International VLBI Service for Geodesy and Astrometry (IVS)

Dirk Behrend

NVI, Inc./NASA Goddard Space Flight Center
Greenbelt, MD 20771, USA

Wolfgang Schlüter

Fundamentalstation Wettzell,
Bundesamt für Kartographie und Geodäsie
D-93444 Kötzting, Germany

Harald Schuh

Vienna University of Technology
Institute of Geodesy and Geophysics
A-1040 Vienna, Austria

1. Introduction

This report summarizes the activities of the International VLBI Service for Geodesy and Astrometry (IVS) during 2003−2007 reviewing the results and progress made. IVS is an approved service of the International Association of Geodesy (IAG) since 1999 and of the International Astronomical Union (IAU) since 2000 and a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) since 2001. The goals of the IVS, which is an international collaboration of organizations that operate or support Very Long Baseline Interferometry (VLBI) components, are

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

The VLBI technique has been employed in geodesy for nearly 40 years. Covering intercontinental baselines with highest accuracy, monitoring Earth rotation at the state of the art and providing the quasar positions as the best approach to an inertial reference frame, VLBI significantly contributed to the tremendous progress made in geodesy over the last decades. VLBI was a primary tool for understanding the global phenomena changing the "Solid Earth". Today VLBI continuously monitors Earth orientation parameters as well as crustal movements in order to maintain global reference frames, coordinated within the IVS. Science and applications set the requirements for the realization and maintenance of global reference frames at VLBI's technical limitations. VLBI, as the unique technique for providing a celestial reference frame and for deriving the full set of Earth rotation parameters, plays the fundamental role of generating the basis for many applications and research in the geosciences.

Being tasked by IAG and IAU with the provision of timely, highly accurate products (Earth Orientation Parameters, EOP; Terrestrial Reference Frame, TRF; Celestial Reference Frame, CRF), but having no funds of its own, IVS strongly depends on the voluntary support of individual agencies that form the IVS. Figure 1 shows the global distribution of the IVS components. More information can be found on the IVS Web site at http://ivscc.gsfc.nasa.gov.

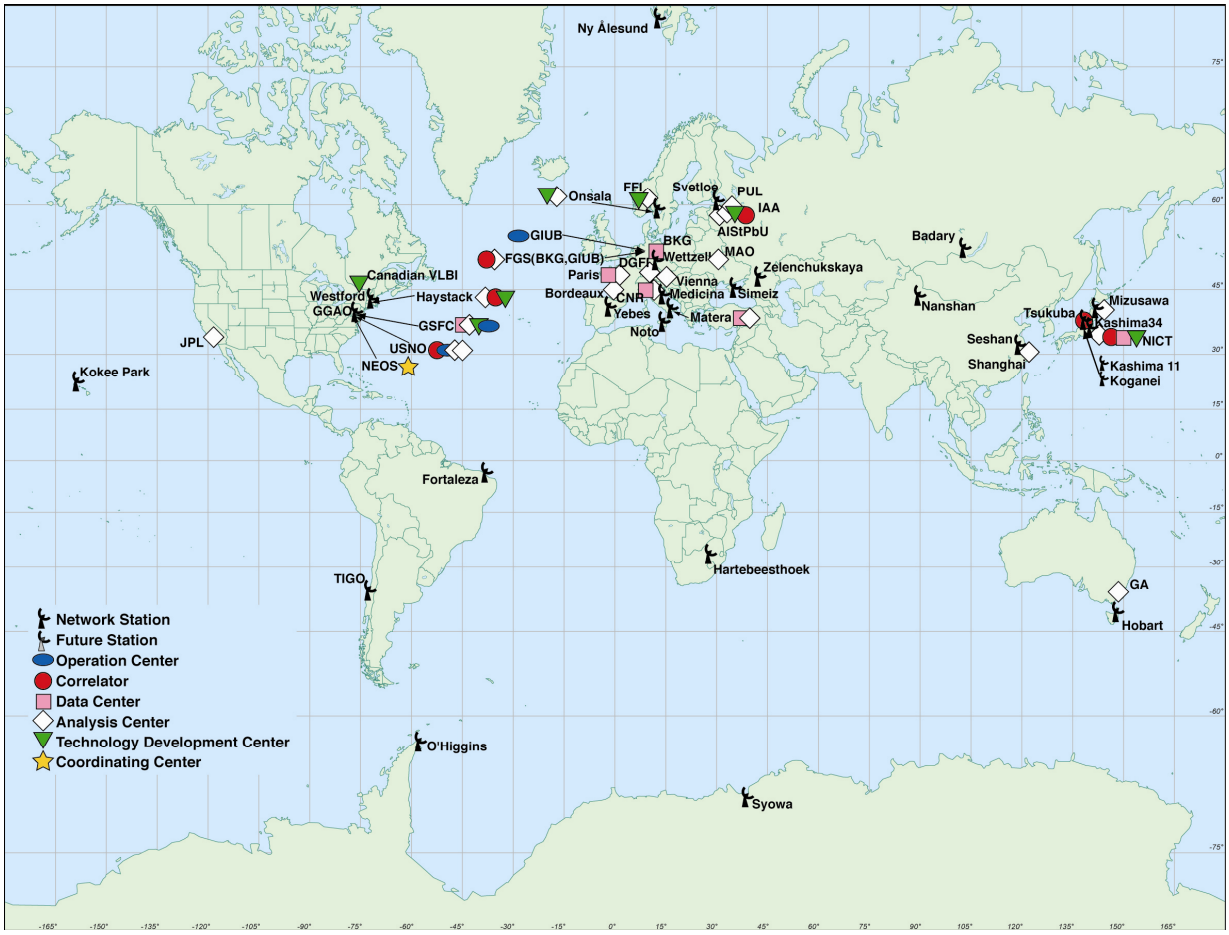

Figure 1. Global distribution of IVS components.

2. Highlights of IVS Activities

Digital recording systems. In the report period a significant improvement was achieved by completely switching from tape-based observing to disk-based observing. Starting in 2003, the tape drives have been successively replaced by the disk-based digital data recording systems Mark 5 and K5. Using digital recording systems the large amount of VLBI raw data can be handled at lower cost and with more reliability. The digital data recorders are the basis for the development of e-VLBI, in which raw VLBI data is transmitted via high-speed networks from the recording stations to the correlators. It also has to be pointed out that the work at the correlator has improved significantly and the correlation procedure, in particular the re-correlation, can now be done much faster. The transition from Mark 4 to Mark 5A went very smoothly, and all observing stations and the correlators are now equipped with disk-based digital recorders.

Observing program. The observing program for 2003–2007 included the following sessions:

- EOP: Two rapid turnaround sessions each week, mostly with 7 stations, some with 6 or 8 stations depending on station availability. These networks were designed with the goal of having comparable x_p and y_p results. Data bases are available no later than 15 days after each session. Daily 1-hour UT1 Intensive measurements on five days (Monday through Friday) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA) and on weekend days (Saturday and Sunday) on the baseline Wettzell (Germany) to Tsukuba (Japan). The daily sessions are recorded using Mark 5 (Wettzell-Kokee) and K5 (Wettzell-Tsukuba) technology. Comparisons of the two series showed good agreement with the IERS C04 series.
- TRF: Monthly (2003, 2004), bi-monthly (2005, 2006), and quarterly (2007) TRF sessions with 16 stations using all stations at least two times per year. The increase from 8 stations in the observing years

2002/2003 to 16 stations in 2004−2007 is largely due to the deployment of the Mark 5 technology, which sped up the correlator processing time significantly. The limiting factor has shifted from correlator to station availability.

- CRF: Bi-monthly RDV sessions using the Very Long Baseline Array (VLBA) and 10 geodetic stations, plus astrometric sessions to observe mostly southern sky sources where the sessions were increased from 8 in 2003, over 10 in 2004, to 16 in 2005−2007.
- Monthly R&D sessions to investigate instrumental effects, research the network offset problem, and study ways for technique and product improvement.
- Tri-annual ~two-week continuous sessions to demonstrate the best results that VLBI can offer, aiming for the highest sustained accuracy.

Although certain sessions have primary goals, such as CRF, all sessions are scheduled so that they contribute to all geodetic and astrometric products. Sessions in the observing program that were recorded and correlated using S2 or K5 technology had the same accuracy and timeliness goals as those using Mark 5. On average, a total of more than 1000 station days per year were used in about 180 geodetic sessions during the year increasing the average days per week which are covered by VLBI network sessions to 3.5.

CONT05. In September 2005, a 15-day continuous VLBI observation campaign called CONT05 was observed. The network consisted of eleven IVS stations. The participating stations conducted extensive testing of their equipment prior to the campaign. The resultant data set is of excellent quality and will likely be used by numerous groups for studies of inter-technique comparisons, searches for geophysical signals, and technique improvement. This is in particular so, as the other geodetic space techniques (GPS, SLR, DORIS) undertook a concerted effort to observe the best possible data sets for the same time and locations.

VLBI Standard Interface. Further developments have been carried out for the VLBI Standard Interface (VSI). Hardware has been built and the VSI software interface was released, which is very important for the combination of the different recording techniques. The Mark 5B recording systems are being developed, which will result in a step forward, as formatters will become obsolete, the problems with the Mark 4 correlator station units will be overcome, and compatibility of the technology will be supported by the integration of VSI.

ICRF-2. At the 16th Directing Board meeting held in September 2006 at Haystack Observatory, a joint IERS/IVS Working Group was formed, whose aim it is to generate the second realization of the ICRF from VLBI observations of extragalactic radio sources, consistent with the current realization of the ITRF and EOP data products. The goal is to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I Working Group on the second realization of the ICRF for adoption at the 2009 IAU General Assembly.

VLBI2010. The IVS Working Group 3 (WG3) prepared a final report titled "VLBI2010: Current and Future Requirements for Geodetic VLBI Systems". This report is a strategic paper and a road map for IVS to motivate new developments and to encourage investments towards the next generation VLBI system. Internally it supports the coordination of the activities to be done by the IVS supporting agencies; externally it documents the continued need for VLBI in the future and provides arguments to request financial support. It also demonstrates that IVS takes seriously its responsibility for preparing the service towards future requirements. Such requirements will arise with the program "Global Geodetic Observing System (GGOS)" of the International Association of Geodesy. GGOS aims at realizing a precise reference frame consistent for decades and consistent with respect to geometric and physical parameters. IVS, as the service which uniquely provides the CRF and the complete set of EOP and which contributes strongly to the TRF, will play a key role in GGOS. As a consequence of the VLBI2010 report the IVS Directing Board established at its 14th meeting held in September 2005 in Washington, DC, the VLBI2010 Committee, which is tasked with promoting the ambitious goals set by the VLBI2010 report.

The VLBI2010 Committee worked on designing and implementing the next generation VLBI system. The work concentrated on Monte Carlo type simulations to investigate the performance of network

configurations, schedules and observing scenarios, and on the broadband delay approach. The broadband approach involves the use of broadband feeds (2–15 GHz) and multiple IF channels to reliably resolve RF phase, even at low signal-to-noise ratios. It will enable extremely precise delay measurements to be made while using comparatively small and cost effective 12-m class antennas. The lower cost of these antennas will make replacement of existing, old antennas and the addition of new stations more affordable.

Earth Orientation Parameters. The official IVS Earth orientation parameter (EOP) series are produced and published routinely by the IVS Analysis Coordinator's office at the Institute of Geodesy and Geoinformation of the University of Bonn, Germany. Two separate series are computed: one as a rapid product with the emphasis on fast correlation and data reduction based on special observing sessions every Monday (IVS-R1) and every Thursday (IVS-R4), the other one as a complete series of all geodetic VLBI sessions and generated every three months. In January 2007 the combination of the input of up to six IVS Analysis Centers was changed from a combination on the level of EOP results to a combination on the basis of datum-free normal equations in SINEX format. The new approach improved the robustness and quality of the combination product significantly. Today, the input of the Analysis Centers agrees to better than 60 microarcseconds, while the combined IVS polar motion results agree with the IGS pole at the 100−130 microarcsecond level.

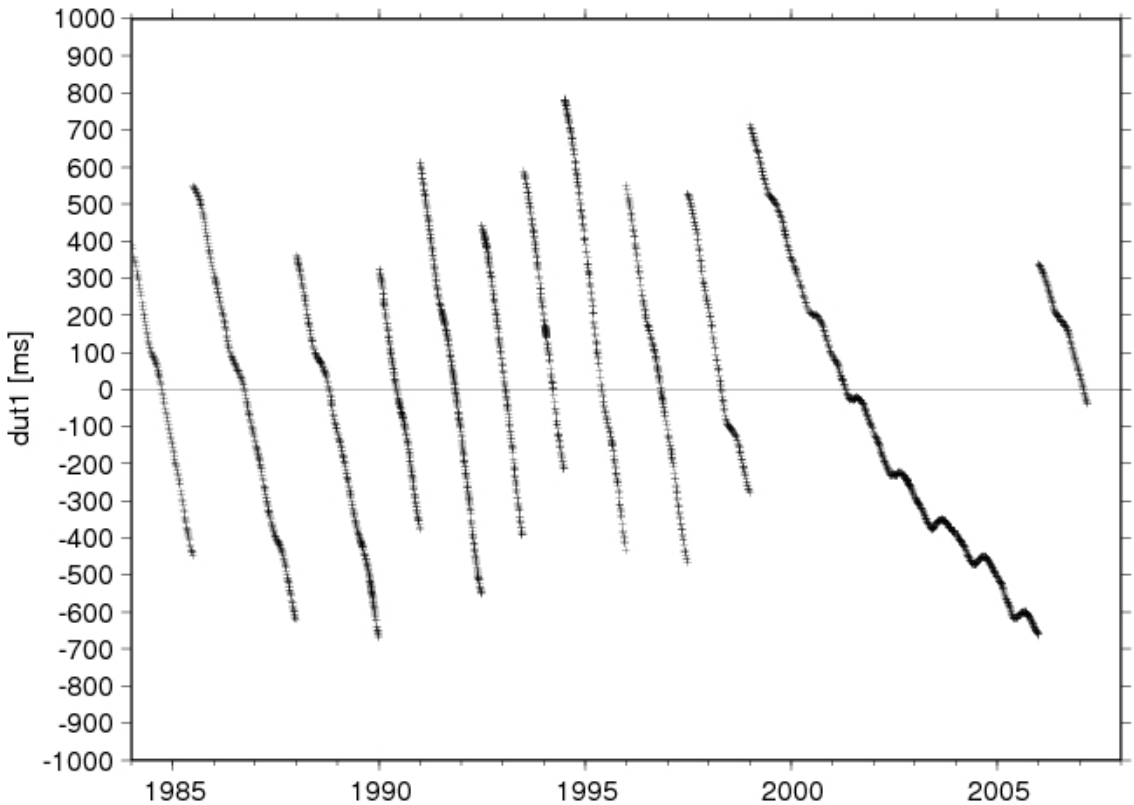

Figure 2. UT1−UTC time series from 1984 to 2007.

Troposphere parameters. The main goal of this product is to obtain reliable tropospheric zenith delay estimates from VLBI data analysis for climate studies and for integrity check with other IAG services, in particular with the IGS. Troposphere parameters turned out to be a valuable indicator for inter-technique and intra-technique analysis inconsistencies. The IVS provides two tropospheric products: short-term results from eight Analysis Centers are available in a series of weekly files with combined tropospheric zenith delay estimates derived from all IVS-R1 and IVS-R4 sessions since January 2002. Until June 2003 the files were created in the IVS Pilot Project phase, whereas starting with July 2003 the combined zenith delay estimates became regular IVS products. Long-term series of tropospheric zenith delays cover all types of VLBI sessions from 1984 until the end of 2004. With over 20 years of data at some stations, it is possible to obtain significant trends of tropospheric zenith delays, which can be directly related to changes of atmospheric water vapour—one of the most important greenhouse gases. Long-term series of tropospheric parameters

from eight individual Analysis Centers and a combined series determined at the Institute of Geodesy and Geophysics, Vienna University of Technology, are accessible from the IVS Data Centers.

Baseline Lengths. Within the framework of the IVS Pilot Project "Time Series of Baseline Lengths" five Analysis Centers provide their results in a special file format to the Data Centers. From these files, baseline lengths and their standard deviations are being computed for the submitting Analysis Centers as well as for a combined series (see example in Figure 3). A graphical user interface was prepared at the Analysis Coordinator's office which assists the user in getting baseline length results and accuracies in numerical and graphical form. After a successful testing phase, the time series of baseline lengths have become an official product of IVS in September 2006.

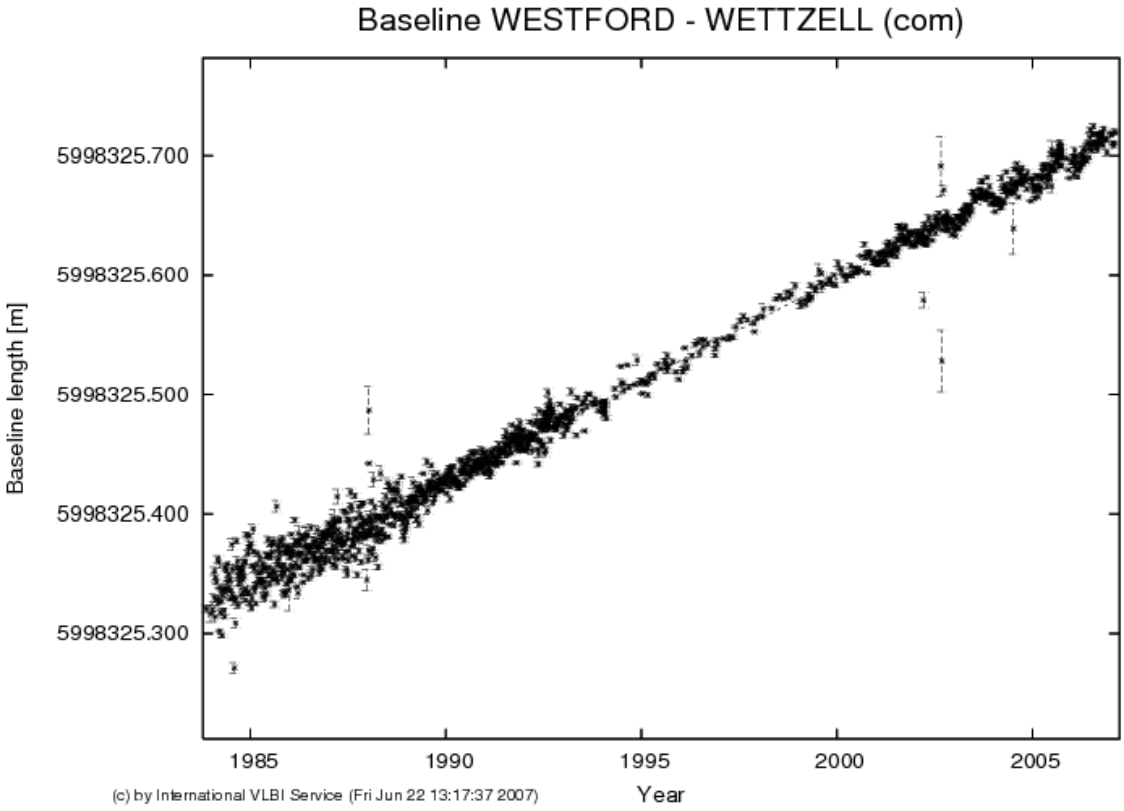

Figure 3. Baseline length evolution of the baseline Westford−Wettzell from the IVS combination solution.

Operations cessation. In 2006, IVS had to face two events that had an impact on the service products. First, the Network Station at Gilmore Creek discontinued its VLBI operations in January 2006 and the telescope—located in Fairbanks, Alaska—was mothballed for an undetermined period of time. The second event was the cessation of the Canadian VLBI operations by Natural Resources Canada in October 2006. In both events, various reasons contributed to the termination of the observations; however, the costs for required upgrades of the worn-out telescopes played a major role in both cases. Today's VLBI network is not sufficiently robust to simply compensate such events without an impact on the final products. Due to the location on the North American continent, the "lost" stations have been of extreme importance to the IVS and, accordingly, their contribution to the IVS observing program was significant. The influence on the product quality could be mitigated to some extent with stations that came online recently such as Zelenchukskaya, Russia.

Upcoming antennas. Projects are under way in several corners of the world to establish several new VLBI sites. In the southern hemisphere, Geoscience Australia is planning to construct three new next generation VLBI antennas (upgrading one existing site and creating two new sites), and Auckland University of Technology, New Zealand will establish one new site. Other projects to be mentioned are running in Korea (Korea Astronomy and Space Science Institute, National Geographic Information Institute), Germany (Federal Agency for Cartography and Geodesy), and India (Indian Space Research Organization).

3. Organization and Meetings

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. During the report period two Directing Board elections took place: December 2004/January 2005 and December 2006/January 2007. At the 17th Directing Board meeting in Wettzell, Germany the new board (see Table 1) elected Prof. Harald Schuh as new chair of IVS. Harald Schuh followed Wolfgang Schlüter, who was the IVS chair since the inception of the service in 1999.

Table 1. Members of the IVS Directing Board during the report period (2003−2007).

a) ***Current Board members (June 2007)***

Directing Board Member	Institution, Country	Functions	Recent Term
Dirk Behrend	NVI, Inc./NASA GSFC, USA	Coordinating Center Director	—
Patrick Charlot	Bordeaux Observatory	IAU Representative	—
Andrey Finkelstein	Institute of Applied Astronomy, Russia	At Large Member	Feb 2007 − Feb 2009
Yoshihiro Fukuzaki	Geographical Survey Institute, Japan	Networks Representative	Feb 2007 − Feb 2011
Hayo Hase	BKG, Germany; TIGO, Chile	Networks Representative	Feb 2007 − Feb 2011
Ed Himwich	NVI, Inc./NASA GSFC, USA	Network Coordinator	—
Kerry Kingham	U.S. Naval Observatory, USA	Correlators and Operation Centers Representative	Feb 2007 − Feb 2011
Chopo Ma	NASA Goddard Space Flight Center, USA	IERS Representative	—
Arthur Niell	Haystack Observatory, USA	Analysis and Data Centers Representative	Feb 2005 − Feb 2009
Ray Norris	CSIRO Australia Telescope Nacional Facility, Australia	FAGS Representative	—
Axel Nothnagel	University of Bonn, Germany	Analysis Coordinator	—
Bill Petrachenko	Natural Resources Canada	Technology Development Centers Representative	Feb 2005 − Feb 2009
Harald Schuh	Technical University Vienna, Austria	IAG Representative, Chair	—
Oleg Titov	Geoscience Australia	At Large Member	Feb 2007 − Feb 2009
Alan Whitney	Haystack Observatory, USA	Technology Coordinator	—
Xiuzhong Zhang	Shanghai Astronomical Observatory, China	At Large Member	Feb 2007 − Feb 2009

b) ***Previous Board members in 2003−2007***

Roy Booth	Hartebeesthoek Radio Astronomy Observatory, South Africa	FAGS Representative	—
Yasuhiro Koyama	NICT, Japan	At Large Member	Feb 2005 − Feb 2007
Zinovy Malkin	Institute of Applied Astronomy, Russia (till Sep 2006); Pulkovo Observatory, Russia	At Large Member	Feb 2005 − Feb 2007
Franco Mantovani	INAF Bologna, Italy	At Large Member	Feb 2005 − Feb 2007
Shigeru Matsuzaka	Geographical Survey Institute, Japan	Networks Representative	Feb 2003 − Feb 2007
Wolfgang Schlüter	BKG, Germany	Networks Representative, Chair	Feb 2003 − Feb 2007

The IVS organizes bi-annual General Meetings and bi-annual Technical Operations Workshops. Other workshops such as the Analysis Workshops and VLBI2010 Working Meetings are held in conjunction with larger meetings and are organized once or twice a year. Table 2 gives an overview of the recent IVS meetings.

Table 2. IVS meetings during the report period (2003-2007).

Time	Meeting	Location
3-4 April 2003	4th IVS Analysis Workshop	Paris, France
22-26 September 2003	2nd IVS Technical Operations Workshop	Westford, MA, USA
9-11 February 2004	3rd IVS General Meeting	Ottawa, Canada
12 February 2004	5th IVS Analysis Workshop	Ottawa, Canada
21-22 April 2005	6th IVS Analysis Workshop	Noto, Italy
9-12 May 2005	3rd IVS Technical Operations Workshop	Westford, MA, USA
9-11 January 2006	4th IVS General Meeting	Concepción, Chile
12 January 2006	7th IVS Analysis Workshop	Concepción, Chile
15 September 2006	1st VLBI2010 Working Meeting	Westford, MA, USA
14 April 2007	8th IVS Analysis Workshop	Vienna, Austria
15 April 2007	2nd VLBI2010 Working Meeting	Vienna, Austria
30 April – 3 May 2007	4th IVS Technical Operations Workshop	Westford, MA, USA

4. References

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