3.4.3 International VLBI Service (IVS)

IVS Organization and Activities

During 2015, 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:

Event	*Location*	*Date*
8th IVS Technical Operations Workshop	Haystack Observatory, Westford, MA, USA	May 4–7, 2015
22nd European VLBI for Geodesy and Astrometry (EVGA) Working Meeting	Ponta Delgada, Azores, Portugal	May 17–21, 2015
16th IVS Analysis Workshop	Ponta Delgada, Azores, Portugal	May 21, 2015
33rd IVS Directing Board meeting	Ponta Delgada, Azores, Portugal	May 22, 2015
IVS 2015 Retreat	DRAO, Penticton, BC, Canada	October 7–8, 2015
34th IVS Directing Board meeting	DRAO, Penticton, BC, Canada	October 9, 2015
4th International VLBI Technology Workshop	Auckland, New Zealand	November 23–26, 2015

- In the summer of 2015 the IVS published the 2014 Annual Report. Furthermore, three IVS newsletters were published in April, August and December to keep the community informed about IVS activities.
- The IVS decided to change the rhythm of reporting of its constituent components from annual to two-yearly. The first Biennial Report is planned to cover the years 2015+2016 and will be published in the first half of 2017.
- In October 2015 the IVS Directing Board and six invited experts held a retreat in order to discuss the current and future challenges of developing the service both to meet the needs and to take advantage of the opportunities of the next decade. A summary of the retreat was prepared and posted online. The discussions of the retreat form the basis of a decadal strategy paper that is under development.

Network Stations and Observing Sessions

A total of 237 geodetic/astrometric 24-hour sessions were observed during the year 2015. The number of observing sessions coordinated by IVS was about ~4.5 days per week, slightly less than in 2014 (~4.7 days/week) but significantly higher than in the years prior (~3.5 days/week). The main reason for the high level of sessions per week was the high number of regional AUSTRAL sessions in the first sixth months of the year. However, in the

second half of the year budget restrictions forced the number of AUSTRAL sessions to go back to the pre-2014 level. The major observing programs during 2015 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 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).

IVS-T2 Bi-monthly sessions coordinated by the Institute of Geodesy and Geoinformation of the University of Bonn, Germany, with 16–18 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 U.S. Naval 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 2015.

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 5 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 2015.

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 2015 six OHIG sessions were observed.

APSG The Asia-Pacific Space Geodynamics (APSG) program operated two sessions in 2015.

AUSTRAL In 2015, 57 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.

JADE The JApanese Dynamic Earth observation by VLBI (JADE) had 18 sessions during 2015. These sessions included the dedicated 32-m dish at Tsukuba and the new 13-m dish at Ishioka. The smaller GARNET dishes at Aira, Chichijima, and Shintotsukawa were all retired by the end of March 2015. The main purpose of the JADE sessions in 2015 was thus the establishment of a stable tie between the new antenna at Ishioka and the existing antenna at Tsukuba.

IVS-R&D Ten research and development sessions were observed in 2015. The goals of the 2015 R&D sessions included the observation of link sources between *Gaia* and the ICRF2 and the observation of the Chang'E-3 lander with VLBI.

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 Radio Astronomy in Bonn (Germany), the correlator at the Shanghai Astronomical Observatory (China), and the correlator at the Geospatial Information Authority of Japan (GSI) in Tsukuba efficiently processed the data recorded for the IVS. The majority of the 24-hour sessions were processed by the Bonn and Washington correlators. Both correlators used the DiFX software correlator; 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 Shanghai correlator analyzed the CRF, APSG, and some AOV sessions. The Haystack correlator processed R&D sessions and some T2 sessions. The Int2 and JADE 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).

Data Analysis

IVS Contribution to ITRF2014

Towards the end of 2014 Zuheir Altamimi asked if the various space-geodetic techniques would be willing to submit data for the ITRF through the end of 2014 instead of 2013 as originally planned. After internal consultation the IVS agreed to do so. A firm deadline

for the submission was February 28, 2015. Hence a major focus for many ACs during the beginning of 2015 was the preparation and submission of the SINEX files to the IVS Combination Center.

The IVS Combination Center combined the submissions into a single IVS contribution. In the process of doing so some anomalies in the individual submissions were noted and the respective ACs notified. This resulted in changing the processing of the data and, in a few cases, fixing some bugs. The various submissions were evaluated for consistency with the other submissions. One of the submissions was not consistent and was ultimately excluded from the IVS combination. The IVS submitted the combination solution before the deadline.

Towards the end of the year many ACs focused on evaluating ITRF2014P – the preliminary version of the ITRF2014. A new feature of ITRF2014P was the inclusion of post-seismic deformation models. The general consensus was that for VLBI processing ITRF2014P provided superior *a priori* station positions than for ITRF2008.

The VLBI contribution to ITRF2014 did not include the effects of pressure loading. Pressure loading is applied in routine VLBI operational analysis. Its omission in ITRF2014 was done primarily because some of the other space-geodetic techniques do not include pressure loading. We believe that this is a serious issue and hope that when the next ITRF is developed all of the techniques will apply pressure loading.

Analysis Workshop

The 16th IVS Analysis Workshop was held on May 21, 2015 in Ponta Delgada, Azores, Portugal. One result of this workshop was moving towards higher data rates, 512 Mbps instead of 256 Mbps, for the R1 sessions, which should improve the precision of the results. Higher data rates mean more data is recorded, which impacts how long it takes to transfer data to the correlator and the correlation time. Because of this it was initially decided to use 512 Mbps for one R1 session per month on a trial basis and to increase the number of sessions using the higher data rate based on our experience.

Another topic noted at the Analysis Workshop were differences between ICRF2, which was completed in 2008, and VLBI solutions that use data through the current time. There appear to be systematic differences in the declination of southern sources. This difference is reduced if sessions involving the AuScope array are eliminated. The origin of this difference is still not understood and may just be due to the weakness of ICRF2.

Thomas Hobiger of Onsala announced a software comparison campaign, the goal of which was to ensure consistency of the software. Various analysis packages would submit the results

Table 1: Progress in the build-out of the VGOS network as of December 2015.

Station	Recent milestone	Broadband readiness
GGAO	test observations	now
Westford	test observations	now on legacy RT
Wettzell	test observations	now
Yebes	test observations	now
Ishioka	test observations	now (S/X/Ka)
Badary	test observations	now (S/X/Ka)
Zelenchukskaya	test observations	now (S/X/Ka)
Kokee Park	RT constructed at site	2016
Santa Maria	RT constructed at site	2017
Noto	receiver under construction	mid-2017 on legacy RT
AuScope	funding for upgrade secured	mid-2017
Tenerife	RT assembled at factory	2018
Onsala	civil construction underway	2018
Ny Ålesund	civil construction underway	2018
Metsähovi	funding secured	2019
Sheshan	funding secured	2019
Hartebeesthoek	funding secured	2019

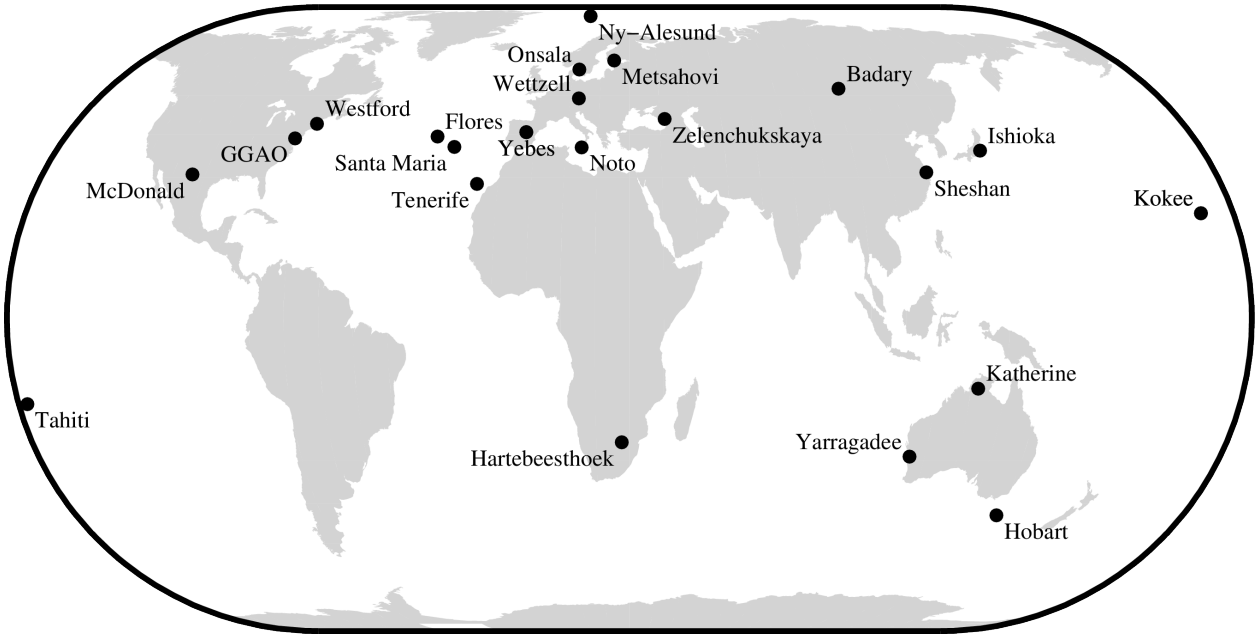

Fig. 1: Projected VGOS network for the year 2020. There is a scarcity of stations in the equatorial and southern hemisphere (South America, Africa) regions. Discussions are underway to at least fill some of these gaps.

of calculations such as 'O−C' and partials. The deadline for submission was December 2015. This is one of a series of sporadic software comparisons dating back to the 1980s.

Technology Development

The IVS technology development continued to focus on achieving operational readiness of the broadband observing as part of the VLBI Global Observing System (VGOS). While the VGOS Observing Plan, which was formulated in 2014, could not be implemented as envisioned in 2015 (but was delayed to mid-2016), there were a number of achievements accomplished: among other things, the VEX2 definition was completed, 1-hour test sessions were observed every two weeks on the baseline GGAO to Westford, the broadband system was brought under Field System control, and operational procedures have been set up similar to the legacy operations. A number of new radio telescopes were constructed and the focus shifted to implementing broadband systems. As many as nine antennas could be ready for operations by mid-2016.

A change was made to the VGOS specifications: the frequency range for VGOS operations was set to 3–14 GHz; however, stations were still encouraged to go down to 2.3 GHz if possible. The Internet connection speeds emerged to be an issue. Currently most stations transfer their data electronically. With full VGOS operations the needed speeds will be too high for the correlators to handle. A workaround will be to initially utilize shipment of modules; hence, stations are encouraged to continue to support module shipping.

Following the approval of the VGOS Observation Plan, a VGOS Data Transfer and Correlation Plan was prepared and approved. Work has commenced on a VGOS Analysis Plan.

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