3.4.4 International VLBI Service for Geodesy and Astrometry (IVS)

IVS Organization and Activities

During 2019, 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. Some highlights of the IVS organization and activities were:

- The 3rd VLBI Training School was held in Las Palmas de Gran Canaria, Spain from March 14–16, 2019. Some 54 participants attended the school.
- The 10th IVS Technical Operations Workshop (TOW) was held at MIT Haystack Observatory from May 5–9, 2019. Directly following the TOW, a VGOS correlation/post-processing workshop was organized.
- The IVS published three IVS Newsletters in April, August and December, keeping the community informed about IVS activities. In August 2019, the proceedings volume of the 10th IVS General Meeting was published.
- A special issue on the Continuous VLBI Campaign 2017 (CONT17) is in preparation in Journal of Geodesy.
- The IVS continued an observing program to determine the alignment of the next radio frame (ICRF3) with the future *Gaia* optical frame by observing ICRF–*Gaia* transfer sources.
- Progress was made in achieving operational readiness of the next generation VLBI system, the VLBI Global Observing System (VGOS). 24-hour VGOS Test sessions were observed on a two-week basis. The network of 7–8 stations has matured enough to make the results available on the Data Center.

Table 1: *IVS meetings in 2019. The EVGA is a regional subgroup of the IVS organizing institutions that are active in geodetic and astrometric VLBI in Europe.*

Event	Location	Date
3rd VLBI Training School	Las Palmas de G.C., Spain	March 14–16, 2019
24th EVGA Meeting	Las Palmas de G.C., Spain	March 17–19, 2019
20th IVS Analysis Workshop	Las Palmas de G.C., Spain	March 20, 2019
40th IVS Directing Board meeting	Las Palmas de G.C., Spain	March 21, 2019
10h IVS Technical Operations Workshop	Westford, MA, USA	May 5–9, 2019
41st IVS Directing Board meeting	Bonn, Germany	September 30, 2019
8th Int'l VLBI Technology Workshop	Sydney, Australia	November 18–20, 2019

Network Stations and observing sessions

A total of 185 geodetic/astrometric 24-hour sessions were observed during the year 2019 using the legacy S/X system. That translates to about $\sim$3.5 observing days per week that were coordinated by the IVS to determine operational products including EOP. Further, there were 487 1-hour Intensive sessions observed for the determination of UT1–UTC. Lastly, twenty-four 24-hour VGOS sessions were observed to further fine-tune the processing steps of the new VLBI system. The major observing programs during 2019 were:

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

Intensive Daily 1-hour UT1 Intensive measurements were 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 Ishioka (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 Ishioka (Japan). In addition, about 120 2-hour Intensive sessions were observed using the VLBA stations at Mauna Kea (Hawaii, USA) and Pietown (New Mexico, USA) and Wettzell.

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany (until September) and the Geodetic Observatory Wettzell, Germany, with 14–16 stations per session. Seven of these sessions were observed to monitor the TRF with all IVS stations.

IVS-CRF The Celestial Reference Frame (CRF) sessions, coordinated by the Hartebeesthoek Radio Astronomy Observatory, provide astrometric observations that are required for improving the current CRF and for extending the CRF by observing ‘new’ sources. Twelve sessions were observed for the maintenance of the CRF in 2019.

VLBA The Very Long Baseline Array (VLBA), operated by the National Radio Astronomy Observatory (NRAO), allocated six observing days for astrometry/geodesy. These sessions included the 10 VLBA stations plus up to four geodetic stations, providing state-of-the-art astrometry as well as information for mapping ICRF sources. Furthermore, the VLBA observed six sessions with the 10-station array concurrent with an IVS-R1 session.

Europe The European geodetic network, coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn and the Geodetic Observatory Wettzell, continued with six sessions in 2019.

IVS-OHIG The purpose of the IVS-OHIG (Southern Terrestrial Reference Frame) sessions is to tie together optimally the sites in the southern hemisphere. In 2019 six OHIG sessions were observed.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2018.

AUSTRAL In 2019, 12 Austral sessions were observed. The purpose is to determine the station coordinates and their evolution in the Australia (AuScope) and New Zealand geodetic VLBI network and to improve the CRF in the southern sky.

AOV The Asia-Oceania VLBI Group for Geodesy and Astrometry (AOV) had 12 sessions during 2019.

IVS-R&D Ten research and development sessions were observed in 2019. The main goal of the 2019 R&D sessions was the observation of link sources between *Gaia* and the ICRF3.

VGOS-T Twenty-four VGOS Test sessions were observed in 2019 coordinated by MIT Haystack Observatory.

Correlators

The correlators at the MIT Haystack Observatory (USA), the U.S. Naval Observatory in Washington (USA), the Max-Planck-Institute for Radio Astronomy (MPIfR) and BKG in Bonn (Germany), the Shanghai Astronomical Observatory (China), the Vienna University of Technology, and the Geospatial Information Authority of Japan (GSI) in Tsukuba efficiently processed the data recorded for the IVS. The majority of the legacy S/X 24-hour sessions were processed by the Bonn and Washington correlators. While the Bonn correlator processed the R1, EURO, T2, Int3, and OHIG sessions, the Washington correlator was responsible for the R4, Int1, and CRF deep south sessions. The Vienna correlator handled the AUSTRAL sessions and the Shanghai correlator analyzed CRF, APSG, and AOV sessions. The Haystack correlator processed select R&D sessions and all VGOS Test sessions. The Int2 sessions were processed at the Tsukuba correlator.

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).

Fig. 1: *Participants of the 3rd VLBI Training School in Las Palmas de Gran Canaria, Spain.*

Education and Outreach

The IVS organized its third VLBI Training School following the rhythm of having a school every three years. The school was held in Las Palmas de Gran Canaria, Spain, in conjunction with the European VLBI meeting and attracted some 54 participants from all over the world: Spain (12), USA (11), China (8), Germany (7), Austria (4), Norway (4), Sweden (2), and Australia, Finland, France, South Africa, Thailand and The Netherlands (1 each). The lectures and hands-on tutorials gave all students a solid foundation and a wealth of information about the VLBI technique over the course of the three days of the event.

After 20 years of usage, the old IVS logo was retired at the end 2019 and replaced by a new one. The new logo has been designed to be usable in grayscale, to be visible at small sizes, to be editable for future customizations, to be reproducible in any file format needed, and to be clear against both light and dark backgrounds.

Fig. 2: *The new IVS logo that replaced the previous logo at the end of 2019.*

Data Analysis

Noteworthy data analysis activities in 2019 concern high-frequency EOP, gravitational deformation of VLBI antennas, loading effects, and source structure. The following subsections describe each of these activities in more detail.

Diurnal and Semidiurnal EOP Variation

Several IVS Analysis Centers participated in the work of the IERS Working Group on Diurnal and Semi-diurnal EOP Variation. Ten different models were evaluated by members of the IVS, the ILRS, and the IGS. Each technique used metrics appropriate to their technique. For example, the IVS looked at baseline repeatability and goodness of fit. The general consensus of all the techniques was that the two best models were 2017a_astro, an empirical model derived from VLBI data by John Gipson, and a model by Desai and Sibois of JPL derived from a TPX08, an altimetry model due to Egbert. Both models were improvements over the current IERS models, and each model had advantages and disadvantages. In order to avoid technique-specific signals, the working group recommended the use of the Desai and Sibois model which is the new IERS standard and will be used in ITRF2020.

Gravitational Deformation

VLBI antennas are structures, with a typical size of 30 m or larger. These antennas deform due to the effect of gravity, and the deformation is a function of the elevation angle. In 1988 Per Thomsen and Tom Clark built a finite-element model for the Gilcreek VLBI antenna and showed that the change in path length could be up to 2.4 mm. This causes a change in the observed differential delay, which in turn causes a change in the estimated geodetic parameters, particularly local up. Beginning in the early 2000s the deformation of several VLBI antennas was directly measured using surveying techniques, leading to a total of six antennas for which we had models. The change in path length can be as large as 97 mm. In preparation for ITRF2020, all IVS Analysis software was modified to be able to incorporate the effect of gravitational deformation.

Loading Effects

The standard IVS analysis includes the effect of pressure loading. Since the other space geodetic techniques do not routinely include these effects, this meant that our estimates of station position were not consistent with other techniques. This is an issue when you are trying to combine data from several techniques. After consultation with the IERS, the IVS came up with the following compromise. We would do our analysis as we normally do, but we would modify the SINEX files that we produced so that loading effects could be removed a posteriori. This essentially involves adding in an additional normal equation vector which is due entirely to pressure loading.

Source Structure

The ideal VLBI source is strong and point-like. In reality we know that the sources have structure. This causes changes in the observed delay. If not correctly accounted for, this will show up as noise in the measurements. In the past few years, several groups have looked at the effect of source structure. Although this is still very much an R&D effort, the results look promising. We anticipate that future VLBI analysis software will include the effect of source structure.

Technology Development

Progress was made in achieving operational readiness of the next generation VLBI system, the VLBI Global Observing System (VGOS). 24-hour VGOS Test sessions were observed on a two-week basis. The network of 7–8 stations has matured enough to make the results available on the Data Center. The fledgling network will observe in operational IVS sessions starting in 2020. It is anticipated that the global network will grow to 25 stations and beyond in the coming years and will eventually replace the legacy S/X system as the IVS production system.

As part of the modernization process, other infrastructure components of the VLBI processing chain have been further developed as well, including the VGOS correlation and post-processing capabilities as well as VGOS data analysis. In May 2019, the Haystack group trained several other correlator groups in the processing of VGOS data in a dedicated workshop. Later in the year, an exercise was performed serving as a “blind test” that involved the correlators at Haystack, Bonn, Washington, Vienna, and Shanghai. Each correlator independently processed the exact same VGOS data (a one-hour VGOS Intensive session) and the results were compared to tease out any discrepancies.

The initial test resulted in slightly differing geodetic results (e.g., station positions, UT1–UTC) that could be traced to differences in the processing steps. These involved the correlator setup, fringe-fitting control file, delay calibration information, signal-to-noise ratio of scans, and treatment of the multi-band delay. A refinement of the data processing procedures largely reduced the discrepancies. In order to ensure that all correlators will process VGOS data consistently and generate validated quality products, a follow-up test using a typical 24-hour, multi-station session is planned for 2020. Given a successful completion, the VGOS correlation load can then be distributed among five correlation centers. Other correlators, like Tsukuba and Onsala, are anticipated to join in the effort.

Publications

K. Armstrong, K.D. Baver, D. Behrend (editors): IVS 2018 General Meeting Proceedings “Global Geodesy and the Role of VGOS – Fundamental to Sustainable Development”, NASA/CP-2019-219039, Greenbelt, MD, USA, 2019, https://ivscc.gsfc.nasa.gov/publications/gm2018/

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