IVS AND ITS IMPORTANT ROLE IN THE MAINTENANCE OF THE GLOBAL REFERENCE SYSTEMS

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ABSTRACT

VLBI technique plays a primary role in the maintenance of global reference frames. The IVS (International VLBI Service for Geodesy and Astrometry) was established in February 1999 in order to support VLBI programs for geodetic, geophysical and astrometric research and operational activities. IVS coordinates the observations, the data flow, the correlation, the data analysis and the technology developments. Today not only science, research and development are making use of the results but also practical applications are dependent on IVS products. Thus, acting within the frame of IAG and IAU, IVS has to guarantee provision of the required results on a regular, timely basis including Earth orientation parameters, position and velocity vectors. The paper will summarize the activities of the service and will give a prospective for the next few years, based on the experiences of the first IVS General Meeting.

GENERAL REMARKS

Beginning in the 70s SLR, VLBI and other space techniques started to play an important role in the understanding of the kinematics and dynamics of the Earth. The breakthrough finally came as a result of the MERIT Campaign [Feissel, 86] and the Crustal Dynamics Project [Smith, 93]. 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 motions.

Since mid 80s the VLBI technique has assumed the important and primary role for monitoring Earth Orientation Parameters (EOP) and it realizes and provides the link between ICRF and ITRF with highest reliability and accuracy. It has to be emphasized that VLBI is the only technique that determines the Celestial Reference Frame (ICRF).

At that time the VLBI Community was organized as the VLBI Subcommission within IAG Commission VIII – CSTG (International Coordination of Space Techniques for Geodesy and Geodynamics), which is also Subcommission B.2 of COSPAR . The president of the CSTG, Gerhard Beutler , encouraged by the success of the IGS (International GPS Service) proposed in 1997 to organize the SLR/LLR and the VLBI subcommissions of the CSTG into comparable services to IGS because:

1. A service will guarantee much more strongly the provision of highly reliable products which are urgently required not only for research but also for practical applications,

2. The SLR/LLR and the VLBI techniques urgently needed more acceptance and support in the scientific community, and
3. Coordination of the activities will strongly concentrate resources and increase the potential to improve the techniques.

T. A. Clark, in his function as chairman of the CSTG VLBI Subcommission, drafted the Terms of Reference (ToR) in October 1997. The final version of the ToR was worked out by a Steering Committee composed of James Campbell (chair), Yasuhiro Koyama, Chopo Ma, Arthur Niell, Axel Nothnagel, Jim Ray and Nancy Vandenberg. The Terms of Reference were presented and approved at both the CSTG Executive Committee and IERS Directing Board meetings in Nice/France in April 1998. They are available at http://ivscc.gsfc.nasa.gov.

OBJECTIVES OF THE IVS

IVS has been recognized as a Service of the International Association of Geodesy (IAG) since July 1999 when the General Assembly was held in Birmingham. The Objectives of IVS are to

- support geodetic, geophysical and astrometric research and operational activities,
- promote research and development activities in all aspects of the geodetic and astrometric VLBI technique and
- interact with users of VLBI products.

The products are strongly related to

- the contribution to the International Terrestrial Reference Frame (ITRF),
- the realisation of the International Celestial Reference Frame (ICRF) and
- determination of Earth Orientation Parameters (EOP).

Nowadays the IVS is a technique center for the International Earth Rotation Service (IERS) and has close interactions with IERS. The VLBI technique uniquely provides the parameters for the ICRF and is the only technique to determine the celestial pole. IVS has to ensure that its products have suitable quality and timeliness.

SUMMARY OF THE IVS COMPONENTS

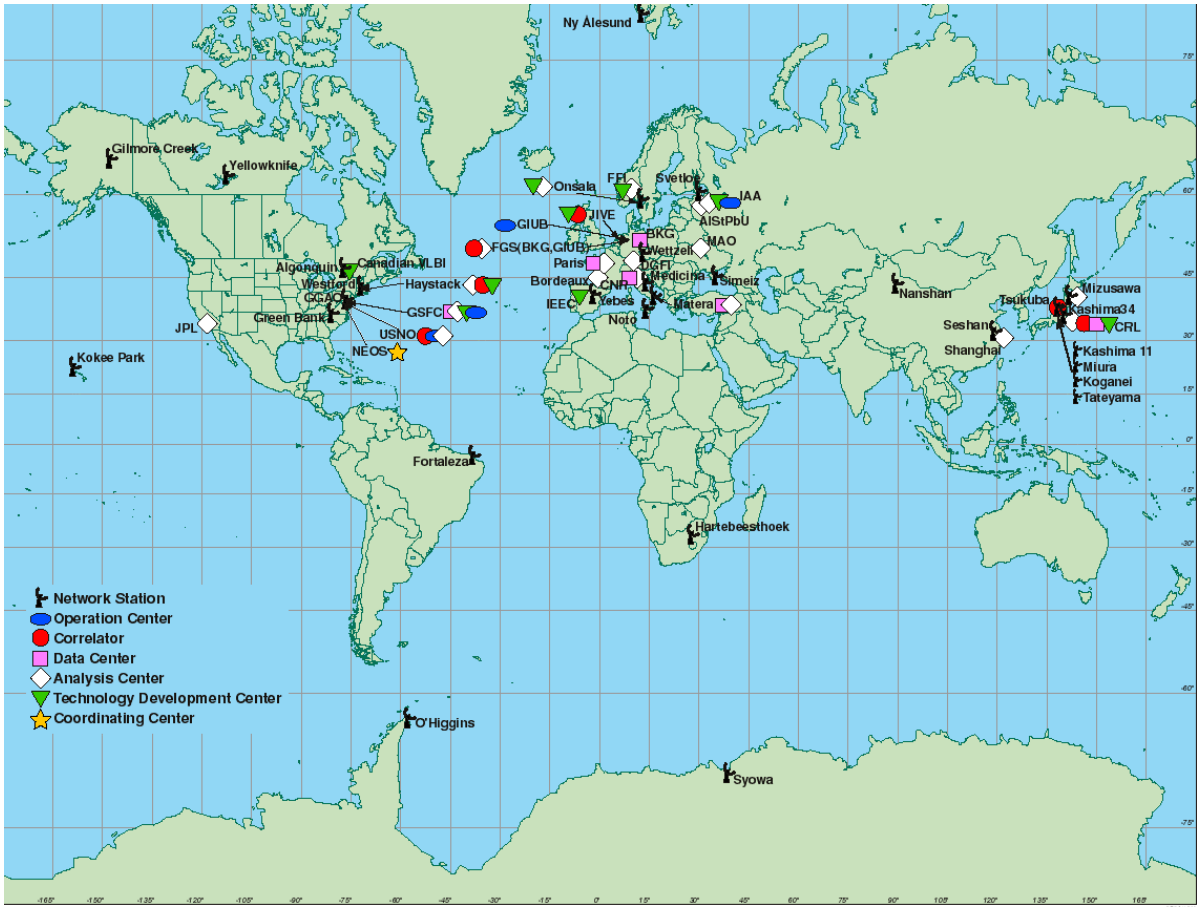
A Call for Participation was released jointly by CSTG and IERS on June 1, 1998. The proposals were evaluated and accepted by the Steering Committee. In summary IVS has today

- ***30 Network Stations,*** concentrated in USA, Europe, Japan and a deficit in the southern hemisphere,
- ***3 Operation Centers*** namely NASA-GSFC, NEOS, Geodetic Institute of the University of Bonn,
- ***7 Correlators*** operated by NEOS(Washington)/USA, NASA(Haystack)/USA, BKG-MPI/Germany, GSI/Japan, CRL/Japan, IAA/Russia, JIVE/Netherlands,
- ***6 Data Centers*** established at NASA-GSFC/USA, Observ. Paris/France, BKG/Germany, CNR/Italy, CRL/Japan and Agenzia Spaziale/Italy,
- ***20 Analysis Centers***, five of them provide IVS core products (IAA/Ru, GSFC/US, USNO/US, BKG/D, OP/F) and 15 Associate AC perform investigations or make other related products,

- ***9 Technology Development Centers*** supporting the recording techniques MK III and MK IV, K4 and S2, and
- ***1 Coordinating Center*** operated by NEOS, a cooperation of USNO and GSFC.

All together there are ***76 components*** representing ***30 Member Organizations*** in 15 countries and more than ***230 Associate Members***

Fig. 1. Overview of the distribution of the IVS componets



SUMMARY OF ACTIVITIES

The 1st Directing Board meeting was held in Wettzell, Germany on February 11, 1999 in order to establish the Service and to initiate activities under the flag of the IVS. On the inauguration date of IVS, March 1, 1999, its web site was available: http://ivs.gsfc.nasa.gov. Soon after, a solicitation for IVS data and analysis was released to obtain proposals from the Operation and Analysis Centers on the provision of products such as correlation results, EOP, and combined analysis. Those products derived by the Analysis Centers were designated to become "official" IVS products. Within the same solicitation the call for an Analysis Coordinator was released.

A Coordinators meeting was held at GSFC on April 8, 1999, to discuss the activities of each coordinator with emphasis on areas where responsibilities of the Coordinators may overlap. The IVS Annual Report was published in August 1999 (electronically) and September 1999 (printed). The intention of the Annual Report was to provide a document on the status of all

components. A procedure was created to standardize the layout, which supported and accelerated the publication of the Annual Report 1999.

The 2000 IVS General Meeting was organized and held in Kötzting, Germany, in the period February 21-24, 2000. It was a successful meeting with more than 120 participants registered. The goals of the meeting were determined by a program committee. The main character of the 1st General Meeting was addressed towards young researchers. Overview talks and tutorials were held before the sessions, in order to introduce the session topic to those who work in different areas. An IVS Analysis Workshop was combined with the General Meeting, held in Kötzting on February 24, 2000 and an initial meeting of a Working Group for mapping the phase centers of GPS transmission antennae was held.

As IVS is the only technique for the realisation of the CRF initial actions were undertaken by the IVS Directing Board to be recognized as a service of the International Astronomical Union (IAU).

It has to be mentioned that the proceedings of 2000 IVS General Meeting were published in June 2000. The proceedings published full versions of nearly all the papers and tutorials. This publication is a very valuable tool, especially for people starting to work in VLBI.

IVS PRODUCTS

Following the goals of IVS, providing products for maintaining global reference frames, IVS is producing Earth Observation Parameters from 24h observation sessions regularly and periodically carried out such as NEOS and IRIS. The parameters in particular are the celestial pole coordinates $d\psi$, $d\varepsilon$, polar motion parameter x_p, y_p, and DUT1.

In addition DUT1 is derived from 2h observation sessions quasi daily, carried out by Wettzell and Green Bank, nowadays Wettzell and Kokee Park.

CRF solutions are regularly derived in order to determine quasar positions or to detect proper motions of quasars. Station positions and velocities are derived from all the observations, which are a strong contribution to the ITRF.

It is planned that IVS will provide EOP with subdaily resolution and baseline length evolutions. The products are available via the primary IVS Data Centers at ftp://cddisa.gsfc.nasa.gov or ftp://ftp.leipzig.ifag.de or ftp://ivsopar.obspm.fr.

VLBI COMMUNITY RESOURCES MANAGED BY IVS

The Coordinating Center (CC) of the IVS coordinates the data acquisition sessions including the observing time on radio telescopes, the magnetic tape usage, and the correlator capacity. The CC has to set up a master schedule as the basis for all its coordinating tasks.

The use of thin tapes, each of which can hold up to 5 Terrabits, has enabled more sophisticated recording modes and correspondingly complex data management at the correlators. The limited supply of thin tapes used for geodesy are drawn from a common pool; each agency has contributed its share of tapes to the pool. The transition to MKIV technology is ongoing, and its full implementation in hardware and software requires additional resources and training.

The correlator time on MK IV correlators (WACO, Bonn, Haystack) is also coordinated by the CC. The observing programs coordinated by IVS are summarized in the Multi-Agency Master Schedule. The following table summarizes the responsible agency and the corresponding observation session type:

- NASA/USNO — NEOS, CORE-A, CORE-B, R&D VLBA, CRF
- FGS — EUROPE, IRIS-S, CORE-O'Higgins
- APSG — APSG
- GSI — Syowa Antarctica

- USNO/BKG/GSI MKIV-/K4 Intensives

INCREASE DATA QUALITY AND RELIABILITY

In order to increase the reliability of the VLBI data and its quality, some improvements will soon become effective. IVS has high quality network stations that employ unique highly qualified techniques. Station visits by the Network Coordinator will support correct operational procedures and will help to avoid misunderstandings, which is evident as the staff qualification is varied. A pool of spare parts will help to overcome or minimize periods of failure, in case severe technical problems occur and the repair requires spares which locally might not be available. The transition from MKIII to MKIV, which currently requires resources for its implementation, will soon be completed. It is expected that the throughput, quantity and quality of the correlation will increase. A good and immediate feedback to the network stations will help to detect upcoming problems and failures.

In the past technical workshops have been held (the so-called Chiefs meetings) in order to inform and train operators and engineers and to make them familiar with the dedicated technique. IVS will hold such operations workshops every two years. IVS plans to develop performance standards so that the stations can evaluate their own performance locally and make any changes necessary to improve it.

IVS is monitoring station performance at all steps in the data flow to help identify problems early and make sure they get fixed. As part of this effort IVS has developed a database that collects performance organized by station. This simplifies keeping track of any problems at each station, helps to determine when they had problems, and whether they have been resolved.

The IVS Network Coordinator is collecting detailed information on the station configuration and collocation with other techniques in a central database. The configuration will provide a ready reference for each station's capabilities. The collocation information will be useful for geodetic analysis efforts where the results from more than one technique are compared.

The products of IVS are not based on the results of only one Analysis Center. It is anticipated that up to five Analysis Centers will provide independent results from the 24hr observation sessions. Employing different software and slightly different strategies, even while using the same standards, can lead to slightly different results. In order to overcome the discrepancies between the solutions, comparisons and combination procedures are being developed by the IVS Analysis Coordinator that will provide the most reliable results as a combination of the solutions. The fact that five solutions will be available will enable elimination of outliers, which finally will increase the reliability of the combined products significantly. Comparison and combination of the products also create competition and will improve the analysis models.

In order to improve the quantity of data, extensions and changes in the observation scenario have to be considered. A tremendous improvement will result from the gradual implementation of the CORE (Continuous Observation of the Rotation of the Earth) program. In 2000 the program covered 2.1 days of observation per week. It is planned to increase the number of days up to 3.0 days in 2001, 4 days in 2002 and finally 6 days in 2003. More automation and remote control of network stations have to be considered as weekend observations will be involved and manpower on weekends will be problematic.

It also has to be strongly considered to extend the CORE to the other recording techniques and to include stations and correlators equipped with K4 and S2 systems.

Improvements in the Network configuration have to be considered. There is a concentration of the network stations in the Northern hemisphere. The network should be better balanced, which requires activation of existing stations for IVS or implementation of new stations in the Southern hemisphere. A new station will be established soon by the Bundesamt für

Kartographie und Geodäsie/Germany in Concepcion/Chile. The Transportable Integrated Geodetic Observatory (TIGO) will installed in the beginning of 2001 and will start providing observations in spring 2001. Additional stations might encouraged to be involved in the IVS activities from related groups such as the EVN (European VLBI Network) or APT (Asia Pacific Telescope).

TECHNOLOGY

The primary technology interests of IVS have focused on three areas:

1. Definition of a VLBI Standard Interface
2. Integration of new high data-rate VLBI systems into the networks
3. Exploration of electronic international transmission of VLBI data ('e-VLBI')

The incompatibility of various VLBI data systems has long been recognized as posing a serious obstacle to the realization of the full potential of VLBI observations. Sporadic efforts have developed over the years to define a common interface standard which would allow observations recorded on different VLBI data systems to be processed at a common correlator, but these efforts have foundered for various reasons.

The establishment of the Global VLBI Working Group (GVWG) in the early 1990s, growing primarily from the space-VLBI community but serving the broader interests of astronomy, and the International VLBI Service (IVS) in 1999, serving primarily the geodetic VLBI community, provided an organizational framework for which efforts at standardization could proceed in a more organized and sanctioned fashion. It was from these roots that the present VSI effort was initiated, led by the IVS Technology Coordinator.

The main goals of the VSI can be summarized as follows:

- Develop a standardized set of hardware and software specifications that will allow interoperability of various VLBI data systems.
- Hide as much as possible the detailed characteristics of various systems so as not to place undue restraints or restrictions on any particular system.
- Support recording on various media (tape, disc, optical, etc) as well as real and quasi real-time data links of any type and a data rates expandable to many Gbps.

The fledgling VSI concept leading to the current specification was first proposed at the time of the GEMSTONE meeting in Tokyo in January 1999 and was discussed by a small interested group at that meeting. Support was then sought and received from IVS and GVWG to create a VSI Technology Coordination Group (VSI-TCG) comprised of experts representing all of the major world institutions involved in the development of VLBI equipment.

Early in the discussions it was decided to separate the hardware and software VSI, concentrating first on hardware, hence this VSI-H specification, to be followed by a companion software specification, VSI-S. The VSI-H specification was shaped by intensive e-mail discussions, plus three (multi-hour!) international telephone conferences and a two-day international VSI meeting held at Haystack Observatory in February 2000.

The VSI-H specification is nearly complete. It is intended as a starting point from which to progress, and will be extended and amended as requirements and technology demand. It is heartening that already at least three groups are known to be developing or adapting VLBI data systems to meet the VSI-H standard.

As for the other IVS technology interests, efforts have been on-going:

- New VLBI data systems have been (or are being) integrated into IVS stations, led by the Mark IV data-acquisition and correlation systems capable of supporting data rates up to 1 Gbps.
- Investigations into the potential for e-VLBI are on-going, primarily focusing on the current and projected economics of wordwide real-time or quasi-real-time high-speed

optical links. Prices for high-speed international connections are rapidly diminishing, though ‘last mile’ connection costs to many stations will remain high.

PROSPECTS

The primary task of the IVS is the coordination of all its components into a highly reliable service and to guarantee high quality and timely products on a long term basis. With the development of standards for the components, it can be expected that the overall data quality, quantity and reliability of IVS products will significantly increase. Improvements have to be considered in the network configuration. Cooperation with related communities such as the EVN or the APT, involvement of all the data acquisition techniques, and the standardization of the data acquisition interfaces all support an increase in the number and balance of the global distribution of network stations. New developments in technology will accelerate data exchange and increase the degree of automation in order to provide timely products. In close cooperation with the other services the strengths of each technique should be exploited to improve all geodetic products. The IVS Working Group on the mapping of GPS phase center involving the IGS and the ILRS is a good example of the attempt to find better solutions in providing and maintaining reference frames for the community.

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