RSI and completed in late 1994. Regular operations began in October of 1995. The delay between completion and starting regular operations happened because its encoders were lent to KPGO for several months.

Table 1. Location of Green Bank 20-meter telescope.

Longitude	79° 49' 31.865" W
Latitude	38° 26' 12.661" N

2. Description of Equipment

Similar to the geodetic antennas at KPGO (Kauai, Hawaii), and Ny Ålesund (Spitzbergen), the 20-meter telescope features a fast slew speed of 2 degrees per second in both azimuth and altitude axes, surface accuracy of about 0.8 mm rms, and an F/D ratio of 0.43 at prime focus.

The prime focus receiver is an NRAO-built S- and X-band dual polarization system using cooled (15 K) HEMT amplifiers. The design is somewhat novel because the RF signals are transmitted to the control room on optical fibers where the LO system and mixers are located. A 500 MHz reference signal locked to a H-maser standard is sent to the receiver on an optical fiber to drive the phase cal unit. The 500 MHz is returned to the control room where a round-trip phase measurement is done.

Typical system temperatures are 45 K at X-band and 30 K at S-band, typical SEFDs are 700-800 Jy at X-band and 400-500 Jy at S-band.

The VLBI recording system consists of a VLBA DAR rack with 14 baseband converters (BBC) and VLBA formatter, and a VLBA-type tape recorder. All experiments for the last two years are recorded only on thin tape.

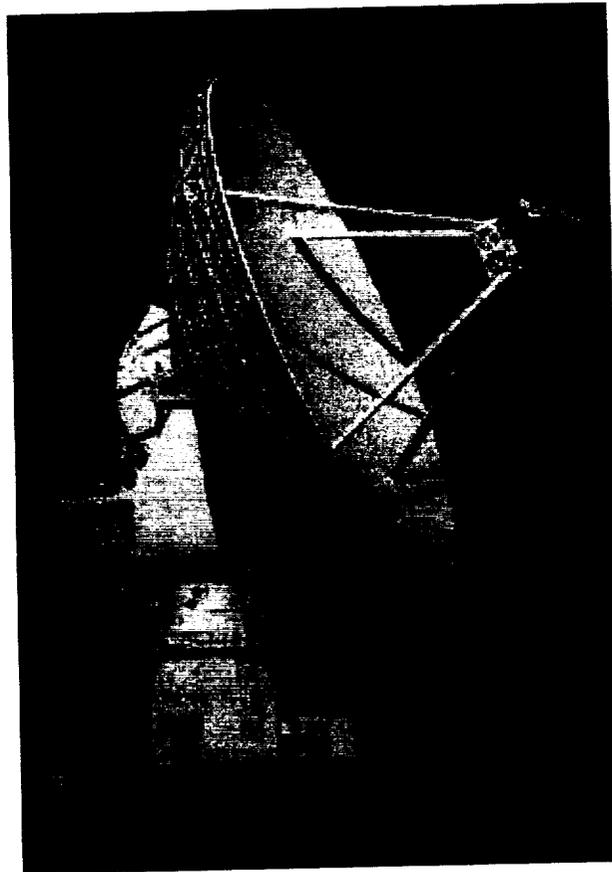


Figure 1. The USNO 20-Meter RSI telescope at Green Bank, WV

3. Technical Staff for the Green Bank 20-meter

The 20-meter project benefits from being located at a major radio astronomy observatory because all phases of maintenance, technical support, and repairs can for the most part be done by the local staff, who support all the telescopes at the site. Cryogenics technicians, telescope mechanics, electronics engineers and technicians, and programmers all contribute small portions of their time to maintenance and repairs of the 20-meter systems.

At the present time, the staff dedicated primarily to the 20-meter operations include two full-time telescope operators (K. Lehman and G. Monk), operations supervisor (M. Chestnut), electronic technician (W. Shank), and "friend of the telescope" (F. Ghigo).

4. Status of the Green Bank 20-meter

The 20-meter primarily supports the USNO weekly NEOS-A and daily INTensive experiments. In the past two years, it has also observed experiments including the VLBA (RDGEO, RDV, and RDWPS), and bi-monthly CORE-B experiments. In 1997-1998 it participated in observations of the Mars spacecraft.

The primary experiments (NEOSA and weekday Intensives) are run with full coverage by tele-

scope operators. The other experiments (CORE-B, RDV, etc) are generally run partly unmanned.

Table 2 summarizes the usage from October 1995 through May 1999; (GLOBAL, etc: includes Reference Frame, GBTies, GLOBALS, CRF, and GEOCAT.) Figure 2 shows total usage in graphical form.

Table 2. Hours scheduled October 1995 through May 1999

Experiments	1995	1996	1997	1998	1999	Total
NEOS-A	274	1237	1296	1304	520	4631
INTensive	37	400	616	659	243	1955
NAVEX	48	91	48	0	22	209
Fringe Tests	6	5	3	6	2	22
GLOBAL, etc.	24	232	22	70	0	348
RDV, RDGEO, RDWPS	0	163	138	133	23	457
CONT96	0	587	0	0	0	0
CORE-B	0	0	113	135	68	316
MARS	0	0	41	6	0	47
TOTALS	389	2715	2277	2313	878	8572
Percent Time Lost	10.1	4.7	2.0	5.4	3.5	

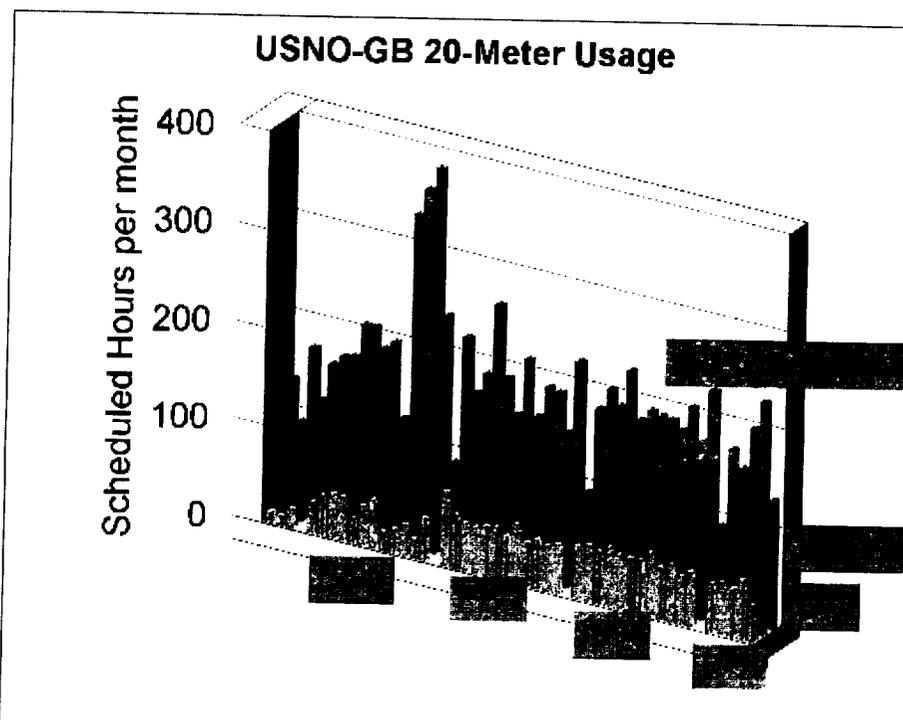


Figure 2. Usage of the 20-meter, 1995-present.

In October 1998, the 20-meter back end electronics and the operations area was moved into a new control building. The new building has shielded control and electronics rooms. The shielding

is primarily to protect the new 100-meter GBT from locally generated RFI. The ST H-maser time standard was also relocated to the new building, where it provides reference and time signals for all systems on the site as well as the 20-meter VLBI system.

Some major maintenance was done during May 1999: oil was changed in all gear boxes, and a leaky oil seal on one of the azimuth motors was replaced.

5. Future Plans

Both the Green Bank and Kokee systems will be upgraded to Mark IV operations early in 2000. New Mark IV formatters and decoders will be obtained, and the recorders will be modified for the faster data rates and for the addition of an extra head stack.

We also plan to install a Turbo Rogue GPS station at Green Bank later this year.

Hartebeesthoek Radio Astronomy Observatory

Ludwig Combrinck

Abstract

This report summarises the current technical parameters of the HartRAO VLBI station. It also gives an overview of our geodetic VLBI activities during the last year and briefly describes our involvement with other space geodesy techniques. Current and envisaged upgrading to the antenna which should improve the performance of HartRAO as a VLBI station are discussed.

1. Geodetic VLBI at HartRAO

HartRAO is located north of Johannesburg, South Africa, in a valley of the foothills of the Witwaters mountain range. 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.



Figure 1. The 26 metre radio telescope. The antenna is located in a valley which shields it from terrestrial RFI.

2. Technical Parameters of the VLBI Telescope of HartRAO

The feed horns used for 13 cm and 3.5 cm are single polarised conical feeds. Both S and X bands have right hand circular polarisation. The RF amplifiers are cryogenically cooled HEMTS. The radio telescope is being upgraded, and we have recently (November 1998) replaced the hydraulic drive with an electric drive. A project has been launched to upgrade the perforated surface panels of the telescope to higher tolerance solid panels.

Table 1. Location and addresses of HartRAO.

Latitude	25.889° S
Longitude	27.686° E
Hartebeesthoek Radio Astronomy Observatory Geodesy Programme PO BOX 443 Krugersdorp, 1740, SOUTH AFRICA	
http://www.hartrao.ac.za/geodesy/geodesy_index.html	

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

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

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	25.914m
focal length f	10.886m
f/d	0.424
surface contour of reflector	$\pm 2.0mm$
wavelength limit	2.5 cm
pointing resolution	0.001°
pointing repeatability	0.004°
X-band (standard $\nu = 8.580GHz$, $\lambda = 0.0349m$)	8.180 – 8.980 GHz
T_{sys}	65 K
S_{SEFD}	1500 Jy
Point source	17.1 Jy/K
3 dB beamwidth	0.092°
S-band (standard $\nu = 2.280GHz$, $\lambda = 0.1316$)	2.210 – 2.344GHz
T_{sys}	40 K
S_{SEFD}	1500 Jy
Point source	9.7 Jy/K
3 dB beamwidth	0.332°
VLBI terminal type	Mark IV
recording media	thin tape only
Field System version	9.3.25
attended VLBI observations	24h, mode C

3. Staff Members Involved in VLBI

The Geodesy Programme draws some manpower from other programs at the observatory, particularly for technical maintenance and operations assistance. The staff members listed have direct VLBI responsibilities, but other staff are sometimes involved in supporting and maintenance roles.

Table 3 lists the HartRAO station staff who are involved in geodetic VLBI.

Table 3. Staff supporting geodetic VLBI at HartRAO.

Name	Background	Dedication	Function	Programme
Ludwig Combrinck	Geodesy	30%	Project Leader	Geodesy
Jonathan Quick	Astronomy	5%	Hardware/Software	Astronomy
William Moralo	Technical	30%	Operator	Geodesy
Peter Stocker	Technical	10%	Day Shift Operator	Electronics
Ferdie Nel	Technical	5%	Night Shift Operator	Electronics

4. Status of the HartRAO Geodetic VLBI Component

During the period of this report (1998 - March 1, 1999) HartRAO participated in several VLBI experiments which are listed in Table 4. We have been participating in VLBI experiments on a regular basis since 1986. Currently about 15 percent of available telescope time is allocated for geodetic VLBI. We have a Mark IV terminal and thin tape recorder. An S2 terminal is used for astronomical VLBI and SYOWA experiments.

Table 4. Participation of HartRAO in Geodetic VLBI experiments for the period 1998 to March 1, 1999.

Date	Exp.	Date	Exp.	Date	Exp.	Date	Exp.
1998-01-13	CA027	1998-01-27	CA028	1998-01-29	IS122	1998-02-12	IS123
1998-02-24	CA030	1998-03-10	CA031	1998-03-23	IS124	1998-03-24	CA032
1998-04-07	CA033	1998-04-13	IS125	1998-04-21	CA034	1998-05-05	CA035
1998-05-11	IS126	1998-05-19	CA036	1998-06-02	CA037	1998-06-15	IS127
1998-06-16	CA038	1998-06-30	CA039	1998-07-13	IS128	1998-07-14	CA040
1998-07-28	CA041	1998-08-11	CA042	1998-08-24	IS129	1998-08-25	CA043
1998-09-08	CA044	1998-09-22	CA045	1998-09-28	IS130	1998-10-05	IS131
1998-10-06	CA046	1998-11-17	CA049	1998-12-01	CA050	1998-12-07	IS133
1998-12-15	CA051	1998-12-29	CA052	1999-01-12	CA053	1999-01-26	CA054
1999-01-28	IS134	1999-02-01	CRF06	1999-02-04	COHIG4	1999-02-08	IS135
1999-02-09	CA055	1999-02-11	COHIG5	1999-02-15	CRF07	1999-02-18	COHIG6
1999-02-23	CA056						

Table 5. Table of eccentricities, VLBI telescope to SLR and GPS (HRAO) reference points.

Reference	Coordinate	Δ	σ (mm)
SLR	X	41.680	15.8
SLR	Y	-66.564	7.5
SLR	Z	-8.131	3.9
HRAO	X	90.236	15.8
HRAO	Y	-132.190	7.5
HRAO	Z	-34.704	3.9

Table 6. Table of Geodetic reference points, ITRF96 Epoch 1997, VLBI, SLR and GPS (HRAO).

Reference	Coordinate	Cartesian (m)	σ (m)	Velocity (m)	σ (m)
VLBI	X	5085442.780	0.006	0.0007	0.0009
VLBI	Y	2668263.483	0.005	0.0192	0.00101
VLBI	Z	-2768697.034	0.005	0.0164	0.0007
GPS	X	5085352.500	0.009	0.0007	0.0009
GPS	Y	2668395.681	0.007	0.0192	0.00101
GPS	Z	-2768731.692	0.006	0.0164	0.0007
SLR	X	5085401.135	0.101	0.0007	0.0009
SLR	Y	2668330.108	0.063	0.0192	0.00101
SLR	Z	-2768688.865	0.071	0.0164	0.0007

5. Future Plans

We are continuing our footprint survey, which has as its main purpose the determination of eccentricities between the GPS, VLBI and SLR reference points as well as the maintenance of a control network to enable stability monitoring of the site on a local scale. The current eccentricities between VLBI and SLR (Table 5) were determined using GPS (Combrinck & Merry 1997) and the SLR to GPS eccentricity values are from 1998 footprint results. We are processing HRAO in a 14 station regional (IGS) network and envisage having a permanent SLR (MOBLAS 6) operational by January 2000. This will strengthen colocation and with accurate eccentricities should tie the independent ITRF (Table 6) coordinates to a high degree of accuracy.

HartRAO has several upgrades in progress which will affect VLBI and general radio telescope performance. The main projects for 1999 are:

1. Upgrade of radio telescope surface.
2. Automation of dichroic.
3. Upgrade of S and X band receivers to dual polarisation.

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Kashima 34-m Radio Telescope

Junichi Nakajima, Yasuhiro Koyama, Eiji Kawai

Abstract

Kashima 34-m radio telescope is a facility of the Kashima Space Research Center, Communications Research Laboratory. The telescope is mainly used for geodetic and astronomical VLBI observations. Brief reports of the current status and on-going projects are presented in this report.

1. Introduction

Communications Research Laboratory (CRL) constructed the Kashima 34-m telescope in 1988 [1]. Since the operation started, 11 years have passed. The telescope has been kept in a good condition and it has joined various VLBI observations continuously. The station is located in the Kashima Space Research Center of CRL which was founded in 1964 near the Pacific ocean. The 34-m telescope (Figure 1) is currently operated and improved by staff in the Radio Astronomy Applications Section. The structure of the telescope below the alidade section is almost identical to NASA DSN 34-m stations, but the equipped frequency range and other electronics are different.



Figure 1. The Kashima 34-m Radio Telescope.

2. Antenna Specifications

2.1. Mechanical System

Although the Kashima 34-m telescope has an ability of the maximum slew rate of 1 degree per second in azimuth, we reduced its speed slightly to prevent mechanical wear in several parts of the telescope expecting to extend the life time of the telescope. The mechanical performance and related parameters of the telescope are shown in Table 1. Annual inspections of the motors and related parameters of the telescope are shown in Table 1. Annual inspections of the motors and preparations of spare units substantially reduced unexpected troubles. Since last year, there has been no observation failures due to mechanical troubles of the telescope. The sub-reflector was re-furnished in 1998. Most of the parts in 5-axis positioning were renewed. Sub-reflector FRP surface was cleaned and re-painted from metal paint layer.

Table 1. Mechanical specification and related parameters of the 34-m radio telescope.

Maximum Speed in Azimuth	0.8°/sec.
Maximum Speed in Elevation	0.64°/sec.
Drive Range in Azimuth	±270°
Drive Range in Elevation	7-88°
Operation Wind Speed	13 m/sec.
Panel Surface Accuracy	0.17 mm (RMS)
Latitude	35°57.3'
Longitude	140°39.4'
Mailing Address	893-1 Hirai, Kashima, Ibaraki 314-0012 Japan

2.2. Receiver System

Currently available receivers are L, C, K and S/X bands. A computer controls the receivers and feed groups in the cassegrain secondary focus. A group of feeds is mounted on an elevator unit called "trolley". With the trolley, selected frequency feeds and receivers are moved to the cassegrain focus. The other receivers are retracted to lower positions. In the case of the C-band receiver, additional sub-reflector adjustments are required because of the offset position of the feed. For all the receivers except C-band, HEMT or FET low noise amplifiers are cooled down to a physical temperature of around 12 K. The C-band receiver is placed in ambient temperature. It takes from 15 minutes to 1 hour to switch observing receivers depending on which receiver is demanded. Intermediate frequency (IF) signals from all the receivers except for the K-band receiver are in the range of commonly used 100-600 MHz band. On the other hand, IF signal of the K-band receiver is in the frequency range of 5-7 GHz. The IF signals are converted to optical signals and sent to the observation room through optical fibers. The wide-band IF signal of the K-band receiver is converted to lower frequency signals in the observation room. Recently, we are experiencing strong interferences which are generated from artificial satellites and mobile phone base stations, especially in L-band. As a result, the observations in the L-band are sometimes very difficult. Current performance of the receiver systems are summarized in Table 2.

Table 2. Receiver performance of the 34-m radio telescope.

Band	Frequency (MHz)	Tsys (K)	Efficiency	SEFD (Jy)
L	1350-1750	43	0.68	
S	2150-2350	83	0.65	348
C	4600-5100	150	0.70	
X	7860-8680	50	0.68	254
K	21900-23900	300	0.57	

2.3. Hydrogen Maser Systems and Time Comparison

Two K4 type hydrogen maser systems are available at the telescope and one of them is used for the frequency reference. The same frequency reference is used at the 11-m antenna station of the Key Stone Project (KSP). Another Hydrogen maser system developed by a Russian group (CHI-80) is also kept running as a backup system. To compare the station clock maintained by the hydrogen maser system with the UTC, a GPS time receiver (AOA) and a Totally Accurate Clock-2 unit are in operation.

2.4. VLBI Back-end System

As of March 1999, K3A (Mark IIIA compatible system developed by CRL), K4, VSOP, and VLBA data recorder systems are available. For observations with the K4 and VSOP data recorder systems, an automatic tape changer unit can be used for a continuous unattended operations for more than a day. For the K4 type 2 and VSOP video converter systems which require IF signal in the range of 500-1000MHz, an IF up converter unit is used to convert the IF signals.

3. On-going Projects

Followings are the major VLBI observation projects which are currently running at Kashima 34-m radio telescope. Schedule of the telescope is determined in the telescope operation meetings based on the pre-determined priorities and requests from users.

K4-TIE experiments A K4 data recorder system has been shipped to the Gilmore Creek Geophysical Observatory at Fairbanks and a geodetic VLBI experiment was performed with the station in January 1999. Four VLBI stations in the KSP VLBI network were also included in the experiment. The main purpose of the experiment was to tie the KSP VLBI network to a global terrestrial reference frame (ITRF). Another experiment with the same stations and Wettzell VLBI station was performed in March 1999.

APT and APSG The Kashima 34-m radio telescope has been participating in APT (Asia Pacific Telescope) and APSG (Asia Pacific Space Geodetic Program) VLBI experiments for geodesy and astronomical purposes.

Pulsar VLBI Since 1997, regular observations were carried out with Kalyazin 64-m radio telescope in Russia. A K4 recorder system has been installed at the Kalyazin 64-m radio telescope. Repeated observations revealed the proper motion of a pulsar [2].

VSOP (VLBI Space Observatory Program) Under the collaboration with the Institute of

Space and Astronautical Science (ISAS), Kashima 34-m telescope joined the space VLBI experiments as a ground telescope. C-band and L-band receivers are mainly used. The Kashima 34-m telescope has an important role especially when the Usuda 64-m telescope is not available.

J-net (Japanese domestic astronomical VLBI network) With three other radio telescopes in Japan which are 45-m telescope at Nobeyama, 10-m telescope at Mizusawa and 6-m telescope at Kagoshima, VLBI observations based on qualified astronomical proposals are performed as the J-net. The purposes of the observations are focused in astronomical studies and most of the J-net observations are done towards K-band water maser emission regions. Intensive monitoring observations of the burst of the Orion-KL were done in 1998.

GALAXY (Giga-bit Astronomical Large Array with cross connect) Utilizing optical networks for the KSP VLBI network and another network for the OLIVE project which is connecting 64-m telescope at Usuda and 45-m telescope at Nobeyama with the correlator facility at Mitaka (National Astronomical Observatory: NAO), three large telescopes have been successfully connected via the Asynchronous Transfer Mode (ATM) high speed network. The network has been established under close cooperation with the the Telecommunication Network Laboratory Group of Nippon Telegraph and Telephone Corporation (NTT). Kashima 34-m and Usuda 64-m telescopes were connected in September 1998. Nobeyama 45-m telescopes will also be connected in 1999. The first fringes between Usuda 64-m and Kashima 34-m telescopes were detected at the correlator facility for the KSP network which is located at Koganei, Tokyo.

4. Technical Staff for the Kashima 34-m Radio Telescope

Engineering and technical staff members who are contributing to observations and operations of the Kashima 34-m are listed below.

- Noriyuki Kurihara, Chief of the Radio Astronomical Applications Section.
- Eiji Kawai, Responsible for operations and maintenances.
- Junichi Nakajima, Responsible for the overall performance and improvements of the 34-m radio telescope.
- Yasuhiro Koyama, Field system and monitoring software development.
- Mamoru Seiko, Hydrogen maser systems and reference frequency signals.
- Hiroshi Okubo, Technical staff for mechanical and receiver systems.
- Hiroo Osaki, Technical staff for software and mechanical systems.
- Yuki Watababe, Engineer from Rikei Corporation.

5. Future Plans

Several mechanical modifications and preventive work are planned for the radio telescope. The antenna system is currently controlled from software developed on a mini computer (HP1000 model A400). The operating system of the antenna and the observation facilities are being replaced with

Field System version 9 under close corporation with Goddard Space Flight Center of NASA. As for the backend system, S-2 recording system will become available for pulsar VLBI observations in 1999. The ambient C-band receiver will be replaced with a new HEMT amplifier packaged in a closed cycle gas cooling system in 1999. Two Giga-bit VLBI recorder systems and a correlator system have been placed at the observation room of the 34-m radio telescope. Experimental observations are performed at the sampling rate of 1024Msps with the 1-bit sampling mode. These systems will be used for general observations after the performance of the system is evaluated.

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Key Stone Project VLBI Stations (Kashima, Koganei, Miura, and Tateyama)

Yasuhiro Koyama

Abstract

Key Stone Project Network consists of four space geodetic observation sites around Tokyo, Japan. The overview of the four sites will be described in this report.

1. Introduction

Communications Research Laboratory (CRL) has been establishing a compact space geodetic observation network around Tokyo, Japan under a project which was named as Key Stone Project [1]. The Key Stone Project network consists of four observation sites at Koganei (Tokyo), Kashima (Ibaraki), Miura (Kanagawa), and Tateyama (Chiba). The geographic locations of these four sites are shown in Figure 1. Table 1 shows the latitudes, longitudes and mailing addresses of the four sites.

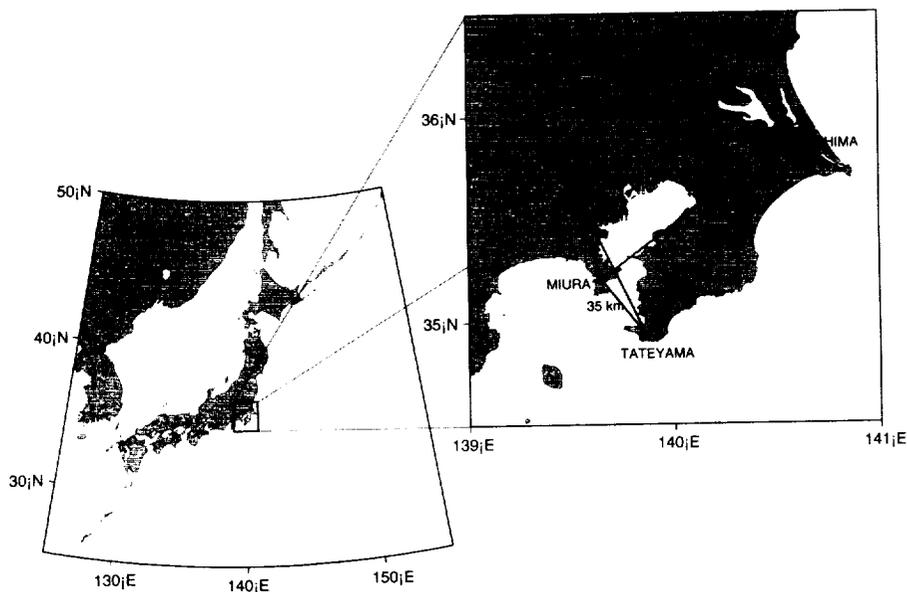


Figure 1. Geographic locations of four Key Stone Project network sites.

At each site, observation facilities of three space geodetic techniques, Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR) and Global Positioning System (GPS), are collocated. An 11 m diameter fully steerable cassegrain antenna for VLBI observations, an optical telescope with an aperture of 75 cm in diameter for SLR observations, and a GPS antenna mounted on top of a stable pillar are placed within about 100 m from each other. While the Kashima and Koganei stations are located where research members of CRL are working, there are no dedicated personnel at Miura and Tateyama stations. The observation system is therefore automated as

Table 1. Locations and addresses of the Key Stone Project observation sites.

Station	Latitude	Longitude	Mail address
Koganei	35°42.6'	139°29.3'	4-2-1 Nukui-kita, Koganei, Tokyo 184-8795
Kashima	35°57.3'	140°39.4'	893-1 Hirai, Kashima, Ibaraki 314-0012
Miura	35°12.4'	139°39.0'	1691 Koenbo, Hasse, Miura, Kanagawa 238-0115
Tateyama	34°56.2'	139°50.9'	1397 Kitatsuka, Inuishi, Tateyama, Chiba 294-0226

much as possible and regular VLBI observations at four stations can be performed without any human interactions in principle [2].

Daily VLBI observations began in January 1995 with a single baseline between Koganei and Kashima, and the full network observations with four stations began in September 1996. As of March 1999, a four station VLBI experiment is performed once every two days with a duration of about 24 hours. High speed Asynchronous Transfer Mode (ATM) communication network connecting the four sites have been established under the collaboration between CRL and the Telecommunication Network Laboratory Group of Nippon Telegraph and Telephone Corporation (NTT). The observed and formatted signals are transferred to the correlator facility at Koganei and processed in real-time. Observations and data analysis of VLBI measurements are fully automated and the analysis results are produced shortly after all observations of an experiment session finished. GPS observations at four sites began in July 1997 and the regular SLR observations began in September 1998.

2. Technical Characteristics

The design of the antenna system at four sites are identical in design except that the Koganei VLBI antenna has a taller pedestal than the other three sites in order to maintain clear sky view as much as possible since the antenna is surrounded by tall woods. The antennas are 11-m diameter cassegrain system with S-band and X-band receivers (Figure 2). The low noise amplifiers are located at room temperature but the performance of the receivers is not so bad, as shown in Table 2 [3].

Table 2. Performance of the antenna (Koganei).

	S-band (7700-8600MHz)	X-band (2100-2500MHz)
Aperture Efficiency	81 %	67 %
System noise temperature	76 K	95 K
SEFD	3030 Jy	6180 Jy

Structure of the antennas is Azimuth-Elevation mount with the ranges of 0° – 540° in azimuth and 5° – 88° in elevation. The maximum slewing speed is 3°/sec in both axes. The antenna and other observation systems are controlled from a Unix workstation with observation control software developed by CRL. The data acquisition system is KSP (K4) VLBI data acquisition system [4].



Figure 2. 11 meter VLBI antenna at Kashima. A GPS antenna is mounted on top of the pillar (right).

3. Technical Staff for the KSP VLBI stations

Technical staff members who are contributing observations and operations of the Key Stone Project VLBI stations are listed below. In principle, no operations are necessary for the regular VLBI observations, but the status monitoring and remote operations are performed from Koganei station where at least one operator is on duty during the daytime period.

- Tetsuro Kondo, Responsible for overall operations and performances.
- Taizoh Yoshino, Leader of the Key Stone Project team in CRL.
- Yasuhiro Koyama, Development of operation and monitoring software.
- Ryuichi Ichikawa, Responsible for Kashima and Tateyama stations.
- Jun Amagai and Kouichi Sebata, Responsible for Koganei and Miura stations.
- Naoki Goto and Muneo Takeda, Operator at Koganei station, Space Engineering Development Co., Ltd.

4. Current Status and Future Plans

Regular VLBI observations at the data rate of 256 Mbps are currently performed once every two days. Unfortunately, the ATM network for the Miura station will be terminated in May 1999, and the regular once-in-two-days experiments will be performed with Kashima, Koganei, and Tateyama stations afterwards. Tape-based VLBI observations at all of four stations will be performed instead once every six days.

The Key Stone Project ATM network was connected with the OLIVE network which is connecting Usuda (64 m antenna operated by Institute of Space and Astronautical Science) and Nobeyama (45 m antenna operated by Nobeyama Radio Observatory). The first successful real-time VLBI observations with the Key Stone Project VLBI stations and Usuda was performed in November

1998. The first successful 1 Gbps VLBI observations were also performed by using the Key Stone Project VLBI sites at Kashima and Koganei in July 1998. Two sets of Giga-bit VLBI system which has been in development by CRL were used and the data were correlated by using the Giga-bit VLBI correlator system at Kashima. The Key Stone Project VLBI stations will be used for such a technical test-bed of the new observation systems developed by CRL.

Seven geodetic VLBI experiments have been performed with the 34 m antenna station at Kashima and the Key Stone Project VLBI stations to make a precise tie of the network to the global terrestrial reference frame. A further tie experiment was performed in January 1999 with the 34 m antenna station at Kashima and Gilmore Creek Geophysical Observatory at Fairbanks and such an experiment was repeated in March 1999. Experiments with Wettzell and Urumqi stations are planned in the future to improve the accuracy of the tie. Ground survey measurements between VLBI, GPS, and SLR reference points at four Key Stone Project observation sites were performed in 1996, 1997, and 1998. These efforts are expected to contribute to a detailed study of the collocation of VLBI, GPS, and SLR.

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Kokee Park Geophysical Observatory

Clyde A. Cox

Abstract

This report summarises the technical parameters and the technical staff of the VLBI System located on the Island of Kauai. Included is an overview of the VLBI activities up to March, 1999.

1. KPGO

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 the 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 summer of 1985. It wasn't 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 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 Aug 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 the use of the 9-meter system was discontinued.

Kokee Park Geophysical Observatory is located on the Island of Kauai in the Hawaiian Islands.

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 ones at Green Bank and Ny Ålesund.

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

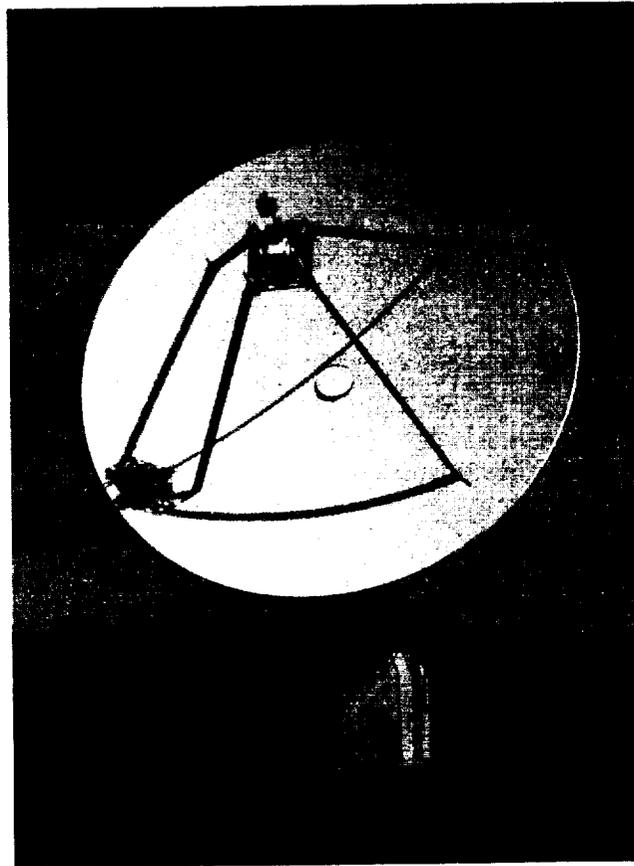


Figure 1. Kokee Park Geophysical Observatory 20m Antenna.

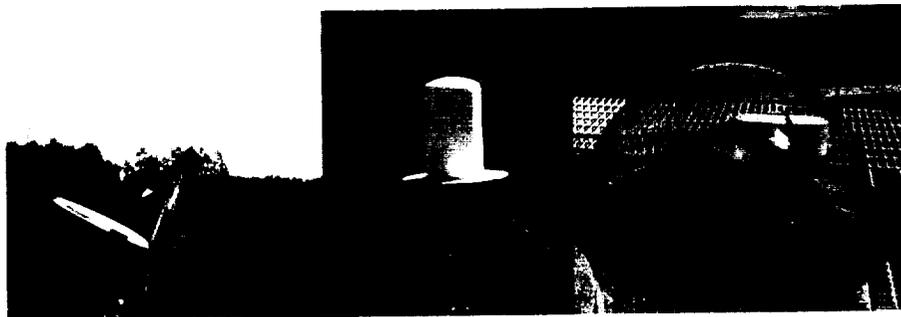


Figure 2. Kokee Park also hosts other systems; PRARE, DORIS Beacon, and IGS (Turbo-Rogue).

3. Technical Staff of the VLBI system at KPGO

The staff at Kokee Park consists of six people who are employed by AlliedSignal Technical Services Corp. under contract to NASA for the operations and maintenance of the Observatory.

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 ²
elevation range	0... 90°
elevation velocity	2°/s
elevation acceleration	1°/s ²
X-band (reference $\nu = 8.4GHz$, $\lambda = 0.0357m$)	8.1 – 8.9 GHz
T_{sys}	40 K
$S_{SEFD}(CASA)$	900 Jy
G/T	45.05 dB/K
η	0.406
S-band (reference $\nu = 2.3GHz$, $\lambda = 0.1304m$)	2.2 – 2.4 GHz
T_{sys}	40 K
$S_{SEFD}(CASA)$	665 Jy
G/T	35.15 dB/K
η	0.539
VLBI terminal type	VLBA
recording media	thin-tape only
Field System version	9.3.17

4. Status of KPGO

Kokee Park has participated in many VLBI experiments since 1984. We started observing with GAPE and are continuing until now with NEOS and CORE. We also participate in the RDV experiments.

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. These three systems are shown in Figure 2.

5. Outlook

USNO will be upgrading the present DAR to Mark IV this calendar year.

Matera CGS VLBI Station

Giuseppe Colucci, Domenico Del Rosso, Francesco Vespe

Abstract

This report summarises the VLBI activities performed at the Matera VLBI station. Also an overview of the technical characteristics of the system and some staff addresses will be 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.

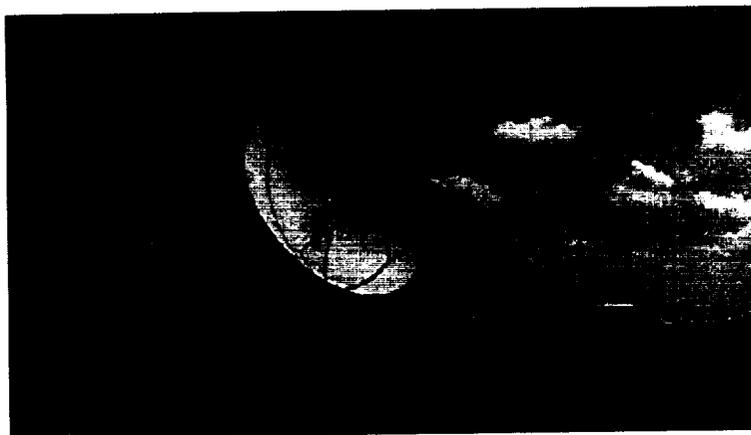


Figure 1. The Matera "Centro di Geodesia Spaziale" (CGS)

The "Centro di Geodesia Spaziale" (CGS) of the Italian Space Agency came into operation in 1983 when a Satellite Laser Ranging SAO-1 System was installed at CGS. Fully integrated in the worldwide network, SAO-1 is in continuous operation since 1983, providing high precision ranging observations of several satellites. Next year the new Matera Laser Ranging Observatory (MLRO), the most advanced Satellite and Lunar Laser Ranging facility in the world, will be installed at the CGS. 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 340 experiments up to August 1998. Besides the participation in the network programs listed above, Matera has been involved also in some Intensive IRIS Campaigns (also during 1998) and in several astronomical experiments. In 1996 the receiver was upgraded to standard wideband and the Mark IV upgrade is now in progress (installation during 1999 planned). The installation of the new Linux PC FS with FS 9.x is in progress too.

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). The receivers were

installed at Cagliari, Medicina, Noto, Genova and Venezia. Currently the IGFN is included in the IGS global network. All the GPS stations are managed by CGS and the data are archived and made available by the CGS WWW server GeoDAF (<http://geodaf.mt.asi.it>).

At the beginning of 1996 the operations of the Precision RAnge and Range-rate Experiment (PRARE) started. Thanks to the colocation of all precise positioning space based techniques (VLBI, SLR, GPS and PRARE), 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, ENVISAT).

2. Technical/scientific

The Matera VLBI antenna is a 20-meter dish with a cassegrain configuration and AZ-EL mount. The AZ axis has ± 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 summarised in Table 1.

The Matera Time and Frequency system is composed 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 frequency source for VLBI.

The control computer is a SWT Pentium/233 PC running Linux and FS version 9.3.23.

Table 1. Matera VLBI Antenna Technical Specifications

Input frequencies	S-band X-band	2210 MHz to 2450 MHz 8180 MHz to 8980 MHz
Noise temperature at dewar flange	S-band X-band	<20 K <20 K
IF output frequencies	S-band X-band	190 MHz to 430 MHz 100 MHz to 900 MHz
IF Output Power with 300 K at the input flange	S-band X-band	0.0 dBm to +8.0 dBm 0.0 dBm to +8.0 dBm
Gain compression	S-band X-band	<1 dB at +8 dBm output level <1 dB at +8 dBm output level
Image rejection	S-band X-band	>45 dB within the IF passband >45 dB within the IF passband
Inter modulation products	S-band X-band	At least 30 dB below each of 2 carriers at an IF output level of 0 dBm per carrier At least 30 dB below each of 2 carriers at an IF output level of 0 dBm per carrier
T_{sys}	S-Band X-Band	55 K 65 K
S_{SEFD}	S-Band X-Band	800 Jy 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
Dr. Giuseppe Bianco	ASI	CGS Director	bianco@asi.it
Dr. Francesco Vespe	ASI	CGS Geodesy Manager	vespe@asi.it
Domenico Del Rosso	Telespazio	Operations Manager	domenico_delrosso@telespazio.it
Luciano Garramone	Telespazio	Station Engineer	garramone@asi.it
Giuseppe Colucci	Telespazio	VLBI contact	colucci@asi.it

4. Status

The Matera station is involved in CORE-A and EUROPE experiments. During 1998 Matera performed also NEOS-A, INTENSIVE and some astronomical experiments coordinated by EVN.

Figure 2 shows the summary of acquisition up to March 1999 in terms of hours of acquisition.

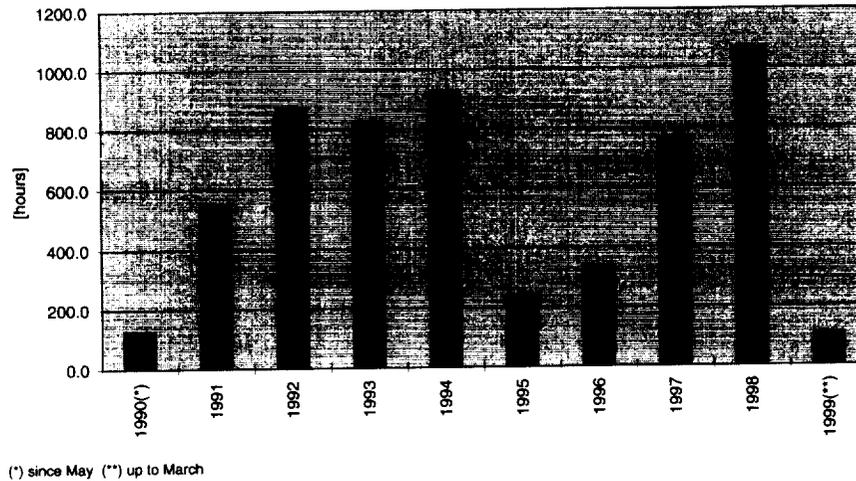


Figure 2. Summary of acquisition from May 1990 to March 1999

5. Outlook

During the second half of the 1999, the system will be upgraded to Mark IV and thin tape operation by MIT Haystack.

References

- [1] G.Colucci, D.Del Rosso, L.Garramone: "Matera VLBI Station Report on the Operational and Performance Evaluation Activities from January to December 1998", available on-line at this address: <http://geodaf.mt.asi.it/GDHTL/matera.html>

Medicina Station Report

Allesandro Orfei, Franco Mantovani

1. Introduction

The Medicina 32-m dish is an alt-az antenna run by the Istituto di Radioastronomia di Bologna del Consiglio Nazionale delle Ricerche. The radiotelescope is located about 30 km east of Bologna, Italy. It is part of the European VLBI Network. Details on the telescope characteristics and equipments can be found at the EVN Home Page (<http://www.nfra.nl/evn/>).

In the last couple of years, the main goal at the Medicina Station was to get the telescope agile in changing the observing frequency. Achieving this goal will greatly increase the observational efficiency of the telescope. Moreover it will make the operation of changing the receivers more safe and it makes this task independent of weather conditions.

The first part of the project has been completed and the new subreflector is fully in operation. The increased flexibility in changing frequency, together with the facility of recording both thick and thin tapes implemented at all the European VLBI Network (EVN) stations has immediately produced an increase in the number of geodetic VLBI observations to which the Medicina Station will take part in 1999.

2. Medicina Station Report

In the following we list the main upgrading in both hardware and software done at the Medicina Station.

2.1. Tape Recording

- a) The thin tape capability has been installed at the station with good results.
- b) A problem due to the sliding of thin tapes has been solved by adopting a new capstan with deeper grooves.
- c) The write head has been replaced at the end of 1998, since it wore out. The new one is of the old Metrum type. The read head is also on its way to die. The new ordered head, made by Spin Physics, will have two triple cap heads mounted.

2.2. Computer Control

- a) A new version of the remote control programme for the S/X receiver has been implemented. It allows monitoring of the receiver status (cryogenic temperature, vacuum pressure and so on) in real time.
- b) To serve different types of observational projects, the computers facilities have been reorganized. Three computers are now available:

- A computer runs the Field System. It can be used to prepare schedules and procedures. The Field System version implemented is 9.3. This machine is connected to the server of the computer

centre in Bologna.

- A computer with the Windows NT operating system serves equipment like the polarimetre and the antenna levelmeters. Moreover, it acquires the GPS-Formatter clock offsets data, it keeps under control the receivers and it drives the movements of the secondary mirror.

- A computer with either Linux or Windows 95 operating systems is used as a general purpose machine and for data acquisition during spectroscopic observations making use of the autocorrelator, etc.

2.3. Upgrading of the Telescope

There are two projects for upgrading the telescope. The first is the completion of the frequency agility project. The second aims to a better efficiency at higher frequencies.

a) In order to complete the frequency agility project for the Medicina dish we are planning to place in the secondary focus room a series of receivers which covers the frequencies between 4.3 GHz and 48 GHz. The electromagnetic design of the eight-feed system is ready and the parameters to design the mechanical support for the receivers are now available. The design of the electronics part of the eight receivers is also at a good stage. The priority is to build the 6 cm and the 5 cm receivers first, to fulfill the EVN requirements about the observing bands which should be available at any station.

b) A project is going on for the implementation on the telescope of an active surface to compensate the loss in efficiency due to gravity deformation of the primary mirror of the parabolic antenna. After a series of tests with the prototype of a mechanical actuator, calculations have been made to figure out the parameters for an "actuators network" which will keep under control the full surface of the dish. In the meantime we are looking for a proper electronics to be used and for an engineering phase of the linear actuator. Furthermore, the cost of more accurate panels for the dish and of the actuators itself have been assessed. A system of this kind, together with new panels of enhanced precision surface, will increase very much the antenna efficiency at frequencies up to 43 GHz.

3. Geodetic Observations

The geodetic experiments run by the Medicina Station in **1998** have been 18 (6 EUROPE, 6 CORE and 6 VLBA).

Three experiments "Mars Pathfinder VLBI", designed for the determination of the Martian Precession Constants, of the relativistic precession of the perihelion of Mars to a few parts per thousand, of the Martian Length of Day to about 1 millisecond, were run on the following dates:

07 Jul MARS-15 (04:00 - 16:00 UT)

14 Aug MARS-16 (03:00 - 15:00 UT)

04 Sep MARS-17 (03:00 - 16:00 UT)

Since the Station has fulfilled the requirements to be a 'CORE' (Continuous Observations of the Rotation of the Earth) Station (namely: a) flexible and automatic frequency change; b) Mark IV terminal; c) TAC for station timing system; d) daily GPS acquisition), it will take part in the "CORE" projects. Moreover, during the present year **1999**, the Station will continue to observe the EUROPE and VLBA experiments. The 38 scheduled projects are listed in Table 2. The list

contains 20 experiments more than in 1998, which represents an increase of more than 100% in observing time allowed for geodetic VLBI.

Tab. 2 - List of Geodetic VLBI observations in 1999

DATE	EXPERIMENT	DATE	EXPERIMENT
12-JAN	CORE-A053	29-JUN	CORE-A065
13-JAN	CORE-B401	13-JUL	CORE-A066
26-JAN	CORE-A054	15-JUL	CORE-B404
01-FEB	EUROPE-47	27-JUL	CORE-A067
09-FEB	CORE-A055	02-AUG	VLBA17
08-MAR	VLBA13	10-AUG	CORE-A068
09-MAR	CORE-A057	12-AUG	CORE-B405
23-MAR	CORE-A058	16-AUG	EUROPE-50
24-MAR	CORE-B402	24-AUG	CORE-A069
06-APR	CORE-A059	07-SEP	CORE-A070
15-APR	VLBA14	05-OCT	CORE-A072
20-APR	CORE-A060	11-OCT	EUROPE-51
26-APR	EUROPE-48	19-OCT	CORE-A073
04-MAY	CORE-A061	02-NOV	CORE-A074
05-MAY	CORE-B403	13-DEC	EUROPE-52
10-MAY	VLBA15	14-DEC	CORE-A077
18-MAY	CORE-A062	16-DEC	CORE-B406
21-JUN	VLBA16	20-DEC	VLBA18
28-JUN	EUROPE-49	28-DEC	CORE-A078

Report from the Noto VLBI Station

G. Tuccari, C. Stanghellini

Abstract

An upgrade of the Noto 32 m antenna is under way. We describe the main points related to a recent past.

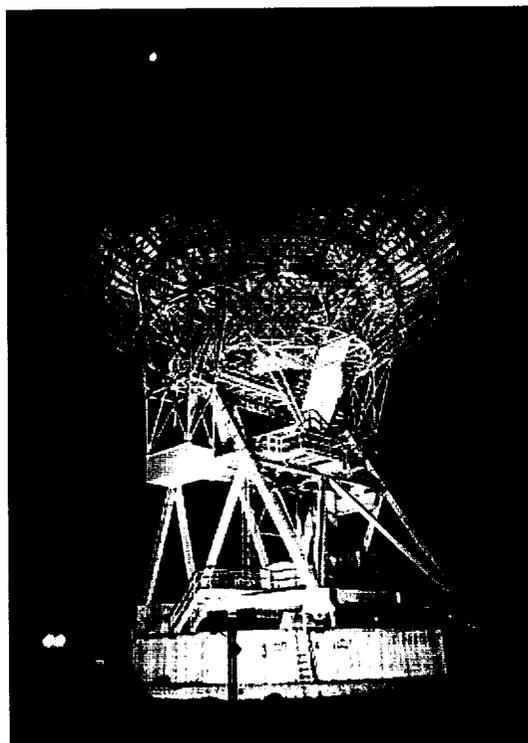


Figure 1. The Noto antenna

1. The Noto VLBI Station

The Noto VLBI station is an alt-az 32 m antenna belonging, as its twin in Medicina, to the "Istituto di Radioastronomia del C.N.R." and is a part of the European VLBI Network (EVN). It is located close to the baroque town of Noto at a latitude of 36.9° .

The staff is composed of: Carla Buemi, Salvo Buttaccio, Corrado Contavalle, Paolo Leto, Gaetano Nicotra, Leonardo Nicotra, Carlo Nocita, Luigi Papaleo, Carlo Stanghellini, Corrado Trigilio, Gino Tuccari, Grazia Umana.

Gino Tuccari is responsible for the technical aspects and the hardware set up of the geodetic experiments, while Carlo Stanghellini is responsible for the schedule, the pre-observation and

post-observation performance checks. Corrado Trigilio is the scheduler and should be contacted to arrange any change in the dates of the observations, or to request the Noto antenna for new experiments.

All the staff contribute as operators and/or in the set up of the system during geodetic experiments.

2. The New Subreflector

During the summer of 1998 the new automatic subreflector positioning system has been mounted and successfully tested. The system, similarly to Medicina, allows now to switch between the secondary mirror and the primary focus receiver in a few minutes. The new equipment avoids the risk to loose geo-experiments due to bad weather conditions and the related difficulty to set the receiver.

3. A New Primary Focus Receiver System

The new primary focus receiver system is under construction and is expected to be operating at the end of 1999. It includes the 2.5, 3.6, 13, 18, 21 cm, and the 250-1000 MHz bands. It represents the second phase of the frequency agility program in Noto. The third phase will get the 0.7, 1.3, 6 cm bands operative in the secondary focus, switching in few seconds through subreflector movement. Regarding the S/X receiver the present and planned system features are:

Table 1. Present and Future S/X Receiver Characteristics

X band	present	future
Polarization:	right	left and right
frequency range:	8.1-8.5 GHz	8.1-8.9 GHz (wide band)
cryogenic	no	yes
Tsys	130 K	35 K
S band	present	future
Polarization:	right	left and right
frequency range:	2.10-2.36 GHz GHz	2.10-2.36 GHz
cryogenic	no	yes
Tsys	140 K	35 K

Both right/right or left/left polarization in the S/X band will be available.

4. A New 12 GHz Receiver for Holography

A new 12 GHz receiver has been added in the primary focus box, able to work phase-locked with H-maser. It is mainly oriented to holography of the main dish. Indeed the efficiency at 22 GHz has increased only a little with respect to the past, due to the use of a new subreflector mirror (rms 0.12 mm), making the surface error determination mandatory. Recent measurements show a deviation from the ideal parabolic shape with a mean rms of about 1.6 mm. Actions to

correct the surface are under evaluation.

5. New Software

New software procedures have been created in order to automatically set the system with the requested observing band.

6. The Mark IV Formatter

The Mark IV formatter is fully integrated in the VLBA environment and both formatters, VLBA and Mark IV, are available. In a near future, when the appropriate Field System version will be available, the Mark IV will be used and VLBA taken as spare. This will allow to avoid manual hardware and software modifications to switch between recording modes.

7. Geodetic Observations

In 1998 Noto took part in 12 geodetic VLBI experiments, namely five CORE-B, five Europe, one NEOS and the BF43A experiment. In 1999 six CORE-B, six Europe and one CRF experiments have been scheduled. It is worth to mention that Noto is deeply involved in the VSOP (plus ground based telescopes which make use of the Canadian S2 recording terminal) survey of compact extragalactic radio sources.

NYAL Ny-Ålesund 20-metre Antenna

Helge G. Digre, Svein Rekkedal, David C. Holland, Rune I. Hanssen, Hans-Peter Plag

Abstract

The 20-m VLBI antenna at the space-geodetic observatory at Ny-Ålesund contributes to the IVS as a network station. In the report period (April 1998 - March 1999), the site has operated and participated in experiments at a normal level. Several maintenance and repair activities were required and changes in station staff have occurred.

1. Introduction

The space-geodetic observatory at Ny-Ålesund is a multi-parameter observing site located at the west coast of Spitsbergen, the main island of Svalbard. For a more detailed description of the geodynamic setting and other observational activities at the observatory, see e.g. [1].



Figure 1. The VLBI antenna at Ny-Ålesund. View is approximately from south-west to north-east. The 20-m radio telescope is located on a small plateau approximately 1.5 km west of the village of Ny-Ålesund at about 45 m above sea level. The small green house seen in the middle of the picture is the control building of the airport, with part of the runway visible in the rightmost corner of the picture. The two black pillars to the right of the airport building and in the right lower corner are well-isolated pillars of the local control network. Photo taken in July 1998.

The VLBI station at Ny-Ålesund was established as a result of a cooperation between NASA, NOAA and Norwegian Mapping Agency. Mechanically, the antenna is an azimuth/elevation which is produced by Radiation System Incorporated, now Comsat, and it is almost identical to the

antennas at Green Bank and Kokee (see Figures 1 and 2). The antenna was assembled the summers 1993 and 1994 and first regular experiment was carried out in the autumn of 1994. The station has been operational since 1st of January 1995.

The VLBI technique is one of several observations carried out at the space-geodetic observatory at Ny-Ålesund. Briefly, we will mention: GPS, GLONASS, PRARE, absolute gravity measurements, Earth tide gravity and tide gage. The different measurements are tied together by means of an accurate control network. This network is extended to the local surrounding (30-50 km) to keep track of eventual local deformation



Figure 2. The VLBI antenna and the control building at Ny-Ålesund. View is approximately from west to east. The building in front is the control building of the space-geodetic observatory. Weather condition is dense fog banks (behind the antenna), which is quite common in summer. Photo taken in July 1998.

Table 1. Main site parameters of NYAL

Location:	Ny-Ålesund, Svalbard, Norway.
Latitude and longitude:	78.9 N, 11.9 E
Operated by:	Statens kartverk (Norwegian Mapping Authority)
Contribution to IVS:	VLBA/RDV, CORE-B, VLBI-Europe, NEOS

2. Technical Parameters of the VLBI Antenna in Ny-Ålesund

The antenna in Ny-Ålesund is of similar type to the ones at Green Bank and Kokee Park. The technical parameters of the antenna in Ny-Ålesund are summarized in Table 2.

Table 2. Technical parameters of the VLBI Antenna at NYAL.

Parameter	Ny-Ålesund
owner and operating agency	NMA
year of construction	1993-1994
radio telescope system	Az-El
receiving feed	primary focus
diameter of main reflector d	20m
focal length f	8.58m
azimuth range	0...540°
azimuth velocity	2°/s
azimuth acceleration	1°/s ²
elevation range	1...90°
elevation velocity	2°/s
elevation acceleration	1°/s ²
X-band (reference $\nu = 8.4\text{GHz}$, $\lambda = 0.0357\text{m}$)	8.1 – 8.9 GHz
T_{sys}	55 K
$S_{SEFD}(CYGNUS - A)$	750 Jy
S-band (reference $\nu = 2.3\text{GHz}$, $\lambda = 0.1304\text{m}$)	2.2 – 2.4 GHz
T_{sys}	35 K
$S_{SEFD}(CYGNUS - A)$	1300 Jy
VLBI terminal type	Mark IV
recording media	thin-tape only
Field System version	9.8.23

3. Staff Related to the Space-geodetic Observatory in Ny-Ålesund

Until summer 1998, the permanent station staff at the observatory has been three persons. In addition, there are two persons at the Geodetic Institute in Hønefoss directly involved in the operation of the observatory. The "permanent" staff are employed on a yearly basis, with a possibility to continue for two additional one year periods. In 1998, a rotation group was set up from the staff at the main institute in Hønefoss. The members of the rotation group have contracts for three years. Each member spends three months in Ny-Ålesund at a time and totally 9 months over the contract period. Thus, the number of staff at Ny-Ålesund is effectively increased to four. The names of the staff members in the report period are given in Table 3.

4. Status of the VLBI Antenna in Ny-Ålesund

The operation of the station at Ny-Ålesund over the report period has been stable. We have had some failures, but these have been mainly due to normal wear and tear.

Mark IV rack: Some work has been done on the Mark IV rack. All the IC sockets on the communication chips on the MAT boards have been changed due to intermittent failures in the

Table 3. Staff related to the operation of the VLBI in Ny-Ålesund.

Hønefoss:	
Section Manager:	Rune I. Hanssen
Group leader:	Svein Rekkedal
Ny-Ålesund:	
Station manager:	
up to 30 April 1999	Leif Morten Tangen
since 01 May 1999	Helge G. Digre
Permanent staff:	David C. Holland
	Roar Kihle
Rotation group:	Kari Buset
	Bente R. Andreassen
	Kjetil Ringen
	Tom Pettersen

communication with the VCs. This work has made things much more reliable, and now this fault rarely occurs. We used good quality gold plated turned pin sockets to replace the original type.

Tape drive: There have been problems with parity errors due to variation of the tape position, which changed with speed and direction. The idler roller was replaced, and solved this problem. We observed that the surface of the old roller was pitted and rough on about 20% of its circumference.

Field System: We are running FS 9.8.23 with the additional software for logging the weather station data during experiments. The Field System with the integrated weather station has worked well, except that the wind sensor mast broke during a violent storm. It has now been replaced with a stronger mast and guying system.

Antenna: We have had failures of the Peltier elements in the receiver heating/cooling system. These devices seem to have a finite life and usually break when the weather is bad (making the replacement more difficult).

We have also experienced problems with our azimuth encoder during colder periods (below -25 C). To improve the reliability, a heated, insulated box has been built to prevent water vapour condensing in the optics.

General: We have now a modern "cherry picker" to replace our elderly International Harvester model. This has made maintenance of the antenna much easier as it is considerably more portable.

Other relevant activities: In 1998, additional geodetic benchmarks have been established in an area with a north-south extension of 30 km and an east-west extension of 50 km. These points enlarge the existing control network consisting of an inner network of 50 by 400 m and some additional points within 5 km of the observatory. The new points were occupied in September 1998 in a five day GPS campaign.

5. Outlook

The maser will have its scheduled bi-annual maintenance check 3 - 10 June 1999. It will be performed by AlliedSignal, Donald A. Rhine.

The azimuth gear boxes have leaking oil seals. They have to be changed during the summer

season. The oil leak has interfered with the azimuth brake systems. The brakes have to be repaired during the summer. The heating elements for the brakes are also defective and have to be changed.

Besides the participation of the VLBI antenna in scheduled experiments, it should be mentioned here that the complete control network will be measured in a GPS campaign in August 1999. The VLBI antenna will be surveyed in August in cooperation with three scientists from Italy and Spain (under the lead of Paolo Tomasi).

We are planning to participate in CORE-3, which will considerably increase the number of experiments per year.

References

- [1] Plag, H.-P., 1999: Measurements of vertical crustal motion in Europe by VLBI. Station report for Ny-Ålesund, Norwegian Mapping Authority. In Schlüter, W. and Hase, H. (eds.): *Proceed. 13-th Working Meeting of European VLBI for Geodesy and Astrometry, Viechtach/Wetzell, February 12-13, 1999*. Bundesamt für Kartographie und Geodäsie, Frankfurt, 65-77.

German Antarctic Receiving Station O'Higgins

Andreas Reinhold

Abstract

This report gives an overview about the technical parameters and the organizing structure of the German Antarctic Receiving Station O'Higgins. It shows the activities since 1992 and gives an outlook about the developments to a Mark IV station during the next years.

1. The GARS O'Higgins at the Antarctic Peninsula

The antenna of the German Antarctic Receiving Station (GARS) O'Higgins is jointly used by DLR (German Aerospace Center) for SAR Data Acquisition of different remote sensing satellites (in priority ERS1 and ERS2) and by BKG (Bundesamt für Kartographie und Geodäsie – formerly IfAG, Institute for Applied Geodesy) for international VLBI experiments. The DLR – as owner of the station – is also responsible for management, infrastructure and logistics. The responsibility for all geodetic observations is in the hands of BKG.

The GARS is located at the site of Chilean Base General Bernardo O'Higgins (Antarctic Peninsula) and was founded in 1989. The antenna and the subsystems were installed in southern summer 1990/91 and the first VLBI experiments were carried out in January 1992. With that O'Higgins was the first VLBI station in operation in Antarctica.

The receiving system is used in campaigns, generally in two campaigns of six to 10 weeks each per year. During the previous campaigns three to seven VLBI sessions were planned per campaign and realised in general.



Figure 1. Geodetic Observatory O'Higgins – Antarctica : INMARSAT antennas at the station roof, PRARE Ground Unit (preliminary mounted in 1995), radome with GPS Turbo Rogue antenna and ERS/VLBI antenna. (October 1995)

In addition to the VLBI equipment other geodetic systems are available at O'Higgins (Figure 1).

Since February 1995 a Turbo Rogue GPS receiver has been permanently working at the station. An underwater tide gauge sensor was installed at the same time and since February 1996 a PRARE ground unit is in communication with the remote sensing satellite ERS2 for precise orbit tracking.

2. Technical Parameters of the VLBI Equipment at O'Higgins

The main instrument of the technical equipment at O'Higgins station is the 9 m antenna (Figure 2) used for both remote sensing satellite data acquisition (DLR) and geodetic VLBI (BKG). The construction of the antenna is laid out to resist wind speeds up to 300 km/h. The antenna system is solidly founded on a site free of ice on bedrock.



Figure 2. The 9 m-antenna at GARS O'Higgins in operation mode (1997).

The technical parameters of the radio telescope are summarised in Table 2. When the German station O'Higgins is unmanned the equipment is in sleeping mode. It takes about seven to ten days to restart the equipment at the beginning of a VLBI campaign. The organization structure is given in Table 1.

3. Technical Staff Working at O'Higgins Station

Table 3 lists the staff which is working during VLBI campaigns in Antarctica and is preparing the VLBI bursts for O'Higgins. There exists a close cooperation and support by the staff of the Fundamental Station Wettzell in case of technical problems or for further technical developments.

Table 1. Location and addresses of GARS-VLBI antenna at O'Higgins

Longitude	57.90° W
Latitude	63.32° S
Bundesamt für Kartographie und Geodäsie Außenstelle Leipzig Karl-Rothe-Straße 10-14 D-04105 Leipzig, GERMANY	
during campaigns: German Antarctic Receiving Station O'Higgins VLBI team Base General Bernardo O'Higgins Territorio Antartico Chileno, CHILE ar@leipzig.ifag.de rw@leipzig.ifag.de	

4. Status of the VLBI Equipment

Since 1992 the VLBI equipment at O'Higgins has been involved in 44 internationally scheduled VLBI experiments for determination of a southern hemisphere reference system, Earth orientation parameters, crustal dynamics and coordinates of southern hemisphere quasars together with 11 other VLBI stations.

After an interruption of continuous observation in 1998 the last VLBI burst at O'Higgins took place in January/February 1999. This campaign was not totally successful due to some technical problems. The problems – for example leaky helium supply (dewar) – are caused mainly on by the extreme climate conditions in this part of the world. The complicated logistical possibilities prevented a short term repair. Only one of seven planned VLBI experiments could be realized (COHIG 5) with results.

The next burst at O'Higgins is in preparation for October/November 1999. All the necessary spare parts are available to repair the cooling system.

The station time system has been controlled by a Cesium until now. During the next campaign it will be replaced by a Totally Accurate Clock (TAC).

5. Outlook

VLBI at O'Higgins depends very closely on a stable hardware configuration because it is not a permanently used station. But it is an important station in this part of the world with a small number of permanent stations. The importance of O'Higgins as a reference station will increase when TIGO will be taken outside of Germany (to the Southern Hemisphere).

It is planned to develop O'Higgins as a station with Mark IV/VLBA equipment. The time table is as follows:

- obtaining of a VLBA/Mark IV suitable DAR (3rd-4th quarter 1999)
- test of O'Higgins-Mark IV/VLBA modules inside new DAR at Wettzell – with equivalent TIGO modules (1st quarter 2000)
- obtaining new FS computer, update FS 9.xxx and Linux at Wettzell (1st quarter 2000)

Table 2. Technical parameters of the radio telescope at O'Higgins for geodetic VLBI

Parameter	O'Higgins-VLBI
owner	DLR
operating agency	BKG
year of construction	1990/91
radio telescope system	Cassegrain
receiving feed	primary focus
diameter of main reflector d	9 m
focal length f	3.6 m
f/d	0.4
surface contour of reflector	± 0.25 mm RMS
azimuth range	$-290^\circ \dots + 290^\circ$
azimuth velocity	$11^\circ/s$
azimuth acceleration	$7^\circ/s^2$
elevation range	$0 \dots 90^\circ$
elevation velocity	$5^\circ/s$
elevation acceleration	$5^\circ/s^2$
X-band	8.0 ... 8.6 GHz
T_{sys}	65 K
S_{SEFD}	6300 Jy
G/T	31.1 dB/K
S-band	2.0 ... 2.4 GHz
T_{sys}	93 K
S_{SEFD}	12500 Jy
G/T	21.4 dB/K
VLBI terminal type	VLBA
recording media	VLBA-recorder normal tapes
Field System version	8.21
attended VLBI observations	24 h during campaigns mode C

Table 3. Staff working at O'Higgins VLBI project

Name	Background	Dedication	Agency
Andreas Reinhold	geodesy	75%	BKG
Reiner Wojdziak	computer science	20%	BKG

- joint tuning of DAR, FS and ACU as a complete system at Wettzell (2nd quarter 2000)
- fringe test, test experiment at Wettzell (2nd-3rd quarter 2000)
- shipment of the Mark IV equipment to O'Higgins (3rd-4th quarter 2000)
- removal of head assembly from recorder at O'Higgins, shipment for thin tape upgrade to

Haystack (4th quarter 2000)

- upgrade to Mark IV, installation of thin tape assembly and FS 9.xxx and system test at O'Higgins (1st quarter 2001)

Campaigns at O'Higgins are planned for 10/11 1999; 01/02 2000; southern spring 2000 and southern summer 2000/2001.

Onsala Space Observatory – IVS Network Station

Rüdiger Haas, Gunnar Elgered, Hans-Georg Scherneck

Abstract

We give a short overview of Onsala Space Observatory (OSO) in its function as IVS Network Station. Current status and plans for the future are described.

1. General Information

Onsala Space Observatory (OSO) is the Swedish National Facility for Radio Astronomy and connected with the Department of Radio and Space Science at Chalmers University of Technology. It is located 30 km south-west of Gothenburg at the Swedish west coast. The site is located on the Eurasian plate in the southern part of the Fennoscandian uplift area.

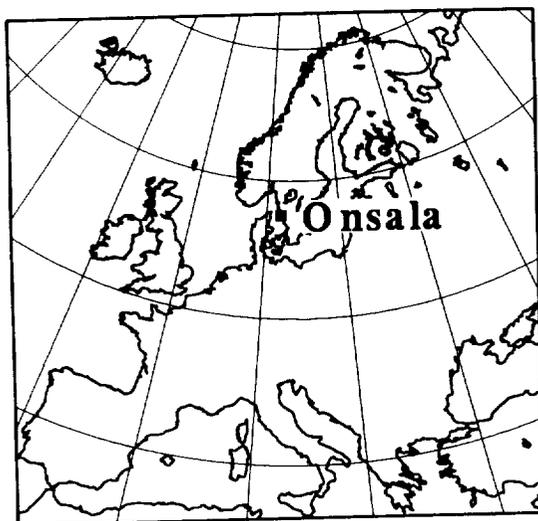


Figure 1: Location of Onsala Space Observatory (OSO) at the Swedish west-coast in the southern part of the Fennoscandian uplift area.

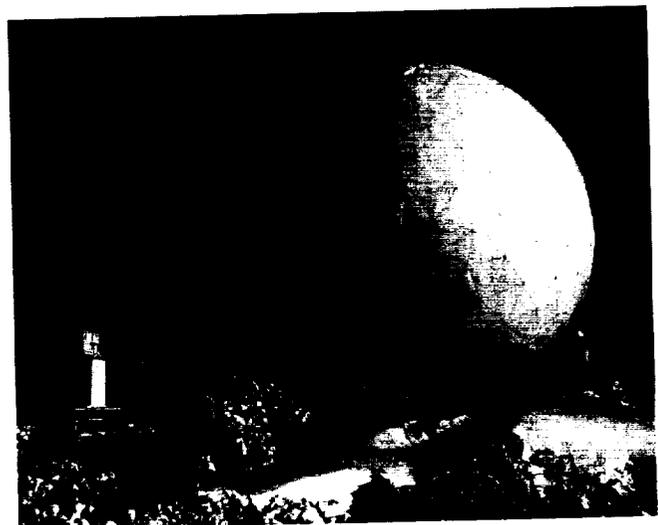


Figure 2: The 20 m radio telescope at Onsala enclosed inside the radome. Note the Onsala water vapor radiometer (WVR) and the GPS antenna of the Onsala IGS permanent station on the left hand and right hand side, respectively.

Table 1. Address and location of Onsala Space Observatory (OSO).

Onsala Space Observatory (OSO)	Longitude	11.93° E
SE-439 92 Onsala, SWEDEN	Latitude	57.40° N
t. +46-31-772-5500,	f. +46-31-772-5590,	http://www.oso.chalmers.se

2. Technical Description of the Geodetic VLBI Equipment at Onsala

The 20 m radio telescope at Onsala used for geodetic VLBI was constructed in 1975/76. It is an az-el mounted telescope enclosed inside a radome and is equipped with a secondary receiving feed system. The slewing speeds are $2.4^\circ/\text{s}$ and $1.0^\circ/\text{s}$ in azimuth and elevation, respectively. The system equivalent flux density values in X- and S-band are 2450 and 3200 Jy, respectively. Onsala uses a Mark-IV data acquisition terminal and since May 1998 triple-cap heads are installed at the recorder unit which enables thin and thick tape operation. There are two hydrogen masers at Onsala, one Oscilloquartz EFOS-7 and one Kartz CH1-75 [1].

The stability of the antenna tower is monitored by permanent measurements of vertical height and temperature of the concrete tower [2]. Inside the concrete wall of the tower are 16 temperature sensors at different height levels and azimuth directions. The temperature measurements started in December 1994. Besides this there is an invar rod mounted at the top of the tower which allows measurement of relative vertical height changes. Figure 3 shows the Onsala invar and temperature measurement devices and approximately 2 years of measurements of temperature and vertical height.

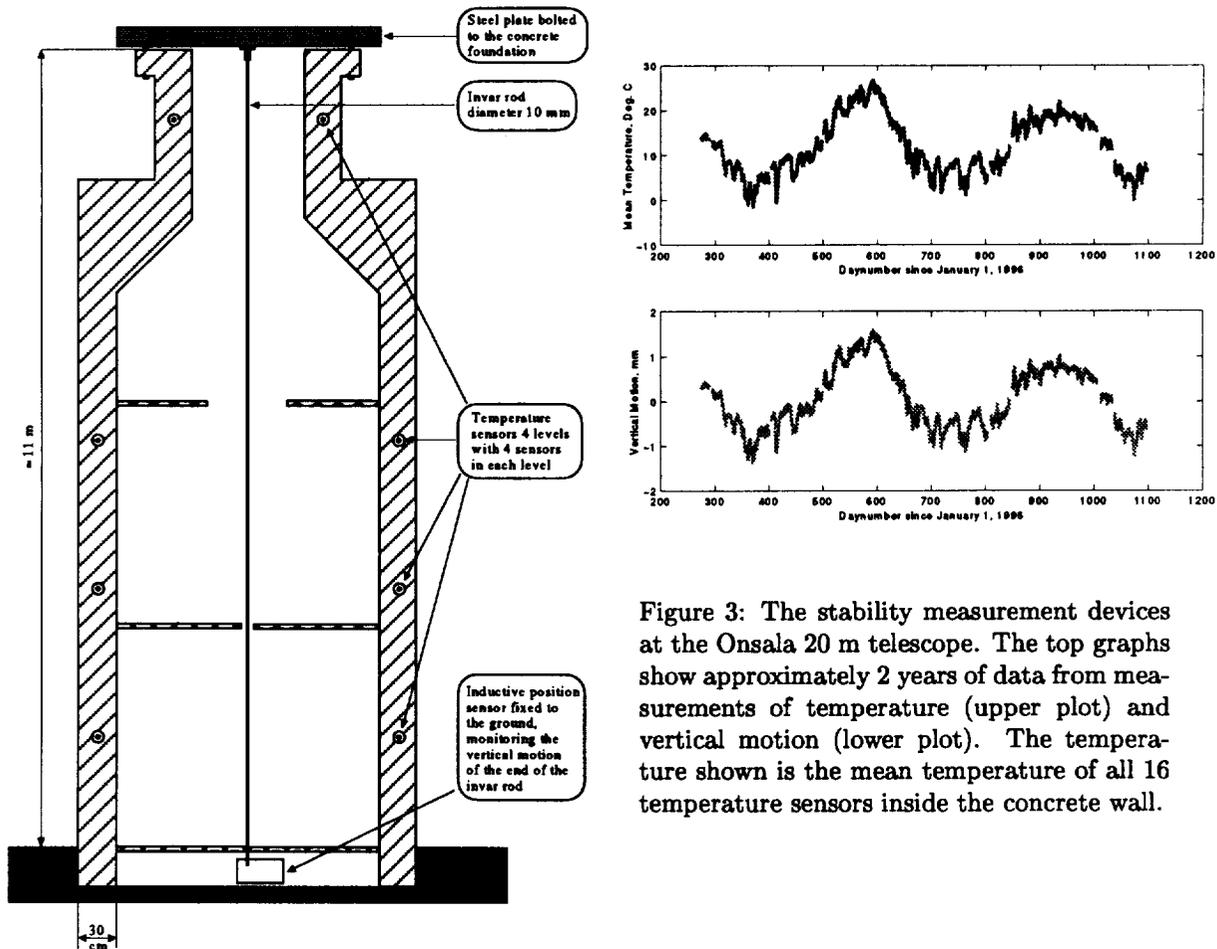


Figure 3: The stability measurement devices at the Onsala 20 m telescope. The top graphs show approximately 2 years of data from measurements of temperature (upper plot) and vertical motion (lower plot). The temperature shown is the mean temperature of all 16 temperature sensors inside the concrete wall.

There is a water vapor radiometer (WVR) located close to the 20 m radio telescope (see Figure 2). The instrument is used continuously for studies of atmospheric properties.

Since 1997 Onsala is also equipped with a Micro Rain Radar (MRR) in order to infer the rain rate and liquid water in the atmospheric boundary layer, and to access the quality of the WVR data.

3. Current Status of Onsala Space Observatory

The pioneering participation in geodetic VLBI of the Onsala Space Observatory dates back to 1968 [3]. In 1998/99 OSO participates in three geodetic VLBI series, the EURO, CORE-B and RDV series with 6 experiments per year each. Figure 4 gives an overview of the geodetic VLBI experiments per year observed and Table 2 lists the geodetic VLBI experiments between March 1998 and March 1999 involving the Onsala Space Observatory.

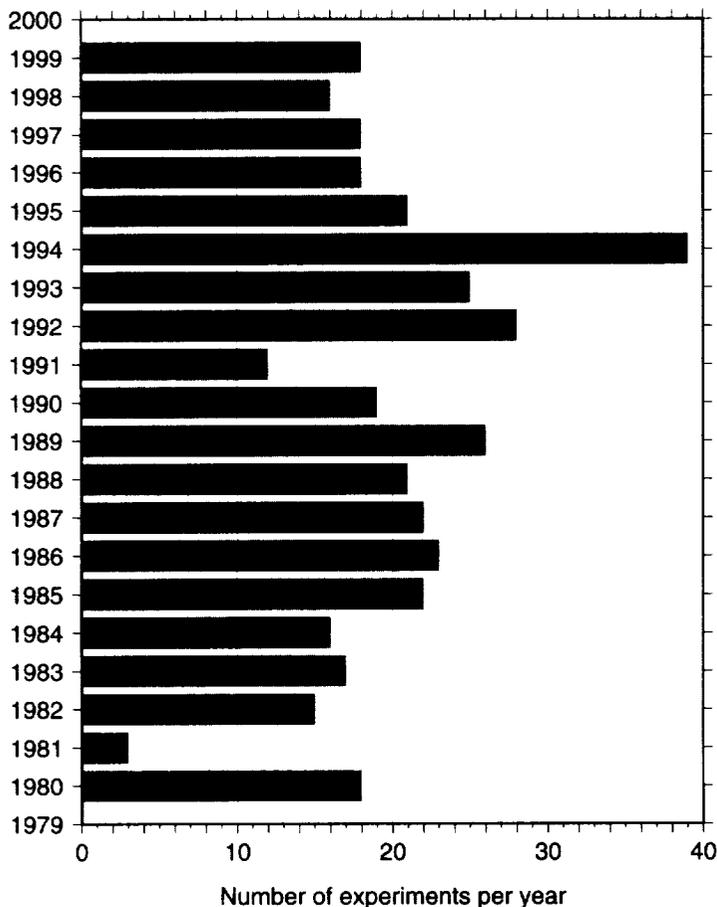


Table 2: Geodetic VLBI experiments involving Onsala Space Observatory between March 1998 and March 1999.

Exper.	Date	Remark
CB107	980311	
CB108	980408	
RDV08	980415	
EURO42	980420	
CB109	980520	
EURO43	980622	50% data lost, tracks overwritten
RDV09	980624	
CB110	980701	
RDV10	980810	
EURO44	980817	50% data lost, tracks overwritten
CB111	980826	antenna pointing problems
RDV11	981001	
EURO45	981012	
CB112	981104	
EURO46	981214	inch-worm motor failure
RDV12	981221	inch-worm motor failure
EURO47	990201	

Figure 4: Geodetic experiments per year involving the Onsala Space Observatory since 1980.

Currently a new S/X-feed system is completed at Onsala to replace the old one using two separate feed horns for the two frequencies. The new one consists of a dual frequency corrugated horn and a two reflector feed system [2]. Most of the system is completed, some remaining parts will be finished in the near future [4].

4. Staff at Onsala Associated with the IVS Network Station

The staff at Onsala associated with the IVS Network Station is: Per Bergman (telescope scientist), Sten Bergstrand (Ph.D. student) Roy Booth (scientist, director), Rune Byström (engineer), Fredrik Corneliussen (technician), Gunnar Elgered (scientist), Lubomir Gradinarsky (Ph.D. student), Rüdiger Haas (scientist), Roger Hammargren (technician), Karl-Åke Johansson (engineer), Lars E.B. Johansson (telescope scientist), Biörn Nilsson (engineer), Hans-Georg Scherneck (scientist), and Borys Stoew (Ph.D. student). (The corresponding e-mail addresses and telephone numbers can be found on the Onsala web page.)

5. Outlook

After installation of the new S/X-feed system we plan to join the CORE-A VLBI experiments on a bi-weekly basis replacing our involvement in the CORE-B experiments. We will continue to participate in the European observation series.

During the summer of 1999 we plan to do a remeasurement of the Onsala local footprint to check the stability of our site. This will include measurements with a GPS antenna mounted in the VLBI telescope in an effort to try to establish a new type of tie between the two observational methods.

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- [3] Scherneck, H.-G., G. Elgered, J. M. Johansson, and B. O. Rönnäng, Space geodetic activities at the Onsala Space Observatory: 25 years in service of plate tectonics, *Phys. Chem. Earth*, Vol. 23, No. 7–8, pp.811–823, 1998
- [4] Elgered, G., R. Haas, and L. Pettersson, The IVS Technology Development Center at the Onsala Space Observatory (this volume)

Status Report of Seshan VLBI Station

Hong Xiaoyu, Liang Shiguang, Qian Zhihan

Abstract

This report summarizes the status of the Seshan VLBI Station.

1. Introduction

The Seshan VLBI Station for astrophysical, astrometric and geodetic applications which is located near Sheshan Town about 30 km far way from the downtown of Shanghai was established in 1987 and is operated by Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS). The first S/X dual band astrometric and geodetic VLBI experiment was carried out in April, 1988. At present, it is a member of the EVN, APT and IVS. Recently, Seshan station also is one of observational bases of the National Astronomical Observatory which was formed in this year.

2. Facilities

The Seshan station is equipped with a 25 m radiotelescope with the capability of S/X dual band observations. A cryogenic receiver with noise temperature of 15 K is used for X-band. The SEFD is 700 Jy at X-band. The upgrade of the extension of the bandwidth from 400 MHz to 800 MHz for X-band receiver is being performed. The SEFD is 2000 Jy for S-band and the higher SEFD is caused by higher noise temperatures of both receiver and antenna. A room temperature receiver with noise temperature of about 50 K is used for S-band. The 25 m antenna was adopted with a waveguide system and it is not good for lower frequency observations, such as 2.2 GHz. The improvement for S-band is under consideration. There also are L-, C- and K-band receivers available at Seshan station which are mainly used for astronomical VLBI and single dish observations.

There are both VLBA Data Acquisition Terminal with 14 BBCs and Canadian Recording Terminal at Seshan station. The upgrade from VLBA to Mark IV in cooperation with JIVE is under way and it is expected that the completion of the Mark IV upgrade will be in the first half of 2000.

Two hydrogen masers manufactured by SHAO are used as a frequency standard for VLBI observations. The stability of the SHAO masers is about 10^{-14} with the time scale of 100-1000 sec.

3. Personnel

The main staff members at Seshan VLBI Station are listed as follows:

Hong Xiaoyu	Research Professor and Chief Scientist
Liang Shiguang	Research Professor and Chief Engineer
Yu Zhiyao	Research Professor
Qian Zhihan	Research Professor
Huang Xinyong	Senior Engineer
Wei Wenren	Senior Engineer
Xue Zhuhe	Senior Engineer

The email accounts for the station are: seshan@center.shao.ac.cn; vlbish@online.sh.cn.

4. Future Plans

In general, it will take one day or more for the frequency switch, especially, the switch between S/X band and C- or K-band. The improvement of the frequency switch is difficult, but it is being considered.

The upgrade of the data acquisition terminal from VLBA to Mark IV and the extension of the bandwidth for X-band receiver is under way mentioned above. It will be completed in the first half of 2000, we expect.

The improvement for S-band is also under consideration. The upgrade of the receiver from room temperature to cryogenic is no technical problem, but budget limitation. The main problems are that the upgrade of the antenna with waveguide system and S/X dual band feed is not so convenient. We are still trying to find a good way to do the improvement.

Simeiz VLBI Station

N. Nesterov, A. Volvach

Abstract

This report summarizes the technical parameters of the "SIMEIZ" VLBI station. It also gives an overview about the VLBI activities during 5 years. Horizontal station velocity was determined and estimates its accuracy are obtained.

1. General Information

The Laboratory of Radioastronomy of the Crimean Astrophysical Observatory (CrAO) with its 22-m radio telescope is located near Simeiz 25 km to the west of Yalta.

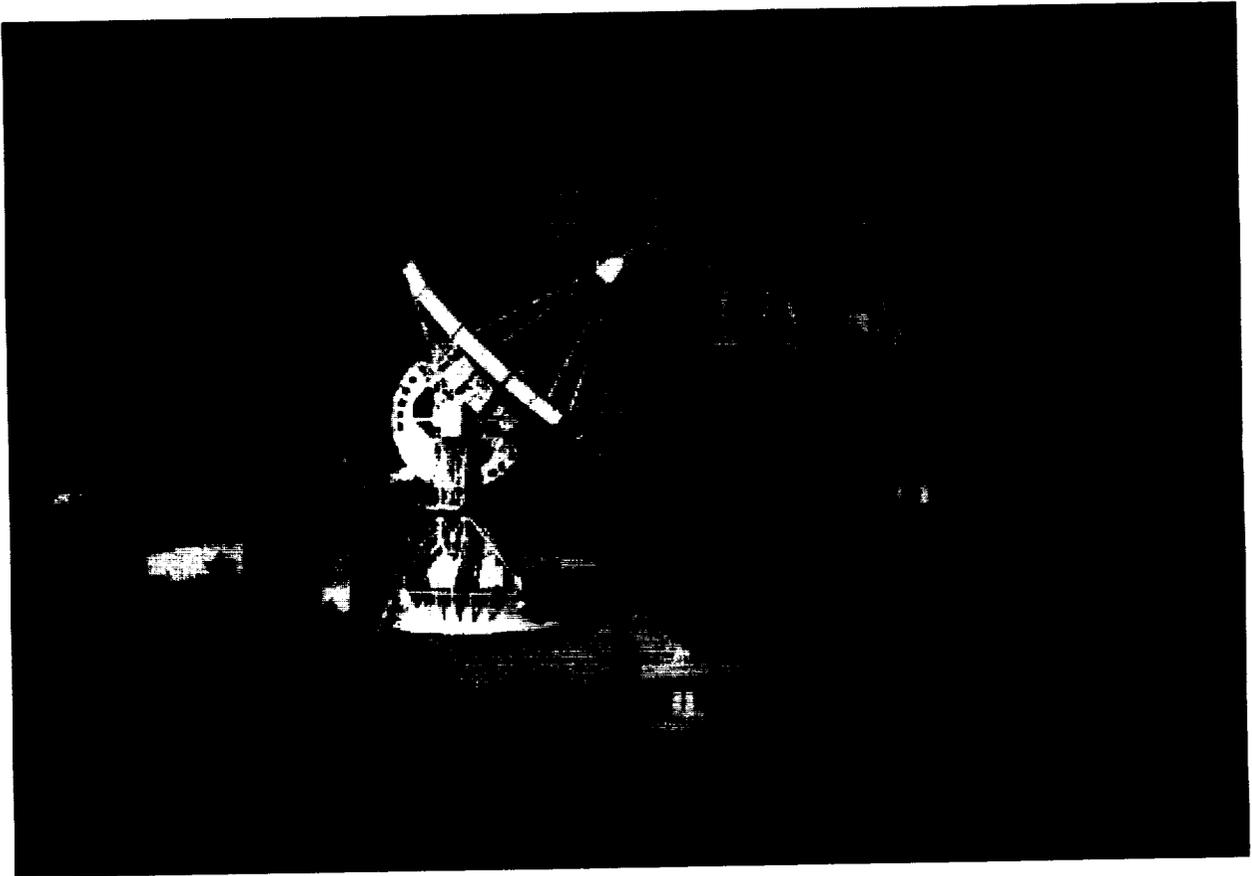


Figure 1. Simeiz VLBI station

The 22-meter radio telescope is situated on the banks of Blue Gulf of Black Sea in South part of Crimea peninsula. It was constructed in 1965 and participated in the first VLBI observations in 1969 in cooperation with USA.

RT-22 operation is supported by control system, consisting of two encoders with accuracy about 3 arcsec (rms), personal computer, CAMAC, quartz time standard, electric engines and other needed equipment and software. The fast RT-22 movement is supported by 2 engines with 20 kW power each, they are used for rapid change of the pointing or to move RT-22 from one source to another. 2 kW engines are used for tracking of the source.

Table 1 shows the antenna parameters.

Table 1. The antenna parameters of the Simeiz station.

Diameter D, m	22
Surface tolerance, mm (root mean square)	0.25
Wavelength limit, mm	2
Feed System	Cassegrain system or primary focus
Focal length F, m	9.525
Focal ratio F/D	0.43
Effective focal length for Cassegrain system, m	134.5
Mounting	Azimuth-Elevation
Pointing accuracy, arc sec.	10
Maximum rotation rate, degree/sec	1.5
Maximum tracking rate, arcsec/sec	150
Working range in Azimuth, degrees (0 to South)	-270 - +270
in Elevation, degrees	0 - 85

The Laboratory provides observing facilities for astronomers from international community and for its own staff:

- a) Very Long Baseline Interferometry (both astrophysical and geodetic projects);
- b) multi wavelength monitoring of Active Galactic Nuclei (AGN) in millimeter domain;
- c) solar and stellar activity investigations at mm-dm wavelengths;
- d) molecular lines observations at mm wavelengths.

2. Status

VLBI observations at the radio telescope were started in 1969 using the Mark I system and Rubidium standard. Further the antenna was included in the global VLBI network for the study of astrophysical objects. The observations were carried out by CrAO and Institute of Space Research at 1.35, 2.8, 6, 18, 49 and 92 cm. The Simeiz station was equipped with MARK-2 system and hydrogen maser frequency standard with stability 10^{-14} .

In June of 1994 the Simeiz station was equipped with terminal Mark IIIA supplied by NASA GSFC with low noise receiver of S/X bands supplied by Institute of Applied Astronomy. That gave the possibility to start fundamental geodetic study and to continue astrophysical VLBI observations with higher sensitivity. Table 2 shows the system parameters of the Simeiz station. Table 3 shows the station activity in 1994-1998.

Hydrogen maser standard at the station had unsatisfactory performance during 1996-1997. Moreover, the electric power was switched off at station often for two or more hours. These two factors resulted in degradation of quality of the data. New maser standard was installed at the

Table 2. The system parameters of the Simeiz station.

F, GHz	0.3	0.6	1.6	2.3	5.0	8.4	22
λ , cm	92	49	18	13	6	3.6	1.3
Tsys, K	150	120	120	80	150 (30)	60	80

Table 3. Simeiz antenna activity.

Years	1994	1995	1996	1997	1998
Number of GEO experiment	8	8	7	4	12
Number of ASTRO experiment	4	31	8	25	10

station in 1998. Time standard and Mark III formatter were supplied by power using UPS device. The observations in 1998 showed that data quality became much better.

3. Analysis

Determination of vertical position during this interval is unreliable while precision of horizontal coordinates of the station was quite satisfactory. Horizontal station velocity and its accuracy was determined using 4.5 years of data. The position of the station at 1997.0 are:

$$X = 3785231.073 \pm 0.004 \dot{X} = 5.5 * 10^{-10} \pm 0.2 * 10^{-10}$$

$$Y = 2551207.417 \pm 0.003 \dot{Y} = 4.9 * 10^{-10} \pm 0.1 * 10^{-10}$$

$$Z = 4439796.362 \pm 0.006 \dot{Z} = 2.3 * 10^{-10} \pm 0.2 * 10^{-10}$$

The final processing of the data was made by Leonid Petrov from the Geodaetische Institut in Bonn.

Table 4 shows the residual velocities with respect to Eurasian plate.

Table 4. Residual velocities respect to Eurasian plate.

Stations	Up(mm/yr)	East(mm/yr)	North(mm/yr)	Corr	D
CRIMEA	3.9 ± 4.5	1.5 ± 1.0	1.9 ± 0.9	0.09	
EFLSBERG	-0.3 ± 0.6	0.5 ± 0.2	-0.4 ± 0.2	0.01	*
MATERA	0.8 ± 0.5	1.1 ± 0.2	4.7 ± 0.2	0.53	
DSS65	2.2 ± 1.2	0.1 ± 0.2	0.1 ± 0.3	-0.27	*
MEDICINA	-2.8 ± 0.5	1.8 ± 0.2	2.1 ± 0.2	0.26	
NYALES20	2.0 ± 1.0	0.0 ± 0.2	0.0 ± 0.2	0.00	*
ONSALA60	3.0 ± 0.3	-0.9 ± 0.2	-0.7 ± 0.2	-0.22	
SESHAN25	0.9 ± 3.7	0.7 ± 2.1	-4.4 ± 2.4	-0.60	
WETTZELL	-0.1 ± 0.3	-0.1 ± 0.1	0.2 ± 0.2	0.12	*

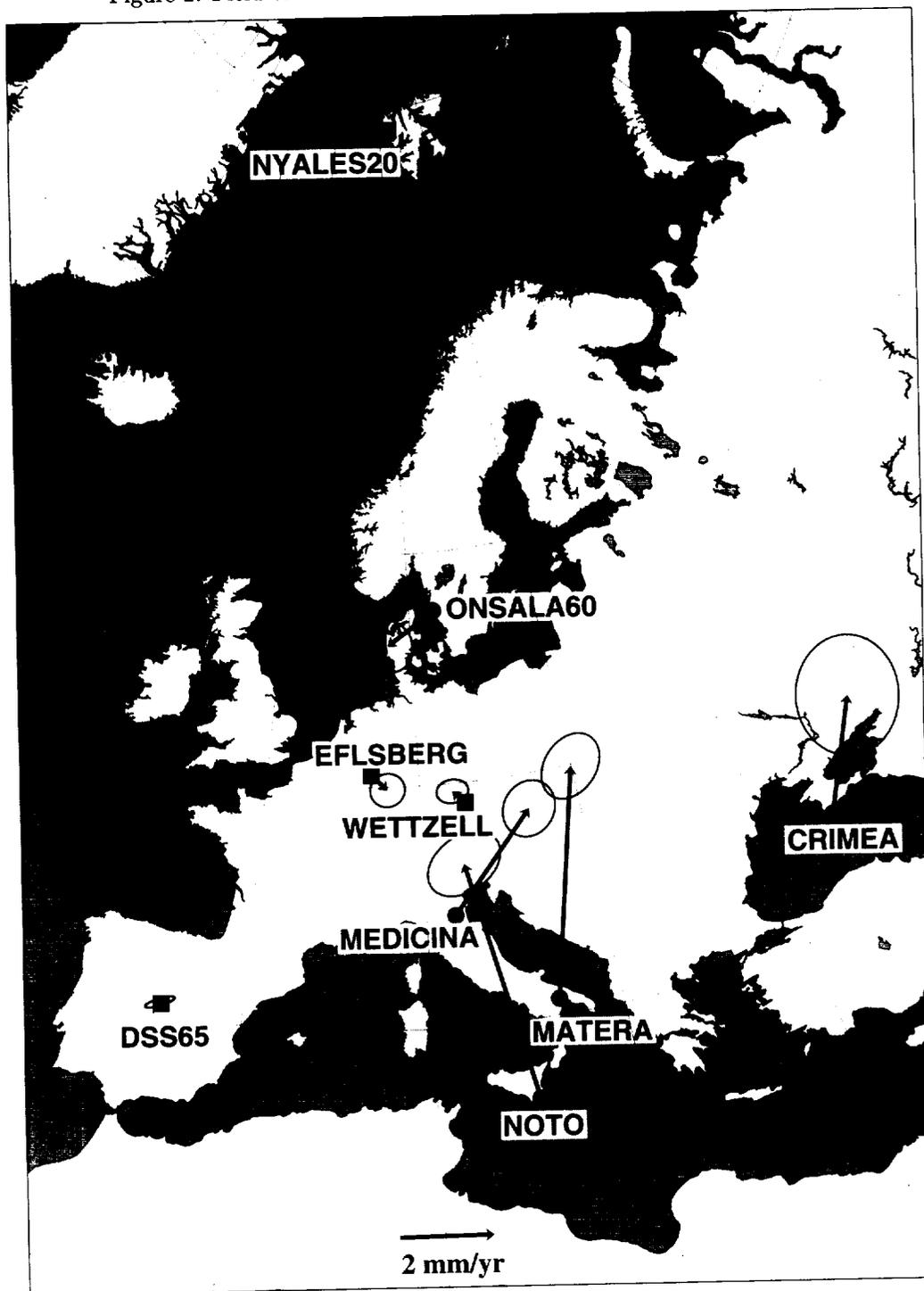
RMS difference of horizontal velocity over defining stations: 0.3 mm/yr. Stations DSS65, EFLSBERG, NYALES20, WETTZELL define plate rotation. Station WETTZELL defines vertical reference.

Figure 2 shows the field of residual velocities with respect to Eurasian plate. Four and one-half years of geodetic VLBI observation at the station Simeiz allow us to conclude that the station moves at azimuth $39^\circ \pm 22^\circ$ with respect to a Eurasian plate with velocity 2.4 ± 1.0 mm/yr where the uncertainty is the estimate of accuracy. Vertical motion is not yet reliably detected.

4. Outlook

New operational system LINUX and Field System were prepared for use with our hardware.

Figure 2. Field of residual velocities with respect to Eurasian plate



- denotes a defining station
- denotes a free station

Svetloe Radio Astronomical Observatory

Sergey Smolentsev, Ismail Rachimov

Abstract

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

1. General Information

Svetloe Radio Astronomical Observatory was founded by Institute of Applied Astronomy (IAA) as first Station of Russian VLBI network QUASAR. Sponsoring organization of this project is Russian Academy of Sciences (RAS). The site for the Observatory was chosen to be Svetloe village located at the Karelian neck nearly 100 km north from St. Petersburg. The basic instruments of the observatory are 32-m radio telescope and technical systems provided realization of VLBI observations.

Svetloe Observatory participated in several regional and global geodetic projects: GIG'91, BSL'93, DOSE'93, DOSE'94, BSL'97, IGEX'98 and is a EUREF permanent station. Its coordinates are defined in ITRF96 and ITRF97 reference frames.

Table 1. Svetloe Observatory location and address.

Longitude	29°47' E
Latitude	60°32' N
Svetloe Observatory Leningrad region, Priozerski district, 188833 Russia	
http://www.ipa.rssi.ru	

2. Technical and Scientific Information

The Svetloe station equipment includes the following main components: 32 m radio telescope, equipped with low noise receivers, frequency and time keeping systems with H-masers, local geodetic network, SLR pad, GPS Trimble 4000 SST receiver and GLONASS A724M receiver, data acquisition system, recording terminal, control computers, local computer network and technical service systems. Local geodetic network is adjusted with accuracy 2–3 mm. Characteristics of the radio telescope and other main components of the station are presented in Tables 2–5.

Frequency and Time Keeping System of Svetloe network station consist of Frequency and Time Standard ensemble, complete set of lock VHF local oscillators and picosecond pulses generators. Frequency and Time Standard ensemble includes four active hydrogen masers CH1-80 developed in Russia. Frequency stability of these masers is presented in Table 6. Frequency and Time calibrations are provided by phase and frequency comparators, passive hydrogen masers CH1-76

used as mobile clock, TV calibration facility, GPS and GLONASS receivers. Local VHF oscillators are locked by reference 5 MHz or 100 MHz signal and provide 10–20 mW power output signals at frequencies 1.26, 2.02, 8.08, 4.5, 22.12 GHz. Picosecond pulse generators utilize the 5 MHz output from frequency standard to produce short duration (about 50 ps) pulses at 1 MHz rate for receivers and down converter phase calibration.

Table 2. Technical parameters of the radio telescope.

Year of construction	1998
Mount	AZEL
Azimuth range	± 270 (from south)
Elevation range	from -5° to 90°
Maximum azimuth - velocity - tracking velocity - acceleration	$1.5^\circ/\text{s}$, $1.5'/\text{s}$, $0.2^\circ/\text{s}^2$
Maximum elevation - velocity - tracking velocity - acceleration	$0.8^\circ/\text{s}$, $1.0'/\text{s}$, $0.2^\circ/\text{s}^2$
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	± 0.5 mm
Frequency capability	1.4–22 GHz
Coordinates of axis intersection (ITRF 96)	$60^\circ 31' 56''.44$ N (Transferred from GPS $29^\circ 46' 54''.97$ E mark 12350M001) H = 86.6 m

Table 3. Parameters of receivers.

Wave band	Frequency range	Input noise temperature
18–21 cm	1.38–1.72 GHz	22 K
13 cm	2.15–2.5 GHz	18 K
6 cm	4.6–5.1 GHz	10 K
3.5 cm	8.2–8.7 GHz (8.9 GHz under testing)	17 K
1.35 cm	22.2–22.7 GHz	90 K

Table 4. Data acquisition system and recording terminal characteristics.

Frequency band	100–600 MHz
Frequency tuning step	10 KHz
Number of down converters	4
Band pass of channels	0.25, 2, 8, 16 MHz
Using of clipping levels	2, 3 or 4
Recording terminal	S2-RT
Format of output data	S2 or Mark III

Table 5. Control computers.

Telescope control computer	Pentium II 350
Field system computer	Pentium 100
Operation system	Linux
Field system version	9.3.25

Additional information: both passive and active hydrogen masers CH1-76 and CH1-80 have been designed and manufactured by KVARZ Institute of Electronic Measurements, Nizhny Novgorod, Russia.

Table 6. Frequency stability of the CH1-80 H-maser.

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

3. Technical Staff

About 30 persons of IAA are involved in VLBI activity at the Svetloe Observatory. Leading persons are listed in Table 7.

4. Present Status of Svetloe Observatory

The construction of the radio telescope at Svetloe was finished in 1998. The main parameters of the radio telescope on 6 cm band (antenna efficiency SEFD) were measured. The tracking system was adjusted with pointing accuracy less than $10''$. First testing spectral observations of OH masers in R and L circular polarization were carried out. Preliminary VLBI observations had been made on the baseline Svetloe – Bear Lakes in December 1998.

Table 7. Leading person of Svetloe Observatory involved in VLBI activity.

Name	Position	Role	Telephone +7-(812)-	E-mail
Prof. Nikolai Koltsov	Chef the Laboratory Signals Conversion and Registration	Data acquisition terminal	235-33-16	nec@ipa.rssi.ru
Dr. Vyacheslav Mardyshkin	Senior Scientific Researcher,	Receivers	230-64-96	vvm@ipa.rssi.ru
Mr. Andrey Michailov	Scientific Researcher	FS software	230-64-96	agm@ipa.rssi.ru
Mr. Alexander Vytnov	Scientific Researcher	Frequency and Time Keeping System	230-74-16	smolen@ipa.rssi.ru
Mr. Eugenie Zhukov	Senior Scientific Researcher	H-masers	230-74-16	smolen@ipa.rssi.ru
Mr. Sergey Syrovoy	Junior Scientific Researcher	Stations software Radio telescope control system	230-64-96	ipatov@ipa.rssi.ru
Vladimir Tarasov	Chief Engineer of the Svetloe Observatory	Technical support	312-36-28	iar@ipa.rssi.ru

5. Outlook

We plan for the near future:

- Final adjustment of all radio telescope systems;
- Measurement of the radio telescope parameters on 13.5/3.5 and 1.35 cm waves;
- Test VLBI observations on 13.5/3.5 cm wave under Field System control;
- Installation of Mark IV data acquisition system in cooperation with NASA;
- Installation of Turbo Rogue GPS receiver in cooperation with OSO.

JARE Syowa Station 11-m Antenna, Antarctica

Kazuo Shibuya, Koichiro Doi

Abstract

Syowa Station is located at 69.0 deg S and 39.6 deg E on East Ongul Island, Antarctica. The Japanese Antarctic Research Expedition (JARE), which is coordinated by the National Institute of Polar Research (NIPR), operates the 11-m S/X band paraboloid antenna for VLBI, and for receiving data from the EXOS-D and the ERS-2 satellites. Brief reports on current status and on-going project of VLBI observations are presented.

1. Introduction

The National Institute of Polar Research (NIPR) constructed an S/X band 11-m paraboloid antenna at Syowa Station, Antarctica in 1989 [1]. Although its main purpose was to receive data from the EXOS-D "AKEBONO" satellite and the MOS-1 "MOMO" satellite, it was designed to be capable of making geodetic VLBI observations. At an initial stage, there was no dedicated back-end system nor stable frequency standards, but a test VLBI observation was made between Syowa, Tidbinbilla and Kashima in 1990 by JARE-30, using a temporary receiver system and a Cesium frequency standard, in close collaboration with the Communications Research Laboratory (CRL). This experiment resulted in a successful baseline determination with Syowa Station [2]. After a long pause of eight years, integration of the permanent receiver/back-end system and hydrogen maser system was made by JARE-39 at the end of December 1997. For the three expeditions from JARE-39 through JARE-41, regular (quasi-seasonal) geodetic VLBI observations were made/planned among the University of Tasmania 26 m antenna at Hobart and the Hartebeesthoek Radio Astronomy Observatory (HartRAO) 26 m antenna, and the first regular experiment (named SYW981 experiment) was made in February 1998. Because JARE members change every year after one-year wintering, the 11-m telescope (Figure 1) was operated and maintained by the staff who participated in JARE from the National Astronomical Observatory (NAO; JARE-39) and from the Geographical Survey Institute (GSI; JARE-40).

2. Antenna Specifications

2.1. Mechanical System

The Syowa 11-m telescope has an ability of the maximum slew rate of 10 degree per second in azimuth within the range from -270 degree to 270 degree, but we operate it under 6 degree per second speed to prevent mechanical wear. The maximum slew rate in elevation is 6 degree per second within the range from 0 degree to 180 degree. As the telescope is covered with a 17 m radius radome, it can endure 60 m/s blizzards, and weathering/corrosion of the antenna panels was found to be insignificant by the inspection made in 1997. Although rare, some part of radome is likely to be covered with snow (especially in September), which decreases the signal strength. The mechanical performance and related parameters of the telescope are summarized in Table 1. Regular inspections of the driving motors and preparations of spare units by the JARE winter-over member from the manufacturer (NEC Corporation) substantially reduce unexpected troubles,

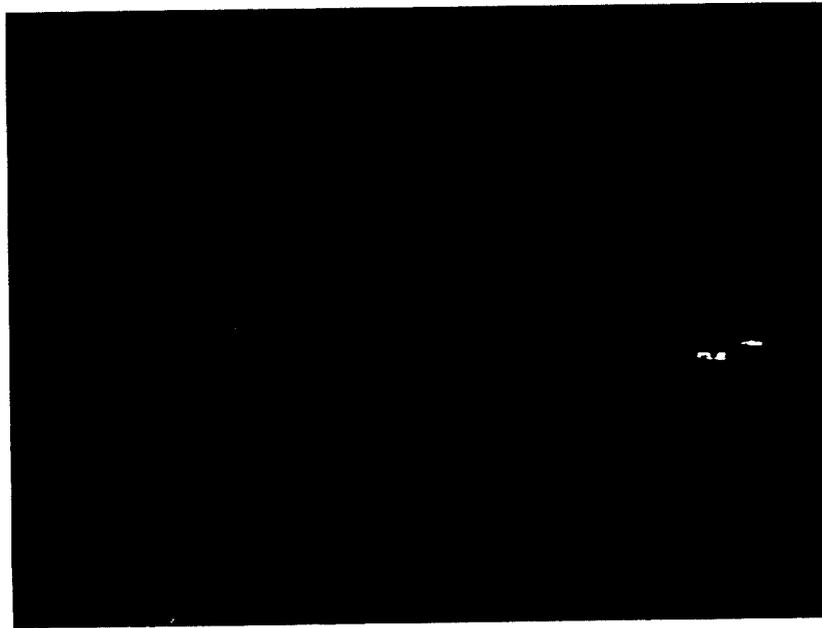


Figure 1. Syowa Station and the antenna radome.

but accidental power failure of the facility caused several damages to the electrical units/boards previously.

Table 1. Specification of the Syowa 11-m antenna.

Maximum Speed in Azimuth	10 °/sec.
Maximum Speed in Elevation	6 °/sec.
Drive Range in Azimuth	±270°
Drive Range in Elevation	0-180°
Pointing Accuracy	within 0.02 ° rms.
Verticality of Azimuth axis	within 0.004 °
Endurance Wind Speed	60 m/sec.
Panel Surface Accuracy	applicable to 22GHz experiment
Latitude	-69°00.4'
Longitude	39°35.2'

2.2. Receiver System

Currently available receivers are S and X bands. The LNAs are not cooled; the system noise temperature for X-band is estimated as around 186 K for the average of 7700-8600 MHz, while that for S-band is estimated as around 91 K for the average of 2100-2500 MHz. According to the source on/off test of ORI-A, aperture efficiency of X-band is obtained as 48%, while that of S-band is obtained as at worst 50%. Thus SEFDs are 11230 and 5300 for the X and S bands, respectively. The receiver characteristics are summarized in Table 2.

Table 2. Receiver performance of the Syowa 11-m antenna.

Band	Frequency (MHz)	T _{sys} (K)	Efficiency	SEFD (Jy)
S	2200-2320	91	0.50	5300
X	7860-8600	186	0.48	11230

2.3. Hydrogen Maser Systems and Time Comparison

Two hydrogen maser systems (Anritsu RH401A) were installed at the site and one of them is used for the frequency reference. Cable length between the hydrogen maser and the receiver unit is 150-160 m. The frequency standard system is also equipped with a Cesium frequency standard (HP8508A), and is synchronized to UTC by using a GPS time receiver.

2.4. VLBI Back-end System

The VLBI back-end system basically adopted at Syowa Station is called K4-TCU (Timing Control Unit) system. Three PCs are used, where the first one is used for VLBI field system (FS9 compatible), the second one is used for pointing control and the third is used for delay calibrations. At present, there are no on-line meteorological sensors, and editing of the log-file from the information by the JARE meteorological observatory is necessary. As a back-up field system, Syowa has a Mark III type field system (called GAOS by GSI). The sampling/recording specification is summarized in Table 3.

Table 3. Sampling/recording specification of the Syowa 11-m VLBI antenna.

Bandwidth	2 MHz or 4 MHz
Sampling rate	4 Mbits/s or 8 Mbits/s
Sampling bit	1 bit
Channels	16
Recording rate	64 Mbits/s or 128 Mbits/s
X band	6 ch, 2217 - 2302 MHz
S band	8 ch, 8210 - 8570 MHz

3. On-going Project

As part of JARE Earth science program titled "Study of dynamical process of the Earth by geodesy and solid-earth geophysics", NIPR made an agreement with the Australian VLBI group and HartRAO to do 48-hour geodetic VLBI observations four times a year for the three expeditions (JARE-39 through -41). Four observations (SYW981, SYW982, SYW983, SYW984) were made in 1998. As the correlator processing of the Syowa data basically depends on the Mitaka VSOP correlator of NAO, and as the hybrid correlation of the S2-K4 data is still in a development stage, baseline solutions for the above experiments are not obtained yet [3]. However, the SYW984 experiment showed clear fringes for any combination of the station pairs, and configuration of the Syowa VLBI system was proved to be adequate for the intercontinental geodetic VLBI observations. JARE is rather flexible concerning programs on station geophysics, and participation in the other international VLBI programs (CRF07 and COHIG-6) was realized in February 1999. The D1 tape recorded data were tried to be copied on a Mark III tape, but time stamps were found to have many bit errors, and copying is not completed yet.

4. Staffs for the JARE Syowa Station 11-m antenna

- Kazuo Shibuya, Project coordinator at NIPR.
- Koichiro Doi, Liaison officer at NIPR.
- Seiji Manabe, Project coordinator at NAO Mizusawa.
- Takaaki Jike (from NAO Mizusawa), Chief operator of JARE-39 (Feb. 1998 - Jan. 1999).
- Teruhito Tanaka, Antenna maintenance staff of JARE-39.
- Yoshihiro Fukuzaki (from GSI), Chief operator of JARE-40 (Feb. 1999 - Jan. 2000).
- Takeshi Ino, Antenna maintenance staff of JARE-40.
- Koichiro Doi (tbd), Chief operator of JARE-41 (Feb. 2000 - Jan. 2001).
- Seiji Takao (tbd), Antenna maintenance staff of JARE-41.

As there are few staffs at NIPR, Antarctic VLBI is accomplished by a consortium with NAO, GSI, CRL and NIPR staffs; the principal scientists are listed as authors of [3].

5. Concluding Remark

Syowa Station is located on a firm bedrock area without sedimentary layer and is situated in a geographically important position for global geodynamics. Colocation observations using DORIS, GPS, PRARE, STS-1 seismometer and pressure- sensor sea-level meter are continuing, e.g. [4]. We have a proposal to continue VLBI for the coming five-year JARE project (JARE-42 through JARE-46).

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Transportable Integrated Geodetic Observatory

Hayo Hase

Abstract

This report summarises the technical parameters and the technical staff of the VLBI module of the transportable fundamental station TIGO. It also gives an overview about the VLBI activities during its test period at Wettzell. The outlook lists the outstanding tasks to improve the performance before TIGO will be used at a remote site abroad.

1. TIGO at Wettzell

The Transportable Integrated Geodetic Observatory consists of a radio telescope for VLBI, an optical telescope for SLR, a GPS array of four GPS permanent receivers, a super-conducting gravimeter, a broad spectrum seismometer, meteorological sensors and an ensemble of atomic clocks. TIGO is still located at the site of the Fundamentalstation Wettzell, since arrangements have to be setup for hosting the entire system and some technical problems need to be fixed before its first operation abroad.

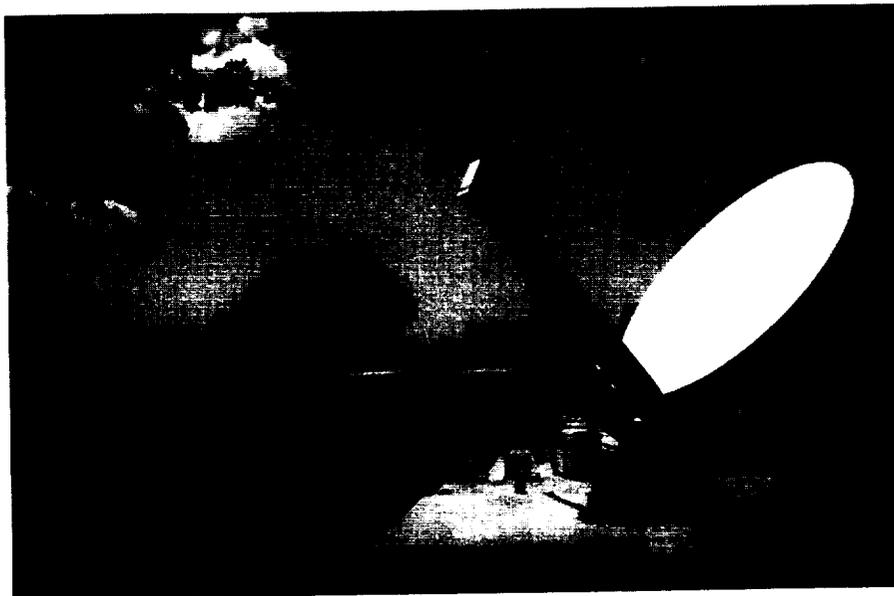


Figure 1. TIGO VLBI module at Wettzell. The 6m-offset radio telescope can be setup within a week by two persons. The operations room is in the air-conditioned container in the background.

Wettzell is located in the Bavarian Forest in the south-east of Germany.

2. Technical Parameters of the VLBI module of TIGO

The largest instrument of TIGO is the radio telescope for VLBI. The design criteria were

Table 1. Location and addresses of TIGO at Wettzell.

Longitude	12.88° E
Latitude	49.14° N
Bundesamt für Kartographie und Geodäsie Projekt TIGO Sackenrieder Straße 25 D-93444 Kötzing, GERMANY http://www.wettzell.ifag.de	

- transportability in 12.20-m standard containers and maximisation of the dish size,
- setup of the radio telescope with muscle power within three days,
- optimisation for the constance of signal-path length under various elevations.

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

3. Technical Staff of the VLBI Module of TIGO

The TIGO VLBI module gains from the experiences of the staff from the 20-m radio telescope. For the use of TIGO at a remote site additional operators and engineers for the maintenance will be necessary.

Table 3 lists the TIGO station staff which are involved in the VLBI module.

4. Status of the TIGO VLBI Module

TIGO participated in several VLBI experiments which are listed in Table 4. Initially a linear polarisation in S-band reduced the SNR to about 50% of the expected one. After the discovery of two broken connectors no fringes indicated a wrong polarisation as delivered by the feed company. Since May 1998 the S-band polarisation is right-hand circular. The performance in X-band is better than specified, in S-band the specifications have not been reached yet. Some improvements are on the agenda for 1999.

TIGO owns the world's first VLBA4 terminal. However the Mark IV formatter is a prototype and the Mark IV decoder is still under development. Both components are expected to be replaced by the final one during 1999.

TIGO was used in several experiments with an offset reference frequency of the H-maser. Usually the reference frequency is 5 MHz. The offset at TIGO was -0.1 Hz to the 5 MHz. This enabled the short baseline determinations between the Wettzell and TIGO radio telescopes. The analysis was done by Leonid Petrov, GIUB, who checked his phase-delay routines with it [1]. The very high accuracy of the phase-delay solution was about ± 0.2 mm which cannot be increased due to mechanical limits of the radio telescope (surface, bearings).

TIGO's cable wrap showed some problems in the azimuth part. The limited space due to its transportability did not leave enough room for about 30 cables. This problem should be solved by introducing four hybrid cables, which have been made specially for TIGO. The installation is planned for spring 1999.

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

Parameter	TIGO-VLBI
owner and operating agency	BKG
year of construction	1995
radio telescope system	offset
receiving feed	primary focus
diameter of main reflector d	6m
focal length f	2.18m
f/d	0.3629
surface contour of reflector	$\pm 0.2mm$
azimuth range	0...540°
azimuth velocity	6°/s
azimuth acceleration	1°/s ²
elevation range	0...90°
elevation velocity	3°/s
elevation acceleration	1°/s ²
X-band (reference $\nu = 8.4GHz$, $\lambda = 0.0357m$)	8.1 – 8.9 GHz
T_{sys}	65 K
$S_{SEFD}(CASA)$	7700 Jy
G/T	35.5 dB/K
η	0.824
S-band (reference $\nu = 2.3GHz$, $\lambda = 0.1304m$)	2.2 – 2.4 GHz
T_{sys}	85 K
$S_{SEFD}(CASA)$	12000 Jy
G/T	22.3 dB/K
η	0.692
VLBI terminal type	VLBA4
recording media	thin tape only
Field System version	9.3.207
unattended VLBI observations	24h, mode C

Table 3. Staff working at the TIGO VLBI module at Wettzell.

Name	Background	Dedication	Agency
Hayo Hase	geodesy	100%	BKG
Olaf Lang	electrical engineering	30%	BKG
Armin Böer	electrical engineering	10%	BKG

5. Outlook

It is envisaged that TIGO has reached a status for its abroad mission to define new fundamental points in the southern hemisphere.

Table 4. Participation of TIGO in VLBI Experiments from the beginning until March 1, 1999.

Date	Experiment	Remarks
1997-11-12	fringe test (Tg-Eb-On)	successful, but weak S-band
1997-12-08	EUROPE-40	first 24h experiment
1998-02-03	EUROPE-41	reference frequency offset
1998-02-10	NA254	reference frequency offset
1998-03-17	NA255	
1998-03-24	NA256	
1998-03-31	NA257	fixing linear polarisation in S-band
1998-04-07	NA258	no fringes
1998-04-14	NA259	
1998-04-21	NA260	
1998-04-28	NA261	
1998-05-05	NA262	S-band RHC polarisation correct
1998-05-19	NA264	
1998-06-22	EUROPE-43	
1998-07-20	SBI98A	reference frequency offset
1998-08-17	EUROPE-44	reference frequency offset
1998-10-12	EUROPE-45	lost due to GPS-time offset in Turbo-Rogue
1998-12-14	EUROPE-46	reference frequency offset
1999-02-01	EUROPE-47	reference frequency offset
1999-02-04	WZTIE-1	reference frequency offset
1999-02-23	NA304	
1999-02-25	WZ4TS	reference frequency offset

An *Announcement of Opportunity* for possible hosting countries will introduce TIGO to foreign institutions. A decision on the first destination should be reached within 1999. Outside Germany TIGO should be used regularly within the CORE project at a new site in the ITRF.

Several tasks must be done at Wettzell beforehand. The agenda for 1999 consists of:

1. Test PC-FS version 9.3.207 based on the Linux kernel 2.0.
2. Test the Mark IV decoder prototype.
3. Replace cables in the TIGO azimuth cable wrap.
4. Improve S-band performance.
 - Make and install a low-loss cable in front of the receiver input.
 - Investigate spillover of 6-m reflector.
 - Replace S-band LNA.
 - Replace dewar.
5. Integration of the Totally Accurate Clock into the VLBA4 system.
6. Install databases for meteorological data.

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Tsukuba 32-m VLBI Station

*Misao Ishihara, Keizou Nemoto, Masao Iwata, Kousei Shiba, Kazuhiro Takashima,
Shigeru Matsuzaka*

Abstract

This report summarizes the specification of our VLBI systems and the members of the Geographical Survey Institute (GSI) VLBI section. We present our history of VLBI activities and the status. Firstly, GSI developed three mobile VLBI systems and had repeated observations with CRL. On the other hand, as GSI installed 1000 permanent GPS stations all over Japan (GEONET), our VLBI strategy has been shifted from domestic mobile experiments to permanent stations and international experiments. Last year GSI constructed a domestic VLBI network with five permanent stations. A main station of our network is Tsukuba 32-m VLBI station (Fig 1). The station also becomes a key station in the international VLBI networks.

1. GSI VLBI site

Our purposes of VLBI activities are the following.

1. Constructing a new geodetic reference frame referred to ITRF94.
2. Simultaneous and continuous monitoring of relative movement of the plates surrounding Japan.
3. Contribution to global environmental preservation and investigations into the geophysical phenomena by joining the International Geodetic VLBI Network.
4. Establishment of a terrestrial reference frame to improve the accuracy of positioning by space geodetic survey techniques.

GSI operates the domestic VLBI network with five stations (Shintotsukawa, Kashima, Tsukuba, Chichijima, Aira) in order to achieve these purposes. GSI also operates 959 GPS stations (GEONET: GPS Earth Observation Network). To connect both networks we carried out a collocation survey by GPS and by total station at each VLBI station. The measured precision was ± 5 mm for horizontal component and ± 2 cm for vertical component. We have a plan of collocation between VLBI and GPS network aiming at the higher precision (± 1 mm).

2. Specification of GSI VLBI systems

GSI has a domestic VLBI network with five stations. The recording system of the network is K4 system. The specification of GSI's five VLBI systems are presented in Table 1.

Diameters of the antennas are 26 m (Kashima), 3.8 m (Shintotsukawa) and 10 m (Chichijima and Aira). Antenna mount type is non-shifted AZ-EL mount. Receivers are designed for S-band and X-band. Recording system is K4 developed by Communications Research Laboratory (CRL). Recording rate was 64 Mbps. The recorded tape was processed with K4 correlator at Tsukuba VLBI Center.



Figure 1. Tsukuba 32m VLBI antenna.

Table 1. Technical parameters of the radio telescopes of GSI.

Parameter	Tsukuba	Kashima	Chichijima	Aira	Shintotsukawa
year of construction	1998	1968	1997	1997	1995
radio telescope (S-band)	cassegrain	cassegrain	cassegrain prime focus	cassegrain prime focus	cassegrain prime focus
Mount	Az-El	Az-El	Az-El	Az-El	Az-El
diameter of main ref.	32m	26m	10.26m	10.26m	3.8m
surface contour of ref.	$\pm 0.5mm$		$\pm 0.5mm$	$\pm 0.5mm$	$\pm 0.5mm$
azimuth velocity	$3^\circ/s$	$1^\circ/s$	$3^\circ/s$	$3^\circ/s$	$2.9^\circ/s$
elevation velocity	$3^\circ/s$	$1^\circ/s$	$3^\circ/s$	$3^\circ/s$	$1^\circ/s$
X-band GHz	7.78 – 8.98	8.05 – 8.55	7.78 – 8.98	7.78 – 8.98	8.18 – 8.98
S-band GHz	2.12 – 2.52	2.20 – 2.40	2.12 – 2.52	2.12 – 2.52	2.21 – 2.45
Recorder	Mark IV, K4	VLBA, K4	K4	K4	K4
Controller	FS9, GAOS	FS9, GAOS	GAOS	GAOS	GAOS

3. Technical Staff of the VLBI group at GSI

Table 2 lists the VLBI staff at GSI.

4. History of VLBI at GSI

The first system was a mobile system with a 5-m diameter antenna. In 1984, GSI had the first VLBI experiment with Kashima VLBI station of Communications Research Laboratory. Since 1986, GSI participated in a project named "VLBI Experiment for Geodetic Application" (VEGA)

Table 2. Staff working at GSI VLBI section.

Name	Position	Jobs
Shigeru MATSUZAKA	IVS Networks Representative	
Misao ISHIHARA	VLBI leader	
Keizo NEMOTO	Colocation chief	Colocation, H-maser, Operation
Masao IWATA	Correlation chief	Correlation, Operation
Kousei SHIBA	Operation chief	Experiments Coordination, Operation
Kazuhiro TAKASHIMA	Analysis chief	Baseline Analysis, Operation
Shinobu KURIHARA	Operator	Baseline Analysis, Operation
Michiko ONOGAKI	Operator	Antenna maint., Operation
Kyoko KOBAYASHI	Assistant	Correlation, Operation

using the mobile system. The purposes of the VEGA project were the detection of crustal deformation, accuracy improvement of the Japanese precise geodetic network, and contribution to determination of GPS satellite orbits.

From 1986 to 1994, GSI repeated mobile VLBI experiments at eight sites in Japan. By comparing with the survey results in 1987 and 1989, GSI succeeded in detecting a velocity of the Philippine plate relative to Kashima of 3.7 cm per year. This plate motion is asserted to be the main force of earthquakes in the Tokai area. The main station of these mobile VLBI experiments was Kashima station (26 m). GSI developed three mobile systems. Diameters of these antennas were 5 m, 2.4 m (with CRL) and 3.8 m. In 1992, the ownership of Kashima VLBI station (26 m) was transferred from CRL to GSI. In 1992, GSI started international VLBI experiments participating in the DOSE project with Kashima VLBI station.

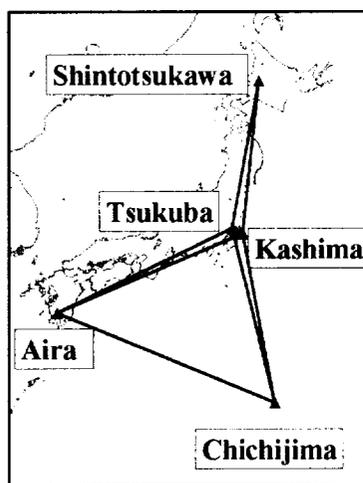


Figure 2. GSI domestic VLBI network.

Distributions of these stations are shown in Fig. 2. Baseline lengths between each station are about 1000 km. Shintotsukawa and Kashima are on the North American plate, Chichijima

is on the Philippine Sea Plate, Aira is on the Eurasian plate. Baseline analysis was done with CALC/SOLVE. After February 1997, GSI had periodical (seasonal) experiments. Standard deviations of baseline length are 6 mm with Shintotsukawa and 4 mm with others in each experiment.

5. Outlook

GSI finished constructing Tsukuba VLBI station (32 m) on 26th March 1998 and had the first (official) experiment in June 1998. We introduced some ideas to guarantee the high performance of Tsukuba VLBI antenna. The back panels and ventilation system keeps the shape of the antenna surface from deforming caused by temperature change. The antenna structure is covered with sunshade panels. GPS antenna is settled on the top of the VLBI antenna for colocation. Helium cooling system is installed for X band receiver. The front-end and back-end are connected with optical transmission devices to improve the SNR. Back-end room is shielded from radio noise and H-maser room is shielded from electromagnetic noise. Mark IV and K4 type recording are available. GSI also is developing a dubbing machine from K4 to Mark IV. IGS station (TSKB) is close by the 32 m antenna (300 m). Colocation at Tsukuba will be achieved at mm-level.

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Urumqi Astronomical Observatory

Liu Xiang, Zhang Jin

Abstract

This report summarises the technical parameters and the technical staff of the VLBI station of Urumqi Astronomical Observatory. It also gives an overview about the VLBI activities during last year at Urumqi.

1. The VLBI station of UAO

Urumqi Astronomical Observatory (UAO) consists of a radio telescope for VLBI, an optical telescope, a GPS station and a telescope for solar observing. UAO is located at the site of the Capital of Xinjiang Province of China, while the 2- m radio telescope is located at Nanshan Mt. Since the beginning of 1999, UAO has been affiliated with National Astronomical Observatories, Chinese Academy of Sciences.

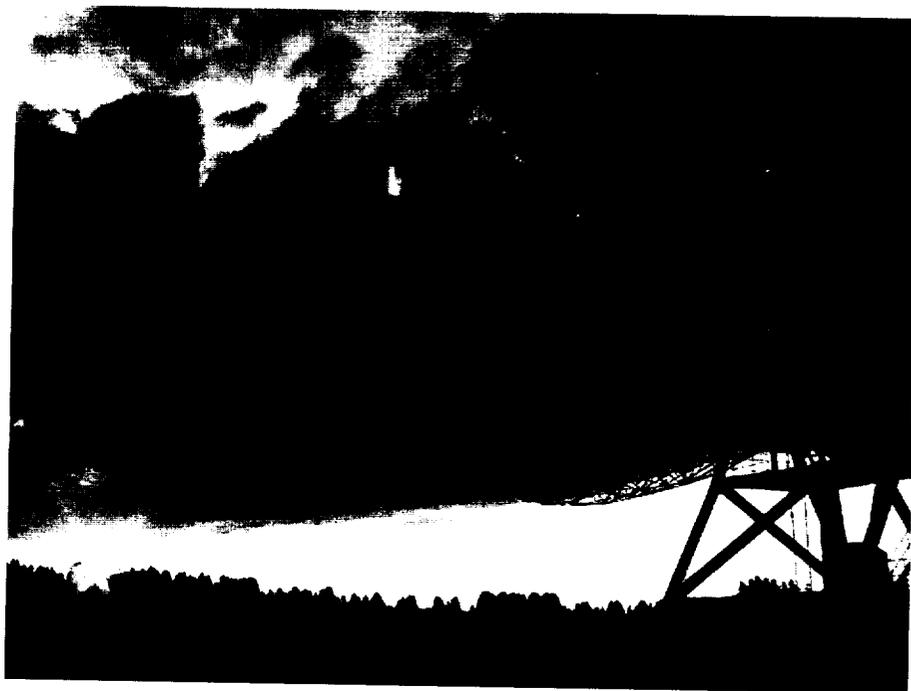


Figure 1. 25m telescope at Nanshan Mt.

2. Technical Parameters of the VLBI station of UAO

The largest instrument of UAO is the radio telescope for VLBI. Tables 1 and 2 list the parameters for the antenna and receivers.

Table 1. UAO Antenna Parameters

Diameter	25m
Working range	AZ $\pm 270^\circ$, EL 4 – 89°
Maximum speed	1°/second for AZ, 0.5 for EL
Maximum acceleration	0.5°/second for AZ, 0.25 for EL
Pointing error	15" (rms)
RFI	There are interferences at 92cm and 18cm bands.
Location	The antenna is sited about 60 km away from the host unit in Urumqi.

Table 2. UAO Receiver Parameters

Band	Frequency range	LO	Pol.	Tsys	SEFD
1.3 cm	22100-24000 MHz	22000MHz	LCP	170K	2580Jy
3.6 cm	8200-8600	8080	RCP	35	290
6 cm	4750-5150	4620	LCP	30	276
13 cm	2150-2450	2020	RCP	180	2440
18 cm	1450-1750	1500	LCP+RCP	85	1394
30 cm	underconstruction				
92 cm	317-337	0	LCP+RCP	90	1265

Back-end systems include Mark IIIA, Mark II, K4.

Timing system: two H-masers with stability 10^{-14} . A GPS (TAC) receiver is installed.

3. Technical Staff of the VLBI station of UAO

Table 3 lists the UAO staff members.

4. Status of the VLBI station

The station is a formal member of EVN, a member of NASA CORE project and China APSG project. It is also a member of APT and Russia LFN.

For S/X band, the system has contributed much observing time to NASA these years. The performance sounds good, except for the phase-cals and the delay measuring system. Another problem is that the FS has not been connected to control the antenna.

The observations were made for CB307-CB312 of NASA, total time is 144 hours, and 48 hours observation for APSG-3 and APSG-4 project of China (S/X band).

The observations were made for 15 projects of EVN at L-band, C-band and K-band, total time is 121 hours. The observations were made for LFN project of Russia, the sum of time is 144 hours (at 92 cm and 18 cm, Mark II mode). Four hours observation was made for Shanghai correlator test. CORE-B501 of NASA was observed in Jan. 1999. EVN session-1 also was conducted in February this year.

VLBI technical activity: a new head of the tape recorder was installed. Aili Yusup worked in Haystack three months for a new S/X band receiver. Zhang Hongbo worked in Jodrell Bank three

Table 3. UAO Technical Staff

Prof. Zhang Jin	chief scientist and general engineer
Zhang Hongbo	vice general engineer
Liu Xiang	the head of vlbi operation group.
Wang Na	responsible for single dish observation.
Aili, Yusup	engineer, vice general engineer.
Shao Minhui	engineer, responsible for H-maser.
Wang Weixia	engineer, responsible for receivers.
Dong Yousuo	engineer, responsible for operation.
Zen Yong	engineer, responsible for the antenna.
Rizwan Mamat	engineer, responsible for Mark IIIA, Mark II and K4.
Aili. E	staff of the operation group.
Jarken. Y	staff of the operation group.
Bao Xinming	staff of the operation group.
Wang Huaxiang	staff of the operation group.
Ma Xuelian	staff of the operation group.
Chen Maozheng	staff of the operation group.
Yang Wenjun	staff of the operation group.

months for Urumqi Mark IV upgrade. A team of 39th institute of China worked at the station half month for the antenna adjustment including main reflector, sub-reflector and pointing. The efficiency of the antenna has raised about 10%. The K-and and L-band are also adjusted.

The plate motion parameters of Urumqi station can be found in NASA Web. Astrophysical VLBI results which the station used can be seen in literature. The single dish observing facilities are undergoing to be established for pulsar timing and H₂O maser observing.

5. Outlook

Mark IV upgrade will be done at the end of 1999 or early 2000. A new S/X band receiver could be installed in this year. A new FS computer will arrive at the station and a connection will be made so as to control the antenna by FS in 1999. It is planed that 30 cm band system could be founded in 1999 according to TOG proposal of EVN. A dual polarized cooling receiver system of L-band is planed to be built in this year in order to fit pulsar timing and VLBI request.

Westford Antenna

Michael Poirier

Abstract

Technical information is provided about the antenna and VLBI equipment at the Westford site of Haystack Observatory.

1. Westford Antenna at Haystack Observatory

Since 1981 the Westford antenna has been one of the primary geodetic VLBI sites in the world. Located ~45 miles northwest of Boston, Massachusetts, the antenna is part of the MIT Haystack Observatory complex.

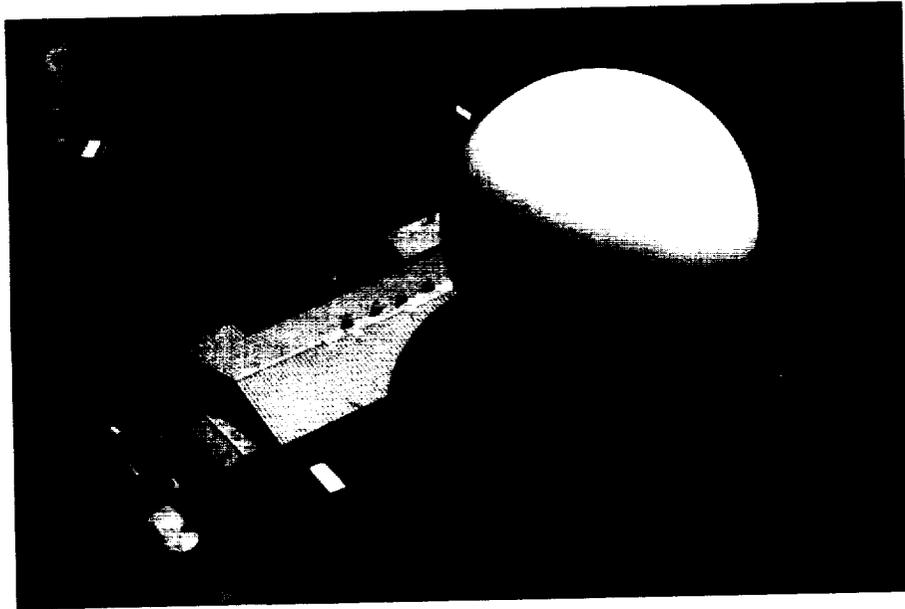


Figure 1. Aerial view of Westford site. The VLBI antenna is inside the radome. The WES2 GPS antenna is on top of the tower in the upper left corner of the photograph.

The Westford antenna was constructed in 1961 as part of the Lincoln Laboratory Project Westford 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.

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.	
http://www.haystack.mit.edu	

2. Technical Parameters of the Westford Antenna and Equipment

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



Figure 2. Wide-angle view of 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 3. 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, and a Pentium-class PC running PC Field System version 9.3.25. The primary frequency and time standard is the NR-3 hydrogen

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 ⁻¹	
elevation slew speed	2° s ⁻¹	
	<i>X-band system</i>	<i>S-band system</i>
frequency range	8180-8980 GHz	2210-2450 GHz
T_{sys} at zenith	50–55 K	70–75 K
aperture efficiency	0.40	0.55
SEFD at zenith	1400 Jy	1400 Jy

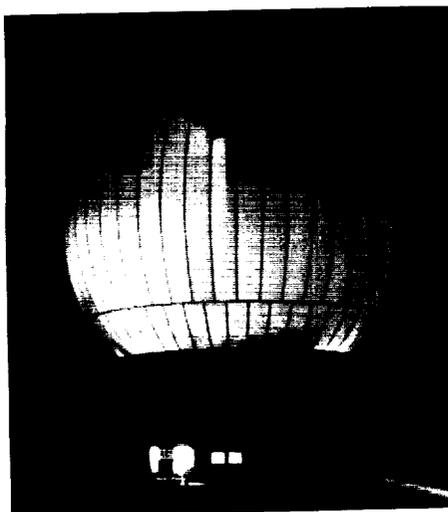


Figure 3. Westford site at night, with radome illuminated from inside.

maser. A TAC GPS receiver provides independent timing information.

Westford also hosts the WES2 GPS site of the IGS network. A Dorne-Margolin GPS antenna is located on top of a tower ~60 meters from the VLBI antenna, and a TurgoRogue 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
Brian Corey	VLBI technical support
Ellen Lautenschlager	observer
Glenn Millson	observer
Michael Poirier	site manager; chief observer
Alan Whitney	site director

4. Status of the Westford Antenna

Westford participates regularly in the CORE-A, CORE-B, IRIS-S and RD-VLBA series of geodetic experiments, as well as in occasional NEOS experiments, fringe tests, and various ad hoc experiments. In the year ending 1999 March 1, Westford participated in a total of fifty-one 24-hour geodetic experiments.

Upgrades to the antenna and VLBI systems over the last two years include:

- replacement of the original antenna controls with a system based on programmable logic controllers
- replacement of the 1970s-vintage analog servo with a digital servo system
- conversion of the Mark IIIA electronics rack and recorder to Mark IV
- replacement of the HP-1000 E-series computer used to point the antenna with a Pentium-class PC that also runs the PC Field System.

The only significant equipment failure during the past year occurred in the cryogenic helium compressor; AlliedSignal shipped a replacement quickly. Roughly twice a year the receiver LNA warms up due to contamination in the cold head, which must then be purged.

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. Outlook

With the advent of the Mark IV correlators and more intensive observing in the CORE program, we anticipate being able to increase by a modest amount the number of geodetic experiments observed annually at Westford.

Two more upgrades to the antenna systems are planned for the coming year: (1) addition of a second drive motor with clutch assembly to each axis, to improve fine movement control, and (2) replacement of the 17-bit position encoder on each axis by a 19-bit, LED-based encoder, to provide improved pointing accuracy and to reduce maintenance costs.

20-m Radiotelescope at Wettzell

R. Kilger

Abstract

This report summarizes some general information of the 20-m radio telescope, the main design and technical criteria and introduces the working staff of the antenna. Additionally it gives an overview of the VLBI observing activities through the present lifetime of the antenna.

1. General Information

The 20-m radio telescope in Wettzell was designed in the years 1980/81 as a project of the former "Sonderforschungsbereich 78 Satellitengeodäsie", hosted at the Technical University Munich; the antenna was constructed in 1982/83 in cooperation with the German companies MAN/VERTEX (VERTEX is former KRUPP). The telescope is an essential part of the Fundamental Station Wettzell, which is operated by the Bundesamt für Kartographie und Geodäsie (BKG) together with the Forschungseinrichtung Satellitengeodäsie (FESG) of the Technical University of Munich (Figure 1).

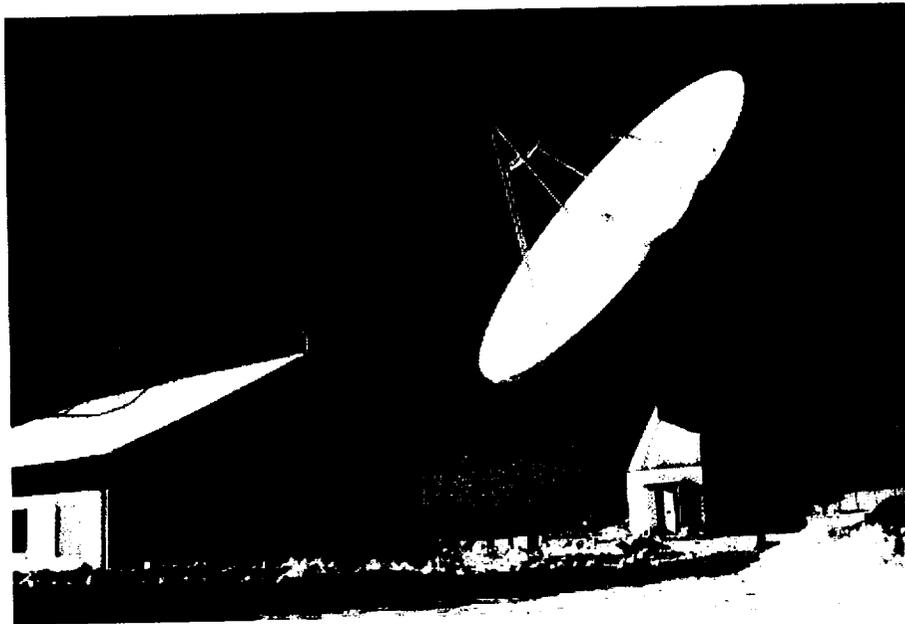


Figure 1. The 20m-radiotelescope and its operation building at Wettzell.

The antenna was designed for geodetic applications and is dedicated 100% to geodetic VLBI observations. It is a "turning head" antenna with a cassegrain geometry; azimuth-, elevation- and boresight-axis intersect to the highest, technically possible precision within one single point, which is the reference point of the antenna.

2. Main Design and Technical Criteria

Geometry of the antenna:

- General Concept: "Turning Head", Cassegrain geometry with coaxial adjusted main- and sub-reflector.
- Main reflector: Mathematical rotational paraboloid, diameter $20m$
orthogonal aperture area $314.2m^2$
focal length $9.0m$
- Subreflector: Mathematical rotational hyperboloid, fixed mounted, diameter $2,7m$

Kinematic Data of the antenna:

- Azimuth axis
 - angle of movement $\pm 270^\circ$ from South
 - velocity $\pm 3^\circ/sec$
 - acceleration $\pm 1.5^\circ/sec^2$
- Elevation axis
 - angle of movement $0 \dots 90^\circ$
 - velocity $\pm 1.5^\circ/sec$
 - acceleration $\pm 1.5^\circ/sec^2$

Surface Tolerances:

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

Further Instrumentation:

- Feedhorn

In 1983 the 20-m radio telescope in Wettzell had been equipped with a dual frequency S/X-band feedhorn of JPL design used for the big 64m-telescopes of DSN, modified to the actual geometry of our 20-m antenna in Wettzell. This feedhorn had been operated more than 12 years with great success until R&D observations enlarged the IF frequency span for geodetic VLBI observations:

X-band from 360 to 720 MHz and

S-band from 85 to 125 MHz.

Since July 1996 Wettzell operates with a new feedhorn manufactured by VERTEX, which was designed according to the enlarged IF frequency span. Due to the fact that Wettzell is a station nearly exclusively dedicated to geodetic VLBI observations, it has implemented only this feedhorn and cannot observe different frequencies in the radio spectrum.

- Receiver

Wettzell started its VLBI observations with an uncooled S-X-receiver with parametric amplifiers on loan from Goddard Space Flight Center. These were used until 1986 and then were replaced by a helium cooled S/X receiver in Haystack standard design for geodetic application. To have the first preamplifiers in S/X-band as close to the feedhorn as possible and to improve the accessibility of the helium cooled dewar the dewar is mounted directly at the output of the X-band waveguide.

- Data Acquisition

Wettzell has a standard VLBI data acquisition terminal with:

- Standard IF Distributor including IF3 module,
- Mark IV Formatter,
- Mark III Decoder,
- 16 Videoconverters upgraded to Mark IV,
- Delay Calibrator (antenna + ground unit)
- TTY Distributor,
- 5 MHz Distributor,
- A rack mounted oscilloscope to monitor phasecal signal permanently and
- Power supply units.

- Tape Units

Wettzell has two Honeywell tape recorder units (Model 96); both have been upgraded for thin tape usage by MPIfR. One unit is still Mark IIIA standard, one unit has been upgraded to Mark IV standard by Haystack Observatory. All operations are done in Mark IV standard since Feb 26, 1999.

- K4

The 20-m radio telescope in Wettzell has a long history of VLBI observations with Japan; they were partly recorded in Mark III, partly in K4 recording technique. Here the data are recorded on D1 cassettes instead of magnetic inch tapes. Presently Wettzell has on loan from CRL, Koganei:

- VLBI Interface Unit DFC 2100 and
- Digital Instrumentation Recorder DIR 1000.

It is planned to purchase these units in the near future.

- Field System

Wettzell runs its VLBI observations presently - May 1999 - with Field System, version 9.3.25.

The Japanese K4 equipment can be operated by a K4 version of Field System, version 9.3.120. This K4 version was developed and installed in Wettzell by Ed Himwich.

- Additional Equipment

A measuring system to determine the relative height of the reference point of the antenna (intersection of Az-, El- and boresight-axis) and the ground is installed inside the 20-m radio telescope. An Invar wire is spanned closely from the reference point of the antenna to the ground; the relative height is taken by an inductive sensor. Since May 1999 the data "relheight" are logged in all log files in "postob" in every observed scan.

Additionally as an integral part of the 20-m telescope a water vapour radiometer is operated; it was designed and built at the ETH-Zrich (Switzerland) by Beat Brki.

- Overall Performance of the Antenna

The overall performance of the antenna can be demonstrated with the three characteristic values:

- System Temperature, TSYS (K),
- Overall Antenna Efficiency, ETA (-) and
- System Equivalent Flux Density, SEFD (K).

All values are a function of
 - observed frequency,
 - elevation angle,
 - weather conditions.

The diagrams show these three values for X/S-band and the expected design values over the IF frequency (MHz); the values were observed at elevation 60° and fine weather conditions (Fig. 2, 3).

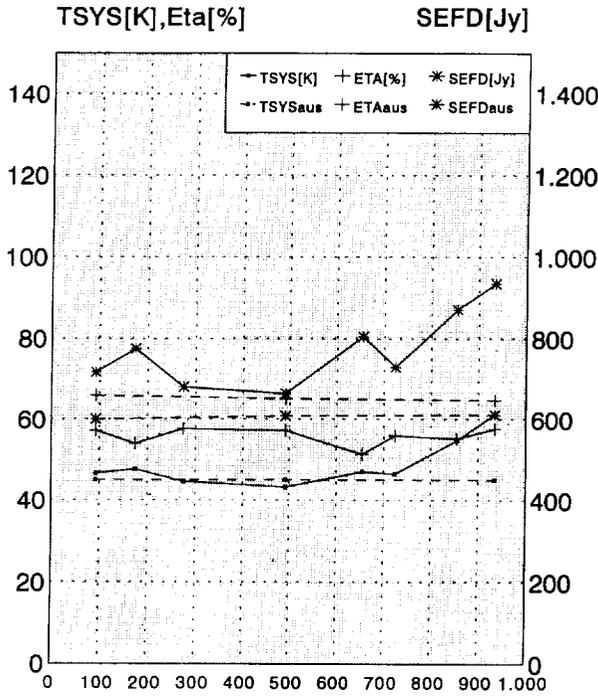


Figure 2. Antenna parameters for X-band at Wettzell.

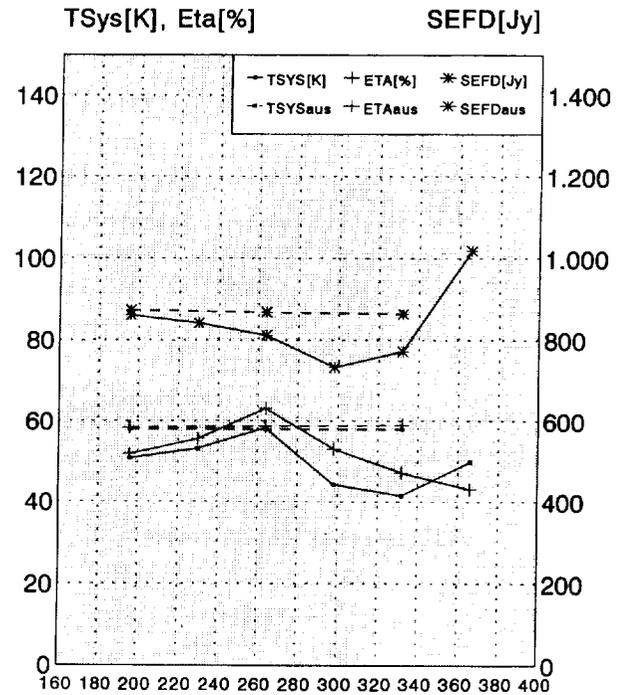


Figure 3. Antenna parameters for S-band at Wettzell.

3. VLBI Observing Activities

The 20-m radio telescope in Wettzell is dedicated 100% to geodetic VLBI-observations; all observations are made in X/S-band only. The observations started in late 1983. A summary of all VLBI observations from 1983 until 1998 is given in Table 1.

Since the beginning NEOS-A is a project with very high priority at Wettzell. In the early days this session had still the synonym POLARIS and partner telescopes were Westford, (old) Fort Davis and Richmond (Florida). This session has the aim to determine with the highest possible precision the coordinates of the rotational pole of the Earth X (marsec), Y (marsec) and $\Delta UT1$ (μsec), as well as the coefficients of nutation and precession. This is the aim of CORE as well; therefore NEOS-A will be integrated into CORE as CORE-2. Meanwhile Wettzell comes close to one thousand NEOS-A sessions and is the telescope with the highest number of performed

observations within the NEOS-A project. Wettzell started from its very beginning in April 1984 together with Westford, now with Green Bank, the INTENSIVE sessions. The interferometer is an East-West baseline with about one Earth radius long baseline, being very sensitive to changes in $\Delta UT1 - UTC$. The session gains from the fact, that both INTENSIVE antennas participate in NEOS-A as well. Therefore the coordinates of the two telescopes and of the observed quasars do not need to be determined by observations; they can be interpolated from NEOS-A sessions. INTENSIVE observations are done every weekday.

Wettzell was part of the observing program IRIS-S from the beginning, a monthly VLBI session including Hartebeesthoek; it is also part of the network EUROPE since its start in 1988.

Additionally Wettzell was involved in the CDP-program of Goddard Space Flight Center (POLAR, X-ASIA, X-ATL, N.ATL, E.ATL (later EUROPE), GLOBAL, R&D, ...).

To some extent Wettzell participates in EVN or special X/S-sessions of MPIfR or astronomical VLBI sessions of universities, whenever there was a possibility.

In near future Wettzell will take part in CORE-2 and CORE-3 within CORE.

Wettzell has often a Japanese K4 data recording system on loan controlled by a K4 Field System since 1999; Wettzell performed with Japanese partners

- special VLBI time transfer sessions,
- additional $\Delta UT1 - UTC$ observations to support parallel $\Delta UT1 - UTC$ measurements with Westford-Greenbank or
- just to support a better geodetic link between European and Asian VLBI stations.

4. Technical Staff of Wettzell

Wettzell benefits from the knowledge and experience of the team:

Bauernfeind, Erhard	mechanical engineer	TU-Munich	100%
Bielmeier, Ewald	electro technician	TU-Munich	100%
Kilger, Richard	mechanical engineer	TU-Munich	100%
Kronschnabl, Gerhard	electronic engineer	BKG	100%
Schatz, Raimund	software engineer	TU-Munich	100%
Schwarz, Walter	electronic engineer	BKG	100%
Zeitlhfler, Reinhard	electronic engineer	TU-Munich	100%
Zernecke, Rudolf	geodetic engineer	TU-Munich	100%

The staff performs

- all the VLBI observations, sometimes assisted by trained students,
- the service of the whole hardware (mechanical, electric/electrical) and software,
- upgrade of the observing system,
- looking for technical problems and bugs and trying to fix them.

Table 1. Summary of VLBI-Sessions observed at the 20m-Radiotelescope Wettzell 1983-1998

Observations	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	$\Sigma(1998)$
IRIS-A, NEOS-A+B	3	67	72	72	72	73	73	73	59	48	60	62	52	53	52	45	936
Intensive $\Delta(UT1)$	-	73	211	276	281	282	287	287	292	236	281	225	287	200	277	247	3742
IRIS-S	-	-	-	4	5	3	3	12	12	12	12	12	12	12	12	10	121
EUROPE	-	-	-	-	-	5	2	4	3	5	4	6	6	6	6	5	52
NASA-Geodesy	-	2	12	12	12	5	1	-	21	22	15	23	15	33	5	6	184
NASA-Astrometry	-	-	-	-	2	2	-	-	-	-	-	-	2	-	8	3	17
USNO	-	-	-	-	-	-	-	-	1	11	6	14	4	4	-	-	40
Uni, MPIFR	-	-	-	-	-	-	-	3	5	-	2	2	3	5	2	4	26
Mobile Campaigns	-	-	-	-	-	-	10	-	4	21	4	4	-	-	-	-	43
1...8 h Measurements	-	16	13	25	27	1	19	23	22	1	1	2	2	6	10	1	167
Other 24 h/Mk2	-	-	1	-	1	7	18	3	9	13	-	2	-	2	-	-	56
Wettzell staff [h]	344	2640	3688	3908	4032	3976	3408	3976	3842	2921	2703	3468	2957	3140	2701	2203	49.907
Students [h]	-	-	-	192	224	56	1140	56	443	1690	1365	808	390	504	214	175	7.457
Total Obs. [h]	344	2640	3688	4100	4256	4032	4548	4232	4285	4611	4068	4276	3347	3644	2915	2378	57.564

Observatorio Astronómico Nacional

Francisco Colomer

Abstract

This report describes the OAN facilities as a network station in IVS. The 14 meter radiotelescope at Yebes participates regularly in the geodetic VLBI campaigns (EUROPE and CORE). The institute staff is also involved in technical development and geodetic research.

1. The OAN Facilities

The Observatorio Astronómico Nacional (OAN) of Spain operates a 14 meter radiotelescope at Yebes (Guadalajara, Spain). This facility is a network station in IVS, and participates regularly in the geodetic VLBI campaigns to study the tectonic plate motions in Europe (project EUROPE), Earth rotation, and pole motion (project CORE). The institute is currently involved in the construction of a new 40 meter radiotelescope that will be available for geodetic VLBI observations in the next few years.

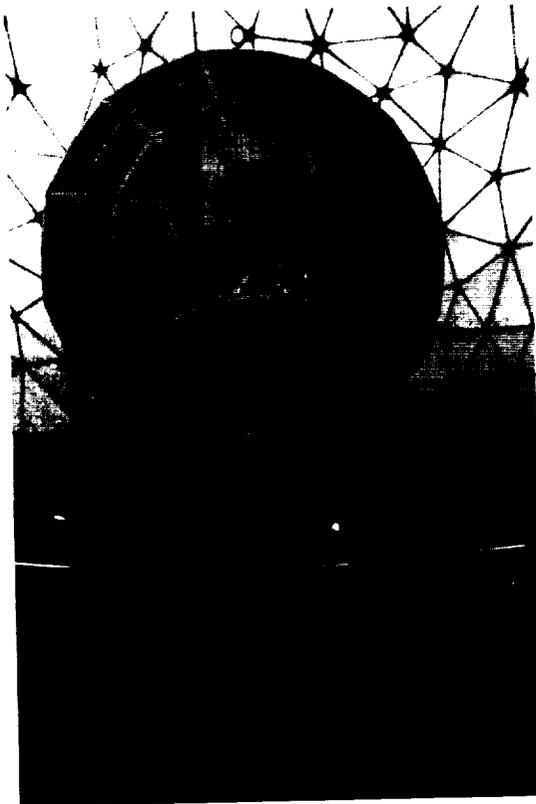


Figure 1. The 13.7 meter radiotelescope of OAN at Yebes (Guadalajara, Spain).

Table 1. OAN location and addresses.

Institute Headquarters: Observatorio Astronómico Nacional	
Physical address	Mail address
Campus Universitario Ctra. N-II, km 33.6 E-28871 Alcalá de Henares	Apartado 1143 E-28800 Alcalá de Henares
http://www.oan.es/	
Yebes radiotelescope: Centro Astronómico de Yebes	
Physical address	Mail address
Cerro de la Palera s/n E-19041 Yebes	Apartado 148 E-19080 Guadalajara
Longitude (WGS84)	3° 5' 21"893 W
Latitude	40° 31' 26"968 N
Height	980.946 m

2. Description of the Station

The main instrument at OAN is the radio telescope [1], used for VLBI. The technical parameters of the radio telescope are summarised in Tables 2 to 4. The instrument is equipped with a dual frequency receiver (S and X bands) used in geodetic VLBI experiments, and also a Q band receiver (41 to 49 GHz) used for astronomical observations. The radio telescope is controlled by two computers (HP1000 and HP2100), that run independently of (but synchronised with) the Field System PC.

Table 2. Technical parameters of the Yebes telescope for geodetic VLBI.

owner and operating agency	OAN (IGN, MEFOM)
year of construction	1976
radio telescope system	altazimutal
receiving feed	cassegrain focus
diameter of main reflector d	13.72 m
focal length f	5.080 m
f/d	0.37026
diameter of geodetic subreflector d_s	2.2 m
focal length f_s	3.547 m
excentricity ϵ	1.557
f/d of equivalent paraboloid	1.7 m
azimuth range	-358 ... 358°
azimuth velocity	1°/s
elevation range	4 ... 89°
elevation velocity	1°/s

Table 3. Receivers used in geodetic VLBI at the Yebes telescope.

Receiver	X-band	S-band
Frequency range (GHz)	8.13 – 8.63	2.21 – 2.35
T_{sys}	77 K	87 K
S_{SEFD}	3300 Jy	3800 Jy
η	0.47	0.38
Polarization	RCP	RCP

Table 4. Characteristics of the VLBI equipment.

VLBI terminal type	VLBA4 (Mark IV formatter, VLBA-G rack and VLBA recorder)
recording media	thick and thin tape, 1" wide
Telescope control computer	HP1000 + HP2100
VLBI system computer	Pentium II/350
Operating system	Debian 2.0r4 (kernel 2.0.34)
Field System version	9.3.25 and 9.3.207
GPS receiver	6 channel TrueTime XL-DC-602
Meteorological station	SEAC-300

The engineers at the OAN laboratories have been involved in the design and construction of low noise HEMT microwave amplifiers at cryogenic temperatures since 1985. These are used at the Yebes telescope, and in other European radio astronomy observatories (e.g. IRAM, Bordeaux, Meudon in France; INPE in Brazil). These amplifiers have been used as well for atmospheric research (Ozone concentration) by other European research projects, like PRONAOS (France) and EMCOR (European Minor Constituent Radiometer, European Union).

3. OAN Staff Working in VLBI

Table 5 lists the OAN staff which are involved in the VLBI studies, some of which can be found at the telescope (CAY) address. The associated members of IVS are indicated with an asterisk.

Table 5. Staff in the OAN VLBI group (Email: vlbi@oan.es).

Name	Background	Role	Dedication	Address
Jesús Gómez-González*	Astronomer	Director	25%	OAN
Alberto Barcia	Engineer	Chief engineer	25%	CAY
Francisco Colomer*	Astronomer	VLBI coordinator	75%	OAN
Pablo de Vicente*	Astronomer	Technical responsible	50%	CAY
Isaac López-Fernández	Engineer	Technical support	30%	CAY
Maria Rioja*	Astronomer	Geodesy researcher	100%	OAN

4. Status of the Geodetic VLBI Activities at OAN

The OAN radio telescope at Yebes has participated in several geodetic VLBI experiments since 1995. The campaigns were performed with partial success, due to a failure of the formatter in the VLBI DAR which prevented the participation of the station in any interferometric observations since the end of 1997. The module was substituted by a Mark IV formatter in February 1999, when successful observations were resumed.

The main contribution of OAN to IVS is the realization of geodetic VLBI observations in the EUROPE and CORE projects. The institute also participates in the European VLBI Network (EVN) for astronomy, taking part in its logistics and carrying out technical development.

Recently, geodetic studies making use of VLBI and GPS data are being performed by OAN staff. These investigations intend to accurately measure the vertical component of the interferometer baselines.

5. Outlook

The OAN radio telescope at Yebes has resumed operations after the faulty VLBA formatter has been replaced by a new Mark IV one. The station participates regularly in the campaigns for the EUROPE and CORE projects.

The construction of a new 40 meter radiotelescope at Yebes has started. This telescope will operate at S/X bands. It is expected to be operational in the next few years.

References

- [1] Barcia, A., Bujarrabal, V., Gómez-González, J., Martín-Pintado, J., Planesas, P.: First spectroscopic observations with the 14-m radio telescope at the Centro Astronomico de Yebes - SiO masers in evolved stars. *Astronomy and Astrophysics*, vol. 142, p. L9, 1985.

Yellowknife Observatory

Mario Bérubé, Calvin Klatt

Abstract

This report gives an overview of the activities at the Yellowknife Observatory. It also summarizes the technical parameters and presents the Yellowknife VLBI team.

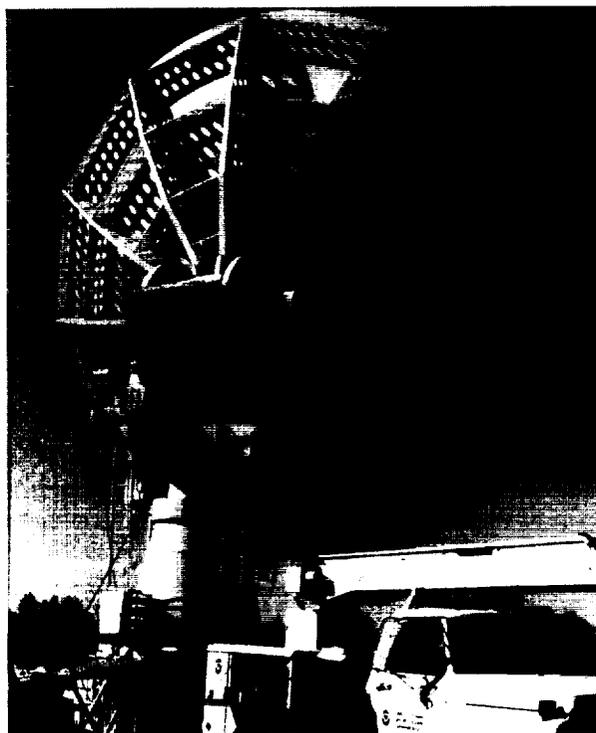


Figure 1. Yellowknife Geophysical Observatory 9 m VLBI Antenna

1. Overview

The Yellowknife VLBI antenna is a 9 meter diameter antenna which has had a very storied past. Formerly the "MV-1" mobile antenna, it 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 operated by the Geodetic Survey Division, Natural Resources Canada. The Yellowknife Geophysical Observatory is operated by the Geological Survey of Canada, Pacific Division, Natural Resources Canada.

2. General Specifications

- Latitude : 62.48 North
- Longitude : 114.48 West
- Reflector : 9 m
- Receiver : S and X cryogenic
- Azimuth speed : 40 degrees per minute
- Elevation speed : 40 degrees per minute
- PCFS version : 9.3.23
- VLBI equipment : Mark III and thick tape drive
- Time standard : NR Maser
- GPS receiver : Rogue

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 (December till March). Once spring arrives, the Yellowknife team prepares the antenna for the upcoming season.

Last summer there were difficulties with the antenna brakes getting stuck moments before the beginning of an experiment. This problem was addressed, and in the near future the Algonquin team will be travelling to Yellowknife to perform a complete check up of the antenna and the VLBI equipment. In addition, the old antenna control unit will be replaced with one similar to that at Algonquin.

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.

A repeat survey is planned to be conducted this year.

5. Yellowknife VLBI Team

The VLBI team in Yellowknife are working for the Geophysical Observatory of the Geological Survey of Canada. Their main work is to operate and maintain the seismic array. For the last few years, the VLBI team has included only two people to take care of the equipment and perform the experiments.

- George Jensen : (25%) electronics equipment
- William Outhwaite : (25%) VLBI logistics, site survey.

6. Operations 1998-1999

Last year Yellowknife was involved in five CORE-B experiments.

OPERATION CENTERS

From the Terms of Reference:

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.



The Bonn Geodetic VLBI Operation Center

A. Nothnagel

The GIUB VLBI Operation Center is located at the Geodetic Institute of the University of Bonn, Nussallee 17, D-53115 Bonn, Germany. In the past year the activities of the GIUB VLBI Operation Center were concentrated on the preparation and organization of several different observing programs:

- **International Radio Interferometric Surveying - South (IRIS-S)**
Twelve Sessions per year with the stations Wettzell, HartRAO, Fortaleza, Fairbanks and Westford.
- **Continuous Observations of the Rotation of the Earth - O'Higgins (CORE-OHIG)**
with stations HartRAO, O'Higgins, Fortaleza, Hobart, Kokee and DSS45 plus one session also including the Japanese Antarctic station Syowa.
- **Measurement of Vertical Crustal Motion in Europe by VLBI (EURO)**
(EU Project FMRX-CT960071)
Six sessions per year with the stations NyÅlesund, Onsala, Wettzell, Simeiz, Madrid (DSS65), Yebes, Medicina, Matera and Noto. Effelsberg and TIGO-WTZL participated occasionally.

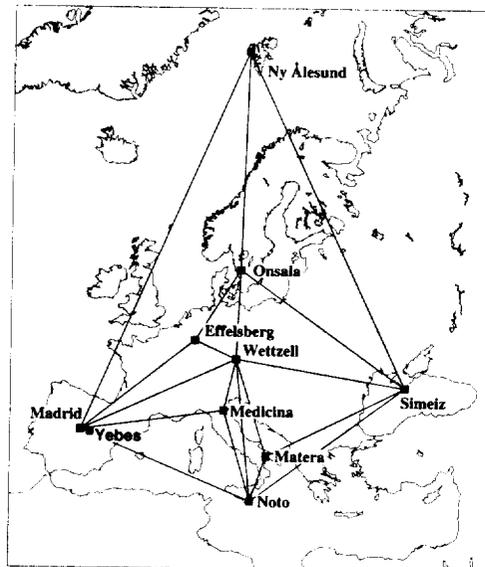


Figure 1. European VLBI network

- **Phase delay and polarization test**
with a subset of European stations (appended to two EURO sessions)

- **Wetzell local ties (WTIES)**

Two sessions between Wetzell 20-m telescope and TIGO-WTZL which are about 59 m apart

The operational tasks mainly consisted of preparing the detailed observing schedules for all sessions listed above. In addition, the dates and technical setups for the last two projects had to be organized while the dates for the first three series were fixed by the IVS CC. The schedules are prepared with the SKED software on HP-UX platforms.

One of the critical items which affects the preparation of the EURO sessions is radio frequency interference from television transmitters at Matera. At this site the receiver is saturated at some of the S-band frequency channels and bandwidth synthesis, therefore, can be performed only with a subset of the usual series of channels. This reduction in channels has adverse effects degrading the signal-to-noise ratio and often corrupting the delay observables. Therefore, new frequency sequences had to be investigated on several occasions. Recently, the interference frequencies have remained relatively stable and the current setup permits undisturbed observations at all frequency sub-bands.

Arno Müskens takes care of the IRIS-S and the CORE-OHIG sessions while Axel Nothnagel is responsible for the EURO project.

CORE Operations Center

Cynthia Thomas, Nancy Vandenberg

Abstract

This report gives an overall view of the CORE program at Goddard Space Flight Center (GSFC). It summarizes the different CORE sessions and gives information about the technical staff. The outlook summarizes the evolution of the different CORE programs.

1. CORE Program Description

The continuous observations of the rotation of the Earth (CORE) program was initiated by the geodetic very long baseline interferometry (VLBI) community in 1997. The program is being carried out using geodetic VLBI stations for data acquisition and VLBI analysis centers for data processing and analysis. The CORE program will evolve over the period 1997-2001.

The goal of the CORE program is to generate an Earth rotation data set of unprecedented time resolution and accuracy for Earth science and global change research. The program will continue to produce basic observational data for studies of the continuous momentum exchange among the solid Earth, the atmosphere, and the hydrosphere, enabling exciting research areas that heretofore have been impossible.

The current Earth orientation parameter goal of the CORE program is $3.5 \mu\text{s}$ for UT1 and $100 \mu\text{s}$ in pole position. The full CORE program has the potential for a typical precision of $1 \mu\text{s}$ in UT1 and $25 \mu\text{s}$ in pole position, for daily sessions with a 5-station network. These values are three times better than those measured weekly with the NEOS network and could be available daily.

The breakthrough in the availability of continuous, high accuracy Earth rotation data is possible due to the Mark IV technology that will become available in late 1999. Improved sensitivity in the Mark IV data acquisition system together with the high playback efficiency of the Mark IV correlator are both necessary to produce the proposed data.

CORE experiments were run with four basic network configurations: CORE-A, CORE-B1, CORE-B2, and CORE-B3 during 1997 and 1998. During 1999, the networks of the CORE-B sessions changed and the sessions were named CORE-B4, CORE-B5, and CORE-B6. The CORE-A sessions are simultaneous with NEOS sessions and CORE-B and NEOS sessions are on sequential days during both 1998 and 1999.

2. CORE Sessions During March 1998 to March 1999

This section displays the purpose of the CORE-A and CORE-B sessions and lists other programs used by CORE.

- CORE-A: These experiments validate the CORE concept of measuring EOP continuously using different networks. Comparisons of the EOP results from simultaneous sessions in 1997 and 1998 have shown fairly good agreement, but there are some puzzling systematic differences. It is hoped that additional data to be obtained during 1999 will contribute to understanding this data set.

The network for CORE-A included Fairbanks, HartRAO, Hobart, Algonquin, Matera and Westford during 1998. Medicina was added to the network during the first quarter of 1999. Tsukuba will be added to the network starting the second quarter of 1999.

- CORE-B: The purpose of these sessions is to provide additional data for comparison of EOP measurements, to obtain long 48-hour data sets for geophysical studies and to provide observing sessions during which the stations can demonstrate their performance and their ability to participate in future regular CORE sessions.

There is data from other programs established by Bonn (IRIS-S, CORE-OHIGGINS, and EUROPE), USNO (NEOS, NAVEX, CRF), and GSI (APSG) that are used by the CORE program. Some of the data is used to help determine the direction of the CORE program during its evolution.

3. Current Analysis of CORE

Comparisons of daily EOP estimates made by the CORE-A, CORE-B and NEOS networks show that there are systematic differences in EOP. There are statistically significant mean offsets of 147 μs , 85 μs , 3.7 μs between X, Y, and UT1 estimates, respectively, from the CORE-A and NEOS networks. Between NEOS and CORE-B, the UT1 difference of 10.6 μs is significant. The source of these differences is under active investigation.

One of the measures of performance of the CORE experiments is the size of the formal EOP uncertainties. The uncertainties range from about 70-100 μs for X-pole, 50-100 μs for Y-pole, and 2.5-3.5 μs for UT1. For most sessions, observed uncertainties are 20-50% greater than EOP uncertainties from simulations using scheduled observations and uncertainties. The observed uncertainties are generally less than the minimal goal of 100 μs for PM and 3.5 μs for UT1.

4. The CORE Family

Figure 1 shows a subset of the CORE family after a Wednesday staff meeting where we come together to discuss the various activities that have taken place during the week and the upcoming events.

Table 1 lists the key technical personnel and their responsibilities so that everyone reading this report will know who to contact about their particular question.

5. Evolution of CORE

Although the CORE observing program for 1999 is proceeding according to plan, the Mark IV correlator plan has changed. The correlator should be available on the planned schedule with Mark III capabilities, but it will not have many Mark IV capabilities until later this year. The Mark IV correlator capabilities that we need for the next step in the evolution of the CORE program are fan-out and increased processing efficiency.

Since the CORE-3 sessions, originally scheduled to start in July, require these capabilities, we delayed the start of CORE-3 until at least the fourth quarter of 1999. The start-up of CORE-3 in October will depend on the correlator capabilities and the performance of the new correlator during its shakedown period.

The start of the CORE-3 sessions will be the beginning of the true CORE program, recording



Figure 1. The CORE Operations Center Family listed from left to right starting with the back row: R. Gonzalez, C. Ma, B. Boyer, D. MacMillan, E. Himwich, B. Schupler, W. Wildes, D. Gordon, K. Refinetti, C. Kodak, K. Baver, N. Vandenberg, T. Clark, and C. Thomas. Please note that all of the CORE family members are not pictured.

Table 1. Key Technical Staff of the CORE Operations Center

Name	Responsibility	Agency
Tom Buretta	Recorder and electronics maintenance	Haystack
Brian Corey	Analysis	Haystack
Irv Deigel	Maser maintenance	ATSC
Frank Gomez	Software engineer for the Web site	Raytheon/STX
David Gordon	Analysis	Raytheon/STX
Ed Himwich	Network Coordinator for CORE stations	NVI, Inc./GSFC
Chuck Kodak	Receiver maintenance	ATSC
Cindy Lonigro	Analysis	Raytheon/STX
Dan MacMillan	Analysis	NVI, Inc./GSFC
David Shaffer	Sources and antenna parameter maintenance	Radiometrics/NVI, Inc.
Dan Smythe	Tape recorder maintenance	Haystack
Cynthia Thomas	Coordinate master observing schedule and prepare CORE experiments observing schedules	NVI, Inc./GSFC
Nancy Vandenberg	Organizer of CORE program and sked manager	NVI, Inc./GSFC
William Wildes	Procurement of materials necessary for CORE operations	GSFC/NASA

in high sensitivity Mark IV modes. The tentative CORE evolution plan for the next few years is summarized in Table 2.

We are working on identifying the participating stations for each new CORE network. We will need more antenna observing to fulfill this plan. The goal for CORE is continuous observing but we recognize that it will be very difficult to fill in the weekend days for CORE-5, -6, and -7. Weekend observing is costly both in funding and in inconvenience to operators. We would appreciate any ideas you have about how to attack this problem. Volunteers for weekend observing would be very welcome!

Table 2. Planned CORE Evolution

Start Date	Experiment Name	Avg Days per Week	Notes
1-Oct-1999	CORE-3 weekly	2.5	NEOS is on day 2
1-Jan-2000	CORE-4 bi-weekly	3.0	Discontinue CORE-A
1-Jul-2000	CORE-1 bi-weekly	3.5	Reduce to two CORE-B networks
1-Jan-2001	CORE-4 weekly	4.0	CORE-B networks as needed

References

- [1] Clark, T.: CORE White Paper, June 2, 1997

The U.S. Naval Observatory VLBI Program: Operations in 1998 and 1999

T.M. Eubanks, B.A. Archinal, F.J. Josties, J.R. Ray

Abstract

As part of its participation in the National Earth Orientation Service (NEOS) the U.S. Naval Observatory (USNO) operates a program in Very Long Baseline Interferometry (VLBI) data acquisition and analysis to monitor changes in the orientation of the Earth on a regular basis. This report provides details both of recent NEOS VLBI operations and intensive operations.

1. VLBI Operations

Current NEOS operations consist of one 24-hour duration NEOS-A observing session, on Tuesday-Wednesday of each week, for Earth orientation, together with daily one-hour duration "intensives" for UT1 determination. The operational NEOS-A network currently includes the VLBI stations at Gilmore Creek (Alaska), Kokee Park (Hawaii), Wettzell (Germany), Fortaleza (Brazil), Ny-Ålesund (Norway), Algonquin Park (Canada), and Green Bank (West Virginia), although at most six stations observe in any one observing session. Nominal operations divide the NEOS since NEOS-A-193 on January 7th, 1997, into "even" NEOS and "odd" NEOS sessions on alternate weeks. (These names arise from the parity of the sequential numbers of these sessions.) The Kokee Park, Wettzell, Fortaleza, and Green Bank stations nominally participate in all NEOS sessions, while Ny-Ålesund participates in the even sessions, and Gilmore Creek participates in the odd sessions, as does Algonquin Park on a roughly once per month basis. The principal reason for this division is to enable the scheduling of simultaneous CORE-A sessions by the NASA Goddard VLBI group, which are always scheduled during even NEOS sessions. All NEOS sessions are routinely processed in time for the next *IERS Bulletin A* on the following Thursday. The databases from these sessions are freely shared with the VLBI community and are contributed to the IVS data centers as soon as they are processed.

The NEOS VLBI data are correlated at the Washington Correlator, which is located at the U.S. Naval Observatory and run by the NEOS. After correlation, fringe fitting, and the removal of any remaining bandwidth synthesis delay ambiguities, data from all available multiple baseline VLBI sessions are used in a series of weighted least-squares solutions to define a USNO VLBI reference frame and to estimate the Earth orientation within that reference frame. An empirically adjusted station velocity model is used in order to adequately model the tectonic motion of the stations over the 20 years of available data, and antenna axis offsets are also adjusted. Details of previous VLBI operations at the USNO are given in the *IERS Annual Report* for 1997 [1].

2. UT1 Intensive Operations

The USNO has operational responsibility for the IRIS / NEOS UT1 Intensive Series. These short-duration single-baseline observations are being continued using the same scheduling and observing procedures as before to ensure continuity with previous results. A nominal intensive session during 1998 and 1999 involved 20 delay observations conducted on the Green Bank NRAO20

to Wettzell baseline. These observations are conducted at the same sidereal time each day, except during the NEOS 24-hour sessions and on Sunday. Starting in 1996, roughly every two months the sidereal time of the intensives is shifted to keep their solar times between 1400 and 1800 UTC. Sunday intensives are not presently observed due to budget restraints; however, two intensives are observed on Saturday. The second Saturday intensive uses the schedule intended for the next intensive series, four hours later in sidereal time, in order to provide a set of overlapping, nearly simultaneous, intensives for each pair of intensive schedules. All of the Intensive data is reduced rapidly, typically within four to seven days of the time of acquisition of data, and the NEOS/IRIS UT1 Intensive files produced by the USNO now extend back to 1984 in one homogeneous solution.

References

- [1] The USNO Annual Report for 1997 is obtainable from
ftp://casa.usno.navy.mil/navnet/iers_report.97.

CORRELATORS

From the Terms of Reference:

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.



The Bonn Astro/Geo Mark IIIA Correlator

Axel Nothnagel, Arno Müssens, Mauro Sorgente

The Bonn Astro/Geo Correlator is located at the Max-Planck-Institute for Radio Astronomy, Auf dem Hügel 69, D-53121 Bonn, Germany. The Bonn Astro/Geo Correlator is a joint activity of the Max-Planck-Institute for Radio Astronomy, Bonn, of the Bundesamt für Kartographie und Geodäsie, Frankfurt a.M., and of the Geodetic Institute of the University of Bonn sharing the responsibilities for acquisition, maintenance and operation.

Currently, geodetic correlations are scheduled for 40% of the operation time and 60% are used for astronomical experiments. The routine correlation tasks, mainly starting computer programs and changing tapes, are performed by up to four under-graduate students providing on average about 50 hours of operational geodetic correlations per week. Arno Müssens and Mauro Sorgente set up the necessary computer files, do fringe search and supervise the students. They are also responsible for additional more sophisticated correlation tasks which require more knowledge and experience.



Figure 1. Bonn Correlator: Tape Drive Section

The following projects have been correlated at the Bonn correlator during the last year:

- **International Radio Interferometric Surveying - South (IRIS-S)**
Twelve Sessions per year with the stations Wettzell, HartRAO, Fortaleza, Fairbanks and Westford
- **Continuous Observations of the Rotation of the Earth - O'Higgins (CORE-OHIG)**
with stations HartRAO, O'Higgins, Fortaleza, Hobart, Kokee and DSS45 plus one session also including the Japanese Antarctic station Syowa
- **Measurement of Vertical Crustal Motion in Europe by VLBI (EURO)**
(EU Project FMRX-CT960071)

Six sessions per year with the stations NyÅlesund, Onsala, Wettzell, Simeiz, Madrid (DSS65), Yebes, Medicina, Matera and Noto. Effelsberg and TIGO-WTZL participated occasionally.

- **Phase delay and polarization test**

with a subset of European stations (appended to 2 EURO sessions)

- **Wettzell local ties (WTIES)**

Two sessions between Wettzell 20-m telescope and TIGO-WTZL which are about 59 m apart

The Bonn Astro/Geo Mark III Correlator is a shared correlator consisting of two blocks of correlator modules for 6 · 14 tracks and 12 · 14 tracks permitting simultaneous correlation in mode C of 3 and 12 baselines, respectively. However, only 10 baselines are correlated routinely in one pass of the 12-crate correlator due to organizational and data flow limitations. The three-baseline correlator is only used for fringe search and sessions which need only a limited number of correlator crates. The data flow and hardware are controlled by HP1000F and HP1000-A900 computers. Eight Metrum/Honeywell playback drives may be switched between correlator units for efficient use of resources. The correlator output is temporarily stored on HP1000F system disks for subsequent transfer to a HP9000-7xx HP-UX computer for fringe fitting, archiving, and export.



Figure 2. Bonn Correlator: Correlator Modules

After their release and degaussing the Mark IIIA tapes are sent back to the observatories for further recordings. At present two types of tapes are in use, regular tapes and extra thin tapes with double recording capacity. In order to keep the wear of the recording magnetic heads low, only one type of tape should be used at a station throughout. However, there is a shortage of thin tapes causing a large discrepancy between tapes requested by the observatories and those being sent to the Bonn correlator. The lack of thin tapes requires additional transportation of tapes from the US correlators to observatories to compensate for the regional imbalance of thin tape supplies. Additional thin tape purchases by BKG are urgently envisaged.

Within the next year the current Mark IIIA correlator will be replaced by a Mark IV correlator for nine stations. The existing playback tape drives have already been upgraded with Mark IV/VLBA style control electronics (32 tracks) and thin tape capability. The infrastructure for the new correlator is being completed and the delivery of the correlator modules is expected soon.

The Haystack Observatory VLBI Correlator

Mike Titus, Brian Corey, Arthur Niell

Abstract

The Haystack Observatory VLBI Correlator supports the IVS by processing approximately 25 geodetic experiments per year. In the coming year the Mark IV correlator will become operational. This will permit increased geodetic VLBI observing time by allowing higher correlator throughput.

1. Introduction

The Haystack Observatory Mark IIIA VLBI correlator [1], located in Westford, Massachusetts, is supported by the NASA Space Geodesy Program and by the National Science Foundation. The available correlator time is divided approximately equally between processing geodetic VLBI observations for IVS and processing millimeter-wave radio astronomy observations for the Coordinated Millimeter VLBI Array. In addition to its role as an operational processor, the Haystack correlator also serves as a development system for testing new correlation modes and hardware improvements and for diagnosing correlator problems encountered either at Haystack or at one of the identical correlators at the U.S. Naval Observatory or at 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.

2. Correlator Operations

The Mark IIIA correlator at Haystack is designed to process simultaneously up to eight stations and 10 baselines with 14 single-sideband frequency channels each. Due to the competing hardware demands from the Mark IV correlator [2] development in the past year the available equipment of the operational correlator has had to be reduced somewhat. Currently eight baselines can be correlated from among six stations. The six tape drives are a mixture of Mark IIIA and Mark IV. The correlator configured for seven stations is shown in Figure 1.

Approximately 90% of the correlator time allocated to the IVS is used for setup and production processing of CORE experiments. The remaining 10% is used for such tasks as correlating fringe checks to test station performance after field equipment changes, testing Mark IV formatters for field certification, processing comparison tests between the Mark IIIA and Mark IV correlators, testing headstacks for viability in field use, and correlating other geodesy-related observations, such as the Mars Global Surveyor and Pathfinder astrometry experiments.

Over the past year 20 CORE B sessions and ten special experiments were processed at the Haystack Mark IIIA correlator.

3. Staff

The following Haystack personnel are involved with correlator activities.

Peter Bolis - correlator maintenance

Tom Buretta - playback drive maintenance

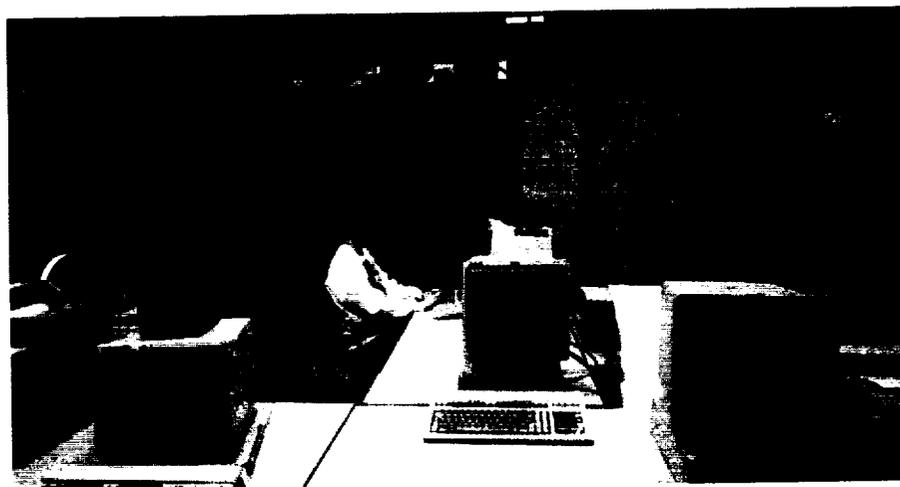


Figure 1. The Mark IIIA Correlator at Haystack Observatory.

Dr. Roger Cappallo - correlator models and control software

Dr. Brian Corey - experiment correlation oversight; station evaluation; technique development

David Fields - playback drive maintenance

Ellen Lautenschlager - correlator operator

Dr. Colin Lonsdale - correlator post-processing software

Glenn Millson - correlator operator

Ed Nesman - correlator maintenance

Dr. Arthur Niell - experiment correlation oversight; technique development

Don Sousa - correlator operator; experiment setup; tape library and shipping

Mike Titus - correlator operations oversight; experiment setup; computer services

Dr. Alan Whitney - correlator architect for Mark III, IIIA, and IV

4. Outlook

We expect to continue the current mode of operation for most of 1999. During the latter part of the year we will make the transition to processing on the new Mark IV correlator. This transition will be the most significant since the introduction of the Mark III system in the early 1980s. We expect a prolonged adjustment period since practically every aspect of operations will change. Although this transition will likely result in reduced efficiency initially, we expect it will provide an opportunity to re-evaluate procedures which will improve the quality and level of service provided to the community in the longer term.

References

- [1] Whitney, A. R.: Capabilities and Performance of the upgraded Mark III Correlator System, IAU, The Earth's Rotation and Reference Frames for Geodesy and Geodynamics, 429-437, 1988.
- [2] Whitney, A. R.: The Mark IV VLBI Data-Acquisition and Correlation System, In: Developments

in Astrometry and Their Impact on Astrophysics and Geodynamics, edited by I.I. Meuller and B. Kolaczek 151-157, 1994.

Key Stone Project VLBI Correlation Center

Mamoru Sekido, Yasuhiro Koyama

Abstract

Communications Research Laboratory has developed two sets of correlator systems at Koganei, Tokyo for the Key Stone Project. One is for tape-based VLBI observations and the other is for real-time VLBI observations. The overview of the correlator systems will be described in this report.

1. Introduction

Communications Research Laboratory (CRL) has been doing regular geodetic VLBI experiments to monitor crustal deformation around Tokyo metropolitan area. The project was named as Key Stone Project (KSP) [1] and the correlator facilities have been developed at Koganei, Tokyo for the project. Two modes of VLBI observations are possible, one is a tape-based VLBI mode [2] and the other is a real-time VLBI mode [3]. The tape-based VLBI observation mode uses ID-1 standard cassette type magnetic tapes to record observed data. In the real-time VLBI observation mode, observation stations and correlator system are connected via high speed Asynchronous Transfer Mode (ATM) network which has been established under collaboration with the Nippon Telegraph and Telephone Corporation (NTT). Technical details of each system are described in Section 2.

The KSP VLBI correlation system is supposed to be routinely operated by persons who are not familiar with VLBI data processing. Therefore, a man-machine interface with GUI was developed for easy operations of the system. Since an operator is on duty only in daytime, the system is designed so that 24 hours of continuous correlation processing magnetic tapes can be performed without the help of an operator once the process is started. The developments of the real-time VLBI correlation system advanced the automation further. In principle, once the real-time correlation processing software (RKATS) is run, the software selects the schedule file of the day and performs correlation processing continuously without any human operations for unlimited days. At the same time, bandwidth synthesis procedures run to process correlator output data. After all the observations in an experiment are finished, Mark III database files are created and the data analysis processes are executed automatically. After all the required procedures are finished for an experiment, the correlator system starts to wait for the next schedule to be executed [4].

Although the KSP correlation system is designed for regular operations with the KSP VLBI stations, the system can also process general VLBI experiment data recorded in the K4 data format. In fact, several kinds of international VLBI experiments have been processed with the KSP tape-based VLBI correlator system. In addition, the real-time VLBI experiments with Nobeyama (Nobeyama Radio Observatory) and Usuda (Institute of Space and Aeronautical Science) have already been successful with optically linked ATM network as described in section 4.

Table 1. Hardware Components of tape-based KSP correlation system

Device name	Functions
Correlator	Correlation processing, correlator model calculation.
DIR-1000	Data play back unit of K4 cassette type magnetic tape.
DFC-2200	Data output for correlator and synchronization of data stream.
DMS-24	Automatic tape changer; 24 ID-1 cassette tapes can be mounted.
Correlation Controller	Controls correlation processing hardware.
Workstation	Provides GUI environments for operators and management of the correlation processing, bandwidth synthesis, and generation of the Mark-III database files.

2. Technical Characteristics

2.1. The KSP Tape-based VLBI Correlation System

The KSP VLBI correlation system is capable of processing six baselines between four stations simultaneously. The appearance of the correlation system is shown in Figure 1.



Figure 1. The KSP tape-based VLBI correlation system at Koganei, Tokyo. The left two racks are automatic tape changer (DMS-24). The right three racks contains correlators, output interfaces, and correlation controller.

The system consists of six sets of single baseline correlators, automatic tape changer units (DMS-24), K4/KSP data recorders (DIR-1000), output interface units (DFC-2200), a correlation controller and a host workstation. Function of each hardware is summarized in Table 1.

Two correlator hardware systems are identical which is developed over VME based digital signal processors. The technical parameters of the correlator system are shown in Table 2.

The correlation process control software (KATS) runs on HP-UX host workstation and provides GUI environment for operation of correlation processing [5]. The correlation processing, bandwidth synthesis procedure, and Mark III database creation are performed just by using mouse clicks and

Table 2. Parameters of the KSP correlator system.

Total data rate	64 Mbps, 128 Mbps, 256 Mbps
Number of Channels	16
Number of lags per channel	32
Control Bus	GPIB
Data Output Method	Ethernet (NFS)

several key strokes on the GUI. Then schedule file and log files can be obtained through the network.

2.2. The KSP Real-time VLBI Correlation System

The KSP real-time VLBI system uses the ATM network over 2.4 Gbps optical fiber instead of magnetic tapes for data transportation. The advantages of the real-time VLBI system are summarized as follows.

1. Fully automated VLBI correlation processing can be realized.
2. Since correlation process is done simultaneously with observation, it is possible to monitor the fringes at real-time.
3. Results of the data analysis can be placed in publicly accessible area in less than one hour after the end of experiment.

The real-time VLBI correlation system also has the capability of processing six baselines between four stations. Two correlator systems are identical. Instead of data recorders (DIR-1000), automatic tape changer units (DMS-24), and output interface units (DFC-2200) which are used in the tape-based system, ATM receivers and ATM VLBI interfaces have been used in the real-time VLBI system.

3. Technical Staff for the KSP VLBI Correlation Center

Technical staff members who are contributing KSP correlation center are listed below.

- Tetsuro Kondo, Responsible for overall operations and performance.
- Taizoh Yoshino, Leader of the Key Stone Project team in CRL.
- Hitoshi Kiuchi, Developments of correlation system and real-time VLBI interfaces.
- Mamoru Sekido, Development of correlation processing software.
- Jun Amagai and Kouichi Sebata, Responsible for management of correlation center.
- Naoki Goto and Muneo Takeda, Operator at the correlation center, Space Engineering Development Co., Ltd.

4. Current Status and Future Plans

The KSP real-time correlation system has been used for regular real-time geodetic VLBI experiments once every two days. Unfortunately the KSP Miura station will be unlinked from the KSP

ATM network in May 1999. From that time, regular real-time VLBI experiment will be performed among the three KSP stations, and tape-based 24 hours VLBI experiments including the Miura station will be performed once every six days.

The tape-based KSP correlation system has been used for processing of several kinds of international VLBI experiments. One of them is colocation aimed experiments which include Kashima 34 m antenna and several foreign stations besides the KSP observation stations.

The Key Stone Project ATM network was connected with Kashima 34 m antenna, Usuda 64 m antenna (operated by Institute of Space and Astronautical Science) and Nobeyama 45 m antenna (operated by Nobeyama Radio Observatory). By using these networks, astronomical radio source survey programs have been performed occasionally when geodetic regular VLBI experiments are not scheduled. The observed data are transferred to Koganei KSP correlation facilities and are processed with the KSP real-time VLBI system.

References

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Tsukuba VLBI Center

*Misao Ishihara, Keizou Nemoto, Masao Iwata, Kousei Shiba, Kazuhiro Takashima,
Shigeru Matsuzaka*

Abstract

This report summarizes the technical parameters and the technical staff of the Geographical Survey Institute (GSI) VLBI section. We present our history of VLBI activities and the status. In 1998 GSI opened Tsukuba VLBI Center as an operation, correlation and analysis center. GSI installed a new correlator system for three stations - three baselines. The correlator unit and the software which controls the each unit have been developed as a KSP correlator in Communication Research Laboratory (CRL).

1. GSI VLBI Correlators

GSI has two different correlator systems. One is OKIVLBC-9100 (NAOCO) which was installed in March 1993. The correlator was developed in National Astronomical Observatory (NAO) and was made by Oki Corp. Ltd. The strong points of the correlator are the equipment for K4 system, 128Mbps maximum process speed, maximum 8192 lag windows and portable equipment. GSI installed it as one baseline correlator.

Another is the CRC-9403 which was installed in March 1997 for multiple baseline to cope with the expansion of the domestic VLBI network. GSI was also equipped with the latest hardware and software for automatic correlation from the point of labor saving.



Figure 1. The K4 correlater at Tsukuba VLBI center

2. Specification of GSI K4 Correlator

GSI has a K4 correlator for multi-baseline correlation. The specification of GSI's K4 correlator are presented.

1. The equipment of correlation process : CRC-9403-CR2
 - 3 stations and 3 baselines
 - process maximum speed at 512 Mbps
2. The equipment of data input : CRC-9403-DT2, Sony-DFC-2200
 - Devidable for CRC-9403-CR2 from K4 Digital Recorder
 - Automatic synchronization with each channel data
3. System controller : CRC-9511-CNT1
 - Function of automatic correlation process
4. Computer : HP9000/D370
 - OS : HP-UX10.2
 - CPU : PA-RISC, PA-8000
 - main memory : 1,024 MB
 - cash memory : 256 MB
 - internal HDD : 10 GB
 - external HDD : 400 GB RAID5
5. Application : Kety KUS880419
 - Support "automatic control" mode
6. Monitor for recording data : CRC-9703-MON1
 - Fourier transform for output data by FFT
 - number of FFT point : 128 - 16,384 points
 - calculation accuracy : 8 bits fixed-point

3. Technical Staff of the VLBI group at GSI

Table 1 lists the VLBI staff at GSI.

4. Status of GSI Correlator

We process the geodetic observation data which are recorded in the domestic permanent sites (Tsukuba, Kashima, Shintotsukawa, Aira and Chichijima) using the GSI correlator. We also process the antarctic observation data of Syowa station for the detection of fringe.

Table 1. Staff working at VLBI section at GSI

Name	Position	Jobs
Shigeru MATSUZAKA	IVS Networks Representative	
Misao ISHIHARA	VLBI leader	
Keizo NEMOTO	Colocation chief	H-meser, operation
Masao IWATA	Correlation chief	Correlation, operation
Kousei SHIBA	Operation chief	Coordination Experiments, operation
Kazuhiro TAKASHIMA	Analysis chief	Baseline Analysis, operation
Shinobu KURIHARA	Operator	Baseline Analysis, operation
Michiko ONOGAKI	Operator	antenna maint., operation
Kyoko KOBAYASHI	Assistant	correlation, operation



Figure 2. GSI VLBI Center is located on the second floor in the building

5. Outlook

GSI has a plan to analyze the five domestic permanent station data and the mobile station data for geodesy. GSI also will process the data for the Syowa station. In 1999, Tsukuba VLBI station will participate in Tsukuba-Wetzell Intensive experiments for UT1. These data will be correlated by GSI K4 correlator because K4 recording system will be used for the experiments.

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Washington Correlator

James O. Martin

Abstract

The report summarizes the work of the Washington Correlator for the year ending March, 1999. The Washington Correlator is dedicated to processing geodetic VLBI for the purpose of providing data for Earth orientation parameters, the radio reference frame, the terrestrial reference frame and related information.

1. Introduction

The Washington Correlator (WACO) is located at 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. The Washington Correlator is dedicated to processing geodetic VLBI, spending at least 90 percent of its time in that role. All of the weekly NEOS-A sessions and daily intensives are processed at WACO, as are most of the bi-weekly CORE-A sessions. The remaining time is spent on reference frame sessions and a few astrometry experiments. WACO currently utilizes a Mark IIIA correlator designed and built by Haystack Observatory that has been operating continuously at USNO since 1986. We anticipate replacement of the existing correlator with the Mark IV correlator in the coming year with concomitant increase in throughput.

2. Correlator Operations

The Washington Correlator, in its present configuration, is shown in Figure 1. With six playback units and 10 crates (14 modules each), it can process up to six stations and 10 (Mark III mode C) baselines at one time. Larger sessions can be accommodated by processing in several passes. WACO also has the capability of splitting the correlator into two systems that can process two sessions at one time, although that capability has not been used during the last year. During the reporting period, four of the playback units at WACO were Mark IV upgrades and two were older style Mark IIIA units. Five playbacks can process thin tape, but only the four Mark IV drives can accommodate high density (56 kbit/inch) recordings.

NEOS-A processing is given priority at WACO. The weekly sessions and intensives are processed as soon as the tapes arrive with all of the participating stations shipping their tapes via express delivery services. The weekly sessions (5-6 stations) are exported 7-8 days after the observation ends and the intensives (two stations) in 2-5 days. The CORE-A sessions, which are processed in the remaining time and use conventional shipping, are prepassed as soon as all tapes have arrived, but are exported with a lag of at least a month. Reference frame sessions are processed on overtime and weekend shifts. The operational budget provides for a basic 80 hours of processing per week with provision for additional 56 hours of overtime if required. During the reported period the Washington Correlator operated to capacity and now carries a backlog of at least one month.

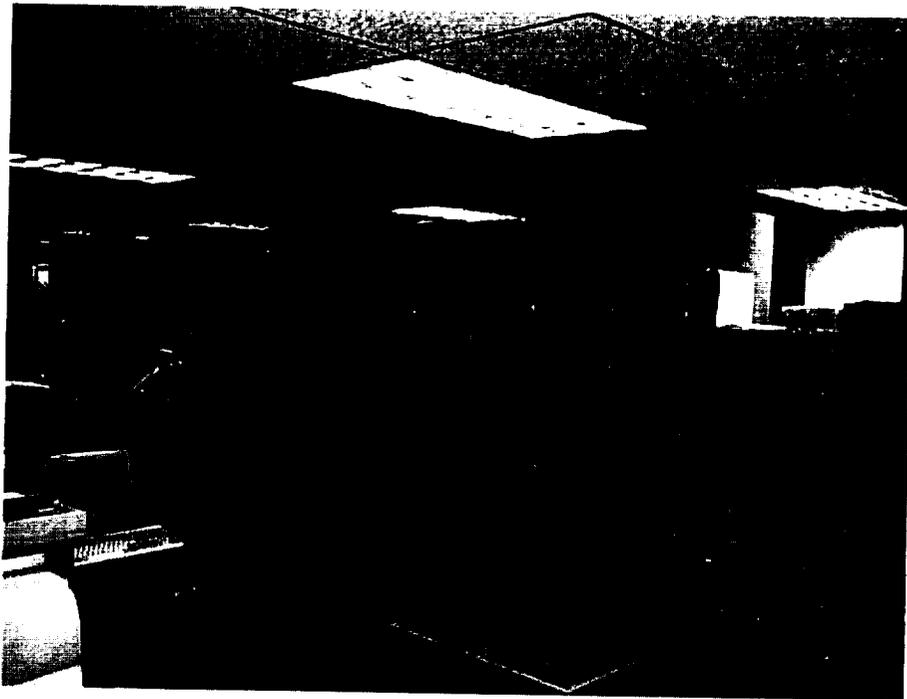


Figure 1. The Washington Mark IIIA Correlator

3. Washington Correlator Staff

The Washington Correlator is under the management and scientific direction of the Earth Orientation Department of the U.S. Naval Observatory. USNO personnel are responsible for oversight of scheduling and processing at WACO including: set-ups, data evaluation, exporting, archiving, correlator testing, software and hardware maintenance, and development efforts as well as contacts with the VLBI community.

The daily operation of the correlator is carried out by a private contractor, AMSC, which supplies a contract manager and correlator operators.

Dr. Kerry Kingham (USNO) - VLBI Correlator Project Scientist, responsible for scientific integrity of correlated data, hardware and software maintenance and upgrades.

James O. Martin (USNO) - VLBI Correlator Project Manager, responsible for process scheduling and evaluation of data. Oversees session set-ups, and prepases. Evaluates station performance.

Bruce Thornton (AMSC) - Operations Manager, responsible for correlator operator scheduling, daily operations, tape shipping.

Harvis Macon (AMSC) - Correlator operator, NEOS-A set-ups.

Valerie Bockarie (AMSC) - Correlator Operator

Michelle Diaz (AMSC) - Correlator Operator

Steven Springer (AMSC) - Correlator operator

Bosun Balogun (AMSC) - Tape librarian

4. Status of the Washington Correlator

The Washington Correlator was fully loaded and operated at capacity up to 136 hours per week, during the reporting period. Currently, four drives are thin tape/high density; four drives have mode A capability, two have only mode C. The four Mark IV drives have excellent playback characteristics, the two Mark IIIA drives are less sensitive and are subject to higher error rates. All ten correlator crates are fully operational. The correlator is controlled by the original (now 15 year old) HP1000 computer but all correlator output is handled by a UNIX workstation (CygX3) utilizing the Haystack Operational Postprocessing Software System (HOPS). This permits efficient data evaluation, exporting and archiving on a system that will easily integrate into the new Mark IV correlator system.

The replacement Mark IV correlator was expected at the end of 1998 but delivery was delayed because of development problems with the station units. As a result, sessions that would have been correlated at WACO, using the higher capacity of the Mark IV correlator, had to be canceled. The delayed delivery of the Mark IV correlator has also postponed plans to reduce the backlog of sessions waiting correlation.

5. Outlook

Plans for the coming year at the Washington Correlator are highly dependent on the final development and delivery of the Mark IV correlator. The correlator crates and boards are now in place at WACO but no further progress can be made until the problems with the station units can be resolved. When the Mark IV correlator is fully operational at WACO, hopefully before the end of 1999, we will use the increased capacity to reduce the backlog and process an expanded IVS observing program. The new correlator is expected to operate at double speed and will be able to process all 15 baselines on a six-station session. Within two years we anticipate adding two more playback units at which time we will be able to process all 28 baselines at once or divide the correlator to process as many as four difference sessions at once. Until then, the Mark IIIA correlator will continue to operate. In any event, before the fall of 1999, WACO should have all six drives upgraded to Mark IV, with mode A, thin tape, high density capability.

DATA CENTERS

From the Terms of Reference:

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.



BKG Data Center

Volkmar Thorandt

1. Technical Description

available VLBI data: 3450 X-Band databases
 3300 superfiles
 covered span of time: September 1976 - March 1999

2. Staff Members

	background	responsibility
Volkmar Thorandt	mathematics	group leader
Dieter Ullrich	cartography	data analysis
Reiner Wojdziak	computer science	data flow, web design

3. Current Status

Technical Equipment for VLBI purposes

- HP 9000/755 (HP UNIX 9.01)
- HP 9000/D280/1 (HP UNIX 10.20)
- HP 9000/735 CONVEX (HP UNIX 9.03), eight processors
- disc space: 35 GBytes
- jukebox: 18 GBytes
- internet rate: 128 KBit/sec

4. Outlook

- set up of the IVS data structure
- input area for analysis centers
- public access to the IVS data
- mirroring of the data centers CDDISA and OPAR
- mirroring of the IVS website (<http://www.leipzig.ifag.de/IVS/>)
- upgrade of the available disc space
- increase of internet rate (2 MBit/sec)

Data Center at Communications Research Laboratory

Yasuhiro Koyama

Abstract

Functions of the IVS Data Center at Communications Research Laboratory is integrated in the Key Stone Project VLBI data analysis system. Databases and analysis results of the Key Stone Project VLBI experiments are archived and disseminated to researchers from the data server.

1. Introduction

As a data center of the IVS, Communications Research Laboratory (CRL) holds and archives data obtained from the geodetic VLBI experiments organized by CRL. Major parts of the data are from the Key Stone Project VLBI experiments [1] but other regional and international VLBI experiments are also included. The analysis results of the experiments performed before October 1992 were summarized in a data analysis report published by CRL [2]. The VLBI experiments with the Key Stone Project VLBI stations began in August 1994 and the analysis results and databases are archived and disseminated to interested users over the network.

2. Data Products

The first Key Stone Project VLBI experiment was performed in August 1994, and the almost daily experiments began in January 1995. At the beginning of the daily observations, duration of the experiments was about six hours. The duration of the experiments was increased to about 23.5 hours to improve the quality of the results in September 1997. At the same time, the frequency of the experiments was decreased from daily to alternate days, instead. Table 1 and Figure 1 show how the number of experiments and valid number of observed delay for each year. Number of experiments was decreased in 1998 but the number of observations was increased substantially.

Table 1. Number of experiments and observed delay used in the data analysis as of March 1, 1999.

Year	Number of experiments	Number of valid observed delays
1994	2	261
1995	172	15837
1996	344	66005
1997	306	287452
1998	183	473864
1991	29	81780
Total	1036	925199

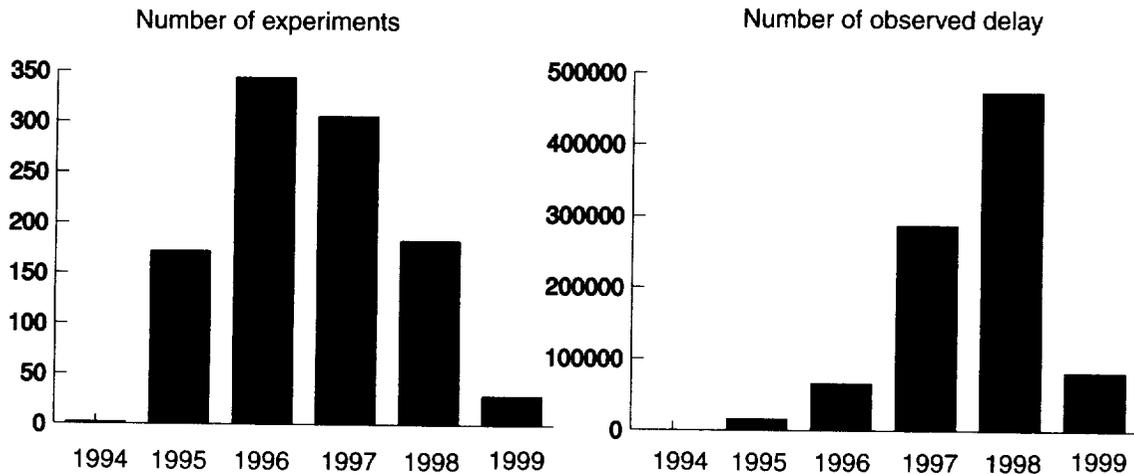


Figure 1. Number of experiments and observed delay used in the data analysis as of March 1, 1999.

3. Technical Staff for the KSP VLBI Data Center

Technical staff members who are contributing data analysis at the CRL are listed below. In principle, no operations are necessary for the regular VLBI observations of the Key Stone Project VLBI network.

- Tetsuro Kondo, Responsible for overall operations and performance.
- Yasuhiro Koyama, Development of various software.
- Jun Amagai and Kouichi Sebata, Maintenance of data server system.
- Naoki Goto and Muneo Takeda, Operator at Koganei station, Space Engineering Development Co., Ltd.

4. Current Status and Future Plans

CRL is also maintaining a mirror site of the WWW homepage for IVS. Those who are geographically close to Japan are encouraged to access the mirror site at <http://ivs.crl.go.jp/mirror/>. The analysis results and detailed explanations of the Key Stone Project are available at <http://ksp.crl.go.jp/>. From the site, the rapid estimates of the Earth's rotation parameters and the variation of the flux densities of the observed sources in the term of correlated amplitudes are also available. At present, the analysis results are described in a format defined by CRL, but the use of the SINEX (Solution Independent Exchange) format is currently planned as of March 1999.

References

- [1] Taizoh Yoshino: Overview of the Key Stone Project, J. Commun. Res. Lab., Vol. 46, No. 1, pp.3-6, March 1999

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- [2] Tetsuro Kondo, Jun Amagai, Yasuhiro Koyama, and Kosuke Heki: Data analysis of geodetic VLBI organized by the Communications Research Laboratory, October 1992
 - [3] Yasuhiro Koyama, Noriyuki Kurihara, Tetsuro Kondo, Mamoru Sekido, Yukio Takahashi, Hitoshi Kiyuchi, and Kosuke Heki: Automated geodetic Very Long Baseline Interferometry observation and data analysis system, *Earth Planets and Space*, Vol. 50, pp.709-722, 1998
 - [4] Yasuhiro Koyama, Kosuke Heki, and Yukio Takahashi: KSP VLBI System; Data Analysis Software, *J. Commun. Res. Lab.*, Vol. 46, No. 1, pp.77-81, 1999

CDDIS Data Center Summary

Carey Noll

Abstract

This report summarizes the current and future plans of the Crustal Dynamics Data Information System (CDDIS) with respect to the International VLBI Service for Geodesy and Astrometry (IVS). Included 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 current and future plans for the system's support of the new International VLBI Service for Geodesy and Astrometry are discussed below.

2. Background

The CDDIS has been operational since September 1982, serving the international space geodesy and geodynamics community. This data archive was initially conceived to support NASA's Crustal Dynamics Project; since the end of this successful program in 1991, the CDDIS has continued to support the science community through NASA's Space Geodesy Program (SGP) and the Solid Earth and Natural Hazards (SENH) activity. The main objectives of the CDDIS are to store all geodetic data products acquired by NASA programs in a central data bank, to maintain information about the archival of these data, and to disseminate these data and information in a timely manner to authorized investigators and cooperating institutions. Furthermore, science support groups analyzing these data submit their resulting data sets to the CDDIS on a regular basis. Thus, 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, 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://cddisa.gsfc.nasa.gov/cddis.welcome.html>.

The CDDIS successfully responded to the 1998 Call for Participation in the International VLBI Service for Geodesy and Astrometry (IVS). This response stated that the CDDIS would support data center activities by providing access to an archive of schedule files, log files, data bases, data products, and other auxiliary files.

3. System Description

The CDDIS archive of VLBI data and products are accessible to the public via anonymous ftp access.

3.1. Computer Architecture

The CDDIS is operational on a dedicated Digital Equipment Corporation (DEC) AlphaServer 4000 running the UNIX operating system. This facility currently has over 300 Gbytes of on-line magnetic disk storage; approximately 25 Gbytes will be devoted to VLBI activities. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is accessible to users 24 hours per day, seven days per week.

3.2. Staffing

Currently, all CDDIS activities are supported by a staff consisting of one NASA civil service employee and three contractor employees as shown in Table 1 below.

Table 1. CDDIS Staff

Name	Position
Ms. Carey Noll	CDDIS Manager
Dr. Maurice Dube	Head, CDDIS contractor staff and senior programmer
Ms. Ruth Kennard	Request coordinator
Ms. Laurie Batchelor	Data technician

4. 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. In brief, an incoming data area has been established on the CDDIS host computer, cddisa.gsfc.nasa.gov. Operation and Analysis Centers deposit data files and analyzed results using specified file names. Automated archiving routines, currently in development and testing by GSFC VLBI staff, peruse the directory and migrate any new data to appropriate directories in the public disk area. These routines migrate the data based on the file name as described in Table 2. Index files in the main subdirectories under /vlbi are updated to reflect data archived in the filesystem. Furthermore, mirroring software has been installed on the CDDIS host computer, as well as at the other primary IVS Data Centers, to facilitate equalization of data and product holdings among these data centers. Figures 1 and 2 illustrate the flow of data and products within the various IVS components.

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 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.

Table 2. IVS Data and Product Directory Structure

Directory	Description
Data Directories	
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
Product Directories	
vlbi/ivsproducts/crf	CRF solutions
vlbi/ivsproducts/eopi	EOP-I solutions
vlbi/ivsproducts/eops	EOP-S solutions
vlbi/ivsproducts/trf	TRF solutions
Other Directories	
vlbi/ivscontrol	IVS control files (master schedule, etc.)
vlbi/ivsdocuments	IVS document files (solution descriptions, etc.)

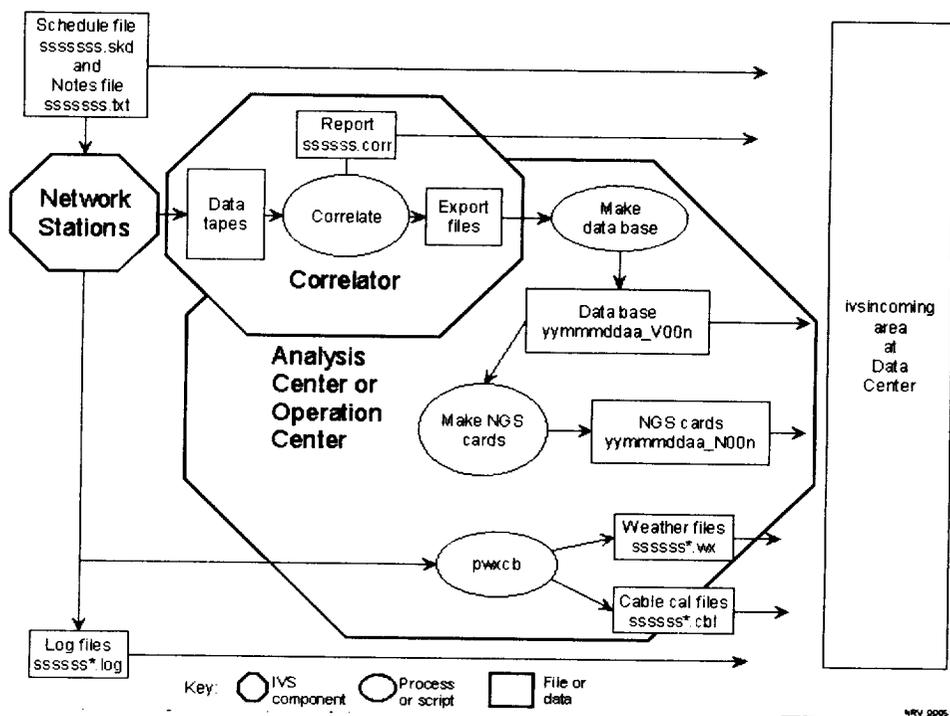


Figure 1. The flow of data and log files from various IVS components to the IVS data centers (Draft).

5. Future Plans

Much of the coming months will be devoted to developing and testing of the software for automated archiving and mirroring between data centers. Although CDDIS staff is not responsible

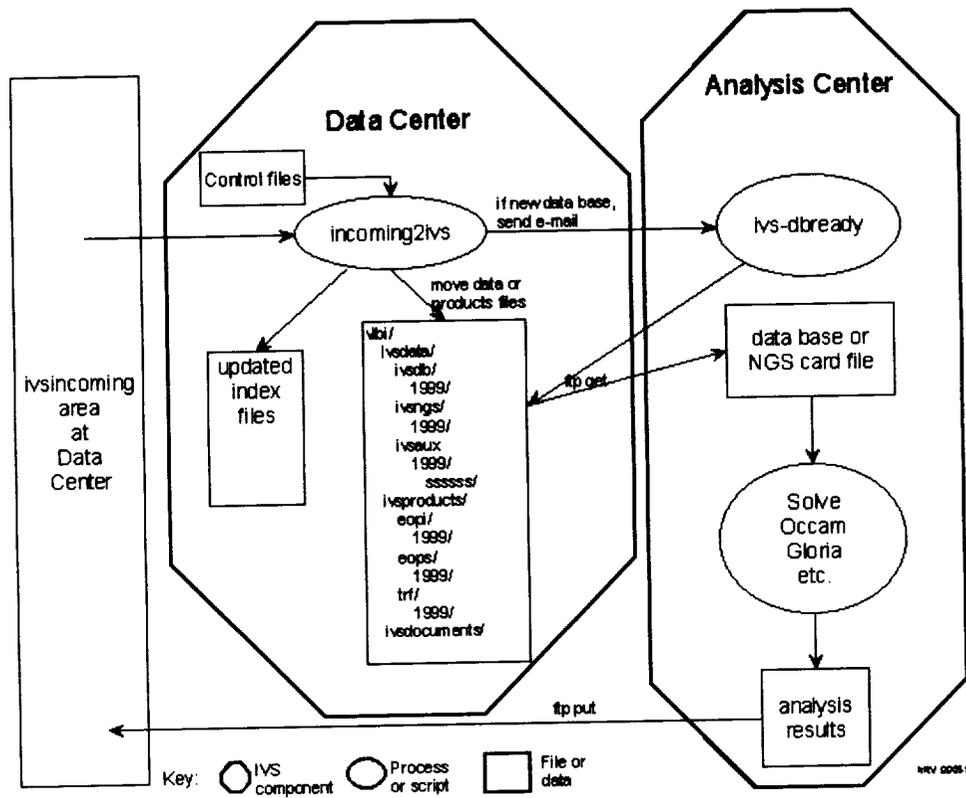


Figure 2. The flow of data within the IVS data centers and flow of products to the IVS data centers (Draft).

for this development, we will work closely with the IVS coordinating center staff to ensure that our system is an active and successful participant in the IVS archiving effort.

Matera GeoDAF Data Center

Giuseppe Colucci, Domenico Del Rosso, Francesco Vespe

Abstract

This report describes the Matera GeoDAF activities and characteristics. At the moment, this Data Center is focused on GPS data and analysis products archive and distribution, but the system was designed to manage VLBI analysis products and data too.

1. General

GeoDAF (Geodetical Data Archive Facility) is located at the Italian Space Agency “Centro di Geodesia Spaziale” (CGS) near Matera, a small town in the South of Italy. At the same location a SLR system (SAO-1), a VLBI Station and a GPS receiver are operated. CGS also controls and manages the Italian GPS Network. In order to archive and distribute these RINEX GPS data and the analysis solutions performed by CGS Analysis Group, the GeoDAF facility was set up in 1985. It was designed to manage SLR and VLBI data too, even if these features were never fully exploited. All these activities are managed on behalf of ASI, by Telespazio S.p.A.

2. Technical/Scientific

GeoDAF is hosted on a HP/G40 server running HP-UX 10.01 (controllare con Maria) and NCSA 1.5.2a HTTPD Web Server. A set of CGI scripts was developed to interface the archive to the users and to manage the file requests for off-line data. The disk data storage capacity is 10 Gb, for off-line storage, DAT, EXABYTE, CD-R AND 9-TRACK TAPE are available also. Fig 1 shows the GPS data flow for the full system.

3. Staff

The list of the GeoDAF staff is provided in Table 1.

Table 1. Matera GeoDAF staff members

Name	Agency	Activity	E-Mail
Dr. Giuseppe Bianco	ASI	CGS Director	bianco@asi.it
Dr. Francesco Vespe	ASI	CGS Geodesy Manager	vespe@asi.it
Domenico Del Rosso	Telespazio	Operations Manager	domenico_delrosso@telespazio.it
Giuseppe Colucci	Telespazio	GeoDAF contact	colucci@asi.it

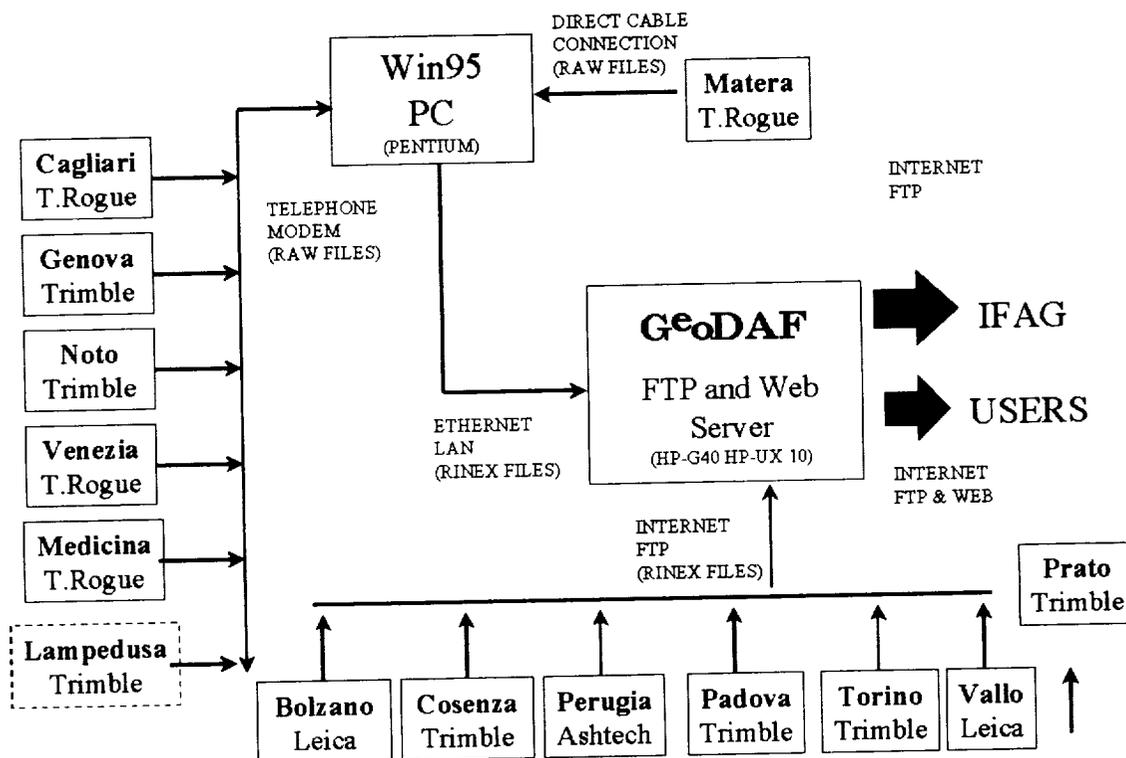


Figure 1. The Matera GeoDAF Data Center

4. Status

The access to GeoDAF services is provided by ANONYMOUS FTP and by Web interface. Currently the GPS data files are available on-line ready to transfer for six months and then they are put off-line on DATs. To obtain these off-line data files, users can simply send e-mails to the GeoDAF user interface account (web@geodaf.mt.asi.it). Also an automated data request system was set up, but this method is not managed by the system at this moment. GeoDAF is completely free, but the users are encouraged to "register" themselves by an on-line Web managed form. Up to June 1998 the registered users are 230, mainly from Italy and other European countries.

5. Outlook

The following upgrade activities are planned in order to improve the performance of GeoDAF:

- * apache web server instead NCSA (no longer under development)
- * new web pages look and optimization
- * increase disk storage capacity (eventually)
- * increase Internet connection (eventually)
- * test of the SLR and VLBI data management features

Italy CNR Data Center Report

P. Tomasi, M. Rioja, E. Gueguen

Abstract

This report summarizes the situation of the Italian CNR VLBI data center. It will give the fundamental information about the structure of the center, its locations, and its activity.

1. Introduction

The Italy CNR VLBI data center is the joint effort of two Institutes of Consiglio Nazionale delle Ricerche (CNR) to improve, working together the capability of VLBI data storage in Italy. The two Institute are:

a) the Institute of Radio Astronomy (IRA) located in Bologna, where the main research activity is carried out, both in radioastronomy and geodesy, but also managing the two VLBI antennas in Medicina (near Bologna) and Noto (in Sicily);

b) The Institute of Informatica and Technology for Space (ITIS), located in Matera at the Center of Spatial Geodesy (of the Italian Space Agency), where VLBI antenna, laser ranging telescope, permanent GPS receiver and PRARE antenna are located.

The IRA has started to store VLBI geodetic databases from 1989 but the databases archived here are mostly concerned with data including European antennas, starting from 1987. In particular most of the databases presented here have VLBI data with at least three European antennas.

From 1997 also ITIS started to store the VLBI databases with the same selection effect, but during 1998 we start to define different task at the different sites. We would like to mention that even ITIS is at the same site as the Italian Space Agency Center for spatial geodesy, that is different institution and this data center is different from ASI data center or GEODAF. We are discussing merging in order to avoid duplication, but up to now the two data centers are separate.

We have specialized the Bologna part to store and analyze single databases, in order to produce a final database, that can be stored in a different format (superfile) and used in global solution. This second part is mostly done in Matera at the ITIS.

2. Computer Available and Routing Access

In Bologna the main computer is HP715/80, the computer name is boira6.ira.bo.cnr.it and the databases are stored in different directories and in different disk as well. The complete list of directories where databases are stored is the following:

- 1 = /data1/mk3/data1
- 2 = /data1/mk3/data2
- 4 = /data/dbase1
- 6 = /data5/dbase5
- 5 = /data4/dbase4
- 7 = /data7/dbase7
- 8 = /data8/dbase8
- 9 = /data9/dbase9

The username for accessing the database at the moment is geo. Password can be asked by sending a mail to tomasi@ira.bo.cnr.it. In the near future the database will be accessed by web.

During 1998 we have also started to work on the possibility of using tropospheric zenith path delay from GPS in order to improve the repeatability of the VLBI geodetic results. For that we have produced, for all the EUROPE databases of 1998, a different copy of the database, with this GPS data stored in the VLBI database as coming from the water vapor radiometer. Also these databases are available on request.

In Matera the main computer is an HP282 computer with internet name hp-j.itis.mt.cnr.it. The database are stored in different directories and the full list will follow:

- 1 = /data1/mk3/data1
- 2 = /data1/mk3/data2
- 6 = /data5/dbase5
- 5 = /data4/dbase4
- 7 = /data8/dbase8
- 8 = /data10/dbase10
- 9 = /data13/dbase13
- 10 = /data14/dbase14

The super file are stored in two different directories:

- /data2/super
- /data10/super10

and the list of superfiles is stored in the file /data1/solvefiles/SUPCAT. The data can be accessed using the username geo, and the password can be asked to tomasi@ira.bo.cnr.it.

For the moment all the data are stored on magnetic disk, but we are planning to move the whole catalog of database to optical disk. The area available on a juke box (already installed in Matera) will be of 80 Gb on line.

Paris Observatory (OPAR) Data Center

Najat Essaïfi

1. OPAR Data Center Functions

The Paris Observatory (OPAR) provides a Data Center for the International VLBI Service for Geodesy and Astrometry (IVS). The purpose is to store files (data and analysis files) from IVS components and to make them available to the community as soon as they are submitted.

The functions of OPAR Data Center are to:

- receive and archive schedule files from the operational 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 products for all users.

All these activities will be made in close collaboration with CDDISA and BKG Data Centers.

2. Staff Members

Staff members who are contributing to OPAR Analysis and Data Center for IVS are listed below:

- Anne-Marie Gontier, responsible for GLORIA analysis software.
- Martine Feissel, scientific developments.
- Najat Essaïfi, responsible for computer science.

3. Current Status

The OPAR Data Center is operational on a HEWLETT PACKARD 9000 Model 715 located at Paris Observatory and running the HP-UX 10.20 operating system. To make all IVS products available on-line, this server is equipped with a 20 Gb disc storage for VLBI activities.

The OPAR server is accessible 24 hours per day, seven days per week through Internet connection with 2 Mbit/s rate.

4. Future Plans

- *Activities with others Data Centers:*

The OPAR Data Center will synchronize its activities with the CDDISA and BKG Data Centers to make all IVS products available as soon as new information arrive.

- *FTP and WWW access :*

Users can reach the IVS products by using the TCP/IP protocol. Both World Wide Web (WWW) and File Transfert Protocol (FTP) will be available. Access to this server will be free for users require to get data. Authorized access is needed for IVS component to put data; username and password would be given on request.

FTP access:

ivsopar.obspm.fr
username : anonymous
password : your e-mail
cd vlbi (directory of IVS products)

WWW site :

<http://ivsopar.obspm.fr/ivs>

- *Structure :*

The directory structure of IVS products will be:

vlbi/	:	Directory for VLBI activities
ivscontrol/	:	Files giving detailed information about directory structure and file name conventions
ivsdata/	:	Directory for VLBI observations (auxilliary files, Calc Data Bases and NGS Card files)
ivsdocuments/	:	Directory for VLBI documents
ivsproducts/	:	Directory for VLBI products (Earth rotation parameters, Celestial and Terrestrial Frame)

- *Enhancement on the hardware :*

The disc space will be increased with regards to IVS products.

5. Contact Information

To obtain username and password or more information about OPAR Data Center the contact address is given below:

Najat Essaïfi
Observatoire de PARIS
61, Avenue de l'Observatoire
75014 Paris - FRANCE
Phone : 33 1 40 51 22 33
Fax : 33 1 40 51 22 91
E-mail : essaifi@hpvlbi.obspm.fr

ANALYSIS CENTERS

From the Terms of Reference:

The Analysis Centers receive and process VLBI data from one or more IVS Data Centers and are committed to produce the core products, without interruption, and at a specified time lag to meet IVS requirements. The IVS core products, at a minimum, consist of Earth orientation parameters, station coordinates, and source coordinates. 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.

IVS Analysis Centers satisfy the following standards:

- Analysis is performed using VLBI software packages that adhere to IVS recommendations.
- Centers perform software development and produce documentation. They periodically compare their products.
- Centers adhere to IERS Conventions. Any exceptions are documented.



Analysis Center of Saint-Petersburg University

Oleg Titov

Abstract

This report summarises the information about current and future activity of analysis center of Saint-Petersburg University.

1. Analysis Center of Saint-Petersburg University

Analysis Center is located in Astronomical Institute of Saint-Petersburg University. This time the analysis center makes an analysis of NEOS-Intensives VLBI sessions for IERS as well as IVS (see part 4).

2. Technical Information

To estimate the UT1-UTC values we make a least squares analysis of the two-hour sessions using OCCAM 3.4 software. Wet delay for reference VLBI station; wet delay, clock offset and clock rate for other stations are regularly estimated. All reductional calculations are in accordance with IERS Conventions 1996. Niell's mapping function is applied for wet delay estimation. We download gzipped VLBI data file in Mark III format from USNO database.

3. Technical Staff of the Saint-Petersburg University Analysis Center

V.Vityazev - Director of Astronomical Institute of Saint-Petersburg University, PhD. General coordination and support of the activity at the Astronomical Institute.

O.Titov - associate professor of Saint-Petersburg University, PhD. Current processing of VLBI data.

4. Status of the Saint-Petersburg University Analysis Center

Analysis Center operates for quick analysis of two-hours VLBI sessions (NEOS-Intensives). UT1-UTC values are estimated and submitted to USNO and Paris Observatory biweekly. IERS takes the results for preparation of Bulletins A and B.

5. Outlook

We are going for next year:

- a. to process the regular weekly NEOS-A VLBI sessions.
- b. to make weekly comparison and combination of Intensive Series EOP.
- c. to provide a documentation about OCCAM software. OCCAM software to be upgrade using the recent recommendations of scientific groups collected since 1996 year.
- d. to participate in comparison of high-frequency EOP variations from different space geodetic techniques.

The Bordeaux Observatory IVS Analysis Center

P. Charlot, B. Viateau, A. Baudry

Abstract

This report gives an overview about VLBI activities in Bordeaux during the past year. It also presents the expected contribution of Bordeaux Observatory to IVS and lists the staff involved in the IVS Analysis Center work. Future plans include the development of a new astrometric observing program on the European VLBI Network (EVN) for densifying the International Celestial Reference Frame (ICRF).

1. VLBI in Bordeaux

Bordeaux Observatory (Fig. 1) is located in the southwest of France (about 600 km from Paris) near the mouth of the Garonne river. It is funded by the University of Bordeaux and the CNRS (National Center for Scientific Research).

The Observatory comprises four scientific groups specialized in radioastronomy, astrometry, planetology, and solar research. The radioastronomy group has long been involved in VLBI observations of active galactic nuclei and maser sources for astrophysical objectives. VLBI astrometry and geodesy is a new activity set up during the past year as a cooperation between the astrometry and radioastronomy groups.

Observatoire de Bordeaux 2, rue de l'Observatoire BP 89 33270 Floirac, FRANCE http://www.observ.u-bordeaux.fr

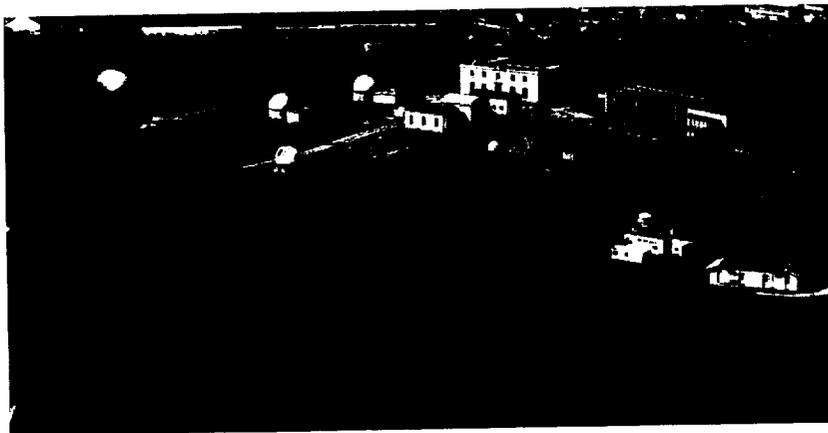


Figure 1. Aerial view and address of Bordeaux Observatory.

2. Expected Contribution to IVS

Our major scientific interest is the celestial reference frame, especially the maintenance and extension of the International Celestial Reference Frame (ICRF). We expect to contribute to this area in the form of:

- **Observational data:**

Our goal is to develop an observing program dedicated to astrometry on the European VLBI Network (EVN) in cooperation with the IAU sub-group in charge of the maintenance and extension of the ICRF. The subsequent data will be submitted to IVS as data products.

- **Celestial frame analyses:**

Our initial plan is to analyze only the data from the expected EVN experiments. Depending on the available support later on, we may develop larger solutions, including additional data from other observing programs, and provide time series of source positions. The aim is to study the ICRF source position stability and the physical phenomena that can affect this stability (e.g. source structure variations).

VLBI analyses will be conducted with the MODEST software, developed and maintained by the Jet Propulsion Laboratory [1].

3. Scientific Staff

VLBI in Bordeaux benefits from experience of researchers with background in both astrometry and radioastronomy. Table 1 lists the staff participating in the IVS Analysis Center work.

Table 1. Staff involved in the IVS Analysis Center work.

Name	Background	Position
Patrick Charlot	astrometry, radioastronomy	permanent
Bruno Viateau	astrometry	post-doc
Alain Baudry	radioastronomy	permanent

4. Overview of Recent Activities

During the past year, astrometric VLBI activities in Bordeaux have focused on the following technical and scientific matters:

- Installation and test of the MODEST software on various computer platforms (HP, Sun, DEC/Unix, DEC/VMS):

These tests have been carried out during a visit of O. J. Sovers (Jet Propulsion Laboratory) at Bordeaux Observatory in the fall of 1998. They revealed a few non-portable features in the MODEST code. These are being corrected, so the MODEST code should be fully portable in the near future.

- ICRF source classification based on observed structure:

The work previously carried out in collaboration with A. L. Fey (U.S. Naval Observatory) [2] has been pursued further for 225 additional sources. As with the previous work, the sources have been separated into four classes according to the magnitude of the expected source structure effects on astrometric bandwidth synthesis delay observations. This classification now covers 392 ICRF sources, and is complete for about 90% of the ICRF sources north of -20° declination [3].

- Study of the optimal use of the EVN for astrometric observations:

Discussions have been initiated about the possible use of the EVN (and JIVE correlator) to supplement the existing astrometric programs ongoing with the VLBA and the DSN for maintaining and extending the ICRF. These concluded that the EVN would be useful for densifying the ICRF, especially towards weaker sources. A subsequent proposal for observing 150 new sources, each source re-observed three times, has been submitted to the EVN.

5. Outlook

Starting next fall, we will have improved computer facilities with a new faster Unix workstation (Compaq DS20/EV6). The MODEST software will be installed on this new workstation along with the NASA SKED program, while the Goddard data base system will stay on our old HP workstation.

If approved by the EVN Program Committee, we expect the initial experiment of the proposed EVN observing program to be carried out within a year. This experiment will be designed to provide first-epoch observations of 50 new sources. Time will be devoted to refine the source selection strategy before scheduling.

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Matera CGS VLBI Analysis Center

Roberto Lanotte

Abstract

This paper summarizes the present status of the VLBI data analysis activities at the Space Geodesy Center (CGS) of Matera and the contributions that the CGS intends to provide as an IVS Data Analysis Center. The center born in 1983 as an SLR station grew in the years including in its facilities a VLBI and a fixed GPS station. It is operated by Telespazio on behalf of the Italian Space Agency (ASI) and is providing not just high quality data but also data analysis support.

1. Introduction

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 [3]. 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 three main space geodetic techniques: VLBI, SLR and GPS. The CGS intends to participate in the IVS as an Analysis Center for:

- Terrestrial Reference Frame analysis products
- Comparison of TRF analysis products and production of a single TRF
- Comparison of results from different space geodetic techniques.

For the VLBI analysis we use the *CALC/f-SOLVE* software on an HP725 workstation.

2. TRF Analysis Products

Analysis of the EUROPE campaign is performed at the CGS since 1992 and its results are regularly presented at the working meetings on European VLBI for Geodesy and Astrometry [2]. Our products from this analysis are station coordinates and velocities. Generally we perform, using *CALC/f-SOLVE*, a “standard” two-step analysis procedure; the first is an “arc solution” which provides the time series of the parameters under investigation, the second solution is a “global solution” where parameters are estimated using all sessions. For this analysis we will provide a solution every year using all data acquired within this campaign.

Also global geodetic VLBI solutions have been carried out and for this kind of analysis we intend to provide solutions, without any particular time schedule, using as many data as possible to determine TRF, CRF and EOP.

3. Comparison of TRF

For the combination of individual TRF products we intend to use the following procedure:

- We assume that the individual TRF are provided in SINEX format.

- Constraints introduced in the solution will be removed for each TRF.
- Application of minimal internal constraints adjustment will be performed on each TRF.
- Combination of all TRFs will be done evaluating a 14 parameters transformation (scale factor, translations, rotations and their time derivatives) using the IERS ITRF as reference frame. This step will produce a unique TRF.

Initially we can provide the combined TRF for the end of 1999. After that date combination will be performed every six months.

Comparison of the TRFs will be performed estimating a 14-parameter transformation between the single TRF and a ITRF that can be the IERS one or that produced by IVS. Feedback to the Analysis Center will be provided in terms of differences between the single TRF and the ITRF.

4. Comparison of Results from Different Space Geodetic Techniques

The space geodetic data analysis activities in the fields of GPS, SLR and VLBI usually carried out at the CGS make the comparison and combination of the results one of our natural objectives. The kind of compared geodetic parameters depend on the particular solution (global, regional).

Results from the analysis of the EUROPE campaign have been extensively compared to those from our SLR and GPS solutions for co-located sites [2]. Results from a worldwide VLBI solution have been compared to SLR global solutions and to ITRF to verify the consistency of different reference systems [1], in terms of rototraslations/scale parameters, of empirical Eulerian poles, where possible, and in terms of Fourier coefficients for the EOPs.

Comparison of results concern:

- Comparison of baseline time series, after removal of the eccentricity vectors among the techniques.
- Evaluation of the 14-parameter transformation between the TRF determined by each technique and the ITRF.
- Determination of the Eulerian poles for each technique and comparison with those coming out from the ITRF.

5. Staff at CGS contributing to the IVS Analysis Center

- Dr. Giuseppe Bianco, Responsible for CGS, ASI (primary scientific/technical contact)
- Dr. Francesco Vespe, Responsible for CGS geodesy activities, ASI (administrative contact)
- Dr. Cecilia Sciarretta, Responsible for scientific activities, Telespazio
- Dr. Roberto Lanotte, Geodynamics scientist, Telespazio.

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Special Associate Analysis Center at Communications Research Laboratory

Yasuhiro Koyama

Abstract

Communications Research Laboratory is performing data analysis on the Key Stone Project VLBI experiments which are currently performed once every two days. The data analysis procedures are fully automated and the results are placed in the publicly accessible area via Internet. Geodetic VLBI experiments which have been organized by the laboratory are also analyzed. These activities are summarized in this report.

1. Introduction

Communications Research Laboratory (CRL) has organized various geodetic VLBI experiments in Japan and with foreign network stations. The analysis results of the experiments performed before October 1992 were summarized in a data analysis report published by CRL [1]. The VLBI experiments with the Key Stone Project VLBI stations began in August 1994 [2] and the analysis of the Key Stone Project VLBI data is the major activity as the special associate analysis center at present.

2. Data Analysis Software and Hardware Systems

For the data analysis of the Key Stone Project VLBI observation data, Mark III database files are created by using software developed at CRL and database handler library routines developed by Goddard Space Flight Center (GSFC) of National Aeronautics and Space Administration (NASA). The theoretical delay and delay rates are calculated by CALC version 8.1 (NASA/GSFC), and the least squares parameter estimations are performed by VLBEST (CRL) [3] [4]. Editing of bad data points and ambiguities are applied by MRKOBS (CRL) and REMAMB (CRL) respectively. The final results are processed and placed in a publicly accessible area via Internet in appropriate data formats. All the processes from the generation of the database files to the publication of the final results are fully automated and no human operations are required.

3. Data Analysis

In the data analysis, site coordinates of the 11-m antenna station at Kashima are fixed to the *a-priori* position in the ITRF96 which was defined by International Earth Rotation Service (IERS). The site coordinates of the other three stations are estimated along with the clock offset and atmospheric zenith delay at the time intervals of 1.5 and 3.0 hours, respectively. The *a-priori* coordinates of the 11-m antenna station at Kashima is derived from the results of seven tie VLBI experiments with the 34-m antenna station at Kashima. Positions of the observed radio sources are fixed to the RSC(WGRF)95R01 and the Earth rotation parameters are fixed to the EOP(IERS)97C04 data set, both of them are defined and maintained by IERS. Every time when the Earth rotation parameters are updated in an e-mail bulletin from IERS, the content of the

bulletin is processed and the affected databases are reanalyzed automatically.

Estimated site positions of the Koganei station are shown in the Figure 1 as an example. The precision of the estimates have been gradually improved. The major improvements were achieved by better temperature control of the receiver system and the use of higher data rate (256 Mbps) for the observations since June 1999 [5]. These results can be accessed at the URL of <http://ksp.crl.go.jp/obsdata.html>.

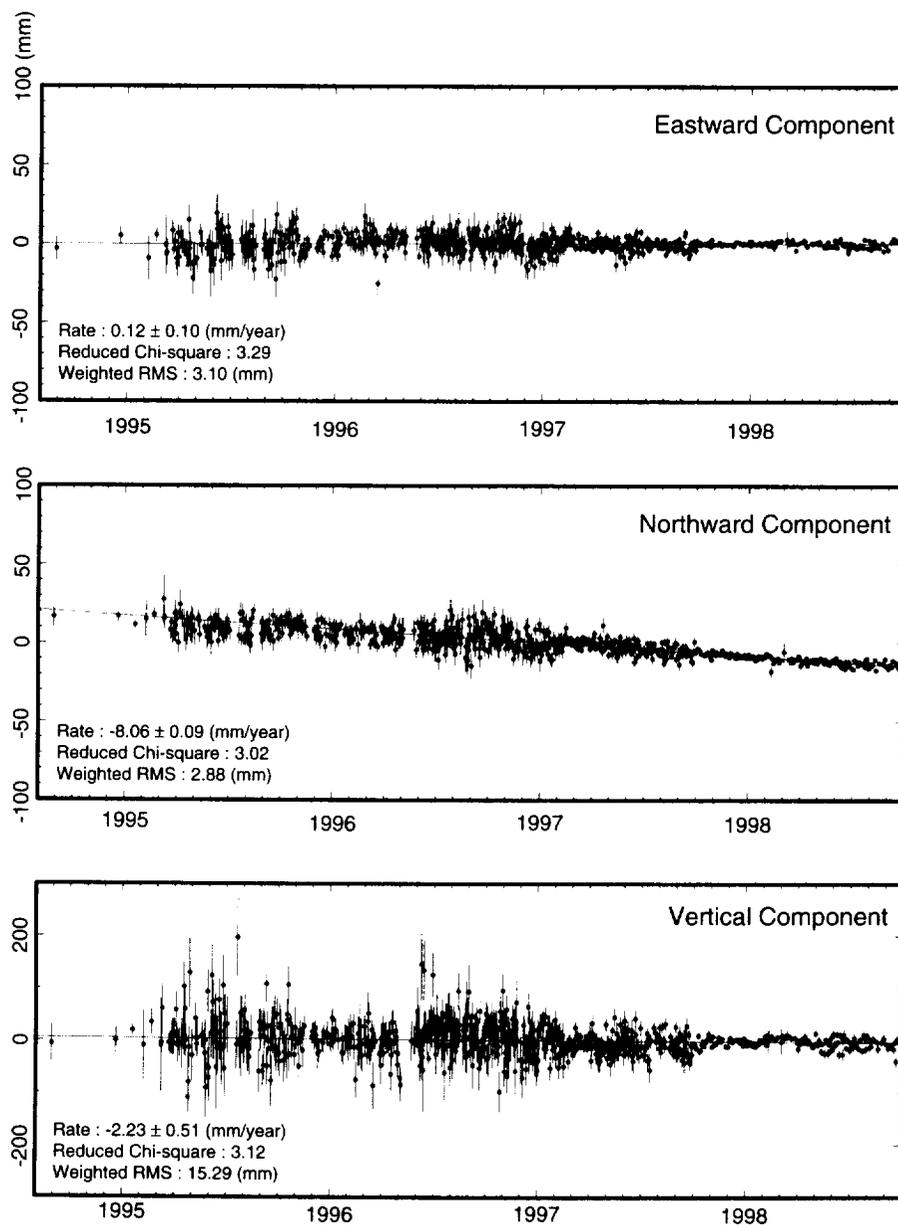


Figure 1. Estimated site positions of the Koganei station.

In addition to the regular data analysis described above, wobble parameters of the Earth's rotation pole position and the time difference between coordinated universal time and the universal

time (UT1-UTC) are estimated by fixing the site coordinates of the four stations. Figure 2 shows differences between the UT1-UTC values published by IERS in the monthly bulletins and the estimated UT1-UTC from the Key Stone Project VLBI data, when only the UT1-UTC values are estimated. Since the data analysis of the Key Stone Project VLBI data is performed immediately after a set of observations are performed, the UT1-UTC estimations are considered to have a potential to be included in a rapid service from IVS.

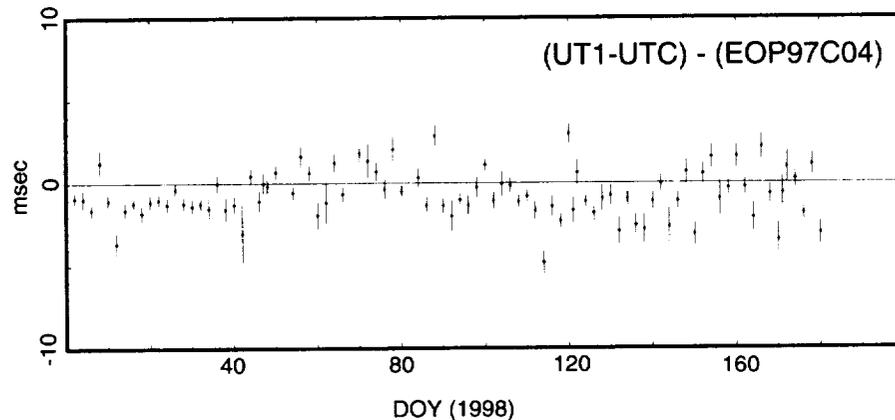


Figure 2. Estimated UT1-UTC values compared with the EOP90C04 data set.

4. Technical Staff for the KSP Analysis Center

Technical staff members who are contributing data analysis at the CRL are listed below. In principle, no operations are necessary for the regular VLBI observations of the Key Stone Project VLBI network.

- Tetsuro Kondo, Responsible for overall operations and performance.
- Yasuhiro Koyama and Masato Furuya, Development of data analysis software.
- Ryuichi Ichikawa, Research for atmospheric modeling.
- Jun Amagai, Maintenance of data analysis system.

5. Current Status and Future Plans

As of March 1999, a replacement of the Unix workstation with a new system is on the way and the new workstation will be used for regular data analysis of the Key Stone Project VLBI observations. The newer version of the CALC (version 8.2) will be used on the new system.

At present, only the zenith atmospheric delay parameters are estimated and a mapping function is used to model the elevation dependency of the atmospheric delay. Effectiveness of estimating tropospheric gradient parameters are being evaluated at present. It is also planned to generate the analysis results in SINEX (Solution Independent Exchange) format.

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DGFI Analysis Center

Harald Schuh, Wolfgang Schwegmann, Volker Tesmer, Hermann Drewes

Abstract

At DGFI both the CALC/SOLVE software (installed at GIUB and accessible via inter net) and the OCCAM package are used for VLBI data analysis, and a thorough knowledge of both software packages exists. The main activities of the DGFI VLBI group during the last year were focussed on the following tasks: artificial intelligence methods, OCCAM modifications, and comparison of CALC/SOLVE and OCCAM

1. Application of Artificial Intelligence (AI) Methods

An important contribution to accelerate the VLBI procedure is a faster and semi-automatic data analysis, which is in particular needed in view of the increasing amount of VLBI data to be processed in the next years. Most of the tasks in the VLBI data analysis are very complex and their automation requires typical knowledge-based techniques, but some tasks can be automated by conventionally programmed algorithms within the existing software. First, a concept for the automation of the Mark III Data Analysis System was developed.

Then, the program PWXCB, which extracts weather and cable calibration data from the log files, was automated by extending the existing Fortran77 program code. The new program is called XLOG. In XLOG the calibration data are extracted from the log files and are checked with respect to their plausibility, then wrong data are deleted. These tasks are done automatically, but in case of probably wrong data the analyst's attention is directed to these suspicious data. At present a beta version of XLOG is being tested to be used for routine application. It is planned to release version 1.0 of XLOG in Spring 1999.

Now, an intelligent assistant for support and guidance of the analyst is being developed using the workbench BABYLON, which is based on methods of artificial intelligence. The construction of the new system to automate the tasks done by the program SOLVE has been started, because these tasks are very complex and require a comprehensive knowledge of the whole procedure of data analysis. The system can also be used as a teaching-system for less experienced analysts. This would be very helpful because there is a shortage of qualified experts and the analyst's training takes a long time.

2. Modification of OCCAM

The OCCAM V3.4 package installed at DGFI was extended by allowing a-priori correlations between the VLBI observables, i.e. including a full variance-covariance matrix. Empirical correlation coefficients had been computed already at the beginning of the 1990s [1], but they were neglected so far due to missing computer capacity and power. Now, the a-priori correlation matrix was constructed with the formerly obtained empirical correlations. They were compared with the a-posteriori correlations between the observables which were taken from a first least squares adjustment. This allows to optimize the determination of realistic a-priori correlations which are in fact rather high. Their consideration in the VLBI least squares fit will improve the results in par-

ticular with respect to more realistic formal errors than those obtained by the present uncorrelated approach. It is planned to do further work on that and on the models used in OCCAM.

3. Comparison of Software Packages (CALC/SOLVE and OCCAM)

At DGFI both the CALC/SOLVE software and the OCCAM package are used for VLBI data analysis. First comparisons of the results have been done. They yield a rather good agreement of the pattern of residuals. However, the geodetic results (baseline components, Earth orientation parameters, ...) still show significant differences probably due to different models used in both software packages and due to the procedures applied for editing the data and choosing the a-priori weights of the observables. The comparisons will be continued in more detail. It is planned to use databases of the IRIS-S sessions for that.

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Combination of Results at FFI – Data Analysis

Per Helge Andersen

Abstract

FFI's contribution to the IVS as an analysis center will focus primarily on a combined analysis at the observation level of data from VLBI, GPS and SLR using the GEOSAT software. This report shortly summarises the current status of analyses performed with the GEOSAT software.

1. Introduction

FFI is centrally located in the Kjeller area, 30 minutes east of Oslo (near Lillestrøm). Here approximately 2400 people are engaged in several research establishments, technical institutions, university branches and Air Force Material Command. FFI is a state operated, civilian research establishment reporting directly to the Ministry of Defence. The number of employees is approximately 550.

For many years FFI has performed research in space science and remote sensing using satellites. As a part of this research FFI has developed a highly sophisticated software (GEOSAT, [2]) for satellite orbit determination and space geodesy. With this software all types of high precision space geodetic observations can be combined and analyzed at the observation level.

2. Status of FFI's Contribution to the IVS

FFI is presently establishing using GEOSAT a database of VLBI, GPS, and SLR observations, residuals, partial derivatives, and arc-by-arc state vectors and covariance matrices estimated on the basis of a combination of VLBI, GPS and SLR data at the observation level. The arc-by-arc state vectors and complete covariance matrices will be combined into a multi-year solution using a highly sophisticated and flexible Square-Root-Information-Filter-and-Smoother, CSRIFS ([1]), which is a part of the GEOSAT software (GEOSAT, [2]).

Our first combined contributions to IVS and IERS will primarily be based on some selected high-quality datasets. In the future the analysis will be extended to a large number of arcs covering many years.

The GEOSAT software will be used in all analyses. All major components of GEOSAT have been successfully validated with a combination of data from VLBI, GPS and SLR. Consistent models for all techniques have been verified at the sub-ppb level. The processing at the arc or session level is completely automated using C-shell scripts.

The CSRIFS program for combining arcs has been successfully applied in the generation of a VLBI-only solution covering 623 sessions during the last 10 years. A paper containing the mathematics of CSRIFS and the results of the VLBI analysis has recently been submitted for publication in *Journal of Geodesy* [1]. Results from a combined analysis of 12 days of VLBI, GPS, and SLR observations in the period Jan 12 - 23, 1994 (CONT94), were presented at the IERS Symposium at GFZ in 1998. Both the VLBI-only solution and the combined solution were submitted to the IERS at the end of March 1999. More complete analyses will be presented at international meetings later in 1999.

We plan, as part of the IVS analysis, to test different analysis strategies related to especially the weighting of the a priori information (observations and a priori parameter estimates), the selection of dynamical parameters to be estimated for the GPS satellites, data editing, the estimation of eccentricity vectors, the use of multi-arc orbital elements for the GPS and the LAGEOS satellites, and the estimation of geophysical parameters.

3. Technical Staff

Table 1 lists the FFI staff involved in IVS activities. The development and validation of GEOSAT have resulted in a substantial theoretical understanding and practical experience with all available types of high-precision space geodetic data (VLBI, GPS, SLR, PRARE, DORIS and radar altimetry).

Table 1. Staff working at the FFI AC and TDC

Name	Background	Dedication	Agency
Per Helge Andersen	geodesy	40%	FFI

4. Outlook

The computation time for the processing of 24 hours of VLBI, GPS, and SLR data is presently approximately 14 hours using a HP C180 (one CPU) computer. We plan to buy a new computer within the end of this year or early next year, probably a HP J5000 (with two CPU's) or a HP J7000 (with four CPU's) including 1 Gb RAM. This should give an increase of a factor 5 or 10 in processing capacity. The disk storage capacity will be extended from 65 Gb to 100 Gb with additional 30 Gb each year. With such a computation power it should be possible to generate global combined multi-technique solutions based on a large number of arcs.

References

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The GIUB/BKG VLBI Analysis Center

Axel Nothnagel, Volkmar Thorandt, Leonid Petrov

1. Overview

The GIUB/BKG VLBI Analysis Center has been established jointly by the Bundesamt für Kartographie und Geodäsie (BKG), Leipzig, and by the Geodetic Institute of the University of Bonn (GIUB). Both institutions closely cooperate in the field of geodetic VLBI maintaining their own analysis groups in Leipzig and Bonn. The responsibilities include data analysis and software development.

Both groups use the Mark III data analysis software CALC/SOLVE/GLOBL which originated at NASA/GSFC. At GIUB the basic SOLVE/GLOBL software has been modified extensively to increase its computational speed and to add several new features. The new software, which is called f-SOLVE, accelerates processing by additional automation procedures.

Both groups use HP9000 Series 700 computers with sufficient hard disk space and Internet connection for their analyses.

2. Data Analysis

The following sessions have been analysed at GIUB and BKG during the last year:

- **Measurement of Vertical Crustal Motion in Europe by VLBI (EURO)**
(EU Project FMRX-CT960071)
Six sessions per year with the stations NyÅlesund, Onsala, Wettzell, Simeiz, Madrid (DSS65), Yebes, Medicina, Matera and Noto. Effelsberg and TIGO-WTZL participated occasionally.
- **Polarization tests**
In order to investigate polarization impurities two regular EURO sessions were extended in which several stations swapped polarization from right circular polarization (RCP) to left circular polarization (LCP) while other stations continued to observe RCP. Fringes at all cross-polarization scans were detected.
- **Wettzell local ties (WTIES)**
Two sessions between Wettzell 20-m telescope and TIGO-WTZL which are about 59 m apart.
- **International Radio Interferometric Surveying - South (IRIS-S):**
Twelve sessions per year with the stations Wettzell, HartRAO, Fortaleza, Fairbanks and Westford.
- **Continuous Observations of the Rotation of the Earth - O'Higgins (CORE-OHIG)**
with stations HartRAO, O'Higgins, Fortaleza, Hobart, Kokee and DSS45.
- **Annual Solution for Submission to IERS**
In addition to the session by session analysis one combined solution is computed cooperatively every year which comprises most of the dual frequency fixed station Mark III data available

worldwide. This solution is the basis for the annual submission to the IERS. Station coordinates and velocities, radio source positions and Earth orientation parameters are estimated in one global solution. Station coordinates, velocities and their covariances are converted into SINEX format which is the input format for contributions to the International Terrestrial Reference Frame maintained by the IERS.

3. Development of Technology of VLBI Data Analysis

- One of the responsibilities of the GIUB analysis group is the preparation of correlator data for export in the form of Mark III data analysis system databases for the sessions correlated at the Bonn Astro/Geo correlator center. In most of the cases this task is straightforward but sometimes it requires some extra efforts. The main reason for additional interaction is radio frequency interference which may saturate individual channels causing some of the delay observables to be corrupted. In this case the fringe fitting process may select the wrong peak of the delay resolution function and may, thus, produce an incorrect delay observable. However, this fact can only be detected when a least squares solution is computed with the program SOLVE. In a subsequent step the residuals of the SOLVE run can be used to narrow the search window in a repeated fringe fitting process. A semi-automatic procedure for this task is available at GIUB.
- Algorithm GAMB for automatic group delay ambiguity resolution was developed and implemented in SOLVE. It serves four purposes: a) resolving group delay ambiguities at both bands; b) estimation of quadratic clock function; c) detection and removing of outliers; d) computation of ionosphere path delay.
- Algorithm ELIM has been developed and implemented in SOLVE for automatic outlier elimination and/or restoration of observations which may have been eliminated in earlier analysis steps. The automatic procedure finds the best candidate for elimination/restoration by least squares residual snooping and repeats the process until the predefined criteria are met. ELIM allows one to carry out the data editing process in an automatic and objective way providing fast and better results than manual editing.
- Algorithm PAMB for phase delay ambiguity resolution. Phase delays are roughly 40-fold more precise than group delays but are lacking the integer number of phase cycles. Algorithm PAMB allows one to resolve these phase delay ambiguities in semi-automatic mode for observing sessions which have to meet certain quality criteria.
- Semi-automatic Web-presentation of data analysis results is being developed. Detailed reports of all VLBI data processed at the GIUB/BKG Analysis Center have been displayed on the Web starting in 1998.
- Internal logic of the software SOLVE was updated in order to reduce overhead, to speed up data processing and to expand the capabilities of the analysis system.

4. Research topics

- **Thermal expansion of radio telescopes**
(in cooperation with Onsala Space Observatory)

In situ measurements of thermal expansion of the Wettzell and Onsala radio telescopes by invar wire are compared with model parameters. The most critical aspects are the temperature transfer into concrete and representative temperature measurements in a radome.

- **Geocentric relativistic VLBI formulation**

Although solar system barycentric and geocentric relativistic formulations of VLBI observations are equivalent, the development of a geocentric model bears some benefits. It includes a separate stellar model and it may be adapted and applied to other space geodetic techniques.

- **Determination of telescope displacements by local engineering work at Medicina and Effelsberg**

Both the Effelsberg and Medicina telescopes have been displaced slightly due to track repairs. Local surveys before and after the displacements are being analysed.

- **Joint least squares adjustment of GPS and VLBI observations**

(in cooperation with DGFI)

A combination of space geodetic measurements at the level of observables is being carried out at DGFI. Special VLBI data preprocessing and solutions are performed at GIUB in support of this research.

- **Investigation of the feasibility of using phase delays in geodetic VLBI**

An extended set of VLBI sessions has been re-analyzed for resolving phase delay ambiguities. Conditions when ambiguities can be resolved as well as differences between group delay and phase delay solutions were investigated.

- **Investigation of the influence of errors in phase calibration of group delay**

Initial steps of studying phase calibration errors have been carried out. In many cases phase calibration is corrupted by phase variations appearing as additive signals. A prototype of a procedure has been developed restoring the phase calibration signal by subtracting spurious signals.

GSFC VLBI Analysis Center Annual Report

David Gordon, Chopo Ma, Dan MacMillan

1. Introduction

The GSFC VLBI group, located at NASA's Goddard Space Flight Center in Greenbelt, MD, is a part of the NASA Space Geodesy Program. Since its inception in the mid 1970's, this group has been involved with and been a leader in most aspects of geodetic and astrometric VLBI. Current major activities include coordination of the international geodetic observing program; coordination and analysis of the CORE program; VLBI technique development; and all types of data processing, analysis, and research activities.

2. Analysis Activities

The GSFC VLBI group has been at the forefront of geodetic research since its beginning, reporting some of the first direct measurements of regional and global tectonic motions in the mid 1980's. Currently, the main research and analysis activities of the group involve improving the measurement and understanding of Earth rotation, improving VLBI analysis techniques, and refining and maintaining the celestial and terrestrial reference frames.

The GSFC VLBI group coordinates the CORE program, which concentrates on making high precision measurements of EOP and other geophysical parameters. We currently conduct about 50 CORE experiments yearly. The long term goal of CORE, along with NEOS, is to provide continuous VLBI monitoring of EOP. It will take several years and full Mark IV correlator capabilities to reach this goal however. The GSFC VLBI group coordinates all aspects of the CORE program, including initial data base processing, analysis and distribution to the VLBI community.

The VLBI group also coordinates and performs the initial processing, analysis, and distribution of several miscellaneous types of experiments, such as the Source Survey experiments. We also obtain and independently re-analyze all available geodetic/astrometric VLBI experiments from other analysis centers, such as the NEOS, CRF, EUROPE, IRIS-S, and others. The group now has a data set approaching 6000 Mark III/IV experiments, spanning some 21 years. We regularly perform large global analysis solutions of this data set, using the SOLVE package, for EOP, TRF, and CRF solutions, and make regular contributions for the maintenance of the ITRF and the ICRF.

A joint activity between the GSFC VLBI group, the USNO VLBI group, and several NRAO personnel has been the RDV program, which uses the VLBA and several Mark IV stations, and concentrates on both high precision geodesy and astrometry. The RDVs are correlated at the VLBA correlator in Socorro and released as FITS-format, station-based visibility data. We use NRAO's AIPS software package for further processing into the regular geodetic observables - delays, rates, and phases. The GSFC VLBI group has taken the lead in developing the processing steps and additional software required for this, but there is still much to be done in this area. AIPS processing currently takes about two weeks per experiment, and the results may suffer from some unknown error sources. The same type of VLBA-style output will also be used by the JIVE

correlator and by a new Chinese correlator and will require the same type of AIPS processing for any geodetic/astrometric experiments.

The GSFC VLBI group cooperates with colleagues at the Bordeaux, La Plata, Paris and US Naval Observatories and JPL in the maintenance and extension of the ICRF. This activity, done under the aegis of the IAU and IERS, updates the ICRF for new sources and improved positions using VLBI data that become available.

The GSFC VLBI group maintains and develops the Calc/SOLVE analysis software system. A major accomplishment during the past year was the completion and release of Calc version 9.0, which provides compliance with the latest IERS Conventions. Calc 9.0, with its much more accurate nutation model, is now in use at the VLBA Correlator and will be installed on the Mark IV and most other correlators. Our group has also been the primary developer of the SOLVE analysis package and the Mark III catalog/archiving system.

An important research area in our group is troposphere modeling. Recent work has shown that atmospheric gradient modeling is improved if reasonable a priori mean site gradients are applied. This technique improves baseline repeatability and reduces the length scale error by 0.1 ppb. It also systematically reduces source declinations by an amount that peaks at around 0.1 mas near the equator, and decreases towards the poles.

During the previous year, our group started a VLBI web site which allows access to all the VLBI experiments in our data set, as well as our latest TRF, CRF, and EOP results and velocity plots from SOLVE analysis. In May 1999, we also began submitting data base files and ancillary files to the CDDIS data center for those experiments we are primarily responsible for.

A recent joint activity of our group, the USNO VLBI group, and Haystack Observatory has been VLBI observations of the Mars Global Surveyor (MGS) spacecraft. Two MGS experiments have been correlated so far, and initial analysis has been made to compute the MGS orbit using a priori VLBI delays and delay partials derived from range and range rate observations. Further work is planned to improve the orbit determination precision.

3. Staff

The GSFC VLBI group consists of approximately 20 civil servant and contractor personnel, led by Dr. Thomas A. Clark. Although many members of the group have some involvement in analysis activities, five members in particular are involved full time or nearly so in analysis activities, and their activities are described below.

Dr. Chopo Ma leads the analysis group. He has been with the VLBI group since the 1970s. He also currently serves as one member of the acting IVS Analysis Coordinator team. His interests and activities include astrometry, the celestial and terrestrial reference systems, Earth orientation, and technique development. He regularly generates the large global EOP, TRF, and CRF solutions submitted annually to the IERS and used in numerous research activities. He heads the T1 subgroup for the maintenance and extension of the ICRS under the IAU Working Group on Reference Systems.

Dr. David Gordon, a member of the VLBI group since 1983, manages all routine data processing and analysis activities for the VLBI group. He also performs the AIPS geodetic processing of VLBA experiments and maintains the initial data processing software at GSFC. He is the primary developer of Calc, PwxcB, several AIPS programs, and numerous minor programs. His interests include global and regional tectonic motions, improving the VLBI modeling, correlator support,

and phase delay development and analysis.

Dr. Dan MacMillan, a member of the VLBI group since 1990, is involved primarily in troposphere modeling and other methods of VLBI technique improvement. His interests and activities include study and characterization of atmospheric gradients and mapping functions; use of meteorological assimilation data to improve atmospheric delay modeling; EOP, TRF, and CRF studies; and analysis system software development (SOLVE). He recently wrote a paper (GRL, Vol. 26, p. 919) on interpretation of VLBI measurements of motions in the Caribbean and South America. He is also studying the problem of why different VLBI networks produce systematically different EOP results. An understanding of this problem will be critical to the success of the CORE program.

Karen Baver is a programmer and analyst who has been with the VLBI Group since 1986. She has responsibility for a wide range of software packages including the SOLVE package; the Mark III data base and solution archive catalog systems; the analysis graphics programs; and the reporting software packages. Karen also supports our web page activities; assists Dr. Ma in generating all types of TRF, CRF, and EOP reports; generates site and velocity plots; and provides assistance to new and current users of the Mark III/IV analysis package.

Cindy Lonigro is a data processing and analysis technician, with the VLBI Group since 1990. She works on initial experiment preparation, data archiving, VLBI web page support, and correlator experiment setup.

Dr. John Gipson retired from the VLBI group in January 1999. John's work and interests included tidal modeling, Earth orientation research, El Nino/La Nina effects, SOLVE development, and numerous aspects of technique improvement.

4. Current Status

The VLBI group moved into new quarters in a new Earth Sciences building at GSFC last February. This presented an opportunity for house cleaning and getting rid of obsolete equipment. The analysis group currently uses one HP C160, and five HP 735 and 745 machines. Unfortunately these are all slow and outdated by today's standards. SOLVE global solutions and AIPS processing place a large strain on these resources. The current manpower situation also sets some limitations on software development and additional research activities.

5. Outlook

During the coming year, the GSFC VLBI analysis center will convert to using Calc 9.0 theoreticals, and will reprocess all earlier data bases through Calc 9.0. We will also install and convert to using the new Fast version of program SOLVE (currently called F-SOLVE). All of our HP computers will be upgraded to the HPUX 10.20 operating system for Y2K compliance. We are hopeful of obtaining more modern and faster computer systems as well. Also, we anticipate that Dr. Leonid Petrov, currently with the Bonn VLBI group, will join our group.

Also during the coming year, the GSFC VLBI analysis center will begin making formal submissions to the IVS of data and analysis products and contributions. These submissions will include:

- NASA experiments in both Mark III data base and NGS card forms.
- Single experiment SINEX format files for NASA experiments.

- A UT1 IRIS-Intensive series, updated weekly.
- A session EOP series, and a Kalman-filtered 1-day EOP series, updated weekly.
- Hourly EOP series for all sessions.
- TRF solutions, updated every three months.
- CRF solutions, updated every six months.

Analysis and Research at the Haystack Observatory

Arthur Niell, Brian Corey

Abstract

Analysis efforts at the Haystack Observatory have been concentrated on improving the accuracy of geodetic VLBI measurements. The primary result has been the development of better models for the variation with elevation of the delay through the atmosphere.

1. Geodetic Research at the Haystack Observatory

Although Haystack Observatory is best known for the design and production of VLBI systems for data acquisition and correlation, considerable effort has been invested in improving the accuracy of geodetic VLBI measurements. This has included the planning and scheduling of special Research and Development projects such as the ATD, ERDE, and the early CONT experiments. All were designed primarily to provide data to investigate how to better measure the vertical component of station position. These and the later CONT series provide an excellent data set for testing model changes intended to improve accuracy.

Analysis

Our analysis of geodetic VLBI data uses the *solvk* package [1] with data bases obtained from Goddard Space Flight Center. The *solvk* set of programs was developed with modeling of the atmosphere a primary concern. One goal of our research is to compare the available geodetic VLBI analysis packages on a set of high quality data in order to evaluate the effect of different models. Of particular interest is any difference in results that may depend on how the atmosphere is parameterized. For example *solvk* models the atmosphere zenith delay and the gradient of the delay as stochastic processes while *solve* allows only a piecewise continuous variation in time but with constraints on the amount of change after fixed time intervals.

Atmosphere Research

The NMF mapping functions [2] that were developed at Haystack for the hydrostatic and wet components of the atmosphere are in wide use for both VLBI and GPS. These were based on a seasonal model and do not accurately reflect daily to weekly variation. A new model is being developed that will make use of daily measurements of the atmosphere to be obtained from assimilated weather data sets or, on shorter time scales, from the output of numerical weather predictions from one of the major forecast services [3].

Instrumentation

Instrumental polarization may be a significant error source as higher accuracy is sought through the use of phase delays. Experiments to determine the polarization characteristics of most antennas in the geodetic network have been carried out and correlated and need only be analyzed.

Terrestrial Reference Frame

The accuracy of the terrestrial reference frame depends on the quality of the ties among the various techniques at common sites. At Westford the GPS and VLBI antennas are only 60 m apart,

and the conventionally measured vector has a nominal accuracy of a few millimeters. However, the apparent difference in vertical position between the GPS and VLBI determinations for the ITRF at the common mark is a few centimeters. Leveling has been repeated, and GPS measurements have been made to confirm the accuracy of the local ties. The leveling repeats within a millimeter for the position of the GPS antenna, but differs from earlier measurements for the VLBI antenna by a centimeter. More seriously, the GPS height has a serious systematic uncertainty of several centimeters that depends on the analysis. This problem, due to multipath and near-field scattering in the vicinity of the GPS antenna [4], is known to affect all GPS sites at some level. Methods to reduce or calibrate the effect are being tested.

2. Outlook

During the first year of IVS we hope to complete the new mapping functions and evaluate the accuracy and feasibility on a large set of VLBI data using *soluk*. These data will provide the basis for comparison with other analysis packages (e.g. *solve*, OCCAM, GLORIA, MODEST) using either the new mapping function or reverting to one currently in use.

Analysis of the polarization data should help us to understand why we are not achieving the accuracy expected for the parameters of the individual VLBI systems. Increasing the number of baselines and stations for which phase delays can be utilized should also provide additional accuracy and better data for studying the atmosphere effects on VLBI.

As errors in the vertical are reduced for all techniques the determination of the Terrestrial Reference Frame can be improved.

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IAA VLBI Analysis Center Report for 1998-1999

*Zinovy Malkin, Elena Skurikhina, George Krasinsky, Vadim Gubanov, Igor Surkis,
Alexander Stotskii*

Abstract

The report contains a brief overview of IAA activity as IVS Analysis Center in 1998-1999 and our plans for near future in the following fields: EOP service, investigation of short-time irregularities in Earth rotation, atmosphere investigations, combination of VLBI data with ones obtained with other space geodesy techniques, comparison of EOP series and software. Results of investigations obtained during period March 1998 – March 1999 are presented.

1. Introduction

Four groups of four labs of the Institute of Applied Astronomy of the Russian Academy of Sciences (IAA) have been involved in processing of the VLBI observations:

1. Lab of Space Geodesy and Earth Rotation: Dr. Zinovy Malkin (head), Elena Skurikhina, Dr. Alexander Voinov, Dr. Mariya Sokolskaya. The main tasks of this group related to IVS activity are: management of the IAA EOP Service, determination of EOP and station coordinates using OCCAM package, combination of VLBI data with other ones, comparison of EOP series and software. Recently ERA package is under installation in the lab, too. See section 2 for more details.

2. Lab of Ephemeris Astronomy: Dr. George Krasinsky (head). The main tasks of this group related to IVS activity are: determination of EOP, station and source coordinates using ERA package [1], combination of VLBI data with SLR and LLR. See sections 2 and 3 for more details.

3. Lab of New Methods in Astrometry and Geodynamics: Prof. Vadim Gubanov (head), Igor Surkis, Sergei Petrov. The main tasks of this group related to IVS activity are: determination of EOP, station and source coordinates using new package QUASAR with emphasis on investigation of stochastic parameters (EOP, troposphere). See section 4 for more details.

4. Laboratory of Radio Physics: Prof. Alexander Stotskii. The main task of this group related to IVS activity is investigation of the Earth atmosphere path delay fluctuations. See section 5 for more details.

2. EOP Service

EOP Service of the IAA based on regular processing of VLBI observations collected from NEOS-A program is being worked beginning from 1997. Package OCCAM is used for routine processing. Both operative and yearly final EOP series have been regularly contributed to IERS.

Last final solution EOP(IAA)99R01 is based on NEOS-A VLBI observations from 05-May-1993 till 16-Mar-1999 (306 sessions with 7 days interval). The solution was obtained using OCCAM package v. 3.5 developed during last year. Model of reduction follows IERS Conventions (1996) except relativistic correction which was computed according to IERS Standards (1992). Celestial reference frame was fixed to RSC(IAA)99R02 (see section 3). Wet tropospheric delays and clock offsets were modeled as random walk stochastic process and estimated using Kalman filter

technique. Wettzell was used as reference station for most sessions. Pole coordinates, UT1-UTC and nutation angles have been estimated. Terrestrial reference frame ITRF97 with the associated velocity field was used for station coordinates.

Random and especially systematic accuracy of this series have been significantly improved as compared with previous solution obtained with OCCAM v. 3.4.

In 1999 the first global solution with package ERA was obtained. Solution includes two series EOP(IAA)99R02 and RSC(IAA)99R02 and based on processing VLBI observations, made in the frame of NEOS-A program (251 sessions observed in 1994-1998). The following data are presented: EOP (X , Y , UT1, $d\psi$, $d\epsilon$), a catalog of 301 sources, and estimated corrections to the sine and cosine coefficients of eight short-periodic terms in UT1 as given by Ray theory (see section 3). After determining the EOP, time scale and atmospheric extra-path delay parameters from diurnal sessions, the observations for each of the five years were processed simultaneously and as a result the improved coordinates of the sources and participated stations were obtained. Coordinates of the station NRAO20 as well as the longitude and latitude of the station Wettzell were fixed. The process was iterated until convergence was reached. Then the resulting catalog of 301 quasars was obtained by averaging the coordinates from the five annual catalogs.

Estimations of accuracy of both EOP series are given in Table 1.

Table 1. Estimated accuracy of the IAA EOP series

Series	X_p , mas	Y_p	UT1, 0.1 ms	$\Delta\psi$, mas	$\Delta\epsilon$, mas
EOP(IAA)99R01	0.22	0.19	0.11	0.35	0.16
EOP(IAA)99R02	0.30	0.29	0.11	0.57	0.22

In the near future we are going to focus our researches on development software, improvement of our analysis products, combination of VLBI EOP (and later SSC) series with ones obtained with satellite techniques, comparison of OCCAM, ERA (and later QUASAR) packages. It is planned also to provide daily coordinate solutions in parallel to operative EOP series. In addition to NEOS-A, observations of other programs will be included in processing, too.

3. Ocean Tidal Effects in Universal Time

Geodetic VLBI observations of 1984-1998 have been processed to estimate eight diurnal and semi-diurnal terms in UT induced by oceanic tides. The estimates were obtained independently for each of the 13 annual time intervals and then their time behavior was studied. We have used VLBI observations of 1984-1998 carried out in the frame of IRIS, CDP and NEOS-A programs (about 530,000 observations excluding for some technical reasons the years 1987 and 1992).

All stages of processing were carried out with the help of the universal program package ERA designed for solving ephemeris and dynamic problem of various types (see [1]). First the observations of each diurnal session were processed separately considering coordinates of stations and quasars as known parameters. In this step we estimated coefficients of a polynomial approximation of the atmospheric delays and the clock behavior, as well as five EOP parameters with their diurnal trends. In the second step the observations of every year were treated simultaneously to estimate corrections to the coordinates of stars and quasars, and corrections to eight ocean tidal terms in UT (sine and cosine components). The theory of the ocean tides, recommended by IERS

standards, was used as a nominal model.

The station NRAO20 was chosen as a reference after the year 1994; for the earlier dates Westford was used as reference station. As constraints we fixed the longitude and latitude of the station Wettzell. The two steps were repeated until convergence was reached. RMS of residuals of the annual series change from 35 ps to 50 ps (for the old observations).

The corrections obtained after averaging the annual estimates of the tidal terms are given in Table 2.

Table 2. Corrections to diurnal and semi-diurnal terms in UT (in μs).

Tide	l	l'	F	D	Ω	θ	sin	σ	cos	σ
Q_1	-1	0	-2	0	-2	1	-0.2	0.2	0.3	0.1
O_1	0	0	-2	0	-2	1	-0.4	0.1	0.0	0.2
P_1	0	0	-2	2	-2	1	0.3	0.3	0.1	0.3
K_1	0	0	0	0	0	1	0.1	0.4	-0.9	0.7
N_2	-1	0	-2	0	-2	2	-0.4	0.2	0.0	0.2
M_2	0	0	-2	0	-2	2	0.2	0.2	0.6	0.3
S_2	0	0	-2	2	-2	2	0.1	0.3	0.3	0.1
K_2	0	0	0	0	0	2	0.9	0.3	-0.1	0.3

The corrections are small affirming the high accuracy of the nominal model. However, some of them are statistically significant. It is interesting to study repeatability of the corrections for every year. For that the phases of the largest corrections (K_1 and K_2 tides) are presented in Fig. 1.

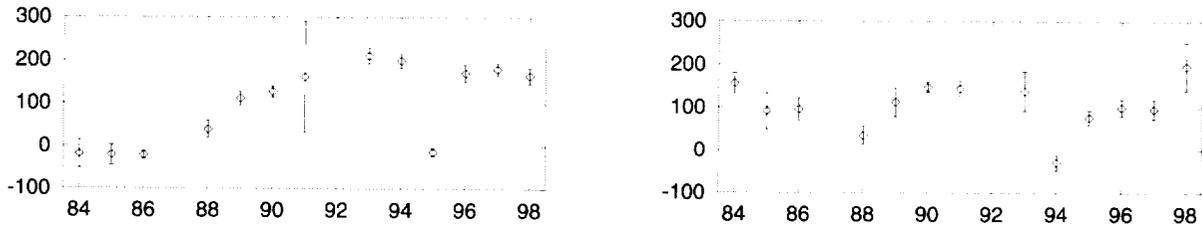


Figure 1. Tides K_1 (left) and K_2 (right): time dependence of phases of corrections.

One can see that the corrections are strongly correlated. Moreover, for K_1 the phase slowly changes with time.

4. Package QUASAR for Processing VLBI Observations

New program package QUASAR designed for scientific studies based upon VLBI observations on global networks is being developed during last year. Calculation of (O-C) values are made in line with the IERS Conventions (1996), they are referred to the ICRF celestial reference frame and the ITRF96 terrestrial reference frame. Parameters are evaluated by means of the least squares collocation technique. Stochastic parameters are as follows:

- a) sub-diurnal fluctuations of the wet tropospheric delay in zenith for all the stations;

b) sub-diurnal variations of hydrogen masers phase for all the stations with respect to a reference station;

c) nearly-diurnal variation of polar motion and Universal time due to geophysical effects.

Main part of the package is already completed and applied for analysis of the CONT'94 campaign. Among the achieved results, the most interesting are the estimates of regular and stochastic components of the wet tropospheric delay for station ONSALA in good agreement with independent WVR-measurements. Important is the fact that taking into account the stochastic parameters decreases by several times the RMS of the residual deviations of the data model and makes them closer to the formal errors given in the Mark III files.

5. Modeling of the Earth Atmosphere Path Delay Fluctuations

In the previous years the model of spatial/temporal structure function of the electrical thickness of the Earth neutral atmosphere was developed [2]. Last solution is presented in Fig. 2.

The model consists of three domains:

- (I) - power-law of 5/3 described three-dimensional small scale turbulence;
- (II) - power-law of 2/3 for two-dimensional large scale turbulence;
- (III) - saturation of random fluctuations and regular variations.

The model parameters - structure coefficients, domain boundaries, and the relationship between spatial and temporal structure functions was defined from radioastronomical and radiosonde measurements. Next year plan is to use the results of VLBI experiments for refine the model parameters and for further improvement of the model especially in the large scale region of the spatial structure function.

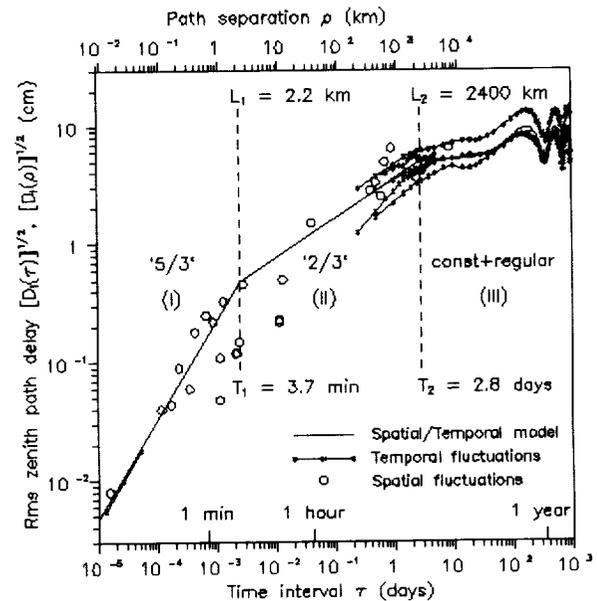


Figure 2. The model of the Earth atmosphere electrical thickness fluctuations.

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Italy CNR Analysis Center Report

P. Tomasi, M. Rioja, E. Gueguen

Abstract

This report summarizes the work of the Italian CNR VLBI analysis center. It will give the fundamental information about the structure of the center, its locations, and its activity.

1. Introduction

The Italy CNR VLBI analysis center is the joint effort of two Institutes of Consiglio Nazionale delle Ricerche (CNR) to improve the quality of the geodetic VLBI results, in particular in the European area. The two institutes are:

a) the Institute of Radio Astronomy (IRA) located in Bologna, where the main research activity is carried out, both in radioastronomy and geodesy;

b) the Institute of Informatica and Technology for Space (ITIS), located in Matera at the Center of Spatial Geodesy (of the Italian Space Agency), where VLBI antenna, laser ranging telescope, permanent GPS receiver and PRARE antenna are located.

The IRA have started to analyze VLBI geodetic database from 1989, using CALC/SOLVE package at the HP1000 at the Medicina station. In the following years that software have been installed on an HP360 workstation and later on on a HP715/50 workstation. From that time the software have been regularly updated following the indications of the VLBI group working at the Goddard Flight Space Center at Washington. We have analyzed here mostly database with some European baselines, generally at least three. The originals databases have been imported from the Geodetic Institute of the Bonn University or from GSFC - Washington, generally via ftp, and in one case via tapes. Most of the database have been reprocessed here in Bologna (using CALC and then SOLVE). During 1998 the European experiments have been released by the Bonn group at the final stage of processing. In these case the database have been used without any more editing.

From 1997 also ITIS have installed the CALC/SOLVE software and after some tests we have specialized the Bologna section to analyze single database, in order to produce the final database. The global solutions have been computed in Matera at the ITIS.

2. Data Analysis and Results

In Bologna the main computer is HP715/80, the computer name is boira6.ira.bo.cnr.it. On it we are now analysing single experiments (interactive solve), the global solutions are run mostly on Matera computer.

During 1998 we have also started to work on the possibility of using tropospheric zenith path delay from GPS in order to improve the repeatability of the VLBI geodetic results. We have inserted that data into the database using the water vapor radiometer route. The tropospheric data have been collected to the Berna site of the IGS. However the IGS data, with an hour interval, are the total tropospheric delay. For that we have subtracted the dry delay, from the VLBI data, in order to produce the "wet" zenith delay. These data have been inserted into the

VLBI database using an update version of DBCAL. In this new version the Niell mapping function was implemented and also some others errors present in the program have been corrected.

We have installed f-solve (L. Petrov) on boira6 (the center name in this case is IRACNR) and we are using this software on a regular basis.

In Matera the main computer is an HP282 computer with internet name hp-j.itis.mt.cnr.it. Also here we have installed f-solve (the center name is ITISCNR) and we are using mostly for global solutions in order to compute the positions and velocities of European stations.

The use of GPS tropospheric zenith path delay have produced some interesting results. On the European database of the 1998, the use of the new way of analysing VLBI data, seems to produce a better repeatability on the European baseline length (Rioja and Tomasi, 1999).

3. References

M. Rioja and P. Tomasi Integrating GPS zenith path-delay measurements into the analysis of geodetic VLBI observations from European Network. - Proceedings of the 13th Working Meeting on European VLBI for Geodesy and Astrometry. W. Schluter and Hase editors, BKG 1999.

JPL VLBI Group Report for 1998-1999

Chris Jacobs, Ojars Sovers

Abstract

This report describes the transitional activities of the JPL Analysis Center.

1. Introduction

For JPL the year from March 1998 to March 1999 has been one of many transitions. We are currently making changes in just about every aspect of our VLBI program.

2. Field Operations

In the field, the transition from Mark III to Mark IV has stabilized and we are striving to improve the operability of the Deep Space Network (DSN) antennas for VLBI. We continue to use both 34m and 70m antennas in Goldstone California, Tidbinbilla, Australia, and Madrid, Spain. These sites are transitioning to the new triple-cap heads thus allowing recording of either the old-style thick tapes or the newer, higher capacity thin tapes.

We also began to collect K-band (19 to 26 GHz) VLBI data on a semi-regular basis. We hope to eventually observe at even higher frequencies. The DSN wants to raise its deep space telemetry carriers from X-band (8.4 GHz) to Ka-band (32 GHz) in order to support higher telemetry rates. Thus we may have an opportunity in the coming years to extend our celestial reference frame work to a new region of the spectrum.

In an effort to tame that long time nemesis of VLBI, water vapor fluctuations, we have been developing an advanced Water Vapor Radiometer (WVR). This instrument measures the brightness temperature of the 22 GHz rotational line and supplements that data with measurements of the temperature vs. altitude. By improving gain stability and narrowing the instrument beam to allow co-pointing at low elevations, we hope to achieve mm level calibrations of water vapor induced path delay variations.

3. Data Processing

Turning to data processing, the JPL Block II Correlator is now reliably correlating Mark IV data recorded at 135 ips. Our next generation correlator, the Block III, is under development and will support a wide range of Mark IV modes while greatly reducing maintenance costs. This upgrade is inheriting technology developed for arraying Deep Space Network antennas for reception of Galileo spacecraft transmissions. This should reduce development time and maintenance costs.

Over the last year we began a fruitful collaboration with a new industry partner, Remote Sensing and Analysis (RSA) of Altadena, California. Many of you have had the good fortune of working with Ojars Sovers and Jack Fanselow—both of whom are now with RSA.

Our MODEST VLBI modelling and parameter estimation software saw two major milestones over the last year. First, the MODEST software was ported from Compaq/DEC VMS to Compaq/DEC Unix as well as HP-UX, Sun Solaris and Linux. The other milestone was the publication

of a comprehensive review article in *Reviews of Modern Physics* (Sovers, Fanselow, and Jacobs, vol 70, no. 4, Oct 98) covering our modelling efforts over the last two decades and reviewing the scientific results produced by the larger VLBI community over a similar period.

4. Publications

Several reports relevant to VLBI analysis were published in JPL's online technical journal, the TMO Progress Reports, which is available at http://tmo.jpl.nasa.gov/tmo/progress_report

1. Jacobs et al., The JPL Extragalactic Radio Reference Frame
http://tmo.jpl.nasa.gov/tmo/progress_report/42-133/133E.pdf
describes in detail our celestial frame work including a lengthy discussion of the current VLBI error budget.
2. Gorham, Designing Optimal Bandwidth Synthesis Arrays for VLBI
http://tmo.jpl.nasa.gov/tmo/progress_report/42-133/133D.pdf
discusses the design of the frequency sequences we use in astrometric/geodetic S/X observing.
3. Jacobs, Phase Calibration Tone Processing with the BlockII VLBI Correlator
http://tmo.jpl.nasa.gov/tmo/progress_report/42-134/134A.pdf
describes in detail the phase calibration tone processing done by the JPL BlockII Correlator.
4. Lanyi, Determination of the Tropospheric Fluctuation Coefficients in VLBI Parameter Estimates
http://tmo.jpl.nasa.gov/tmo/progress_report/42-133/133I.pdf
discusses our use of a combined temporal-spatial observation covariance in the analysis of VLBI data. This is an alternative approach to the more common technique of stochastic estimation of temporal variations.

Finally, our multi-year collaboration with colleagues from several institutes has been documented in Ma et al., The International Celestial Reference Frame based on VLBI Observations of Extragalactic Radio Sources

<http://www.journals.uchicago.edu/AJ/journal/issues/v116n1/970504/970504.html>

This paper describes the new IAU celestial reference frame which since 1 Jan 1998 has been the official definition of coordinates on the sky.

5. Outlook

So considering all the above developments, one can see that it has been a fruitful year for our group. The many ongoing transitions will be taking us into a number of new areas in the coming years. We look forward to these opportunities and to continued collaboration with our colleagues in the IVS.

IVS Analysis Center at MAO UNAS

Sergei Bolotin

Abstract

The report briefly describes current and planning MAO activity in the field of the VLBI data processing.

1. MAO UNAS Analysis Center

The MAO VLBI Analysis Center was established by Main Astronomical Observatory of the Ukrainian National Academy of Sciences in 1994. It is located in MAO Primary building (see Fig. 1).

The main goal of the Center is developing software for VLBI data processing. It is also to prepare global solutions of EOP, CRS and TRS to make a submission to IERS on an annual basis.

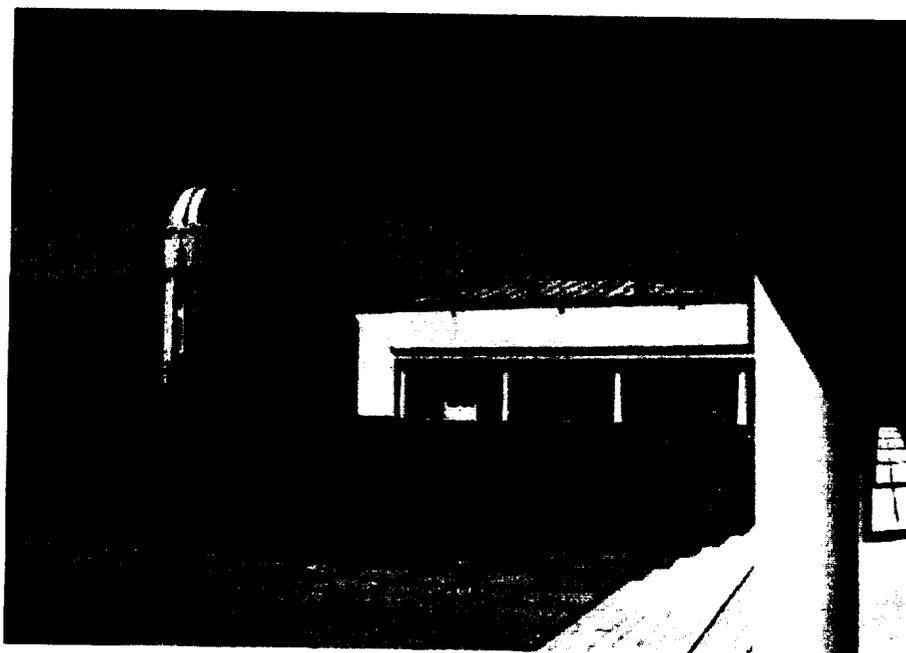


Figure 1. Main Astronomical Observatory, Ukrainian National Academy of Sciences, Kiev. General view.

2. Technical Parameters

The VLBI data processing software SteelBreeze developed by the Analysis Center is able to make a global solution of a set of the Earth Orientation Parameters, Celestial and Terrestrial Reference Systems. It is also able to produce the estimation of the parameters with high time resolution (e.g., [1] and [2]).

The software is running on the dedicated Pentium-II computer with 192 Mb RAM and 19 Gb total space of SCSI hard disks. It is possible to expand both RAM and HDD set if necessary.

3. Technical Staff of the Center

We have a small and dynamic group of persons who are contributing to IVS:

- Yaroslav Yatskiv, professor, Space Geodynamics Dept., MAO: general coordination;
- Sergei Bolotin, astronomer, Space Geodynamics Dept., MAO: data processing, development of the software;
- Olexander Molotaj, astronomer, Kiev University Observatory: analysing and combining of catalogues of radio sources (CRS).

4. Current status

The development of version 1.2 of the SteelBreeze software has been finished. It has been used in the VLBI data processing of the annual IERS submission from 1995 until 1998. An example of the software's screen shot is shown on the Fig. 2.

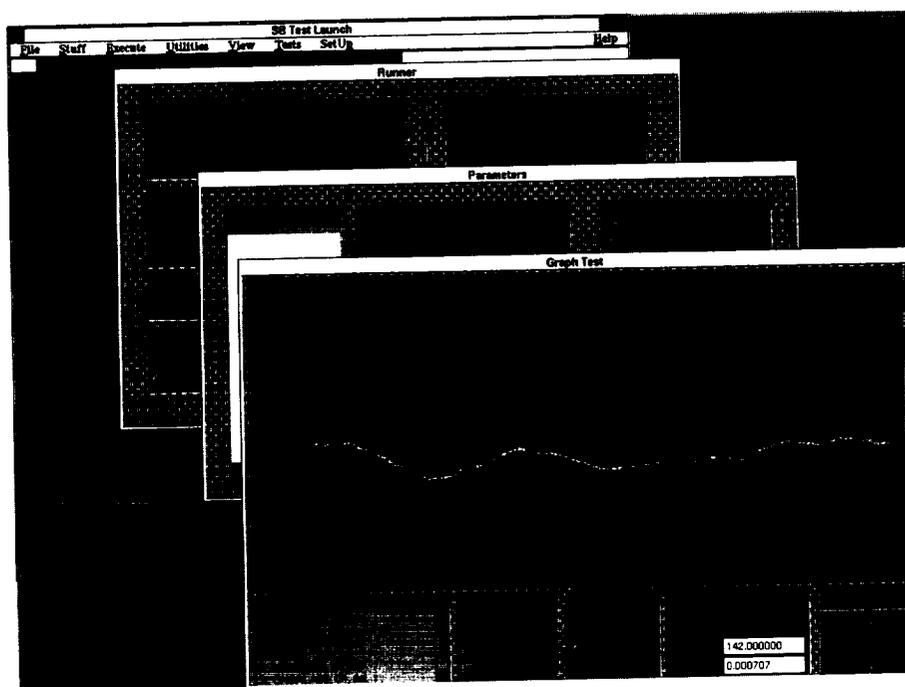


Figure 2. A screen shot of the SteelBreeze-1.2 software.

5. Future Plans

During these past years we have discovered weaknesses in the software design and now we are planning to produce a new version of the SteelBreeze. This new version will be essentially

improved and will be run on the most of popular hardware platforms. We are also going to make a submission of our results of global solutions of the EOP/TRS/CRS to IVS annually.

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Paris Observatory Analysis Center OPAR: Report on Activities January 1998 - March 1999

A.-M. Gontier, M. Feissel, N. Essaïfi, D. Jean-Alexis

Abstract

The OPAR Analysis Center, its organisation and technical means are briefly presented. The general scientific and operational aims of the Analysis Center are summarized. The current state of two projects that were developed during 1998 and up to 1999 March is described: the operational determination of UT1-UTC from the intensive sessions, and the studies of the stability of the celestial reference frame.

1. The OPAR Analysis Center

The team

The analysis center is run by the following team: A.-M. Gontier is the head of the group, N. Essaïfi is in charge of all the technical and database aspects, M. Feissel is participating in the scientific developments, D. Jean-Alexis is in charge of the operational analysis. There are two associated members, M. Bougeard and D. Gambis.

Characteristics of the analyses

Analyses are performed using the software GLORIA (GLObal Radio Interferometry Analysis) developed at Paris Observatory. The software package has available a number of models, including those recommended in the IERS Conventions (1996) [9]. The GLORIA modelling was compared in detail with that of MODEST [4]. The two models agree within 1 ps on delays and 1 fs/s on delay rates.

The solve segment of the software uses the SRIFT algorithm. The input data are extracted from the Calc VLBI database files (delay, delay rate), collected automatically from an IVS Data Center, preferably the Paris Observatory one. The complete observation/results database is managed with Oracle system. The computer used to perform analyses is an HP735 under Unix that will be replaced, in the middle of 1999, by an HPC200.

Main objectives of the Analysis Center

Already operational:

- Operational calculations for the Earth's orientation (intensive sessions).
- Studies of the celestial reference frame.
- Software development and documentation.

Under development:

- Operational calculations for the Earth's orientation (24h sessions).
- Multi-week operational calculations for the terrestrial frame.

Further plans:

- Provide feedback about station performance.
- Perform global, multi-year analyses.
- Participate in multi-technique combination projects.

2. Analysis of the Intensive Sessions

Results for 1998-1999

The IRIS Intensive VLBI observations obtained over 1998-1999 on a single baseline have been analysed. The program consists of 20 daily observations of about 16 sources observed on a single baseline. The following stations are used:

40441S007	Greenbank	Jan-Dec	4443 observations kept
14201S004	Wettzell	Jan-Fev, May-Jun	3947 observations kept
12734S005	Matera	Mar-Apr	563 observations kept
40408S002	Gilcreek	Jun, Oct, Nov	137 observations kept

Every two months the list of observed sources is changed except for five of them. This schedule results in two month batches with nearly constant geometry and sidereal time of observation; every Saturday, the schedule for the next bi-month is observed in addition to the current one. The observation scheme is optimised for the determination of universal time (UT1-UTC). With the available observations the four other parameters which can be estimated together with UT1-UTC from one session are the clock offset and the clock rate between the two stations, and a tropospheric zenith delay for each station.

The first date of analysis is 1998 JAN 03 (MJD: 50816.8). The data analysis uses as adopted references the ITRF97 and its velocity field for the terrestrial frame, the ICRF for the celestial frame, the EOP(IERS) C 04 series for the pole coordinates (x_{pm} , y_{pm}) and the IERS(1996) Theory of Precession/Nutation [9] referred to the ICRF [2] for the celestial pole offsets ($d\psi$, $d\epsilon$). The UT1 results have no diurnal/semi diurnal variations (taken off using the Ray 1995 model [9]). The other modelisations are: the IERS TN 13 model [10] for the solid Earth tides, the Scherneck model [9] for ocean loading and the Niell model [11] for the troposphere mapping function.

Statistical editing of observations results in the deweighting of 15% of the observations in the average. The estimation of UT1-UTC obtained from this analysis is shown in figure 1. The global rms postfit residuals is 45 ps. The mean difference of the series with EOP(IERS) C 04 is equivalent to 0.1 mas.

Sensitivity to the adopted references

Because of the minimal geometry of a one-hour observing session, the UT1 results are expected to be sensitive to the a priori references that are adopted in the analysis as well as to the particular set of sources observed [4, 5]. Our approach is to adopt entirely the IERS references. In practice this can be done in several ways. A series of tests was conducted during 1998 to evaluate the influence of the choice of references. The successive experiments (Table 1) concerned the terrestrial frame (including the site velocity field) and the celestial pole offsets.

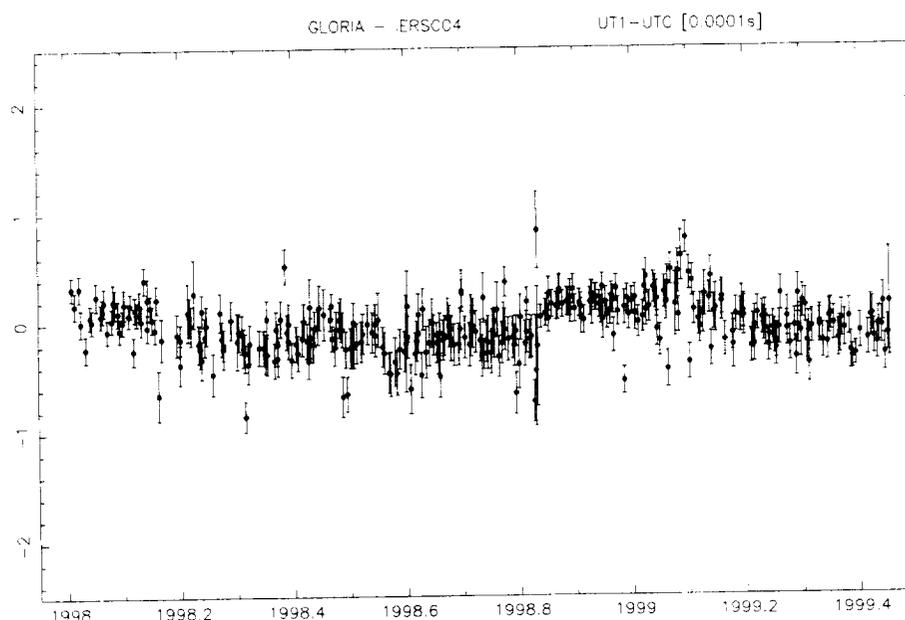


Figure 1. Estimated UT1-UTC with respect to EOP(IERS) C 04 for 1998-1999.

Table 1. Sets of a priori fixed references: terrestrial reference frame and celestial pole offsets. The celestial reference frame and the coordinates of the pole were held respectively to the ICRF and EOP(IERS) C 04. The combination corresponding to figure 1 is set #5.

	terrestrial frame		celestial pole offset
1	ITRF94 (epoch 1993.0)	NNR_Nuvel1A	EOP(IERS) C 04
2	ITRF96 (epoch 1997.0)	NNR_Nuvel1A	EOP(IERS) C 04
3	ITRF96 (epoch 1997.0)	NNR_Nuvel1A	IERS (1996) model
4	ITRF97 (epoch 1997.0)	NNR_Nuvel1A	IERS (1996) model
5	ITRF97 (epoch 1997.0)	velocity field	IERS (1996) model

The effects of the changes are summarized in Figure 2 where the discrepancy of the estimated UT1-UTC with EOP(IERS) C 04 are plotted under the form of weighted means for the six schedules implemented in 1998. The error bars are the standard errors of the means. Each point results from all observations of the same schedule, be it during the main time frame, or on the Saturdays in the previous schedule time frame.

The change from the sets of a priori #1 to #2 (change of ITRF and of reference epoch for the velocities) is particularly large (30 microseconds) for the second bi-month, the only one in which Matera is used—its predicted coordinates change by about 2 cm, both in X and in Z. The rms post-fit residuals decrease by 5-10% in experiment #2. These effects suggest that the NNR_Nuvel1A velocities are not optimal to model the observations. The next change (#2, #3) consists in replacing an operational series of the celestial pole offsets by the recommended model. The differences of the estimated UT1-UTC with IERS become more consistent (decrease of the error bars by 25-30%). The results of experiments #3 and #4 suggest the presence of a seasonal difference. However, the

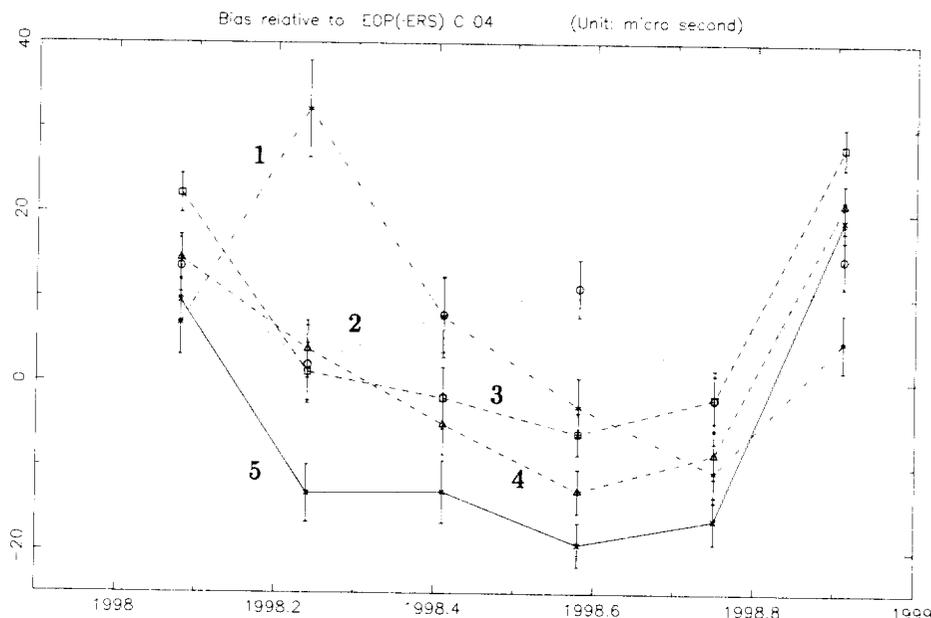


Figure 2. Weighted means of the discrepancy between estimated UT1-UTC and EOP(IERS) C 04 for the five experiments.

last change (#4, #5), that consists in the replacement of the NNR_Nuvel1A velocity field by the one determined with the ITRF, shows a different structure: the adoption of observed velocities changes by 8 microseconds the level of results involving Matera, and the possibility of systematic differences per bi-month becomes more probable. In the investigation described in the next paragraph, we found that several sources in each bi-month schedule have positions discrepancies in 1998 in the range 0.3-0.8 mas. This changes may explain part of the biases in UT1.

3. Stability of Radio Source Positions

After the adoption of ICRS by the IAU [2], studies are necessary to assess the stability of the ICRF and to prepare its future revision. This study is based on a series of source positions per session computed by M. Eubanks (ftp: casa.usno.navy.mil/navnet/frame20.arcs.iers). A total of 75000 individual positions are available for 610 sources from August 1979 through March 1999. The positions per session are expressed in a unique reference frame that is close to the ICRF. A number of sources have an observational history dense enough to build continuous time series of coordinates at a constant time-interval (e.g. 0.5 year, 1.0 year).

Figure 3 show examples of the time evolution of coordinates for three of the defining sources of ICRF, 1308+326, 1606+106, and 2145+067, under the form of weighted yearly averages referred to their respective means over 1983-1999. The error bars shown are the standard errors of the averages. The numbers of observations available each year are also shown in the plot. Those three sources were chosen because they were mentioned as having potential stability problems in the discussions for preparing a new analysis of the celestial reference frame (study group chaired by C. Ma).

A distinct feature of these time series, that is also true for the other sources, is the continuous

improvement in quality with time, as can be seen from the error bars of the yearly averages. Results after the start of 1990 are quite better than those in the earlier period. However, instabilities with sizes several times the error bars are also present. This calls for a systematic study of the time series of coordinates in order to derive a statistical qualification of their time-stability.

It is reminded that the sources published with the ICRF [5] were categorized as *defining* for those with the most precise and accurate coordinates, *candidates* for those that were assumed suitable for precise astrometric purposes but need additional observations, and *other* for those judged not suitable for precise astrometric reference due to large variability in the emission structure or other observational problems, even if they had a rich observational history. This original classification is based on a number of quality criteria, such as quality of data and observational history, consistency of coordinates derived from subsets of data, and repercussions of source structure. Due to the data available, in particular source structure mapping at a single epoch, these criteria involved little consideration of time evolution.

The following is an illustration of a complementary approach, based on the Allan variance analysis [1]. In a few words, this technique allows to distinguish characteristic time variability spectra, such as white noise, flicker noise and random walk. It is applied to 65 sources for which a continuous series of coordinates at 0.5 year interval could be built over 1990-1999. The results are shown in Table 2. Considering the time span of available good quality data, this qualification of stability is valid up to about five years. For comparison with the existing categories, the results are shown separately for the *Defining*, *Candidate*, and *Other* sources, roughly in decreasing order of stability. Most of the sources show a white noise spectrum over the time span studied. In such a situation, accumulating data should help improving progressively the coordinates. For the minority of sources that are found to have a flicker noise spectrum, extending the time span of observations are not expected to result in the stabilization of the estimated coordinates.

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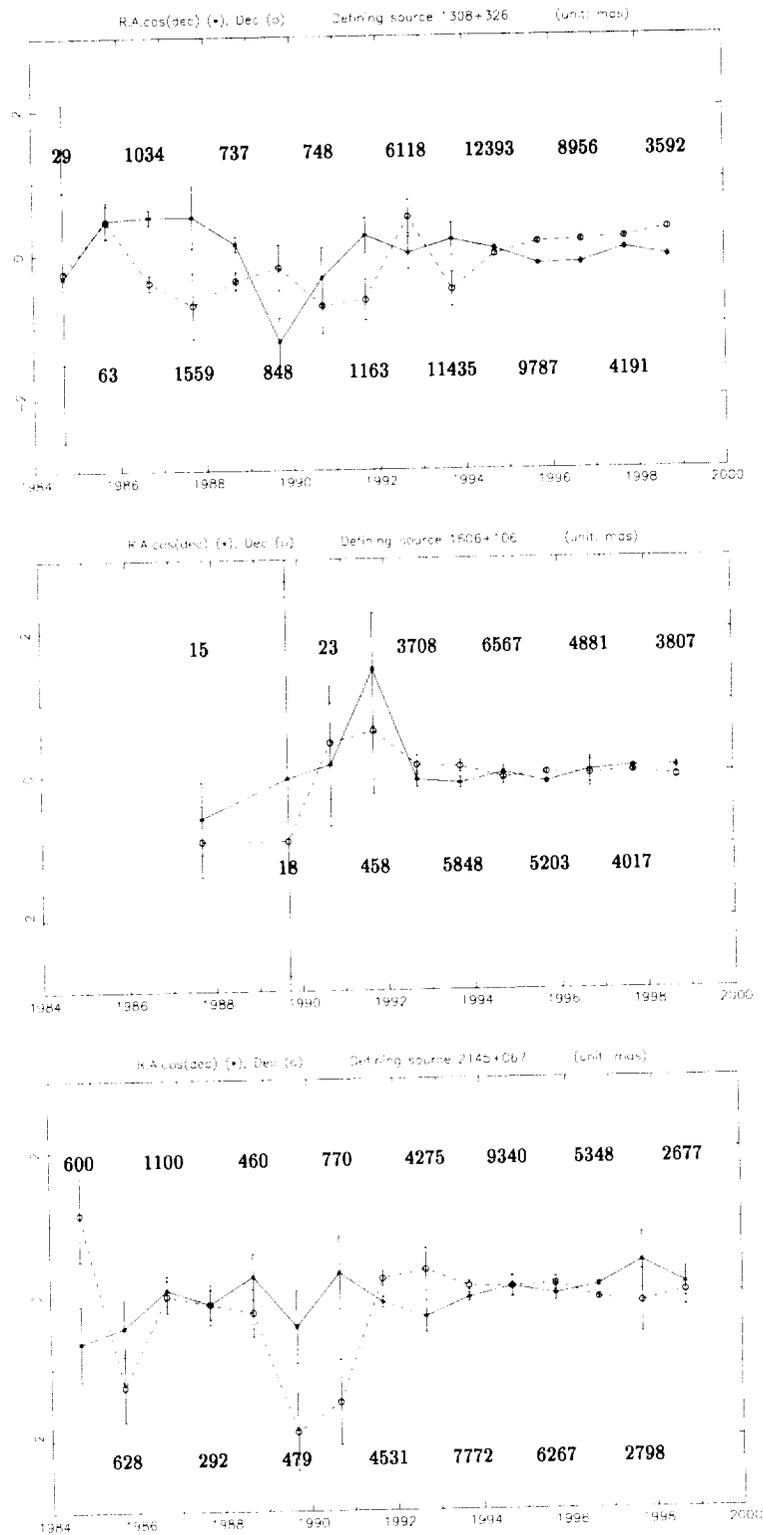


Figure 3. Yearly average coordinates for three defining sources, 1984-1999. The numbers of observations are given alternatively up and down for each year

Table 2. Stability for a one-year sampling time (unit: μas) and spectral type of radio source instabilities (1990-1999) in Right Ascension *cos(declination) and in declination.

Source	stability μas		stability spectrum		Source	stability μas		stability spectrum	
	σ_α	σ_δ	White	Flicker		σ_α	σ_δ	White	Flicker
Defining									
1128+385	43	38	δ	α	2145+067	94	112	δ	α
0014+813	49	46	δ	α	1057-797	157	95	α, δ	
1637+574	53	59	α	δ	0954+658	143	121	α, δ	
0642+449	53	62	α, δ		0235+164	116	252	α, δ	
1606+106	69	61	α, δ		0637-752	252	154	α, δ	
0133+476	90	61	α, δ		1038+528	48	361	α, δ	
1308+326	92	97		α, δ	0457+024	649	592	α	δ
Candidates									
1357+769	16	34	α	δ	1749+096	143	209	α	δ
0552+398	31	25		α, δ	2234+282	162	165	α, δ	
1803+784	45	54		α, δ	1614+051	151	229	α, δ	
0851+202	73	66	α, δ		0229+131	148	256	δ	α
1611+343	32	103	α, δ		0119+041	153	287	α, δ	
1739+522	84	100	α, δ		0458-020	101	393	α, δ	
1156+295	56	199	α, δ		0823+033	122	392	α, δ	
0528+134	117	87	α, δ		0201+113	129	334	δ	α
0202+149	86	147	α, δ		2355-106	261	936	α, δ	
0657+172	72	230		α, δ	0336-019	354	579	α, δ	
1044+719	108	114	δ	α	1244-255	315	933	α	δ
0814+425	132	203	α, δ		1519-273	588	1831	α, δ	
Other									
0923+392	90	30	α	δ	1354+195	374	259	α, δ	
1638+398	91	88	δ	α	1921-293	190	517	α, δ	
0300+470	94	123	α, δ		2255-282	347	288	α, δ	
0735+178	84	128	α, δ		1633+382	466	323	α	δ
2200+420	85	172	α, δ		0537-441	389	583	α, δ	
2007+777	190	53	α	δ	0420-014	202	750	α	δ
1741-038	69	351	δ	α	1815-553	616	468	α, δ	
2243-123	51	558	α, δ		1622-253	563	761	α, δ	
1334-127	141	169	α	δ	0208-512	649	860	δ	α
0212+735	163	164	δ	α	0048-097	492	1031	α, δ	
0727-115	147	164	α, δ		1034-293	718	1179	α, δ	
1610-771	133	202	α, δ		1958-179	248	1153	α, δ	
1901+319	134	227	α, δ		2128-123	384	2166	δ	α
0953+254	182	201	α, δ						

The IVS Special Analysis Center at the Onsala Space Observatory

Rüdiger Haas, Hans-Georg Scherneck, Gunnar Elgered, Jan M. Johansson

Abstract

We give a short overview about the Onsala Space Observatory (OSO) in its function as an IVS Special Analysis Center. We present topics currently worked on at Onsala and describe future plans.

1. Introduction

The Onsala Space Observatory (OSO) is active as an IVS Special Analysis Center. OSO focuses on a number of special problems which can be investigated using and developing VLBI databases and analysis programs, and providing ancillary parameters. There is no intention and no capability at Onsala to do global VLBI analysis on a routine basis.

2. Staff at Onsala associated to the IVS Special Analysis Center

The staff at Onsala associated to the IVS Special Analysis center is: Hans-Georg Scherneck (scientist), Gunnar Elgered (scientist), Jan M. Johansson (scientist) and Rüdiger Haas (scientist). Corresponding e-mail addresses and telephone numbers can be found on the Onsala web page.

3. Special Analysis at Onsala

Solid Earth tides:

Space geodetic observations are affected by site deformations caused by solid Earth tides. Geodetic VLBI data are used to determine frequency dependent complex Love and Shida numbers and the complex eigenfrequency of the Free Core Nutation resonance [1].

Ocean tide loading:

Ocean tide loading is the second largest Earth deformation effect after the solid Earth tides. Geodetic VLBI observations are sensitive to this effect and it has to be accounted for in the analysis of geodetic VLBI data. Several different theoretical ocean tide loading models exist which are based on different ocean tide models [2], [3]. Ocean tide loading parameters are provided from OSO for all VLBI stations world wide. Estimates of ocean tide loading effects from geodetic VLBI observations can be used to verify and/or refine the theoretical ocean tide loading models [4].

Ocean tide loading and Earth orientation:

Ocean tide loading influences the determination of Earth orientation parameters with space geodetic techniques. Particularly mismodelling of horizontal ocean tide loading possesses a common rotation mode for a network of space geodetic stations. Neglect or mismodelling will therefore contaminate the derived Earth orientation parameters by so-called "virtual polar motion and UT1 variations". In a recent paper [5] we presented predictions for this effect for different currently used geodetic VLBI networks used for Earth rotation studies. The predictions are proved by analysis of the CONT94 VLBI data.

Atmospheric loading: Redistribution of atmospheric masses loads the Earth's surface and leads to large-scale deformations. Corrections for this effect based on different theoretical approaches are introduced in the analysis of VLBI data [6]. Empirical estimates for the effect are compared to theoretical predictions. A data base with atmospheric loading predictions based on global pressure fields has been generated for 1989–1997.

European geodetic VLBI network:

Concerning the European geodetic VLBI network the analysis at Onsala concentrates on the development of alternative analysis strategies. In collaboration with the Geodetic Institute of the University of Bonn (GIUB) we developed a two-step analysis strategy to derive realistic station displacements [7]. Based on a session by session analysis of the data in a second step station displacements are derived. This approach allows, as compared to usual vector solutions, an improved quality check of the derived displacements since obvious deviations are detected and cross-talk of station deficiencies can thus be reduced.

Integrating VLBI and GPS:

The different space geodetic methods have their advantages and disadvantages. Especially for the determination of absolute sea level changes it is useful to integrate several space geodetic techniques. For this purpose we work on the combination of GPS data from the BIFROST project with European VLBI data [8].

Thermal deformation of VLBI radio telescopes:

VLBI radio telescopes deform due to thermal influences, an effect that is continuously monitored at Onsala [9]. The thermal deformation effects show seasonal and short term behaviour. A simple model for the effect based on the telescope dimensions and ambient temperature has been described in [10]. In collaboration with the Geodetic Institute at the University of Bonn (GIUB) we started the collection of telescope dimensions to model the thermal deformation effect routinely in the VLBI analysis using SOLVE (see <http://giub.geod.uni-bonn.de/vlbi/thermal-ex/index.html>).

Water vapor in the atmosphere:

Water vapor in the atmosphere influences radio wave propagation and so affects the colocated techniques VLBI and GPS at Onsala. The colocated water vapor radiometer (WVR) is sensitive to emission close to the water vapor emission line. Good agreement is found for the atmospheric zenith parameters derived from simultaneous observations using the three techniques [11] [12].

4. Outlook

Special emphasis of our analysis in the near future will be on Earth tides and ocean tide loading. We will work on new formulations of loading models and the implementation into VLBI analysis software. Of importance will be parameter estimation and covariances with other parameters like terms of polar motion and UT1.

We will work on a strategy for a combined determination of parameters of the Free Core Nutation resonance from solid Earth tide deformations and nutation.

Work with global atmospheric pressure fields will be continued and used for studying atmospheric loading effects and the corresponding parameter estimation. Of special concern are dynamic

response effects in near-by oceanic basins.

We will continue to study analysis strategies for the European geodetic VLBI network in order to derive the most reliable station displacements. These results will be interpreted with respect to geophysical models.

We will continue to investigate thermal deformation of VLBI telescopes and other local effects. The actually monitored vertical deformations due to thermal expansion will be used to calibrate simple models for this effect.

We will use simultaneous observations with the colocated techniques of VLBI, GPS and WVR to study atmospheric properties. We will study the effect of incorporating atmospheric propagation delay corrections derived from the other techniques in the analysis geodetic VLBI and its impact on parameter estimation.

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VLBI Research Activities for Astrometry and Geodesy at Shanghai Astronomical Observatory

Jinling Li, Guangli Wang, Zhihan Qian

Abstract

This report summarizes the current status, research activities and plans of the astrometric and geodetic VLBI group of Shanghai Astronomical Observatory for VLBI and IVS.

1. Introduction

Under the umbrella of Chinese national reforming and opening policy, the Creative Project of Chinese Academy of Sciences, which will be carried over to the next century, was started last year. Personnel and research activities of the astrometric and geodetic VLBI group of Shanghai Astronomical Observatory (SHAO), also as one of the 27 research groups of the National Astronomical Observatory, were reorganized to fit with this project. In this report we will address to colleagues our current status, research activities and plans for future work in order to promote basic understandings and cooperations.

2. Current Status and Research Activities

2.1. The Astrometric and Geodetic VLBI Group, SHAO

The Astrometric and Geodetic VLBI Group at SHAO was established in the middle of the 1980s. At that time, the VLBI group belonged to the Radio Astronomy Division, SHAO. The research divisions were reformed and the Center for Astro-geodynamics Research was established at SHAO in 1995. Since then, the Astrometric and Geodetic VLBI Group belongs to this center. Recently, the VLBI Group and the fundamental astrometry group were combined as one group, and is one of the research groups of the National Astronomical Observatory.

The members of the VLBI Group are as follows:

Li, Jinling	<i>Research Professor, head of the VLBI Group</i>
Qian, Zhihan	<i>Research Professor</i>
Jin, Wenjing	<i>Research Professor</i>
Yan, Haojian	<i>Research Professor</i>
Wang, Guangli	<i>Research Assistant</i>
Wang, Shuhe	<i>Associate Research</i>
Zhou, Ruixian	<i>Senior Engineer</i>
Tang, Zhenghong	<i>Research Assistant</i>

The NASA/GSFC's Geodetic VLBI software, CALC8.2/SOLVE/GLOBL which has been installed on a HP C-180 workstation is used for VLBI data analysis.

2.2. Global Solution for Astrometric and Geodetic VLBI Experiments

Shanghai Astronomical Observatory is one of the VLBI data analysis centers of the International Earth Rotation Service (IERS) and the International VLBI Service (IVS). We have submitted our analysis results to IERS annually. This year, our analysis covers the celestial and terrestrial reference frames (CRF and TRF) and Earth Orientation Parameters (EOP), and is based on all the historical astrometric and geodetic VLBI observations available to us up to January of 1999. It is the first time for us to perform a global solution with the data spanning more than 20 years.

Comparisons of our solutions with ITRF (96), ICRF (RSC (WGRF) 95 R01) and EOP (IERS) C04 are performed. For CRF, the three orientation angles are not significant at the level of precision of 0.02mas . However, though no significant values are found for the three deformation parameters, local deformations up to 0.5mas are still identifiable. Details are still under investigation. For TRF, the orientation angles and their rates of change are not significant respectively at the precision level of 0.1mas and 0.05mas/yr . Detailed comparisons with ITRF96 show that our solution gives higher motions for the eastern part of the Eurasian plate in the southeast direction and for Australian plate in the south direction by several millimeters per year. About EOP series, the systematic differences and the relative drifts are also not significant respectively at the precision level of 0.1mas and 0.05mas/yr . These show that our solutions this year are pretty good.

2.3. Asia-Pacific Space Geodynamics Project

The Asian-Pacific Space Geodynamics (APSG) project was sponsored and organized by Prof. Shuhua Ye, Academician of the Chinese Academy of Sciences (CAS) in 1996, and is an international cooperation program being carried over to the next century. The primary objectives for the APSG project are to measure and monitor the current crustal movement and deformation in the Asian-Pacific region using high precision space geodetic techniques such as VLBI, GPS and SLR, and so to investigate various crustal motion rooted natural hazards, such as earthquakes, volcanic eruptions, etc. The project is expected to contribute to the means for mitigating and preventing natural disasters as well.

In October of 1997, the astrometric and geodetic VLBI group of SHAO, cooperating with GSFC VLBI group, NASA, USA, organized the VLBI experiments of the first APSG campaign. The second APSG VLBI campaign was carried out in November of 1998. We presently intend to organize one campaign per year in the following years. Each campaign consists of two 24-hour sessions.

From data analysis of the 1997 and 1998 APSG VLBI campaigns, the followings are illustrated:

- The mean accuracy of the baseline length measurements for the VLBI stations in the Asian-Pacific region is about 1.3×10^{-9} , which is consistent with the repeatability of baseline length measurement for other VLBI stations in the world.
- Regarding the VLBI measurements of the station velocities, they are in good consistence with the predictions of NUVEL1A-NNR for stations such as Gilcreek, Alaska (USA) and Hobart, Tasmania (Australia). However, they are not well consistent for stations such as Sheshan and Urumqi (China), Kashima (Japan) and Kokee, Hawaii (USA). Therefore, the plate motion model well describes the large-scale behaviors of global tectonic plates, rather than contemporary deformations taking place within plates or along boundary region.
- The detected eastward motion of Sheshan station and the north by northeast motion of

Urumqi station are of important significance to the study of the modern crustal movement of China, which directly indicates the effect of the northward movement of the Indo plate on the rising Tibetan Plateau and on the motion of the Tian Shan mountain area in the northwest part of China as well as on that of the eastern part of China.

- The westward motion of the Kashima station of Japan is closely related with the westward motion of the Pacific plate.

2.4. Chinese National Research Projects

Our activities are also involved in several Chinese national research projects, such as:

- Contemporary Crustal Motion and Geodynamics;
- Crustal Movement Observation Network of China;
- Mechanism and Prediction of Chinese Continental Intensive Earthquakes.

Outstanding characteristics such as high precision repeatability for long baseline length measurements and providing high precision observations in the quasi inertial deep space background, make VLBI one of the key supporting techniques of these projects. We mainly undertake the coordination of VLBI experiments, data processing, archive and reduction. Also, we provide the data analysis results of the change rates of baseline components and current motions of VLBI sites in China for further investigations.

2.5. Application Studies and Modeling of Data of VLBI

We are also devoted to application studies of VLBI to the establishment and maintenance of celestial and terrestrial reference frames (CRF and TRF), and the determination of Earth orientation parameters (EOP) and their interpretation.

On the CRF, we are interested in factors related to maintenance and stability, such as the method for the selection of defining sources, improvement of position precision of other sources, identification of local deformations, source structure and its variation, the rotational Galaxy and so on. We are also devoted to the improvement of the proper motion precision of Hipparcos stars using historical plates archived in Sheshan Section of Shanghai Astronomical Observatory, to precise position determination of optical counterparts of radio sources with CCD, and so to the tie between the optical and radio frames.

On the TRF, we are interested in the determination of local motion of stations relative to the prediction of plate models. Then, regional local motion can be statistically identified. These are important inputs for geodynamic studies of current crustal movement. Because of the high repeatability for the measurement of long baseline length, VLBI station is qualified as high precision reference point for regional geodesy.

On modeling the data, we are devoted to the improvements for corrections of the atmosphere effect.

3. Plans for VLBI and IVS

VLBI will continue to play an important role in the establishment and maintenance of celestial reference frame, the determination of Earth orientation parameter and in global and regional

studies of crustal motions. We will be devoted much to global and regional VLBI data reduction, applications and modeling data.

4. Recent publications

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- Jinling Li, Guangli Wang. Corrections to the IAU 1976 precession constant and the coefficients of the IAU 1980 nutation series from VLBI observations. *Chinese Science Bulletin*, 1998, Vol.43 No.12, 1019-1023
- Jinling Li, Dawei Zheng, Guangli Wang. An analysis of the pole offset series in EOP (GSFC) 96 R 01. *Publications of Yunnan Observatory*, 1998(2), 33-44
- Jinling Li. An introduction of the SVD algorithm and its test of artificial data. *Annals of Shanghai Astronomical Observatory*, 1998 (19), 16-21
- Jinling Li, Dawei Zheng. The temporal variations of the free core nutation, *Acta Astronomical Sinica*, 1998, Vol.39, No.3, 308-312
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- Jinling Li, Zhihan Qian, Guangli Wang. The motion of the Shanghai collocation site relative to the Eurasia plate. In: *Proceedings of the international workshop on geodetic measurements by the collocation of space techniques on earth*. January 25-28, 1999, at the Communications Research Laboratory, Koganei, Tokyo, Japan. pp184-188

Earth Orientation Analysis from the U.S. Naval Observatory VLBI Program

T.M. Eubanks, B.A. Archinal, F.J. Josties, J.R. Ray

Abstract

As part of its participation in the National Earth Orientation Service (NEOS) the U.S. Naval Observatory (USNO) operates a program in Very Long Baseline Interferometry (VLBI) data acquisition and analysis to monitor changes in the orientation of the Earth on a regular basis. This report describes the VLBI observations conducted by the USNO, the methods of data reduction and analysis, and the Navy 1999-3 reference frame created for use in operational VLBI data reduction for Earth orientation. The major differences between Navy 1999-3 and the previously used 1998-10 system consist of changes in the atmospheric parameterization, and a change in the *a priori* Terrestrial Reference Frame (TRF) used from ITRF-96 to ITRF-97. This report provides details both of recent NEOS VLBI operations, and of the Navy 1999-3 system.

1. VLBI Operations

Current NEOS operations consist of one 24-hour duration NEOS-A observing session, on Tuesday-Wednesday of each week, for Earth orientation, together with daily one hour duration "intensives" for UT1 determination. The NEOS VLBI data are correlated at the Washington Correlator, which is located at the U.S. Naval Observatory and run by the NEOS. After correlation, fringe fitting, and the removal of any remaining bandwidth synthesis delay ambiguities, data from all available multiple baseline VLBI sessions are used in a series of weighted least-squares solutions to define a USNO VLBI reference frame and to estimate the Earth orientation within that reference frame. This report provides details on the procedures and models used at the USNO in the reduction of these data.

2. The Navy 1999-3 Reference System

The current USNO VLBI practice is to define a reference system and to realize the frame anew from each (weekly) global solution. For some purposes, however, such as the reduction of the UT1 Intensive data, it is desirable to use a fixed reference frame based on a particular solution in the Navy 1999-3 system; this will be called the "reference" solution. The results from both the reference solution and the "current" (i.e., most up-to-date) solution are available on the World-Wide-Web [2], and the technical description for this system is described in [3]. All of the VLBI results described in this report are based on the reference solution, which is also the solution submitted to the IERS for the 1998 IERS Annual Report. The reference 1999-3 solution used 2,295,502 delay and rate observation pairs from 2695 observing sessions, with useful data on 652 sources from 1119 baselines and a total of 115 observing stations. The reference Navy 1999-3 solution has a Weighted Root Sum Square (wrms) delay residual scatter of 29.97 picoseconds, and a wrms phase delay rate scatter of 89.67 femtoseconds / second. The reference time adopted was January 1, 1997.

2.1. Differences Between the 1998-10 and 1999-3 Systems

The Navy 1999-3 reference system is intended for operational use by the U.S. Naval Observatory (USNO) VLBI program in the reduction of VLBI data for the determination of Earth orientation. It is in general very similar to the Navy 1998-6 system in its 1998-10 realization, which is described in the IERS Annual Report for 1997 [1]. The differences between the 1999-3 and the earlier 1998-10 system are:

- The ITRF-97 is used instead of the ITRF-96 to define the origin of the system. The system is tied to the *a priori* TRF by minimal constraints, such that there is no-net rotation, translation, rotation rate and translation rate between the *a priori* TRF and its VLBI realization. Further details on these constraints are provided below.
- The Niell Mapping Function (NMF) is used instead of the MTT mapping function.
- The constraints on the piecewise linear tropospheric gradient model were changed from 25 mm and 25 mm day⁻¹ to 1.25 mm and 15.0 mm day⁻¹.

Note that the Celestial Reference Frame tie has **not** changed: both systems are tied to the International Celestial Reference Frame (ICRF) [5] through a no-net rotation constraint.

In a detailed analysis of the differences between the 1998-10 and 1999-3 systems [4], the parameterization changes are found to cause about 60-80 micro arc second (μas) scatter in the Earth Orientation Parameters (EOP), while the TRF change causes a rotation of order 200 μas and a rotation rate of as much as 40 $\mu\text{as yr}^{-1}$.

2.2. Models Used in the VLBI Reduction

The data used in the report are processed with models consistent with the *IERS Conventions*[6] to the maximum extent possible, with the CALC 8.2 software being used throughout in the data reduction process. The NMF dry tropospheric mapping function is used to relate line of sight tropospheric propagation delays to the tropospheric zenith delay, the NMF wet mapping function is used for the tropospheric zenith parameter partial, and an elevation angle lower limit of 7 degrees is used in all solutions. The IERS standard model for both horizontal and vertical deformations due to ocean tidal loading is applied, although neither atmospheric loading deformations of the ground nor thermally induced antenna deformations are modeled at present.

Unmodeled variations in the tropospheric propagation delays and the relative time offset between the station clocks are a significant source of error in geodetic VLBI. The surface pressure, temperature and relative humidity are recorded at each station and the pressure is used to estimate the variations in the hydrostatic zenith tropospheric propagation delay. Further variations in this quantity are treated by the estimation of piecewise continuous linear models directly in the least squares solutions. A new piecewise continuous linear function is introduced every 60 minutes for the zenith tropospheric propagation and every 90 minutes for the relative station clocks. In order to account for variations of atmospheric properties near each observing station, parameters of a linear gradient model for the tropospheric propagation delay are now estimated, with an East-West and North-South piecewise continuous linear gradient function being estimated for each station every 3 hours.

2.3. The Terrestrial Frame Tie

The USNO Navy 1999-3 Earth orientation reference frame is obtained directly in a solution for all terrestrial and celestial reference frame parameters, subject to minimal ties to *a priori* reference frames. This makes it possible to estimate the TRF, CRF and the Earth orientation parameters for all observing sessions simultaneously in one solution. The TRF tie is to the ITRF-97, and consists of no-net translation and rotation, together with translation rate and rotation rate constraints, to the positions and velocities of the 27 stations given in the technical description [3]. Only the horizontal components of position and velocity are used in these constraints, and the sum over each component is weighted by the corresponding diagonal element of the inverse covariance matrix. There is no constraint of any sort on the frame scale or scale rate. In general, collocated VLBI stations are used to derive independent velocity estimates. There are six collocated pairs of stations where this could not be usefully done for one of the two stations, or, in the case of Fort Ord, it was judged better to have one rate estimate. These close station pairs, also described in the technical description [3], were constrained to have the same velocities in the solution. For 26 stations, there was insufficient data to estimate a meaningful velocity, and so the data from these stations were only used to estimate the station positions, with their velocities being those given in ITRF-97. In addition, 14 stations suffered from discontinuous position shifts, either due to earthquakes or due to repair or other changes at the station, and for these stations a step-function in position was estimated together with one station velocity for the entire period of data. Further details on all of these special cases is given in [3].

2.4. The Celestial Frame Tie

The Celestial Reference Frame (CRF) is tied in rotation to the positions of 198 of the 212 defining sources of the IAU International Celestial Reference Frame (ICRF). Fourteen defining sources, as described in [3], were dropped from this constraint as they have not provided good data in recent observations. Again, the sum over each component used is weighted by the corresponding diagonal element of the inverse covariance matrix.

2.5. Details on the Changes in Atmospheric Parameterization

The Niell Mapping Function (NMF) was adopted for the first time in the Navy 1999-3 system. (The “dry” mapping function is used with the surface pressure and the Saastamoinen hydrostatic model [6] to calculate the *a priori* tropospheric delay, while the “wet” mapping function is used for the zenith delay partial.) Although this was done primarily because this mapping function is thought to produce a more reliable absolute VLBI frame scale, there is also internal evidence that the NMF is better than the MTT mapping function used previously [4].

In the Solve software used for VLBI data reduction at the USNO, the tropospheric gradients are estimated as piece-wise continuous linear functions, and both the 1998-10 and 1999-3 systems introduce a new gradient rate pair (North-South and East-West gradients) every 3 hours at each station, in order to capture the observed diurnal gradient variations. There is one constraint on the bias of each component of each station, averaged over the entire session, plus a constraint on each piece-wise linear rate parameter. The *a priori* values for these parameters are currently zero, so using any constraint will statistically bias the results towards zero. In the 1998-10 system the constraints were set to be “loose,” at 25 mm and 25 mm day⁻¹. This was found to cause problems

with the VLBI data from before ~ 1986 , which have very poor gradient determinations, and it seemed desirable to tighten these constraints. Adopting too strong a gradient constraint, however, also causes problems as most stations have a persistent bias of $\sim 1/2$ mm in the North-South gradients, due to the equatorial bulge of the troposphere, and there are also observed variations at seasonal, diurnal, and maybe other periods. The 1999-3 constraints were determined by adopting a criteria that neither the observed annual nor diurnal gradient oscillations should be attenuated by more than $\sim 10\%$ in the recent data, which yielded a gradient offset constraint of 1.25 mm, and a rate constraint of 15 mm day^{-1} .

2.6. EOP Parameterization

The USNO Earth orientation results are obtained from the long duration experiments in a multi-parameter least squares adjustment for UT1, polar motion and both components of nutation, together with the minimally constrained CRF and TRF, in addition to piecewise linear clock and troposphere models. Additional baseline-dependent clock offsets are added whenever the non-closure of the clock estimates around station triangles is judged to be significant. The operational USNO solutions also estimate the rate of change of the UT1 and polar motion for each observing session. These rate estimates, converted to the more geophysically useful " χ " excitation parameters, are provided routinely. The TRF and CRF are now updated in the course of each solution, and the updated reference frames are now routinely provided in addition to the Earth orientation parameters.

3. UT1 Intensive Data Reduction

The UT1 Intensive Series is derived from short-duration (~ 1 hour) single-baseline observations conducted solely to monitor daily changes in the UT1. One difference between the intensive solutions and the regular NEOS solutions lies in the treatment of nutation and polar motion, which are not estimated in the intensive solutions, but are instead held fixed to the values given in the IERS Bulletin A, linearly interpolated to the epoch of the data. The station coordinates and velocities, axis offsets, and the source positions are fixed at the *a priori* values given by the Navy 1999-3 reference frame, with the reporting epoch for each observing session being the mid-point of the session. The NEOS/IRIS UT1 Intensive files produced by the USNO now extend back to 1984 in one homogeneous solution.

3.1. High-Frequency EOP Variations and the Intensive Results

The current accuracy of VLBI Earth orientation results is sufficient to clearly detect tidally coherent diurnal and semi-diurnal variations in UT1 and polar motion, mostly due to the non-linear response of the oceans to the luni-solar gravitational tides. These variations can be a significant source of systematic error, and so have been removed from the 1999-3 solutions using the empirical hf966b model prepared by John Gipson and his colleagues in the Goddard Space Flight Center VLBI group. The model values are not added back into the UT1 and polar motion estimates, so that the orientation results provided in the operational Earth orientation solutions are close to the 24-hour average values for the Earth orientation centered on the epoch of observation. The same model is used in the reduction of the IRIS/NEOS Intensives. Again, the model values are not added back into the Intensive results; these short duration estimates thus do not reflect the true

orientation at the reporting epoch, but are instead closer to the 24-hour average for the reporting epoch.

References

- [1] The USNO Annual Report for 1997 is obtainable from
ftp://casa.usno.navy.mil/navnet/iers_report.97.
- [2] The availability of the Navy 1999-3 system is described in
<ftp://casa.usno.navy.mil/navnet/README.n9903>.
- [3] The USNO Technical Descriptions for the full Navy 1999-3 solution, and the Intensive solutions, are obtainable from
<ftp://casa.usno.navy.mil/navnet/n9903.descript> and
<ftp://casa.usno.navy.mil/navnet/n9903.int.descript>.
- [4] A memo giving further details of the Navy 1999-3 system is currently available in draft form from
ftp://casa.usno.navy.mil/navnet/postscript/ivs_memo_1.ps.
- [5] Ma, C., et al., 1998, *AJ* **116** 516-546.
- [6] McCarthy, D.D., (edt.), *IERS Conventions 1996*, IERS Technical Note 21, Observatoire de Paris, Paris, 1996.

TECHNOLOGY DEVELOPMENT CENTERS

From the Terms of Reference:

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.



Canadian VLBI Technology Development Center

Wayne Cannon, Calvin Klatt

Abstract

The S2 VLBI data record and playback systems, developed at CRESTech's Space Geodynamics Laboratory on the campus of York University, are now in use around the world for a variety of radio astronomy, VLBI, and space VLBI applications in over a dozen countries.

The S2 VLBI correlator, developed jointly by the the Canadian Space Agency, the Geodetic Survey Division of NRCan, the Herzberg Institute for Astrophysics, and the Space Geodynamics Laboratory has been operational in a six station configuration for more than two years at the Dominion Radio Astrophysical Observatory (DRAO) in Penticton BC, Canada mainly in support of space VLBI observations. The "end-to-end" completion of the S2 VLBI system will be achieved with the final deployment of the frequency switched, S2 VLBI data acquisition system. The frequency switched S2 VLBI data acquisition system is intended to enable geodetic VLBI measurements with sensitivities comparable to the Mark IIIA using only two base band converters. The Canadian geodetic VLBI program using the S2 system also involves the development of the Canadian Transportable VLBI Antenna (CTVA) to be used to establish quasar referenced geodetic control points over the Canadian landmass.

The next-generation, S3, VLBI system capable of 1 Gbit/sec recording with unattended record times as long as 60 hours using robotic tape changers, is also under active development at the Space Geodynamics Laboratory.

1. Introduction

The Canadian VLBI Technical Development Center is a collaborative effort of the Space Geodynamics Laboratory of the Center for Research in Earth and Space Technology, (SGL/CRESTech), 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

2.1. Introduction

The Canadian S2 geodetic VLBI program involves development of a complete "end-to-end" geodetic VLBI system and operational capability. This effort involves a wide range of activities including development of the frequency switched, S2 VLBI data acquisition system, enhancement of the S2 correlator capabilities to process frequency switched VLBI observations, utilization of a transportable antenna and the expansion of analytical capabilities for scheduling and analysis.

2.2. S2 VLBI Data Acquisition System (S2-DAS)

The S2 VLBI data acquisition system is being jointly developed by SGL and the GSD. The S2-DAS is designed to accept up to four IF inputs between 100 MHz and 1000 MHz and to accommodate up to four VLBA/Mark IV-type single sideband baseband converters (BBCs). Each BBC in the S2-DAS is provided with a local oscillator (LO) that is independently frequency switchable under computer control over the entire 900 MHz IF range. LO frequency switching in the S2-DAS is

phase coherent and requires less than 1 ms to settle to within 1 degree of its final phase. Resolution of the LO is 1 Hz, limited only by software. The objective of the development of the S2-DAS is to enable high sensitivity, bandwidth synthesis, group delay measurements for geodetic VLBI without appealing to a more costly parallel IF/baseband sub-system.

The "end-to-end" S2 geodetic VLBI system including the transportable antenna, the frequency switched S2-DAS, and the "frequency switched" S2 correlator are currently undergoing a program of shakedown field testing. This field testing program is designed to progressively test and debug all aspects of the system, culminating in the demonstration of a high precision geodetic capability.

2.3. S2 VLBI Correlator

The Canadian S2 VLBI Correlator development has been supported by the Canadian Space Agency (CSA) as a contribution to the international space VLBI missions (RadioAstron, VSOP) and has been in a "production" operational mode for space VLBI for more than two years.

The Canadian S2 Correlator is a six station correlator using S2 playback terminals and is designed to handle S2 frequency switched bandwidth synthesis data. Recent activity has focussed on the development of post processing software to reduce the UVFITS standard output of the correlator to a format usable in the CALC/SOLVE analysis software package.

2.4. Canadian Transportable VLBI Antenna (CTVA)

The CTVA is a 3.6-m radio telescope acquired to facilitate densification of the terrestrial reference frame in remote regions. The antenna will be colocated with GPS elements of the Canadian Active Control System (CACS) to provide fiducial station positions. The GSD is responsible for CTVA system development.

In 1997 the antenna was moved from the Ottawa area to a site at the Dominion Radio Astrophysical Observatory (DRAO) near Penticton, B.C. In the past year several site-related tasks have been completed. Recent work focusses on antenna sensitivity and system stability and reliability.

2.5. CTVA Specifications

- Reflector : 3.6 m diameter
- Receiver : S and X (uncooled)
- Azimuth speed : 150 degrees per minute
- Elevation speed : 60 degrees per minute
- PCFS version : 9.3.17
- VLBI equipment : S2 VLBI data acquisition system and S2 VLBI data record system
- Time standard : CH-75 Transportable Hydrogen Maser

2.6. S2 Geodetic Experiment Scheduling, Operations and Analysis

The Canadian Geodetic VLBI program involves all aspects of Geodetic VLBI operations, from experiment design through analysis. Considerable effort in the past year has been made to establish experiment design, optimal scheduling and analysis capabilities. Scheduling is currently performed

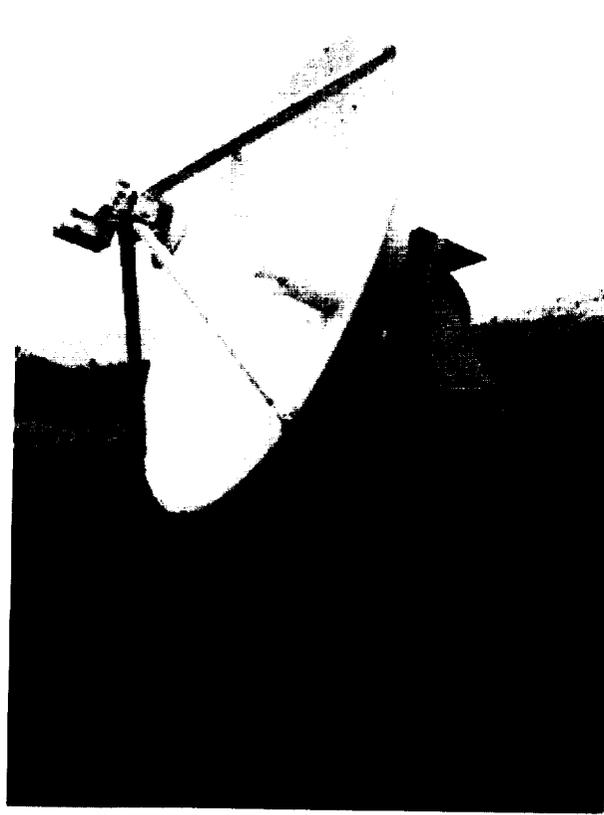


Figure 1. Canadian Transportable VLBI Antenna (CTVA)

using SKED, SCHED and DRUDG. The current version of SKED is not S2-tape friendly, requiring the use of SCHED for final schedule production.

The simulation capabilities of SKED have been used for optimization of geodetic S2 schedules. These simulations require the SOLVE software, which was installed at GSD in 1997-1998. The GSD installation of CALC/SOLVE and associated software approximately matches that at the USNO. Local changes to the software in the past year have been made to account for the anticipated differences between S2 and Mark III/Mark IV databases.

The GSD has successfully proposed to support the IVS by providing a VLBI Analysis web site which is expected to be available in "Beta" form in the coming year.

2.7. Interferometric Experiments in 1998

The developmental experiments listed in 1 have been performed using the S2 VLBI system and the CTVA. Fringes have been obtained in each S2 interferometric experiment.

Table 1. Canadian S2 Development Experiments: 1998

Experiment	Date	Stations	Principal Objective
CG002	July 10, 1998	CTVA-ARO	Interferometer Sensitivity
CG003	July 30, 1998	CTVA-ARO	Frequency-Switching Functionality
CG004	August 20, 1998	CTVA-ARO	Automatic Gain Control
CG005	October 19, 1998	CTVA-ARO	Overall System Performance

2.8. Staff Responsibilities

Table 2 lists staff responsibilities for the S2 development.

Table 2. S2 Geodetic VLBI System Development Team Members

Team Member	Principal Interest/Activity
Mario Bérubé	CTVA, Operations
Marc Bujold	S2 DAS Software
Georg Feil	S2 DAS Software
Calvin Klatt	Scheduling, Analysis
Alexander Novikov	S2 DAS Hardware
Bill Petrachenko	Overall Project Leadership, Correlator, CTVA, DAS
Josef Popelar	Scientific Leadership

3. The S3 and S3-E VLBI Data Record and Playback Systems

3.1. Introduction

The Space Geodynamics Laboratory has begun work on the development of the S3 VLBI data record and playback system, which will resemble the S2 in that it will consist of an array of eight digital videotape transports. A brief description of the S3 and progress to date on its development is presented below.

The S3 is designed as a VLBI data record/playback system based on an array of eight digital video tape transports with a modular architecture similar to the S2 consisting of two rack mountable or "desk top" S3 Tape Transport Array Modules (S3-TAMs) and one rack mountable or "desk top" S3 Data, Signal, and Control Module (S3-DSCM). Each tape transport in the S3 array will record/playback VLBI data at a rate of 128 Mbit/sec for an overall data rate of 1024 Mbit/sec. The unattended data record/playback time at a data rate of 1024 Mbit/sec for the S3 will be 2.5 hours with longer unattended record/playback times available in the S3 when used at lower bandwidths using a subset of tape transports. For example:

DATA RATE	UNATTENDED OPERATION TIME
1024 Mbit/sec	2.5 hours
512 Mbit/sec	5 hours
256 Mbit/sec	10 hours
128 Mbit/sec	20 hours

The S3-Extended (S3-E) VLBI data record and playback system would be a dual, 16 tape transport, version of the S3 which could record/playback VLBI data at a rate of 2048 Mbit/sec with an unattended record/playback time of 2.5 hours.

The S3 and S3-E would both be available with an optional robotic tape changer. The S3 robotic tape changer would permit operation of the S3 at data rates of 1024 Mbit/sec for as long as 60 hours without operator intervention. The cost of recording media for the S3 is expected to be \$140 (US) per hour at a data rate of 1024 Mbit/sec and for the S3-E \$280 (US) per hour at a data rate of 2048 Mbit/sec.

3.2. Staff Responsibilities

Table 3 lists staff responsibilities for S3 development.

Table 3. S3 VLBI Data Record and playback System Development Team Members

Team Member	Principal Interest/Activity
Wayne Cannon	Project Management, Scientific Objectives
Georg Feil	S3 Software, Software Management
Bryan Feir	S3 Software, Transport Control
Paul Newby	Signal Channel Electronics, Engineering Management
Alexander Novikov	S3 Software and Hardware

Technology Development Center at CRL

Tetsuro Kondo

Abstract

Communications Research Laboratory (CRL) has led the development of VLBI technique in Japan and has been keeping high activities in both observations and technical developments. This report gives a review of the Technology Development Center (TDC) at CRL and summarizes recent activities.

1. TDC at CRL

Communications Research Laboratory (CRL) has been leading the development of the VLBI system in Japan. CRL started the development of the K3 VLBI system in 1979 which is compatible with the Mark III VLBI system developed by the US group and successfully carried out a US-Japan VLBI in 1983. CRL then developed the K4 VLBI system, which facilitated ease in both operation and transportation. In October 1990, the International Earth Rotation Service (IERS) designated the Communications Research Laboratory (CRL) and Haystack Observatory (in the United States) as Technical Development Centers (TDC). In September 1996, the IERS directing board designated CRL as TDC again. In accordance with the establishment of the International VLBI Service (IVS) for Geodesy and Astrometry on March 1, 1999, the function of the IERS VLBI Technical Development Center was taken over by that of the IVS Technology Development Center. CRL participates in IVS as one of the Technology Development Centers.

VLBI Technology Development Center (TDC) at the Communications Research Laboratory (CRL) is supposed

- 1) to develop new observation techniques and new systems for advanced Earth's rotation observations by VLBI and other space techniques,
- 2) to promote research in Earth rotation using VLBI,
- 3) to distribute new VLBI technology,
- 4) to contribute the standardization of VLBI interface, and
- 5) to deploy the real-time VLBI technique.

The CRL TDC meeting, attended by the ordinary members from inside the CRL and special members from the outside, is held twice a year. The special members advise the committee concerning the plan of technical developments. The TDC newsletter is published biannually by CRL to inform the VLBI community about its current activities. The newsletter is also available through the Internet at following URL <http://www.crl.go.jp/ka/radioastro/tdc/index.html>.

2. Staff Members of CRL TDC

Table 1 lists the staff members at CRL who are members of IVS and are involved in the VLBI technology development center at CRL.

Table 1. Staff Members of CRL TDC (alphabetical).

Name	Works
Amagai, Jun	Optical-linked RF Interferometer
Ichikawa, Ryuichi	Analysis software
Kaneko, Akihiro	Operation software
Kawai, Eiji	Antenna system
Kiuchi, Hitoshi	K4 (KSP) VLBI system, real-time VLBI, and high-speed recorders
Kondo, Tetsuro	Leader of the CRL TDC
Koyama, Yasuhiro	Operation, monitoring, and analysis softwares
Kurihara, Noriyuki	Antenna System
Nakajima, Junichi	Giga-bit VLBI system
Sebata, Kouichi	Observation support system
Sekido, Mamoru	Correlation processing software
Takahashi, Yukio	Analysis software
Yoshino, Taizoh	Leader of the Key Stone Project team in CRL

3. Recent Activities

3.1. Real-Time VLBI

CRL has developed a compact VLBI network named KSP which consists of four stations around the Tokyo metropolitan area and is dedicated to monitoring the crustal deformation (Figure 1)[1][2]. In 1995, the KSP started regular observations. Observations and analyses are fully automated in the KSP. Real-time VLBI technique using a 2.488 Gbps ATM communications network (STM-16) was also developed on the KSP network in cooperation with the Nippon Telephone and Telegraph Corporation (NTT)[3]. Now routine observations spanning 24 hours are carrying out every other day using the real-time VLBI technique. Measurement accuracy in terms of the repeatability of baseline length measurements reaches about a 2-mm level in our VLBI network [4].

This real-time VLBI technique is now used to realize a large virtual radio telescope by connecting a 64-m antenna at USUDA and a 34-m antenna at Kashima besides KSP stations to increase sensitivity to detect very weak radio sources. Test observation was successfully carried out in December 1998 [5].

3.2. Giga-bit VLBI System

In parallel with the KSP operation, the Giga-bit VLBI system consisting of a high speed sampler (1Gsps/4ch/2bit) and a high speed digital data recorder (1024 Mbps) has been developed to increase the sensitivity of observations (Figure 2). Test observations using this system were carried out on the Kashima-Koganei baseline of KSP VLBI network on July 10, 1998, and the first fringes were successfully detected [6]. Data were processed by GICO (Giga-bit COrrrelator) which consists of UWBC (Ultra Wide Band Correlator) originally developed for the Nobeyama Millimeter array of the National Astronomical Observatory. The processor is an XF type correlator

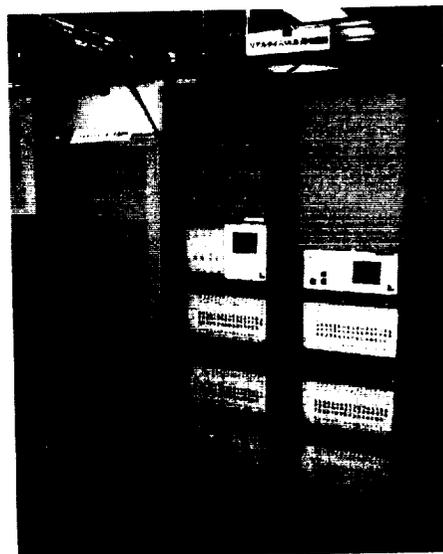
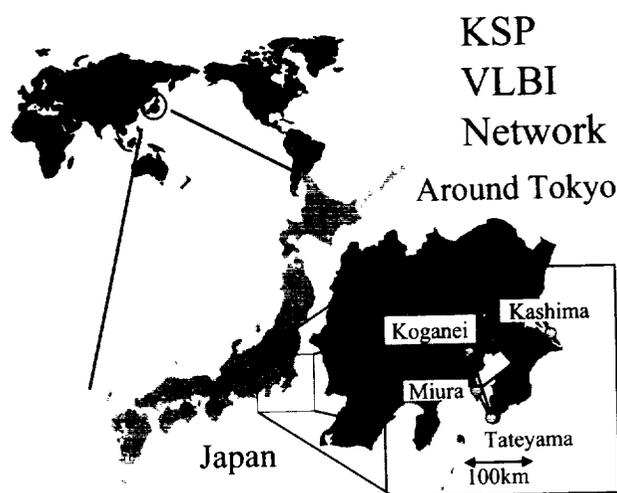


Figure 1. Location of the Keystone Project VLBI network (left) and the real-time correlation processing system (right).

with 256 lags of cross-correlation function capable to process at 2048 Mbps.

3.3. Optical-linked RF Interferometer

In addition to these technology developments, a different approach to increase the accuracy of measurements has been investigated. It is an optical-linked RF interferometer aiming to measure phase delay precisely [7]. The concept of optical-linked RF interferometer is a connected-element interferometer. RF signals received by antenna are directly converted into optical signals and then transmitted through a fiber optic link instead of use of metal lines like a coaxial cable. In a connected-element interferometer, common local oscillator signals are used for the frequency conversion of RF signals from each antenna. Thus no clock parameter estimation is necessary in a baseline analysis unlike in general VLBI analysis for geodetic purpose. Even though higher stability against the temperature change is expected for optical fiber link than metal lines, delay change occurred in the transmission line should be compensated for the application of precise geodetic observation. Maximum fiber length capable to use in this system was estimated from signal-to-noise ratio analysis at fiber optic links. It was estimated to be about 40 km when the combination of Ortel 3541A laser diode and Ortel 4515A photo detector is used.

3.4. VLBI Standard Interface

Besides these technology developments, CRL TDC is contributing to establish the VLBI standard interface (VSI) which is first proposed by Dr. Alan R. Whitney, Technology Coordinator of IVS. We have had meeting several times to discuss VSI in Japan.



Figure 2. Completed Giga-bit recorder (left) and UWBC-GICO experimental correlator (right)

4. Future Perspectives

CRL TDC will continue to make efforts to develop new technologies introduced in this report and to apply them to actual observations. We also have a plan to develop “Internet VLBI” system in cooperation with the NTT which is the succession of the current real-time VLBI technique but aims at realizing more economical (lower running cost) and flexible connections between VLBI stations by using the Next Generation Internet (NGI).

Acknowledgements. The real-time VLBI technique for the KSP has been developed in cooperation with the Telecommunication Network Laboratory Group of Nippon Telegraph and Telephone Corporation (NTT). We thank all staff members of NTT involved in the real-time VLBI Project for their efforts to maintain the high speed network of the KSP. The large virtual radio telescope project has been promoted in collaboration with the Institute of Space and Astronautical Science (ISAS), National Astronomical Observatory (NAO), and NTT. The Giga-bit VLBI system has been developed under a cooperative effort by Communications Research Laboratory, NAO, and Tokyo University. We would like to express deep appreciations to colleagues in these organizations.

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Combination of Results at FFI – Software Development

Per Helge Andersen

Abstract

FFI's contribution to the IVS as a Technology Development Center will focus on the development of software (GEOSAT) for a combined analysis at the observation level of data from VLBI, GPS and SLR. This report shortly summarises the current status of the GEOSAT software development and validation including some future plans.

1. Introduction

FFI is centrally located in the Kjeller area, 30 minutes east of Oslo (near Lillestrøm). Here approximately 2400 people are engaged in several research establishments, technical institutions, university branches and Air Force Material Command. FFI is a state operated, civilian research establishment reporting directly to the Ministry of Defence. The number of employees is approximately 550.

For many years FFI has performed research in space science and remote sensing using satellites. As a part of this research FFI has developed a highly sophisticated software (GEOSAT, [2]) for satellite orbit determination and space geodesy. With this software all types of high precision space geodetic observations can be combined and analyzed at the observation level.

2. Goals for FFI's Contribution to the IVS

Based on contributions from a number of analysis centers the International Earth Rotation Service (IERS) calculates on a regular basis realizations of a terrestrial and a celestial reference frame including their interconnections given by the Earth Orientation Parameters (EOP). It is a serious problem that the individual solutions submitted to the IERS are calculated using different software with partly inconsistent models and strategies. This can lead to inconsistencies within one technique of several mm in station coordinates. The between-technique inconsistencies can be as high as 1 cm in the combined IERS solution for the terrestrial reference frame. The GEOSAT software will for the first time make it possible to perform analyses of VLBI and satellite tracking data with one consistent model and strategy.

Analysis of data from any of the IERS techniques requires the calculation of a large number of parameters. Some of these parameters are highly correlated leading to a reduction in accuracy. The strength of VLBI is in the determination of distances and directions while the satellite techniques are especially important for the determination of the Earth's center of mass. In order to obtain high-precision results with VLBI and GPS the water vapor content of the troposphere or the zenith wet delay must be precisely estimated. The introduction of SLR data, independent of the water vapor, will contribute to the decorrelation of the zenith wet delay parameter from all the other estimated parameters especially the height component of the station coordinates. In general, the combination of independent and complementary information from different types of data will reduce the parameter correlations and lead to more accurate results.

There are several additional advantages with the combination of VLBI and satellite tracking

data: the estimated satellite orbital elements, radio source coordinates, and EOPs will be realized in a long-term stable celestial reference frame realized primarily by the radio sources. This means that the GPS and SLR observations for the first time can be used in the determination of UT1 itself and not only the length of day (LOD). Another advantage is that all estimates of geodetic and geodynamic parameters are given in the same realization of a terrestrial reference frame. Finally, the combined analysis of VLBI, GPS, and SLR can be used to estimate the eccentricity vectors between the different antenna phase centers within each colocated station. It is a fact that much eccentricity information is missing and some of the existing information is quite unreliable or inaccurate.

FFI will, as a Technology Development Center for IVS, develop the GEOSAT software to demonstrate the feasibility and potential of a combination of VLBI, GPS and SLR data at the observation level. We will especially focus on the establishment of consistent observation models for all three techniques. The a posteriori residuals will be investigated in order to detect systematic technique-dependent errors. Solutions for the individual techniques will be compared with a combined solution to evaluate the contribution from each technique to the determination of important geodetic and geodynamical parameters.

The different data types are combined for each arc at the observation level using a UD-factorized filter. The arc length is defined by the length of the VLBI session. The arc-by-arc state vectors and complete covariance matrices are combined into a multi-year solution using a highly sophisticated and flexible Square-Root-Information-Filter-and-Smoother (CSRIFS, [1]). Four parameter levels are available in the CSRIFS program and any parameter can, at each level, either be represented as a constant or a stochastic parameter. The batch length can be made time- and parameter-dependent. The state vectors will include station coordinates and velocities for some selected multi-technique stations in addition to Earth orientation parameters (EOP), radio source coordinates, and other geophysical and geodynamical parameters.

3. Status

All planned components of GEOSAT have been successfully validated with a combination of data from VLBI, GPS and SLR. Consistent models for all techniques have been verified at the sub-ppb level. The processing at the arc and session levels are completely automated using C-shell scripts. In some cases the processing crashes and additional work must be done in order to make the processing scheme more robust against errors in the input data.

The CSRIFS program for combining arcs has been successfully applied in the generation of a VLBI-only solution covering 623 sessions during the last 10 years. A paper containing the mathematics of CSRIFS and the results of the VLBI analysis has recently been submitted for publication in *Journal of Geodesy*.

4. Technical Staff

Table 1 lists the FFI staff involved in IVS activities. The development and validation of GEOSAT have resulted in a substantial theoretical understanding and practical experience with all available types of high-precision space geodetic data (VLBI, GPS, SLR, PRARE, DORIS and radar altimetry).

Table 1. Staff working at the FFI AC and TDC

Name	Background	Dedication	Agency
Per Helge Andersen	geodesy	40%	FFI

5. Outlook

The computation time for the processing of 24 hours of VLBI, GPS, and SLR data is presently approximately 14 hours using a HP C180 (one CPU) computer. We plan to buy a new computer within the end of this year or early next year, probably a HP J5000 (with two CPUs) or a HP J7000 (with four CPUs) including 1 Gb RAM. This should give an increase of a factor 5 or 10 in processing capacity. The disk storage capacity will be extended from 65 Gb to 100 Gb with additional 30 Gb each year. With such computation power it should be possible to generate global combined multi-technique solutions based on a large number of arcs.

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Goddard Space Flight Center IVS Technology Development Center

Ed Himwich, Nancy Vandenberg, Tom Clark

Abstract

The GSFC IVS Technology Development Center (TDC) develops station software including the Field System (FS), 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. Introduction

The GSFC IVS Technology Development Center (TDC) develops hardware, software, algorithms, and operational procedures. It provides manpower for station visits for training and upgrades. There are other technology development areas at GSFC covered by other IVS components such as the GSFC Analysis Center.

The current staff of the GSFC TDC consists of Tom Clark, Nancy Vandenberg, Ed Himwich, Chuck Kodak, Raymond Gonzalez, and William Wildes.

The remainder of this report covers the status of the main areas of development that are currently being pursued.

2. Field System

Several major enhancements for the Field System (FS) are planned for this year. These will include: mode independent parity checks, Y2K compliance, sequential dual recorder support, automated Tsys, an SEFD analysis tool for antenna calibration, and user interface enhancements.

The most significant of these changes is the Y2K upgrade. In addition to making the FS operate in year 2000 and beyond several other small improvements were undertaken at the same time. The resulting changes are fairly substantial. These changes include: 4-digit year and punctuation in log file time tags, correct operation across year boundaries, use of punctuation in timed wait commands, and upgrades to all post processing software ("logex", "logpl", "xtrac", "pdlpt") to support new and old log formats.

Mode independent parity checks will remove the need to change parity procedures depending on the mode and recording speed.

Sequential dual recorder support is intended to allow longer periods of unattended operation at stations with two recorders. In this approach one recorder would have its tape filled, then the operation would switch over to the other tape drive. The tape can then be changed on the first drive whenever is convenient, perhaps just before the second tape is filled.

Automated Tsys is similar to mode independent parity checks in that it will free the operator from having to adjust the Tsys measurement procedures depending on the recording mode. In this case DRUDG will emit mode specific procedures for "preob" and "midob".

A new analysis tool will be developed for examining SEFD data from ONOFF to estimate gain curves and other performance information.

The user interface will be improved. This will include an improved log display window with better scrolling capability. A more sophisticated window manager may be used as well.

3. Hardware

The development of Totally Accurate Clock (TAC) systems continues. The new 8-channel units show RMS precision compared to USNO at the 30 nanosecond level or better. TACs are now readily available commercially. The new control software is Windows 95/98/NT based and very robust.

To replace the antique FTS8400 GPS timing receivers, NASA has adopted the TAC plus an HP53131A counter plus Windows-based software to control the TAC and make routine data logs of timing data. These are being implemented now at several VLBI and SLR stations.

A new meteorological sensor package is being developed. The pressure, temperature, and humidity sensor is the same as used in many GPS installations and for SLR2000. The new wind-speed sensor has no moving parts.

4. Site Visits

GSFC will provide personnel for several site visits this year. The visits will include some combination of upgrades, training, and troubleshooting. The exact mix will be depend on the station's needs. Station that will probably be visited this year include: Fairbanks, Goldstone, Kashima34, Kokee Park, Noto, Shanghai, Tsukuba, and Urumqi.

5. SKED and DRUDG

The GSFC Technology Development Center is responsible for development, maintenance, and documentation of the SKED and DRUDG programs. These two programs operate as a pair for preparation of the detailed observing schedule for a VLBI session and its proper execution in the field. The normal flow is that first SKED is run at Operation Centers to make the .skd file that contains the full network observing schedule. Then the stations use the .skd file as input to DRUDG for making the control files and procedures for their station.

A major upgrade to SKED in 1997 was the ability to schedule continuous tape motion. This feature is used only for RDV sessions; it is not generally available because it still has some quirks.

We will add the ability to write a VEX output file to SKED just in time for use by the Mark IV correlator. We also plan to add the ability to schedule K4 and S2 experiments using their native tape characteristics instead of faking the footages assuming Mark III/IV tapes.

DRUDG is distributed with Field System updates. SKED is distributed via anonymous ftp to the Goddard server. A new release of the SKED software is planned for fall 1999. The release will also include updated documentation.

6. VEX

GSFC works in collaboration with Haystack and JIVE to develop the VEX scheduling language. This year a new release, 1.6, is planned. This will add some significant new features, but which ones have not be finalized at this point. In addition to added new features, some of the changes

will be oriented toward helping smooth operation of the system when VEX schedules are used. We also hope to begin implementing VEX observation logs and tables of ancillary data, such as cable and sysystem temperature, this year.

A library of VEX writing utilities will be developed this year. This will complement the existing VEX reading utilities.

IVS Technology Development Center at Haystack Observatory

Alan Whitney

Abstract

Recent and planned activities of the IVS Technology Development Center at Haystack Observatory are reviewed, with an emphasis on the Mark IV correlator, Mark IV decoder, and thin-film head array projects.

1. Mark IV Correlator

Introduction

The Mark IV correlator development at Haystack Observatory is nearing completion. Copies of this correlator will soon be in place at USNO in Washington, D.C., MPI/Bonn in Germany, and MIT Haystack Observatory in Westford, Massachusetts. A nearly identical copy is in operation at JIVE in Dwingeloo, The Netherlands. Development of the Mark IV VLBI correlator system is a joint U.S.-European effort, with sponsorship by NASA, USNO, and the Smithsonian Institution in the U.S., and BKG, JIVE, and NFRA in Europe. Two large correlators for connected-element interferometers, in Westerbork, The Netherlands and on Mauna Kea, Hawaii, are also based on the same correlation engine as the Mark IV correlators.

In the initial implementation the USNO, MPI, and Haystack correlators will all support ~ 8 stations, though the architecture allows easy future expansion to many more stations.

Features of the Mark IV Correlator

The Mark IV correlator system is designed as a major upgrade of the venerable Mark IIIA correlator, which has been in use since 1985 at Haystack, USNO, and MPI/Bonn. The characteristics of the Mark IV correlator can be summarized as follows:

- 1 Gbit/sec/station playback rate, expandable to 2 Gbits/sec/station
- Scalable architecture allowing up to 32 stations with 16 channels/station, all baselines correlated simultaneously
- Compatibility with Mark IIIA, Mark IV and VLBA format tapes
- Station-based XF architecture utilizing full-custom VLSI correlator chips
- 4 \times playback speedup compared to Mark IIIA correlator
- Extensive use of VEX files for correlator operation/configuration
- Updated HOPS post-correlation package

Architectural Overview

Figure 1 shows a simplified block diagram of a 16-station, 1 Gbit/sec/station Mark IV correlator. Each Playback Unit (PBU) is attached to a Station Crate which reconstructs the data from the tape into channels and then applies the proper computer model to the delay and delay rate of the data. The delay, delay rate, and phase models for each channel of each station are periodically

inserted into the data streams transmitted to the Correlator Crate. In order to minimize cabling complexity between the Station Crates and the Correlator Crate, the transmission between them takes place over high-speed serial links on coax cable.

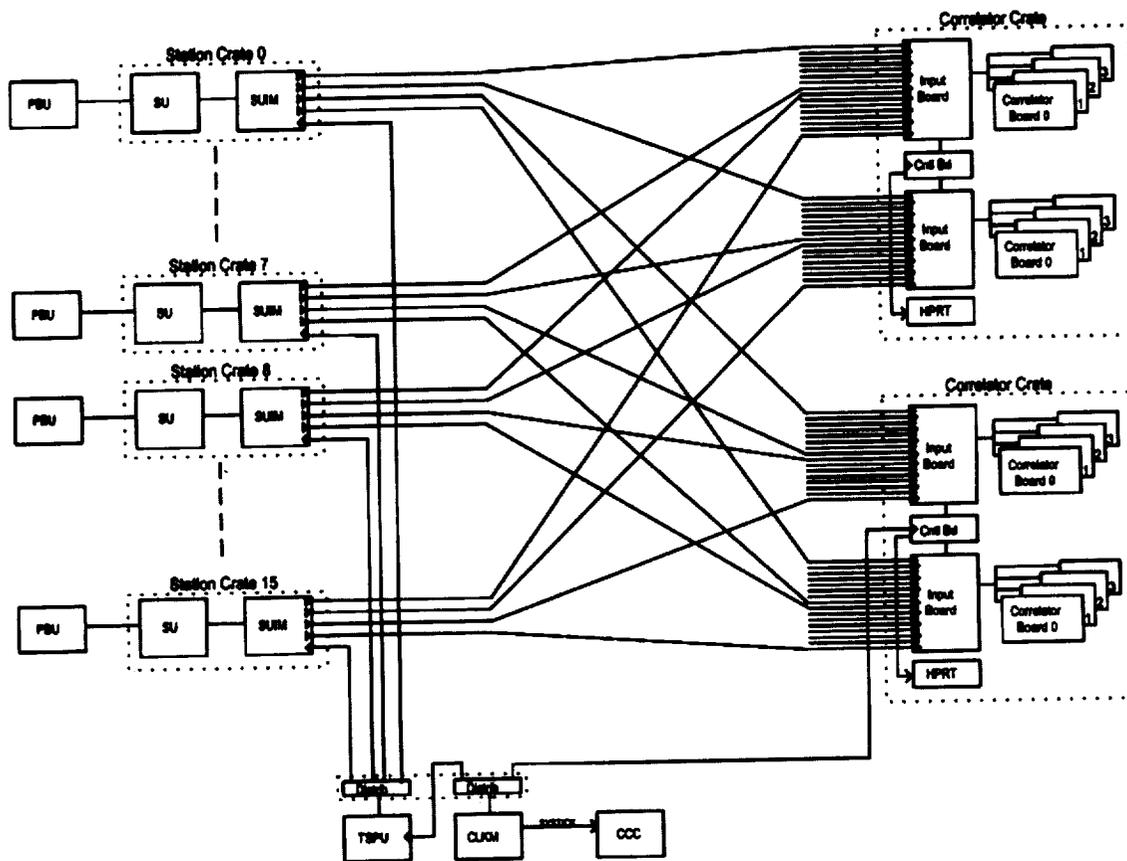


Figure 1. Block diagram of Mark IV correlator.

At the Correlator Crate the data are resynchronized and passed to the Correlator Board where the station parameters are captured and are used to compute the baseline processing parameters supplied to the correlator chips. The lag-correlation results are periodically read from the correlator chips and passed to the Correlator Control Computer (CCC) for further processing.

Correlator Chip and Board

Haystack Observatory was responsible for the development of the correlation engine, which includes a full-custom VLSI correlator chip and the correlator board which hosts the correlator chips. Approximately 10,000 chips were fabricated by Hewlett-Packard. The characteristics of the correlator chip are as follows:

- Full-custom CMOS with $\sim 1,000,000$ transistors
- 1 or 2 bits/sample
- 64 MHz clock rate

- 512 lags which can be re-arranged internally into several independent correlator sections, each having from 16 to 512 lags
- 8 internal 32-bit phase generators and rotators for rotation rates to full channel bandwidth
- internal bit-shift/phase-shift algorithm
- internal vernier-delay management
- 24-bit latchable ripple counter on each lag
- Power dissipation: $\sim 3W$ at 64 MHz
- 208-pin PGA package, ~ 2 inches square

Figure 2 shows a single correlator board. Each correlator board, which is approximately 40 cm by 50 cm in size, hosts 32 correlator chips, two high-speed DSP chips, and 10 64x64 custom ASIC crossbar switches. The characteristics of a correlator board are as follows:

- 32 VLSI correlator chips
- access to 64 2-bit data streams configurable through 10 64x64 custom ASIC cross-bar switches
- 64 MHz maximum clock rate (tested to 70 MHz)
- 16,384 real lags per board, flexibly configurable
- support of 128 baselines of 32 complex lags per baseline for a single channel
- auto-correlation modes



Figure 2. Mark IV correlator board.

Each correlator crate houses eight correlator boards. Two such crates are necessary for a full 16-station, 1-Gbit/sec/station correlator.

Status and Plans

All Mark IV correlator hardware has been constructed, and software development is in the final stages, with deliveries of operational correlators to USNO and MPI/Bonn expected in late summer or early fall of 1999. Figure 3 shows a diagram of the final configuration with 8 playback units. The correlator rack is in the center, and each Station Crate is surrounded by the four playback units it serves. The Mark IV correlators will replace the Mark IIIA correlators now currently in use at these locations.

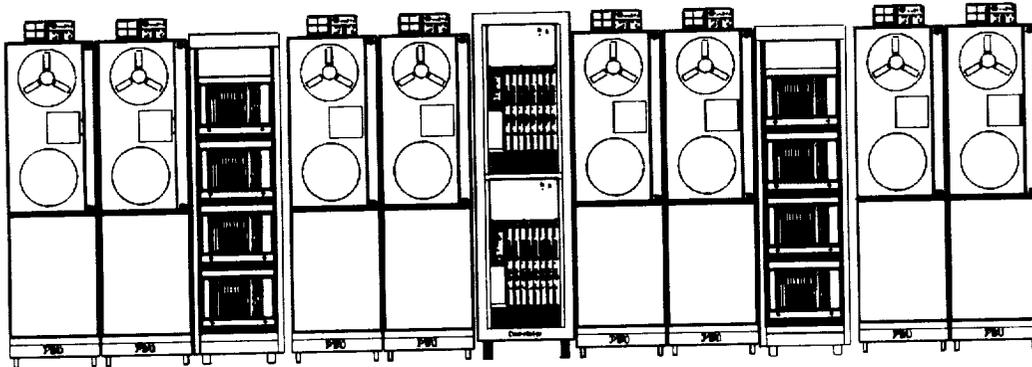


Figure 3. Mark IV correlator configuration with eight playback units.

2. Mark IV Decoder

The Mark IV decoder module is designed as a plug-in upgrade/replacement for the Mark III decoder. As a direct replacement, it acts as a two-channel data-quality analyzer operating the same way as the Mark III decoder, that is, it accepts two tape-tracks of data from either the formatter or from the playback-monitor tracks on the recorder. However, it can operate at up to the full 18 Mbps rate of the Mark IV formatter.

In addition, the Mark IV decoder accepts four selectable channels of 2 bits/sample data from the Mark IV formatter via a separate connector on the rear panel. These data can be analyzed by an internal Mark IV correlator chip to simultaneously extract up to four arbitrarily placed phase-cal tones from any of the four selected channels, or the correlator chip may act as a state counter for a single selected channel. Future plans include the ability of the correlator chip to also extract high-resolution bandpass information from any or all of the selected Mark IV formatter channels.

The Mark IV decoder utilizes a Motorola 68340 processor with 64 MB of internal RAM, of which about 60 MB is available for data capture, either from one playback track or from one Mark IV formatter channel. The data may then be read out from the decoder either through the standard MAT bus or via a separate high-speed SCSI connection.

Production of a number of Mark IV decoders is now proceeding at Haystack Observatory. The design will soon be transferred to industry and made available to interested parties.

3. Thin-Film Head Array Project

Haystack Observatory is working with industry, with support from NASA, NRAO and JIVE, to develop thin-film (TF) head array technology suitable for use with VLBI. In particular, the goal of the project is to develop a thin-film array replacement for the current headstacks used in the Mark IV/VLBA recording systems.

Thin-film head technology utilizes semi-conductor fabrication techniques to construct read/write heads. Write heads are created by constructing thin-film coils which drive a magnetic gap in the conventional manner. Read heads utilize magneto-resistive technology (MR) which is increasingly prevalent in the hard disc industry. These read/write head pairs are deposited in arrays along a 1-inch substrate bar; standard wire-bonding techniques are used to attached flexible printed-circuit assemblies to the bar for access by the external world.

Haystack has received and tested several prototype TF/MR headarrays and has found excellent performance under a wide variety of tape speeds and tensions using an innovative "flat-lap" contour invented at Haystack. This "flat-lap" contour has been extensively analyzed, both theoretically and experimentally, and is now understood to actually create a suction of the tape to the head in such a way as to always maintain excellent head-to-tape contact.

In addition to excellent performance, the TF/MR headarrays show practically no wear after thousands of hours of operation; this is due to the extremely hard substrate material used in their manufacture.

Haystack Observatory is now exploring with industry ways in which these TF/MR headarrays can be replicated in a cost effective way. Our goal is to be able to manufacture a complete headarray assembly for a price substantially less than a conventional headstack. Negotiations with industry in this regard are now underway. A new design for the read/write electronics will be required to support the TF/MR headarrays. Work on these components will accelerate once the availability of the headarrays is assured.

4. Mark IV Acquisition Systems

To help stations that currently have either Mark IIIA or VLBA data acquisition systems convert to Mark IV, we are providing assistance through acquisition of hardware, installation of the new hardware at the stations, and training the local staff in its use. In the past year we helped upgrade the systems at Hartebeesthoek and Wettzell, and in the coming year we will upgrade Matera and O'Higgins.

5. Personnel

The Haystack Observatory scientists, engineers, and technicians who have contributed to the work described in this report are Will Aldrich, John Ball, Ed Beauchemin, Tom Buretta, Peter Bolis, Roger Cappallo, Kevin Dudevour, David Fields, Roger Genereux, Joel Goodman, Hans Hinteregger, Colin Lonsdale, Sinan Müftü, Ed Nesman, Arthur Niell, Alan Rogers, Stu Sherman, Dan Smythe, Alan Whitney, and Ken Wilson.

Institute of Applied Astronomy Technology Development Center

Alexander Ipatov

Abstract

Our Institute was organized as a main research institute in the geodetic VLBI field of Russian Academy of Science, especially for scientific development and constructing Russian technical facilities for Quasar project. This report describes the 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, which develop hardware and software for this project. Now the 32 m radio telescope in Svetloe is under preparing to take part in international VLBI network observations, radio telescope in Zelenchukskaya is under testing and in Bodary – under construction.

2. Technical/Scientific

Dish metal constructions. This group is responsible for dish, electrical drive, main reflector and subreflector quality, and geodesy adjustment.

Antenna tracking control system. The IAA developed software allows control the antenna TNA-400-1 by the computer Field System on the base of own exchange protocol.

Table 1. Technical characteristics of antenna tracking control system radio telescope TNA-400-1.

Characteristic	Azimuth	Elevation
speed in the "low speed" mode	not more than 3'/sec.	not more than 50"/sec.
speed in the "high speed" mode	not more than 1°10'/sec.	not more than 55'/sec.
Tracking error	not more than 10"/sec.	not more than 10"/sec.

Receivers. Receivers on the 32 m telescope are installed in the secondary focus and can be interchanged as required. Changing a receiver from standby to operation requires only changing position of subreflector. At the present there are five receiver systems (10 channels) providing observation R and L circular polarisations simultaneously.

Table 2. Receivers Parameters.

Band, cm	Input Noise temperature, K
18/21	10
13	10
6	10
3,5	17
1.35	60

Our hardware staff is continuing investigations of new dish in Svetloe station. It has performed: adjustment and main parameters measurement of radio telescope in Svetloe Network Station, the quality Investigations of cryogenically cooled receivers installed on antenna in Svetloe, determine calibration noise signals for the receivers of all bands. Observation of the references sources, maintenance receivers and cryogenic equipment in Svetloe Network Station, assist and training station staff for routine operations on service receivers and refrigerators equipment.

The new radiometric registration device was designed. This design was implemented for providing of single dish observations in four wide band channels simultaneously, antenna performance and pointing measurements. It is connected to IF outputs of cryoelectronic receivers and controlled by Mark IV Field System program.

Table 3. Data of the module.

Frequency band, MHz	100 ÷ 1000
Channels Number	4
Radiometer type	switching or compensation
Quantizer capacity	13
Cumulation time, s	0.1 or more

It was elaborated the software integrated into the Field System environment for control of this device. The software permits radiometer data recording into the special file during VLBI observations in coordination with the experiment schedule or the using of Field System for single dish observations scheduling. The software makes the standard Field System programs "fvpt" and "onoff" workable with radiometric registration. This was implemented using new Field System feature: station specific detectors support. The software for the control of antenna and radiometric registration was complemented with operator interface programs. The programs work in the XWindow environment on the FS computer and provide the possibility of visual graphical monitoring of antenna position and radiometer data in real time. The operator programs also permit control of antenna and other equipment with graphical interface.

DAT. Four-channel data acquisition rack with Canadian recording terminal S2 was worked out and installed at the Svetloe observatory and is using for VLBI experiments (on baselines Svetloe-Bears Lake-Pushino, Svetloe-Evpatoria-Bears Lake).

Frequency and Timing System. The active hydrogen masers CH1-80 are used at the network station Svetloe. Frequency stability of this maser is presented in Table 5.

IAA found in 1998-1999 years the local Frequency and Time Standard at Technology Development Center for metrology supporting of the VLBI observations. This Frequency and Time

Table 4. Data of the system.

Frequency band, MHz	100 ÷ 600
Frequency tuning step, kHz	10
Number of down converters	4
Bandpasses, MHz	0.25, 2, 8 and 16
Using of clipping levels	2, 3 or 4
Recording terminal	S2-RT
Format of output data	S2 or MarkIII

Table 5. Frequency stability of maser.

Sample time interval	$(AllanVariance)^{1/2}$
1 sec	$3 \cdot 10^{-13}$
10 sec	$3 \cdot 10^{-14}$
100 sec	$1 \cdot 10^{-14}$
1000 sec	$5 \cdot 10^{-15}$

Standard includes active hydrogen maser CH1-70, passive hydrogen masers CH1-76, cesium and rubidium quantum clocks. Passive hydrogen maser CH1-76 may be used as mobile clock.

Time and frequency calibrations are provided by mobile clock, TV calibration facility, GPS receiver 4000 SST Trimble Navigation and GLONASS receiver A-724M.

Microwave holography equipments. In the years of 1997-98 the original microwave holography measuring system was created in the Institute of Applied Astronomy. The accuracy of holography measurements in one scan is of 0.12 mm. In February of 1999, after preliminary geodetic adjustment, the first session of the microwave holography measurements was carried out.

Seven scans with resolution of 0.75 m were used for measure the phase errors and amplitude distribution on the aperture. The holography adjustment of the dish at Svetloe station will be made during this summer.

Communication and Calculation Systems. The project VLBI network Quasar foresees creation of system remote control and data real-time processing of spectral and VLBI-observations.

To the moment, the hardware and software system has been designed and checked in IAA, which allows to do spectral and correlate processing limited samples of videosegments (at 20 MHz) from VLBI station Svetloe with the special processor TISS1-M (placed in S.Petersburg).

The Automatic meteorological station. The parameters are presented in Table 6.

3. Technical Staff

For all persons the IAA address (Zhdanovskaya st., 8, St. Petersburg, 197110, Institute of Applied Astronomy (IAA) RAS, Russia, Director Andrey Finkelstein, FAX: +7-812-230-74-13) is common.

Table 6. The parameters of the automatic meteorological station.

Measured parameter	Range	Accuracy
Temperature (C)	-50 ÷ +50	0.25
Pressure (mba)	600 ÷ 1090	0.5
Humidity (Mean wind velocity (v) for 10 min (m/s))	1.5 ÷ 40 8 ÷ 55	0.5+0.05v 0.5+0.05v
Max. wind velocity (v) for 10 min (m/s)	0 ÷ 360 Yes/No	10
Wind direction (degree)	0 ÷ 150	0.2+0.05P
Rain	Yes/No	
Sample rate:	1 min (except wind velocity), 10 min, 1 hour.	

Table 7. Technical Staff.

Prof. Alexander Stotsky	Main Scientific Researcher	Radio Physics Radio holography	+7-812-235-32-16	stotskii@ipa.rssi.ru
Prof. Nikolai Koltsov	Chef the Laboratory Signals Conversion and Registration	VLBI and radiometric registration system	+7-812-235-33-16	nec@ipa.rssi.ru
Dr. Sergey Smolentsev	Vice Director	Time keeping frequency standard	+7-812-230-74-16	smolen@ipa.rssi.ru
Dr. Alexandre Salnikov	Chef the Laboratory Communication and Calculation Systems	Network Communication Computers	+7-812-230-83-51	ais@isida.ipa.rssi.ru
Dr. Edward Korokin	Chef the Laboratory of Radio Antennae	Dish metal constructions	+7-812-230-74-15	amf@ipa.rssi.ru
Dr. Irina Ipatova	Senior Scientific Researcher	Receivers Antenna performance	+7-812-230-64-96	ipatov@ipa.rssi.ru
Dr. Vyacheslav Mardyshkin	Senior Scientific Researcher,	Receivers Refrigerators Antenna performance	+7-812-230-64-96	vvm@ipa.rssi.ru
Mr. Andrey Michailov	Scientific Researcher	FS software Radio telescope control system	+7-812-230-64-96	agm@ipa.rssi.ru
Mr. Dmitriy Ivanov	Scientific Researcher	Receivers Refrigerators Antenna performance	+7-812-230-64-96	ipatov@ipa.rssi.ru
Mr. Sergey Syrovoy	Joiner Scientific Researcher	Stations software Radio telescope control system	+7-812-230-64-96	ipatov@ipa.rssi.ru

4. Outlook

At the new IVS year we are planning:

- To include the VLBI site Svetloe into routine CORE-A observations.

- Holography adjustment in Svetloe.
- Receivers and cryogenic equipment installation at new dish in Zelenchuckskay.
- Adjustment of reflector and feed system in new dish, including holography adjustment.
- Parameters measurement at new dish and testing VLBI observations.

Institut d'Estudis Espacials de Catalunya (IEEC)

Dirk Behrend, Antonio Rius

Abstract

We summarize the tasks and work carried out at the Institut d'Estudis Espacials de Catalunya (IEEC) regarding geodetic VLBI within the frame of the IVS. Main activities are, firstly, geodetic surveillance of the DSS65 VLBI antenna at the Robledo (Madrid) site; and, secondly, investigations pertaining to improvements of the tropospheric correction using GPS, WVR, and local meteorological data as well as meteorological models.

1. General Information

The Institut d'Estudis Espacials de Catalunya (IEEC) is located in Barcelona in the north-east of Spain. It occupies quarters in the Nexus building (Figure 1) of the Universitat Politècnica de Catalunya (UPC) North Campus in the west-end of town (see also Table 1).

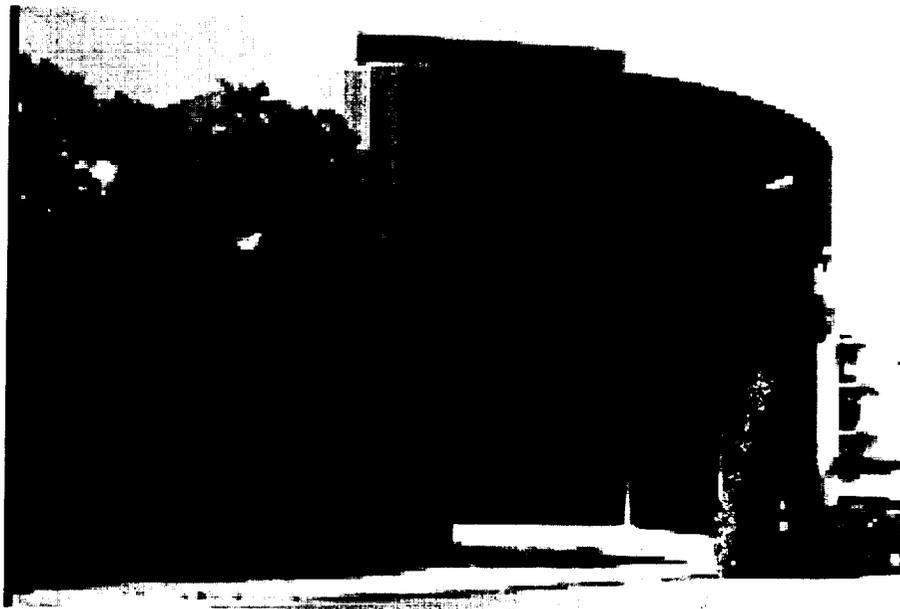


Figure 1. Home of the IEEC: the Nexus building of the UPC North Campus.

IEEC is a research unit of the Consejo Superior de Investigaciones Científicas (CSIC), the Spanish research council. In the IVS it fulfills the task of a technology development center. The main study areas lie in the determination of the stability of VLBI sites, i.e. the surveillance of the horizontal and vertical stability of the antenna reference point, and in improving the modelling of atmospheric parameters.

Table 1. Addressing the IEEC using different means.

Address Type	Current Address
geographical address	longitude $\lambda = 2.11^\circ\text{E}$ latitude $\varphi = 41.39^\circ\text{N}$
postal address	Institut d'Estudis Espacials de Catalunya Edif. Nexus-204, Gran Capità 2-4 E-08034 Barcelona, Spain
WEB address	http://www.ieec.fcr.es

2. Technological Developments in Progress

For the DSS65 VLBI antenna at the NASA Madrid Deep Space Communications Complex (MDSCC), Spain, the stability of the antenna site was controlled using geodetic measurements taken at different epochs and covering the time span from 1988 to 1998. A least squares evaluation procedure yielded 3D-coordinates of the antenna reference point with an accuracy of a few mm. Thus, the antenna can be considered stable in position (showing no significant change) over the past decade. This excludes a significant 7 mm change in the north component in March 97. The height, on the other hand, has undergone two significant height changes: an uplift of 17 mm from December 88 to March 97 and an uplift of 6 mm from March 97 to June 97. For more information the reader is referred to the following references: [1], [2], and [3].

In addition to VLBI, the DSN station at Robledo (Madrid) also runs collocated microwave techniques. These comprise a GPS receiver and a water vapour radiometer (WVR). Data from these techniques as well as local meteorological data and, eventually, meteorological models are utilized to improve the modelling of atmospheric parameters. Corresponding investigations are currently underway.

3. Staff Members Working in the VLBI Field

The IEEC staff members who are involved in VLBI work and are contributing to the IVS consists of two people (cf. Table 2).

Table 2. Staff members in IVS related work.

Name	Background	Dedication	Agency
Dirk Behrend	geodesy	100%	IEEC
Antonio Rius	astronomy	50%	IEEC

Antonio Rius had been a member of the technical staff of the MDSCC from 1975 to 1985 being responsible for the radioastronomical activities, before he became head of the Earth Sciences Department of the IEEC. Dirk Behrend is financed by the European Community in the TMR network grant FMRX-CT960071 "Measurement of Vertical Crustal Motion in Europe by VLBI".

4. Current Status of IVS Related Activities

The evaluation of the already performed geodetic observation campaigns is accomplished and the results have been published. It is planned that future campaigns, which should be performed on a yearly basis, be evaluated using the same software and the results be published as soon as possible.

The application of GPS technology to studying the water vapour distribution and evolution in the study area of the MDSCC is underway. Comparisons with results from independent techniques (e.g. WVR) as well as with values retrieved from meteorological models will further the understanding of this crucial variable and are currently in progress. Eventually, the understanding of the water vapour distribution will help to improve the modelling of the atmospheric parameters in the analysis of VLBI data.

5. Future Plans and Outlook

For this spring/summer, it is scheduled the next geodetic observation campaign of the DSS65 antenna. Furthermore, it is planned to investigate additional possibilities of controlling the DSS65 site stability. This stems primarily from the fact that there exists a large time gap of about nine years between the first and the second geodetic control measurements.

Another critical point associated with the geodetic surveillance concerns the stability of the local geodetic network. So far, it was assumed that there was no significant change in the stations of this network. As this might not be completely true, it is vital to also control the coordinates of the local net. Thus, a control survey of this net is planned for later this year.

As the water vapour distribution at the VLBI site is a crucial variable, additional information sources should be exploited to improve the modelling of the atmospheric parameters. This summer a new water vapour radiometer will be installed at the MDSCC: a D2 radiometer from JPL. It is envisaged that data from this WVR be evaluated at the IEEC. The software package to be used shall be an in-house product which is largely based on the "hotrid" package running at Onsala Space Observatory (OSO), Sweden.

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The IVS Technical Development Center at the Onsala Space Observatory

Gunnar Elgered, Rüdiger Haas, Lars Pettersson

Abstract

We give a short overview of the activities at the Onsala Space Observatory related to the function as an IVS Technology Development Center. We concentrate on the ongoing work with the development of a new S/X-band feed system for the 20-m telescope and the design and construction of a new microwave radiometer.

1. Staff at Onsala Associated with the IVS Technology Development Center

The staff at Onsala associated with the IVS Technology Development Center is: Rune Byström (engineer), Gunnar Elgered (scientist), Lubomir Gradinarsky (Ph.D. student), Rüdiger Haas (scientist), Jan M. Johansson (scientist), Karl-Åke Johansson (engineer), Lars Pettersson (engineer), Hans-Georg Scherneck (scientist) and Borys Stoew (Ph.D. student).

2. Technical development at Onsala

2.1. New S/X feed system

The development of a new S- and X-band feed is ongoing. It consists of two feed reflectors used for both S- and the X-band. A more detailed description of the feed has been reported earlier [1], [2]. Two dual-band corrugated horns have been manufactured. The first version turned out to have a frequency band which was not centered correctly. A second, rescaled version was measured and showed a good antenna diagram for both bands. The coaxial waveguide transformer (COWAT) is the component which makes it possible to have access to the X-band ports (Right Hand Circular Polarization and Left Hand Circular Polarization) that are inside the coaxial S-band waveguide, before transforming the S-band coaxial waveguide into the S-band septum polarizer in circular waveguide (see Figure 2). Also the prototype COWAT was found to have the center frequency slightly off the desired value and it is now being redesigned. Simulations show that a reduction in length of some parts of the COWAT will lower the center frequency. The amount of reduction has not yet been decided. An X-band polarizer of septum type has been built (see Figure 4) and measurements show that it works though more measurements are needed before it can be decided if it fully meets the specifications. The S-band polarizer will be a scaled version of the X-band polarizer and has not yet been manufactured.

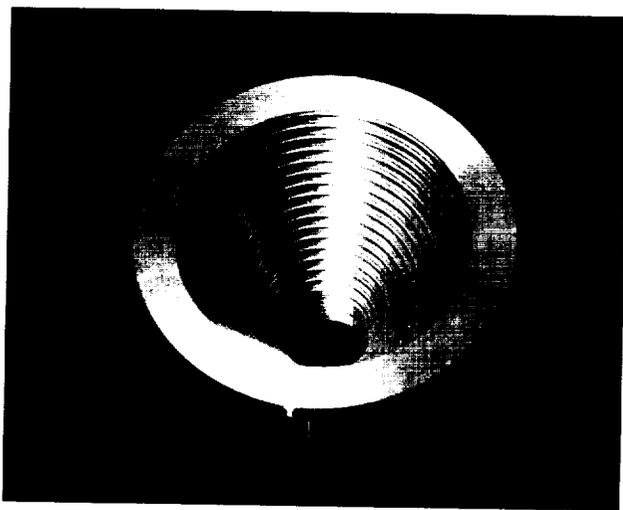


Figure 1: The dual-frequency corrugated horn.

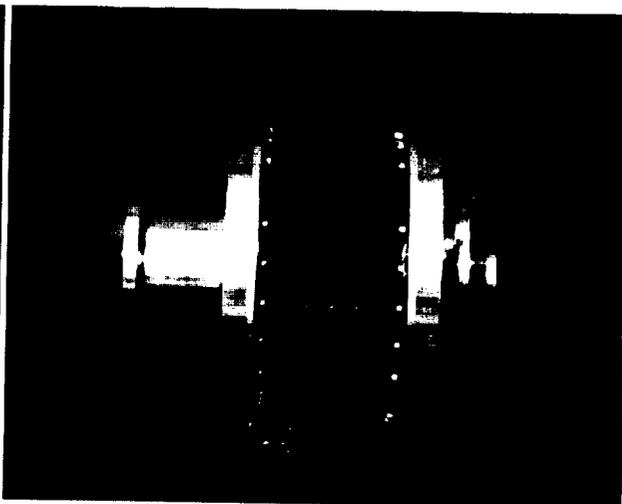


Figure 2: The coaxial waveguide transformer (COWAT). Note the X-band waveguide with output ports for both right and left circular polarizations.



Figure 3: The feed horn and the COWAT mounted together.

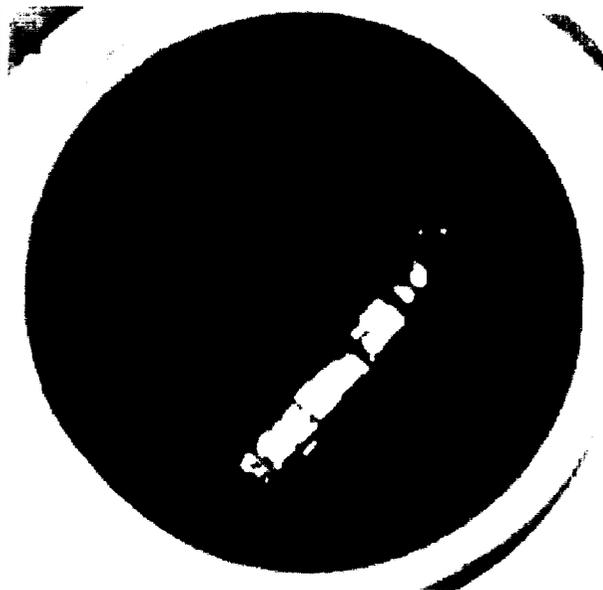


Figure 4: View into the COWAT showing the X-band septum polarizer sitting inside. The polarizer uses a stepped metal septum to separate the two modes into two rectangular waveguides for right hand and left hand circular polarization.

2.2. A Micro Rain Radar

In the fall of 1997 a small radar was obtained for characterization of rain events at the Onsala Space Observatory. It is a Frequency Modulated-Continuous Wave (FM-CW) radar and is

always measuring in the zenith direction. A picture of the radar is shown together with a block diagram in Figures 5 and 6. The radar measures the velocity spectra of the falling drops. From these data the rain rate and the liquid water density can be inferred. During the first year the radar was operating to a height of 1200 m with a range resolution of 200 m. The data so far used is the rain rate at the height of 200 m. This information is used to develop an independent method to firstly have an archive of rain events at the Onsala site, and secondly to assess the quality of microwave radiometer data used for propagation delay studies. A preliminary investigation concerning the use of rain radar data for automatic editing of microwave radiometer data was recently presented. It was found that the earlier used threshold value of 0.7 mm liquid water content is reasonable when trying to eliminate microwave radiometer data acquired during rain [3].

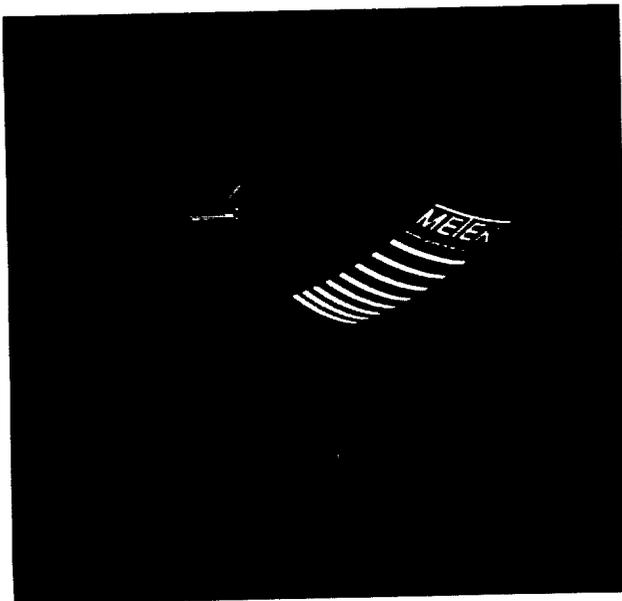


Figure 5: The zenith looking Micro Rain Radar (MRR) at the Onsala site.

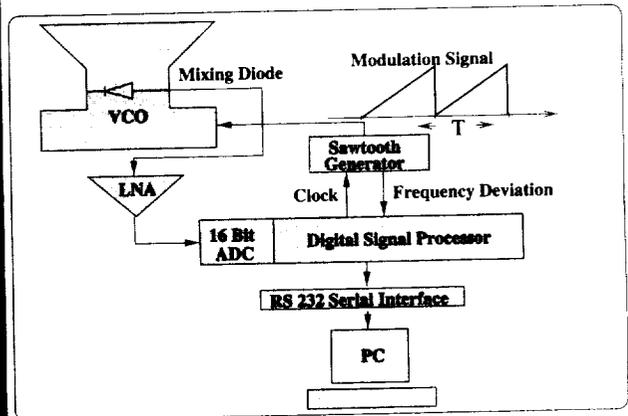


Figure 6: Block diagram of the Micro Rain Radar (MRR) at the Onsala site.

2.3. A New Microwave Radiometer

A second microwave radiometer for observations of the atmospheric emission around the 22 GHz water vapor emission line is being developed [4]. The main application will be comparison measurements at the Onsala site. Temporary measurement campaigns at other sites, e.g. in the Swedish GPS network, are also planned. A major difference compared to the existing Onsala radiometer is that the half power antenna beam widths are approximately 2° instead of 6°. Figure 7 shows the design of the instrument and Figure 8 shows the microwave part.

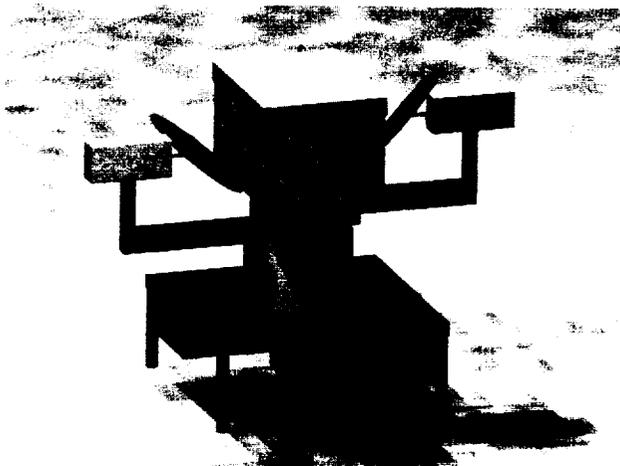


Figure 7: The design of the new microwave radiometer. Using two synchronized flat mirrors the antenna beams will be sensing the sky in the same direction.

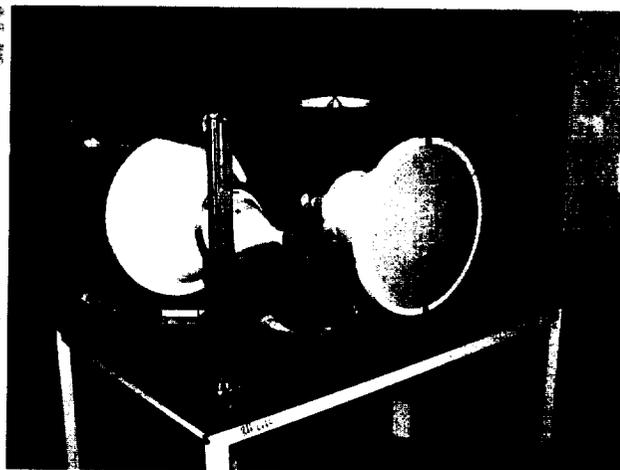


Figure 8: The microwave part of the new radiometer. The horn antennas are equipped with lenses and are looking in opposite directions.

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IVS
INFORMATION



IVS Terms of Reference

1. Summary

1.1. Objectives

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. The primary objective of IVS is to foster VLBI programs as a joint service to support geodetic, geophysical, astrometric, and other research and operational activities. 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.

1.2. 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.

1.3. 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

1.4. 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 component described in the next section. IVS will accept proposals at any time for any of its components. Such proposals will be reviewed by the Directing Board. The IVS components are the following:

- Network Stations
- Operation Centers
- Correlators
- Analysis Centers
- Data Centers

- Technology Development Centers
- Coordinating Center
- Directing Board
- Associate Members
- Corresponding Members

1.5. Coordination

Specific activities for technology, network data quality, and data products are accomplished through the functions performed by three coordinators:

- Technology Coordinator
- Network Coordinator
- Analysis Coordinator

2. Components

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 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 produce high-quality results for its users. These activities are performed by Analysis Centers, which contribute to the IVS core products, and by Associate Analysis Centers, which contribute other specialized products. Two types of Associate Analysis Centers are recognized: Global and Special.

The Analysis Centers receive and process VLBI data from one or more IVS Data Centers and are committed to produce the core products, without interruption, and at a specified time lag to meet IVS requirements. The IVS core products, at a minimum, consist of Earth orientation parameters, station coordinates, and source coordinates. 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.

The Global Associate Analysis Centers process all the observed VLBI data. Some process data directly from Correlators and then make available as products the final VLBI database files and SINEX files. Others start with these database to perform their analyses, but will process all the databases.

The Special Associate Analysis Centers analyze selected databases for one (or more) specific interests, such as regional data processing, terrestrial reference frame maintenance, or Earth orientation results.

In addition, all types of IVS analysis centers satisfy the following standards:

- Analysis is performed using VLBI software packages that adhere to IVS recommendations.
- Centers perform software development and produce documentation. They periodically compare their products.
- Centers adhere to IERS Conventions. Any exceptions are 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, and other organizations,
- provide the Secretariat of the Directing Board.

Through a reciprocity agreement between IVS and IERS the Coordinating Center serves as the VLBI Coordinating Center for IERS, and as such its designated representative, subject to the Directing Board approval, is a member of the IERS Directing Board. Such a representative is a non-voting member of the IVS 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.

2.8. 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.

2.9. 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.

2.10. 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.

2.11. Directing Board

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.

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
- Coordinating Center Director

Selected by Directing Board upon review of proposals from the relevant IVS component (see below):

- Technology, Network, and Analysis Coordinators (3 total)

Elected by Directing Board upon recommendation from the Coordinating Center (see below):

- Members at large (2)

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: 14

The four appointed members are considered *ex officio* and are not subject to institutional restrictions. The other 10 persons must be members of different IVS components. 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 as possible. All elected members serve staggered four-year terms once renewable.

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. Networks representatives can be nominated by well-defined, operating networks accepted as such by the Directing Board. 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.

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.

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.

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.

The Secretariat of the Directing Board is provided by the Coordinating Center.

2.12. IVS Associate Members

Individuals affiliated with organizations that participate in any of the IVS components 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.

2.13. IVS Correspondents

IVS Correspondents 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 correspondents 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

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IVS Components

(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 Observatorio Espacialdo Nordes (ROEN)	Centro de Rádio Astronomia e Aplicações Espaciais	Brazil
Gilmore Creek Geophysical Observatory	National Earth Orientation Service	USA
Goddard Geophysical and Astronomical Observatory	NASA Goddard Space Flight Center	USA
National Radio Astronomy Observatory, Green Bank	U. S. Naval Observatory	USA
Hartebeesthoek Radio Astronomy Observatory	Hartebeesthoek Radio Astronomy Observatory	South Africa
Key Stone Project Koganei 11m antenna	Communications Research Laboratory	Japan
Key Stone Project Kashima 11m antenna	Communications Research Laboratory	Japan
Key Stone Project Miura 11m antenna	Communications Research Laboratory	Japan
Key Stone Project Tateyama 11m antenna	Communications Research Laboratory	Japan
Kokee Park Geophysical Observatory	National Earth Orientation Service	USA
Matera	Agenzia Spaziale Italiana	Italy
Medicina (Italy)	Istituto di Radioastronomia CNR	Italy
Mizusawa	National Astronomical Observatory of Japan	Japan
Noto (Sicily)	Istituto di Radioastronomia CNR	Italy
Ny Ålesund Geodetic Observatory	Norwegian Mapping Authority	Norway
ERS/VLBI Station O'Higgins	Bundesamt für Kartographie und Geodäsie	Germany
Onsala Space Observatory	Chalmers University of Technology	Sweden
Seshan	Shanghai Observatory, Chinese Academy of Sciences	China
Simeiz	Laboratory of Radioastronomy of Crimean Astrophysical Observatory	Ukraine
Svetloe Radio Astronomy Observatory	Institute of Applied Astronomy	Russia
JARE Syowa 11m antenna	National Institute of Polar Research	Japan

Transportable Integrated Geodetic Observatory (TIGO)	Bundesamt für Kartographie und Geodäsie	Germany
Tsukuba VLBI Station	Geographical Survey Institute	Japan
Nanshan VLBI Station of Urumqi Astronomical Observatory (UAO)	Shanghai Observatory, Chinese Academy of Sciences	China
Westford Antenna, Haystack Observatory	NASA Goddard Space Flight Center	USA
Fundamentalstation Wettzell	Bundesamt für Kartographie und Geodäsie and Forschungseinrichtung Satellitengeodäsie der Technischen Universität München	Germany
Observatorio Astronómico Nacional - Yebes	Instituto Geografico Nacional	Spain
Yellowknife Geophysical Observatory	Geodetic Survey Division, Natural Resources Canada	Canada

Operation Centers

Component Name	Sponsoring Organization	Country
Geodetic Institute Bonn	Geodätisches Institut der Universität Bonn	Germany
CORE Operation Center	NASA Goddard Space Flight Center	USA
NEOS Operation Center	National Earth Orientation Service	USA

Correlators

Component Name	Sponsoring Organization	Country
Bonn Astro/Geo Correlator at the Max-Planck-Institute for Radio Astronomy	Bundesamt für Kartographie und Geodäsie and Geodätisches Institut der Universität Bonn	Germany
EVN Data Processor at JIVE	Joint Institute for VLBI in Europe	Netherlands
Key Stone Project	Communications Research Laboratory	Japan
MIT Haystack Observatory Correlator	NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy Correlator	Institute of Applied Astronomy	Russia
Tsukuba VLBI Center	Geographical Survey Institute	Japan
Washington Correlator	National Earth Orientation Service	USA

Data Centers

Component Name	Sponsoring Organization	Country
BKG, Leipzig	Bundesamt für Kartographie und Geodäsie	Germany
Communications Research Laboratory	Communications Research Laboratory	Japan
Crustal Dynamics Data Information System (CDDIS)	NASA Goddard Space Flight Center	USA
GeoDAF	Agenzia Spaziale Italiana	Italy
Italy CNR	Istituto di Radioastronomia CNR	Italy
Observatoire de Paris	Observatoire de Paris	France

Analysis Centers

Component Name	Sponsoring Organization	Country
Astronomical Institute of St.-Petersburg University	Astronomical Institute of St.-Petersburg University	Russia
Bordeaux Observatory	Observatoire de Bordeaux	France
Centro di Geodesia Spaziale (CGS)	Agenzia Spaziale Italiana	Italy
Communications Research Laboratory	Communications Research Laboratory	Japan
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 Flight Center	NASA Goddard Space Center	USA
Haystack Observatory	NASA Goddard Space Flight Center	USA
Institute of Applied Astronomy	Institute of Applied Astronomy	Russia
Italy CNR	Istituto di Radioastronomia CNR	Italy
Jet Propulsion Laboratory	Jet Propulsion Laboratory	USA
Main Astronomical Observatory	National Academy of Sciences, Kiev	Ukraine
NAOJ	National Astronomical Observatory of Japan	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	U. S. Naval Observatory	USA

Technology Development Centers

Component Name	Sponsoring Organization	Country
Canadian VLBI Technology Development Center	Space Geodynamics Laboratory, Geodetic Survey Division, Dominion Radio Astrophysical Observatory, Canadian Space Agency	Canada
Communications Research Laboratory	Communications Research Laboratory	Japan
Forsvarets forskningsinstitutt (FFI)	Norwegian Defence Research Establishment	Norway
Goddard Space Flight Center	NASA Goddard Space Flight Center	USA
MIT Haystack Observatory	National Earth Orientation Service	USA
Institute of Applied Astronomy	Institute of Applied Astronomy	Russia
Institut d'Estudis Espacials de Catalunya	Institut d'Estudis Espacials de Catalunya	Spain
Joint Institute for VLBI in Europe (JIVE)	Joint Institute for VLBI in Europe	Netherlands
Onsala Space Observatory	Chalmers University of Technology	Sweden

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Brazil

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CRESTech Space Geodynamics Laboratory

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Shanghai 200030

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South Beijing Road 40

sub-5

Urumqi

Xinjiang 830011

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2 rue de l'Observatoire
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Sackenrieder Straße 25
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Ibaraki 314-0012

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National Institute of Polar Research

1-9-10 Kaga

Itabashi-ku

Tokyo 173-8515

Japan

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Geographical Survey Institute, JAPAN

Kitasato 1 Tsukuba

Ibaraki

Japan

<http://vldb.gsi-mc.go.jp/sokuchi/vlbi/>

Geodetic Institute, Norwegian Mapping Authority

Kartverksveien

Hønefoss

Norway

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Krugersdorp 1740
South Africa
<http://www.hartrao.ac.za>

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E-28800 Alcalá de Henares
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Onsala Space Observatory
SE-439 92 Onsala
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<http://www.oso.chalmers.se>

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334247 Yalta
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RT-22 Crimea
Ukraine
<http://giud.geod.uni-bonn.de/vlbi/stations/rt22.html>

Main Astronomical Observatory, Ukrainian National Academy of Sciences
Main Astronomical Observatory
Golosiiv
252650 Kiev-022
Ukraine
<http://www.mao.kiev.ua>

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4800 Oak Grove Drive
Pasadena, CA 91109
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<http://www.jpl.nasa.gov>

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Off Route 40
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USA
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Gilmore Creek Geophysical Observatory

NOAA/NESDIS CDA Station
GCGO/VLBI
1300 Eisele Rd
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Kokee Park Geophysical Observatory

Kokee State Park
P.O. Box 538
Waimea, Hawaii 96798
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NASA Goddard Space Flight Center

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Greenbelt, MD 20771
USA
<http://lupus.gsfc.nasa.gov>

National Radio Astronomy Observatory (NRAO)

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Green Bank, WV 24944
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List of Acronyms

APSG	Asia Pacific Space Geodetic Program
APT	Asia Pacific Telescope
ARO	Algonquin Radio Observatory (Canada)
ASI	Agenzia Spaziale Italiana (Italian Space Agency)
ATSC	AlliedSignal Technical Services Corporation
BKG	Bundesamt für Kartographie und Geodäsie (Germany)
CAS	Chinese Academy of Sciences (China)
CDDIS	Crustal Dynamics Data Information System (USA)
CDP	Crustal Dynamics Project
CGS	Centro di Geodesia Spaziale (Italy)
CNR	Consiglio Nazionale delle Ricerche (Italy)
CORE	Continuous Observations of the Rotation of the Earth
CRAAE	Center for Radio Astronomy and Space Applications (Brazil)
CRF	Celestial Reference Frame
CRL	Communications Research Laboratory (Japan)
CSTG	Commission on International Coordination of Space Techniques for Geodesy and Geodynamics
CTVA	Canadian Transportable VLBI Antenna
DGFI	Deutsches Geodätisches Forschungsinstitut (Germany)
DORIS	Doppler Orbitography by Radiopositioning Integrated on Satellite
DSN	Deep Space Network
EOP	Earth Orientation Parameters
EVN	European VLBI Network
FESG	Forschungseinrichtung Satellitengeodäsie (Germany)
FFI	Forsvarets forskningsinstitutt (Norwegian Defence Research Establishment)
GARS	German Antarctic Receiving Station (Antarctica)
GCGO	Gilmore Creek Geophysical Observatory (USA)
GGAO	Goddard Geophysical and Astronomical Observatory (USA)
GIUB	Geodetic Institute of the University of Bonn (Germany)
GLORIA	GLOBAL Radio Interferometry Analysis
GPS	Global Positioning System
GSFC	Goddard Space Flight Center (USA)
GSI	Geographical Survey Institute (Japan)
GeoDAF	Geodetical Data Archive Facility (Italy)
HartRAO	Hartebeesthoek Radio Astronomy Observatory (South Africa)
IAA	Institute of Applied Astronomy (Russia)
IAG	International Association of Geodesy
IAU	International Astronomical Union
ICRF	International Celestial Reference Frame
IEEC	Institut d'Estudis Espacials de Catalunya (Spain)

IERS	International Earth Rotation Service
IRIS-S	International Radio Interferometric Surveying-South
ITRF	International Terrestrial Reference Frame
IUGG	International Union of Geodesy and Geophysics
IVS	International VLBI Service for Geodesy and Astrometry
JARE	Japanese Antarctic Research Expedition (Japan)
JIVE	Joint Institute for VLBI in Europe
JPL	Jet Propulsion Laboratory (USA)
KPGO	Koike Park Geophysical Observatory (USA)
KSP	Keystone Project (Japan)
LNA	Low noise amplifier
MAO	Main Astronomical Observatory (Ukraine)
NAO	National Astronomical Observatory (Japan)
NASA	National Aeronautics and Space Administration (USA)
NEOS	National Earth Orientation Service (USA)
NGS	National Geodetic Survey (USA)
NIPR	National Institute of Polar Research (Japan)
NOAA	National Oceanic and Atmospheric Administration (USA)
NRAO	National Radio Astronomy Observatory (USA)
NRCan	Natural Resources Canada
OAN	Observatorio Astronómico Nacional (Spain)
OPAR	Paris Observatory (France)
OSO	Onsala Space Observatory (Sweden)
PRARE	Precision RAnge and Range-rate Experiment
ROEN	Rádio-Observatório Espacial do Nordeste (Brazil)
SEFD	System Equivalent Flux Density
SGP	Space Geodesy Program (USA)
SHAO	Shanghai Astronomical Observatory (China)
SINEX	Solution INdependent EXchange format
SLR	Satellite Laser Ranging
TAC	Totally Accurate Clock
TIGO	Transportable Integrated Geodetic Observatory (Germany)
TRF	Terrestrial Reference Frame
UAO	Urumqi Astronomical Observatory (China)
USNO	U. S. Naval Observatory (USA)
UT1	Universal Time
UTC	Coordinated Universal Time
VLBA	Very Long Baseline Array (USA)
VLBI	Very Long Baseline Interferometry
VSOP	VLBI Space Observatory Program
WACO	Washington Correlator (USA)
WVR	Water Vapor Radiometer

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