3.4.3 International VLBI Service (IVS)

Report for 2008

During 2008, IVS continued to fulfill its role as a service within the IAG and IAU by providing necessary products for the maintenance of global reference frames: TRF, CRF, and EOP. In March 2008 the fifth IVS General Meeting (GM2008) took place at the Institute of Applied Astronomy (IAA), St. Petersburg, Russia. Two IVS Directing Board meetings were held, one in March at IAA, St. Petersburg, Russia, and the other in September at the Dominion Radio Astrophysical Observatory, Penticton, BC, Canada. The nineth IVS Analysis Workshop was held on March 7, 2008 in connection with the GM2008. The seventh International e-VLBI Workshop was held at Shanghai Astronomical Observatory (SHAO), Shanghai, China in June 2008.

IVS Organization and Activities

In June 2008 the IVS issued a call soliciting proposals for the installation and operation of IVS Combination Centers and additional Operational Analysis Centers and Associate Analysis Centers. Combination Centers are a new type of Analysis Centers that are tasked with preparing IVS combination products in cooperation with the Analysis Coordinator in a timely fashion. At its September meeting the IVS Directing Board approved the proposals from BKG/DGFI, Germany and from the Korea Astronomy & Space Science Institute (KASI) to become Combination Centers. DGFI changed from an Associate to an Operational Analysis Center and Sternberg Astronomical Institute (SAI) of Moscow State University became a new Operational Analysis Center. At the beginning of the year the Max Planck Institute for Radioastronomy, Bonn, Germany already applied for becoming an IVS member organization for the operation of the Bonn Correlator. The proposal was unanimously approved at the March Directing Board meeting.

IVS published its 2007 Annual Report in May 2008 and three newsletter issues (April, August, December) which keep the community informed about IVS activities. The Proceedings of the Fifth IVS General Meeting were published in August 2008 in the Russian „Nauka“ (Science) series.

Network Stations

A total of 1267 station days were used in 187 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.5 days per week, similar to previous years. The total number of sessions and of station days increased with respect to the previous year due to the observation of the two-week long continuous VLBI campaign 2008 (CONT08). The major observing programs during 2008 were:

IVS-R1, IVS-R4 Weekly (Mondays and Thursdays) 24-hour, rapid turnaround measurements of EOP. Data bases are available no later than 15 days after each session. These sessions are coordinated by

NASA Goddard Space Flight Center (R1) and the U. S. Naval Observatory (R4).

Intensive Daily 1-hour UT1 Intensive measurements are made on five days (Monday through Friday, Int1) on the baseline Wettzell (Germany) to Kokee Park (Hawaii, USA), on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan), and on Monday mornings (Int3) in the middle of the 36-hour gap between the Int1 and Int2 Intensive series on the network Wettzell (Germany), Ny-Alesund (Norway), and Tsukuba (Japan).

CONT08 A fifteen day campaign of continuous VLBI sessions, observed in the second half of August 2008 and coordinated by the IVS Coordinating Center at NASA Goddard Space Flight Center. The goal of the campaign was to acquire state-of-the-art VLBI data over a two-week period to demonstrate the highest accuracy of which VLBI is capable.

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn with 12 stations per session. These sessions were observed to monitor the TRF with all IVS stations scheduled at least 3–4 times during the year.

IVS-CRF, IVS-CRMS, IVS-CRD The Celestial Reference Frame (CRF) sessions, the CRF median-south (CRMS), and the CRF deep-south (CRD) sessions, all coordinated by the U.S. Naval Observatory, provide astrometric observations that are required for improving the current CRF and in extending the CRF by observing “new” sources. Eighteen sessions were observed for the maintenance of the ICRF in 2008 primarily in the southern hemisphere. Eight of them were scheduled with emphasis on the far southern hemisphere (CRD) and three with emphasis on the median south.

VLBA The Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO), continued to allocate six observing days for astrometry/geodesy. These sessions included the 10 VLBA stations plus up to 7 geodetic stations, providing state-of-the-art astrometry as well as information for mapping ICRF sources.

Europe The European geodetic network, coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, continued with six sessions in 2008.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had nine sessions. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D Nine research and development sessions were observed in 2008. Three of them were scheduled to observe high redshift radio sources, three to test 512 Mbps recording modes for possible usage in the continuous VLBI campaign 2008 (CONT08), and three to vet geodetic sources for the second realization of the ICRF.

The Network Coordinator's data base of station performance showed a data loss of 15.1%, slightly worse (3.7%) compared to 2007. For the CONT08 campaign the data loss was 9.3%. The most significant causes of data loss were antenna reliability (19.2%), RFI (14.8%), and receiver problems (13.8%). Unidentified problems accounted for about 17.7% of the loss.

Correlators

The correlators at Haystack Observatory (USA), the U.S. Naval Observatory (USA), and at Max Planck Institute for Radioastronomy (Germany) continued their efficient processing of the data recorded on Mark 5 disk media. Several 24-hour sessions are now correlated in less than a day. The correlator at MPIfR Bonn routinely used its 1 Gbps connection for electronic data transfer (e-transfer) with several network stations that are already connected. A high-speed connection of the USNO correlator further progressed and is expected to be available in the first half of 2009.

Data Centers

The IVS Data Centers continued to receive data bases throughout the year and made them available for analysis within one day of correlation. The Data Centers also continued to receive solutions from Analysis Centers. All data and results holdings are mirrored several times per day among the three primary IVS Data Centers.

IVS Operational Data Analysis and Combination

The combination process for the two IVS EOP series (rapid and quarterly solutions) has been continued exclusively on the basis of datum-free normal equations in SINEX format. In 2008, six IVS Analysis Centers (BKG, DGFI, GSFC, IAA, OPA, and USNO) contributed to the IVS combined products by providing input in the correct format. The rapid solutions contain only R1 and R4 sessions and new data points are added twice a week as soon as the SINEX files of the six IVS Analysis Centers are available. The SINEX file submissions should not be later than 48 hours after the correlation is completed. A Web page is automatically updated which states the timeliness of the latest submissions of the R1 and R4 sessions.

For the quarterly solution, updated every three months, almost all available data of 24-hour sessions from 1984 onwards are used. Since this series is designed for EOP determinations, those sessions are excluded that are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The results are reported in two EOP time series, the rapid solution file (ivs08r1e.eops) and the quarterly solution file (ivs-08q4e.eops), in the IVS EOP Exchange format. Companion files containing the nutation offsets in the X, Y paradigm are routinely generated through a standard transformation process (ivs08r1X.eops, ivs08q4X.eops).

VTRF2008

In 2008, it became obvious that a new TRF for the IVS EOP determinations had to be computed for several reasons. ITRF2005, used in 2007 and 2008, has a noticeable deficit due to the pole tide error which had been made in the IVS contribution to ITRF2005. The post-quake movements of GILCREEK in ITRF2005 lacked the continuity of the piece-wise linear elements, thus introducing discontinuities. In addition, for the sites of SVETLOE, ZELENCHK, and BADARY either only limited observations had been available for ITRF2005 or no observations had been available yet. Of course, all other stations took their benefit from more data in the new computations as well. VTRF2008 is being used for all combinations of IVS since December 2008.

Thermal Expansion of Radio Telescopes

Thermal expansion effects have been considered already for a long time but concerted activities to include it in IVS data analysis have only started in 2008. At the Nineth IVS Analysis Workshop in St. Petersburg, it was decided to make thermal expansion modeling the first chapter of the IVS Analysis Conventions. This should serve as a proper reference for all analysis descriptions. In addition, a decision was made to use the GPT model (Boehm et al. 2007) to compute the reference temperature for each telescope. Any expansion effect can and should now be computed relative to these mean temperatures. In the meantime, the current status of thermal expansion modelling has been documented in a refereed paper (Nothnagel, 2008) which is the written documentation of Chapter 1 of the IVS Analysis Conventions.

One of the necessary parts of a model for expansion effects is a list of all telescopes‘ construction dimensions. In such a list, all dimensions like effective height of the elevation axis above the ground for azimuth-elevation telescopes or height of primary axis above secondary axis for polar or XY antennas, just to name a few, have to be tabulated for all telescopes. Quite some effort has been invested to collect the information for this list and further efforts are still necessary to gather the missing information for a few more

telescopes. The list is available under <http://vlbi.geod.uni-bonn.de/IVS-AC/Conventions> together with the reference paper.

Since the reference temperatures of all telescopes are long-term means from a model, no effective change in the realizations of terrestrial reference frames are expected. However, annual variations in station coordinates, especially in the height component, are expected to reduce. Consequently, Earth orientation parameters from VLBI observations may also be affected, mainly with an annual signature.

Technology Development

The VLBI2010 Committee of the IVS submitted a Progress Report on the status of the development of the next generation geodetic VLBI system (VLBI2010 system), which summarizes the progress made in the development of the new system up to the end of 2008. The report covers Monte Carlo simulations showing the impact of the new operating modes on the final products. A section on system considerations describes the implications for the VLBI2010 system parameters by considering the new modes and system-related issues such as sensitivity, antenna slew rate, delay measurement error, RFI, frequency requirements, antenna deformation, and source structure corrections. This is followed by a description of all major subsystems and recommendations for the network, station, and antenna. Then aspects of the feed, polarization processing, calibration, digital back end, and correlator subsystems are covered. A section is dedicated to the NASA proof-of-concept demonstration. Finally, sections on operational considerations, on risks and fallback options, and on the next steps complete the report.

One important outcome of the 7th International e-VLBI Workshop was the creation of a task force to study and recommend a universal VLBI data format that is suitable for both on-the-wire e-VLBI data transfer, as well as direct disk storage. This task force, called the VLBI Data Interchange Format (VDIF) Task Force, is envisioned as the first of a two-part effort, the second of which will address standardization of e-VLBI data-transmission protocols. The formation of the VDIF Task Force was prompted particularly by the increased e-VLBI activity and the difficulties encountered when data arrive in different formats from various instruments and various parts of the world. A final report to the VLBI community is expected in early 2009.

References

Boehm J, Heinkelmann R, Schuh H (2007) Short note: a global model of pressure and temperature for geodetic applications. J Geod 81: 679–683. doi:10.1007/s00190-007-0135-3

Nothnagel A (2008) Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI. J Geod, DOI 10.1007/s00190-008-0284-z

Report for 2009

IVS Organization and Activities

During 2009, the IVS continued to fulfill its role as a service within the IAG and IAU by providing necessary products for the maintenance of global reference frames: TRF, CRF, and EOP. On March 25, 2009 the IVS celebrated its 10th anniversary in a special whole day event with invited speakers in Bordeaux, France. The celebration took place after the 19th Working Meeting of the European VLBI Group for Geodesy and Astrometry (EVGA), March 23–24, 2009 in Bordeaux. The 10th IVS Analysis Workshop was held on March 26, 2009 in Bordeaux, directly after the 19th Working Meeting of the EVGA.

The IVS Directing Board had its first meeting after the elections 2008/2009 also in Bordeaux, prior to the 19th Working Meeting of the EVGA. The second IVS DB meeting was held at the end of August in Buenos Aires, Argentina, prior to the IAG Scientific Assembly 2009.

The IVS organized the VLBI2010 Workshop on Future Radio Frequencies and Feeds, held March 18–20, 2009 in Wettzell and Höllenstein, Germany. The VLBI2010 Project Executive Group (V2PEG) was established in March 2009 to support the implementation of VLBI2010. The 8th International e-VLBI Workshop was held in Madrid, Spain, in June 2009. The 5th IVS Technical Operations Workshop (TOW2009) was held April 27–29, 2009 at Haystack Observatory, USA.

In 2009, Karadeniz Technical University, Trabzon, Turkey, was accepted as a new IVS Associated Analysis Center. The station Warkworth, New Zealand, operated by the Auckland University of Technology, was welcomed as an IVS Network Station. The BKG/DGFI Combination Center commenced operation in October 2009.

In the summer of 2009 the IVS published the 2008 Annual Report. Furthermore, three IVS newsletters were published in April, August and December to keep the community informed about IVS activities. The progress report of the VLBI2010 Committee (V2C) with the title “Design aspects of the VLBI2010 system” was published in June 2009.

Network Stations

A total of 1309 station days were used in 158 geodetic/astrometric sessions during the year. Observing sessions coordinated by IVS remained at an average of ~3.1 days per week, similar to previous years. The major observing programs during 2009 were:

IVS-R1, IVS-R4 Weekly (Mondays and Thursdays) 24-hour, rapid turnaround measurements of EOP. Databases are available no later than 15 days after each session. The NASA Goddard Space Flight Center (R1) and the U. S. Naval Observatory (R4) coordinate these sessions.

Intensive Daily 1-hour UT1 Intensive measurements are made on five days (Monday through Friday, Int1) on the baseline Wettzell (Germany)

to Kokee Park (Hawaii, USA), on weekend days (Saturday and Sunday, Int2) on the baseline Wettzell (Germany) to Tsukuba (Japan), and on Monday mornings (Int3) in the middle of the 36-hour gap between the Int1 and Int2 Intensive series on the network Wettzell (Germany), Ny-Ålesund (Norway), and Tsukuba (Japan). Svetloe (Russia) participated as third station in 21 Int1 sessions.

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany, with at least 12 stations per session. Seven of these sessions were observed to monitor the TRF with all IVS stations scheduled at least 3–4 times during the year.

IVS-CRF The Celestial Reference Frame (CRF) sessions, coordinated by the U.S. Naval Observatory, provide astrometric observations that are required for improving the current CRF and in extending the CRF by observing 'new' sources. Four sessions were observed for the maintenance of the ICRF in 2009.

VLBA The Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO), continued to allocate six observing days for astrometry/geodesy. These sessions included the 10 VLBA stations plus up to 7 geodetic stations, providing state-of-the-art astrometry as well as information for mapping ICRF sources.

Europe The European geodetic network, coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, continued with six sessions in 2009.

IVS-OHIG The purpose of the IVS-OHIG (Southern Terrestrial Reference Frame) sessions is to tie together optimally the sites in the southern hemisphere. The participating sites include all the sites available in the south.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2009.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had seven sessions during 2009. These sessions included the dedicated 32-m dish at Tsukuba and are designed to monitor the domestic network within the ITRF.

IVS-R&D Ten research and development sessions were observed in 2009. The main objective in 2009 was to improve scheduling strategy for the Intensive sessions.

IYA09 The IVS contributed on November 18/19, 2009 to IAU's and UNESCO's International Year of Astronomy 2009 by a "VLBI super session" that involved 33 network stations and observed more than 240 of the ICRF2 defining sources within 24 hours. This session is the largest geodetic VLBI session that ever was observed.

The database of station performance, maintained by the IVS Network Coordinator, showed a data loss of 21.5%, which was unfortunately worse (+6.4%) than 2008. However, this increase can to a large extent be explained by a different way of handling accounting station failures. The most significant causes for data loss were related to antenna problems (29.4 %) and receiver problems (18.6 %). Unidentified problems accounted to 14.2 % of the data losses. The total number of experiments in 2009 was 15% less than 2008, but the number of stations per session increased to 7.9 on average.

Correlators

The correlator at Haystack Observatory (USA), the correlator at the U.S. Naval Observatory in Washington (USA), the BKG/MPIfR correlator at the Max Planck Institute for Radioastronomy in Bonn (Germany) and the correlator at the Geographical Survey Institute (GSI) in Tsukuba, Japan continued their efficient processing of the data recorded for the IVS. The Haystack correlator increased its correlation hours by ~20 % and processed e.g. all R&D sessions and the IYA09 experiment. The Washington correlator processed all R4 and Int1 sessions, and the still remaining CONT08 session. Since mid of 2009 the Int1 data from Wettzell are e-transferred directly to the Washington correlator, speeding-up the turnaround time for these sessions. The Bonn correlator routinely used its 1 Gbps network connection for e-transfer from several network stations in Europe and Japan and processed e.g. all R1, Europe OHIG , and Int3 sessions. The Int2 sessions were processed at the GSI correlator in Tsukuba, Japan, in a completely automated mode with turnaround times of less than 1 hour after the end of an observing session. Additionally, the Tsukuba correlator processed four ultra-rapid 24-hour dUT1 sessions on the baseline Onsala–Tsukuba.

Data Centers

The IVS Data Centers continued to receive databases throughout the year and made them available for analysis within one day of correlation. The Data Centers also continued to receive solutions from Analysis Centers. All data and results holdings are mirrored several times per day among the three primary IVS Data Centers at BKG (Germany), Paris Observatory (France), and Goddard Space Flight Center (USA).

IVS Operational Data Analysis and Combination

The combination process for the two IVS EOP series (rapid and quarterly solutions) has been continued exclusively on the basis of datum-free normal equations in SINEX format. In 2009, six IVS Analysis Centers (BKG, DGFI, GSFC, IAA, OPA, and USNO) contributed to the IVS combined products by providing input in the correct format. The rapid solutions contain only R1 and R4 sessions and new data points are added twice a week as soon as the SINEX files of at least five IVS Analysis Centers are available. The SINEX file submissions should not be later than 48 hours after the correlation is completed. A web page is automatically updated which states the timeliness of the latest submissions of the R1 and R4 sessions (see <http://vlbi.geod.uni-bonn.de/IVS-AC/data/timeliness_2.html>).

Every three months the quarterly solution is updated. For this solution almost all available data of 24-hour sessions from 1984 onwards are used. Since this series is designed for EOP determinations, those sessions are excluded that are observed with networks of limited extension or which are scheduled for a different purpose like radio source monitoring.

The results are reported in two EOP time series, the rapid solution file and the quarterly solution file, both in the IVS EOP Exchange format. Solutions files are available in two forms, expressed with nutation offsets dX, dY referred to the IAU2006 precession-nutation model excluding free core nutation, and with nutation offsets dPsi, dEps referred to the IAU2000A precession-nutation model excluding free core nutation.

Contribution to ITRF2008

The IVS contribution to the ITRF2008 was generated at the IVS Analysis Coordinator's office. It consists of session-wise datum-free normal equations which are the result of a combination of individual series of session-wise datum-free normal equations provided by seven IVS Analysis Centers (BKG, DGFI, GSFC, IGGB, OPA, SHA, and USNO). All these individual series are completely reprocessed following homogeneous analysis options according to the IERS Conventions 2003 and the IVS Analysis Conventions.

Based on the experience gathered since the combination efforts for ITRF2005, the consistency of the individual VLBI solutions has improved considerably. The agreement in terms of the WRMS of the terrestrial reference frame (TRF) horizontal components is 1 mm and of the height component is 2 mm. Comparisons between ITRF2005 and the combined TRF solution for ITRF2008 yielded systematic height differences of up to 5 mm with a zonal signature. These differences can be related to a pole tide correction referenced to a zero mean pole used by four of five IVS ACs in the ITRF2005 contribution instead of a linear mean pole path as recommended in the IERS Conventions. Periodic annual variations

in scale are reduced considerably from 2.7 mm to 1.7 mm due to the correction for thermal expansion of the radio telescopes.

Realization and adoption of ICRF2

The Second Realization of the International Celestial Reference Frame (ICRF2) was adopted in August 2009 at the XXVII General Assembly of the International Astronomical Union (IAU) in Rio de Janeiro, Brazil, as Resolution B3. The ICRF2 replaced the previously used first realization (ICRF) effective 1 January 2010. The International Earth Rotation and Reference Systems Service (IERS) published as IERS Technical Note No. 35 (<http://www.iers.org/TN35>) about the computation of the ICRF2. The ICRF2 was an effort of a joint IERS/IVS working group and was overseen by an IAU working group. ICRF2 contains precise positions of 3414 compact extragalactic radio sources, more than five times the number in the ICRF. Further, the ICRF2 is found to have a noise floor of ~40 microarcseconds, some 5–6 times better than ICRF, and an axis stability of 10 microarcseconds, nearly twice as stable as ICRF. Alignment of ICRF2 with the International Celestial Reference System (ICRS) was made using 138 stable sources common to both ICRF2 and ICRF-Ext2.

Technology Development

During 2009 progress continued towards the goal of a next-generation VLBI2010 system, e-VLBI, and other technical aspects. Some important highlights were:

In March the IVS organized the VLBI2010 Workshop on Future Radio Frequencies and Feeds in Wettzell and Höllenstein, Germany. At this workshop several crucial decisions for VLBI2010 were taken. It was decided e.g. that the broadband frequency range should be 2.2-14 GHz, that VLBI2010 should be backwards compatible with the previous S/X-systems, that the future telescopes should allow a future inclusion of frequencies up to Ka-band, that an end-to-end VLBI2010 demonstration should be performed in early 2012, and that a transition plan from S/X to VLBI2010 should be developed. Subsequently, a VLBI2010 Project Executive Group (V2PEG) was established in March 2009 to support the implementation of VLBI2010.

At the Technical Operations Workshop in May 2009 three different types of digital backends (DBEs) were intercompared by zero-baseline correlation tests. The DBEs included the European DBBC, the Chinese CDAS, and the DBE1 developed by Haystack Observatory, USA. In general, good agreement was found.

The VLBI Data Interchange Format (VDIF) Task Force presented the VDIF specification at the June 2009 eVLBI meeting in Madrid. The proposal was accepted and ratified.

The VLBI2010 Committee (V2C) authored a progress report with the title “Design aspects of the VLBI2010 system” that was published in June 2009.

In November 2009 a VEX2 Task Force was created to further develop the current VEX (VLBI Experiment Documentation) file format.

During 2009 a phase-calibration system for VLBI2010 was developed and tested, work continued to complete a broadband feed-horn for VLBI2010, to develop the next generation digital backend and an improved data recording system that allows higher data rates.

Work continued to set up a VLBI2010 test bed involving the Westford telescope and the MV3 antenna at NASA/GSFC.

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