International GNSS Service (IGS)

The International GNSS Service (IGS, where GNSS stands for Global Navigation Satellite System) was established in 1994 with a mission to provide the highest quality GNSS data and products for scientific use. The IGS provides numerous products to the scientific community. Products of particular interest to the IERS include the Earth rotation parameters as well as global tracking station coordinates and velocities (typically obtained from a reprocessing effort), which serve as the GNSS technique contribution to the realization of the International Terrestrial Reference Frame (ITRF). In the generation of operational products, the IGS adopts the latest realization of the ITRF and IERS conventions, and thus provides its user community with direct access to these IERS products.

IGS activities and developments in 2016 that are of interest to IERS are summarized within this report. The information herein was compiled from the 2016 IGS Technical Report, which includes detailed report sections by the heads of all of the IGS Components and Working Groups. The Technical Report should be consulted for more detailed information regarding the IGS activities in 2016. It is available for download from the publications section of the IGS website www.IGS.org.

Routine Operational Activities

IGS network stations are maintained and operated globally by many institutions, making tracking data openly available at different latencies - from daily RINEX files to real-time streams - for public use. These data contain either the legacy GPS and GLONASS observations, or the full set of potential signals/measurements for all available GNSS. IGS tracking data, which is held by each of the four global Data Centers on permanently accessible servers, increased in volume over the last year by more than 2 Tb (20 million files). Many of these data are also redundantly provided through the IGS regional Data Centers.

The IGS Analysis Centers and Associate Analysis Centers utilize tracking data from between 70 to more than 350 stations to generate and control the quality of highest-precision products up to four times per day. Product Coordinators combine these contributions to the so-called IGS product on an operational basis and assure their quality. Nearly 1.4 Gb IGS final, rapid, and ultra-rapid product files (GPS and GLONASS) as well we 28 Mb IGS real-time products are made available weekly; additionally, ionosphere (4 Mb per day) and daily troposphere files (3 Mb per day) for more than 300 stations are also produced.

The interest of users in IGS products is documented by the download statistics that records typically over 940 000 files (140 Tb) downloads per day (CDDIS statistics). The Central Bureau assumes responsibility for day-to-day management of the service, interaction with station operators, and answering to a typical number of 150-200 questions and requests from users per month. All these activities are performed all year and day-by-day, with high redundancy and reliability based on the pooled resources of more than 200 institutions worldwide.

Network Status The Central Bureau monitors a globally distributed network of 505 select GNSS tracking stations that operate according to the IGS guidelines, more than one third of them are providing an extended set of observations for the new systems. Approximately 189 IGS stations provide real-time data streams so support the IGS Real Time activities.

The IGS has been using the IGb08 realization of the ITRF2008 reference frame for its products since GPS week 1709 (7 October 2012). This contains coordinates and velocities of 232 stations, where only a globally well distributed subset of 91 stations are used as so-called core sites for the datum definition when generating the IGS products.

Within the year 2016 the new IGS14 realization of the ITRF2014 reference frame has been prepared. It contains the coordinates and velocities for 252 stations. For 113

of them the coordinates are affected by the change of the related antenna phase center model. The geographical distribution of the stations is shown in Figure 1 . In October 2016 most of the Analysis Centers started to generate an additional product series in order to verify the impact of the new reference frame realization on the IGS products. Starting with GPS week 1934 (29 Janaury 2017) all IGS products are related to the new reference frame.
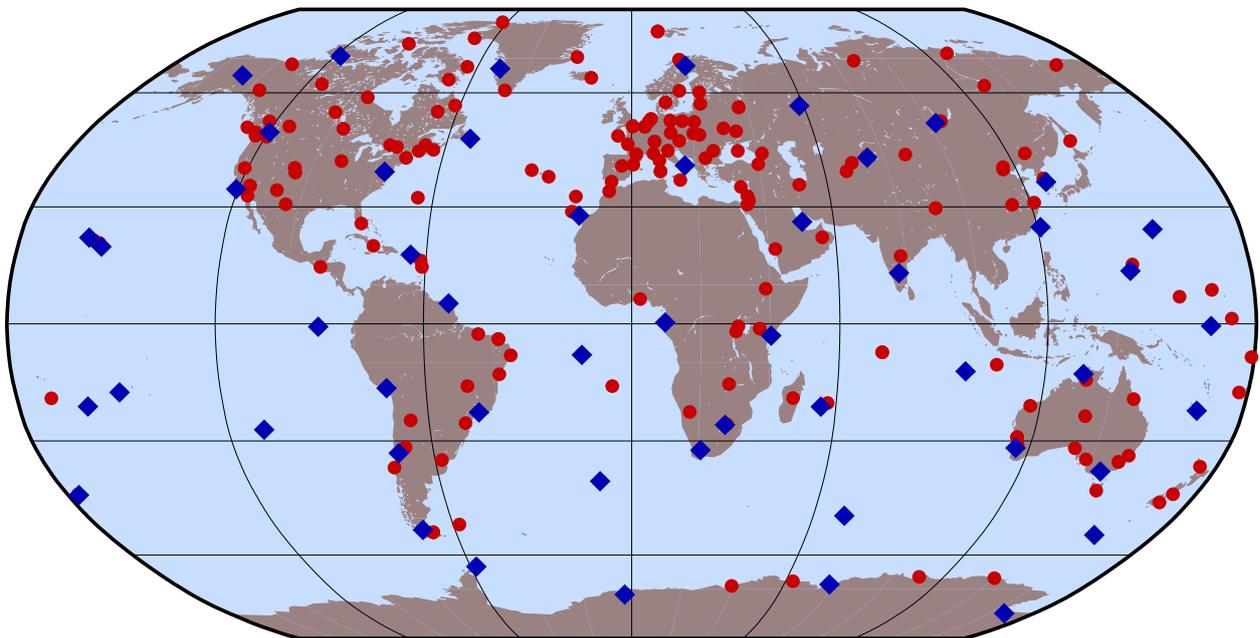

Fig. 1: *Geographical distribution of the stations with given coordinates and velocities in IGS14 realization of the ITRF2014 reference frame. The blue diamonts indicate the location of the 51 core stations to be used for the datum definition when generating the IGS products.*

Analysis and Core Product Generation

The IGS core products have continued to be routinely combined and delivered to users in a timely manner through 2016. To ensure continued production of high-quality IGS products, the Analysis Center Coordinator (ACC) performed high-level oversight and quality control of Analysis Center (AC) products, combination performance, and maintenance of the ACC website with updated plots. Also performed was coordination among ACs to assimilate changes made by them and to ensure that the best analysis models and

procedures are used, along with coordination among the other relevant IGS components, preparation of component reports.

Despite a few minor delivery delays caused by power or network outages of the combination server, all of the IGS core products met availability targets (Table 1). The product reliability and quality of the IGS Ultra-rapid and Rapid products has remained similar to previous years. To improve the reliability of the GLONASS Ultra-rapid product, more AC contributions are needed. Details regarding the effects of these factors on the IGS products are described within the Analysis Center Coordinator Section of the IGS Technical Report.

To establish the combination software on two Amazon cloud computers has proven itself in daily use, in particular because two institutions GA and MIT are coordinating this activity.

Real-time Service The IGS Real-time Service (IGS-RTS) was launched in April 2013. Real-Time GNSS observation data from a global observation network is provided via the IGS-RTS observation casters. Eight RT Analysis Centers (RT-AC) and two RT Combination Centers (RT-CC) contribute to the service. The IGS-RTS provides real-time orbit and clock corrections for GPS, four RT-ACs include GLONASS as well. In addition, experimental orbit and clock corrections are available for GLONASS, BeiDou and Galileo as well as code and phase biases and ionospheric corrections. Two RT-CCs combine orbit and clock corrections to three combined product streams: two GPS-only product streams and one stream containing GPS+GLONASS corrections. At present, the positioning performance using Precise Point Positioning (PPP) is at the level of 10cm and will be improved as more correction data become available. All IGS-RTS observation and product data streams are based on open RTCM standards. The service is focused on supporting geophysical applications, such as natural hazards monitoring in the

framework of GGOS, but it will also support a large variety of applications in positioning, navigation, time transfer, system monitoring, and others.

More information and an updated status of the service can be found on the RTS website at rts.igs.org.

Multi-GNSS Extension

The Multi-GNSS Experiment (MGEX), considered a key project that will enhance IGS capabilities to support the emerging satellite navigation systems, has proceeded with high priority since its launch in February 2012. At the Governing Board meeting in February 2016 it became the status of a Pilot Project. In order to keep the well established acronym it was renamed to *Multi-GNSS Extension (MGEX)*.

As decided at the IGS 2014 workshop in Pasadena, California, USA, the related dataflow of RINEX 3 files with an extended set of observations into the operational structures is successfuly integrated into the legacy dataflow. This activity was coordinated by the infrastructure committee and did involve all relevant components of the IGS (station manager, data and analysis centers, and several working groups). Nowadays, about 40% of the IGS stations deliver their data in RINEX 3 format using the the new longer station IDs, as foreseen in the RINEX 3 format description.

The focus of MGEX is now on the data processing. Several ACs provide solutions for the new satellite systems with different latency, completeness, and strategies. More information on the current status can be found on the webpage www.igs.org/mgex. This page also contains some comparisons demonstrating the current performance of the different contributions.

Formats and Standards

The joint IGS/RTCM RINEX Working Group is responsible for maintenance of the RINEX format. The latest adapted version is RINEX 3.03. While tracking data from GNSS-capable equipment shall be solely available in RINEX 3 after a target date to be specified, tracking data from legacy

receivers will continue to be available in RINEX 2 for the foreseeable future.

The IGS Infrastructure Committee has established a transition plan to the general usage of RINEX 3 format within the IGS. In the current phase the new and longer station IDs are incorporated into the various product file formats. Additional potential changes in the file formats (mainly driven by the needs of/development in the MGEX Pilot Project) are currently under discussion.

Governance

Since beginning of 2015 Gary Johnston is the chair of the IGS Governing Board. Other members of the governing board have been replaced for various reasons during the year 2016. The current list of members can be seen at the web page http://www.igs.org/about/gb.

The IGS Governing Board met three times in 2016: first on 07 February, for a business meeting prior the IGS Workshop in Sydney, Australia; a second business meeting on 17 April, during the EGU General Assembly in Vienna, Austria; and finally on 11 December for its regular end-of-year meeting prior to the AGU Fall Meeting in San Francisco, California, USA. The IGS Executive Committee - consisting of Rolf Dach, Gary Johnston , Chuck Meertens, Ruth Neilan, Chris Rizos, and with regular participation of Steve Fisher and of WG Chairs as required - met several times in 2016 by teleconference.

Strategic Planning

The current IGS Strategic Plan covers the period 2013-2016. During the year 2016, three dedicated sessions of the governing board with interested guests were organized in order to discuss the future vision of the IGS. The visions and other concerns brought up in these meetings will be reflected in the next IGS Strategic Plan 2017-2020.

IGS Workshop

The IGS 2016 Workshop was hosted by Geoscience Australia, Land Information New Zealand, and the University

of New South Wales in Sydney, Australia. More than 178 participants from more than 21 countries attended the workshop. The main theme "GNSS Future" was well reflected in the scientific program that did review the history and also provided an outlook into the future of the IGS. The workshop presentations, posters and recommendations can be found on the IGS website at http://www.igs.org/presents/workshop2016.

The next IGS Workshop will be held 3-7 July 2017 in Paris, France, and hosted jointly by l'Institut national de l'Information Géographique et Forestière (National Institute of Geographic and Forestry Information) and Le Centre National d'Études Spatiales (National Centre for Space Studies).

Outreach The IGS is well represented on the GGOS Coordinating Board. It also plays a leadership role in the International Committee on GNSS (ICG), in particular by co-chairing Working Group D on Reference Frames, Timing and Applications, and by participating in the planning for the international GNSS Monitoring and Assessment System (iGMAS). The latter activity resulted for instance in the common working group between IGS and iGMAS. The IGS is also well represented in the International Earth Rotation and Reference Systems Service (IERS) and in IAG Sub-Commission 1.2 on Global Reference Frames, in the RTCM SC104, and others.

There are numerous IGS-related publications released in 2016. Please visit http://www.igs.org/library for the directory as maintained by the IGS Central Bureau and based on the input information from the components.

Rolf Dach

Table 1: IGS core products and availability targets. Availability is defined as the percentage of time that accuracy, latency and continuity of service meet target specification.

		Sampl. Interv.	Accuracy	Latency	Submission	Target Avail.
GPS Satellite Ephemerides / Satellite & Station Clocks						
Broadcast (for comparison)	Orbits Sat. clocks	1 s	≈100 cm ≈5 ns RMS ≈2.5 ns SDev	real time	continuous	99.99%
Ultra-Rapid (predicted half)	Orbits Sat. clocks	15 min	≈5 cm ≈3 ns RMS ≈1.5 ns SDev	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	Orbits Sat. clocks	15 min	≈3 cm ≈150 ps RMS ≈50 ps SDev	3-9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Rapid	Orbits Sat. & sta. clocks	15 min 5 min	≈2.5 cm ≈75 ps RMS ≈25 ps SDev	17-41 hours	daily at 17 UTC	95%
Final	Orbits Sat. & sta. clocks	15 min 5 min	≈2.5 cm ≈75 ps RMS ≈25 ps SDev	12-18 days	weekly every Thursday	99%
Real-time	Orbits Sat. clocks	5-60 s 5 s	≈5 cm ≈300 ps RMS ≈120 ps SDev	25 seconds	continuous	95%
GLONASS Satellite Ephemerides						
Ultra-Rapid (predicted half)	Orbits	15 min	≈10 cm	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	Orbits	15 min	≈5 cm	3-9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Final	Orbits	15 min	≈3 cm	12-18 days	weekly, every Thursday	99%
Geocentric Coordinates of IGS Tracking Stations						

Positions of real-time sta.	horizontal vertical	daily	≈3 mm ≈6 mm	1-2 hours	daily	99%
Final positions	horizontal vertical	daily	≈3 mm ≈6 mm	11-17 days	weekly every Wednesday	99%
Final velocities	horizontal vertical	daily	≈2 mm/yr ≈3 mm/yr	11-17 days	weekly every Wednesday	99%
Earth rotation						
Ultra-Rapid (predicted half)	PM PM rates LoD	daily	≈200 μas ≈300 μas/day ≈50 μs	predicted	4x daily at 03, 09, 15, & 21 UTC	95%
Ultra-Rapid (observed half)	PM PM rates LoD	daily	≈50 μas ≈250 μas/day ≈10 μs	3-9 hours	4x daily at 03, 09, 15, & 21 UTC	95%
Rapid	PM PM rates LoD	daily	≈40 μas ≈200 μas/day ≈10 μs	17-41 hours	daily at 17 UTC	95%
Final	PM PM rates LoD	daily	≈30 μas ≈100 μas/day ≈10 μs	12-18 days	weekly every Thursday	99%
Atmospheric parameters						
Final tropospheric zenith path delay with N, E gradients	5 min	≈4 mm (ZPD)	< 4 weeks	daily	99%	
Final ionospheric TEC grid 5 deg (lon) × 2.5 deg (lat)	hourly	≈2-8 TECU	≈11 days	weekly	99%	