3.4.2 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 a variety of 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 2019 that are of interest to IERS are summarized within this report. The information was compiled from the 2019 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 2019. 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. This global network makes 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 in RINEX 2 format, or the full set of potential signals/measurements for all available GNSS in RINEX 3 format. IGS tracking data, which is held by each of the five global Data Centers on permanently accessible servers, increased in volume from 2 TB to 11 TB (135 million files) over the last 5 years, supported by significant additional storage capabilities and resilient redundancy provided by 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 into official IGS products on an operational basis including a quality control procedure. Nearly 3.5 GB of IGS Final, Rapid, and Ultra-rapid product files (GPS and GLONASS) as well 28 MB of IGS real-time and 225 MB of for IGS MGEX products are made available weekly. Additionally, ionosphere (5 MB per day) and daily troposphere files (3.2 MB per day) for more than 300 stations are produced.

The level of interest of users in IGS products is best exemplified by the download statistics, indicating typically over 1.7 billion files (170 TB)

downloads during the year (according to the Crustal Dynamics Data Information System (CDDIS) at the NASA Goddard Space Flight Center, an IGS Global Data Center). The Central Bureau assumes responsibility for day-to-day management of the service, interaction with station operators, and answering from users on a regular basis. These activities are performed all year and day-by-day, with high redundancy and reliability, through the pooled resources of 142 self-funding organizations from 45 countries worldwide.

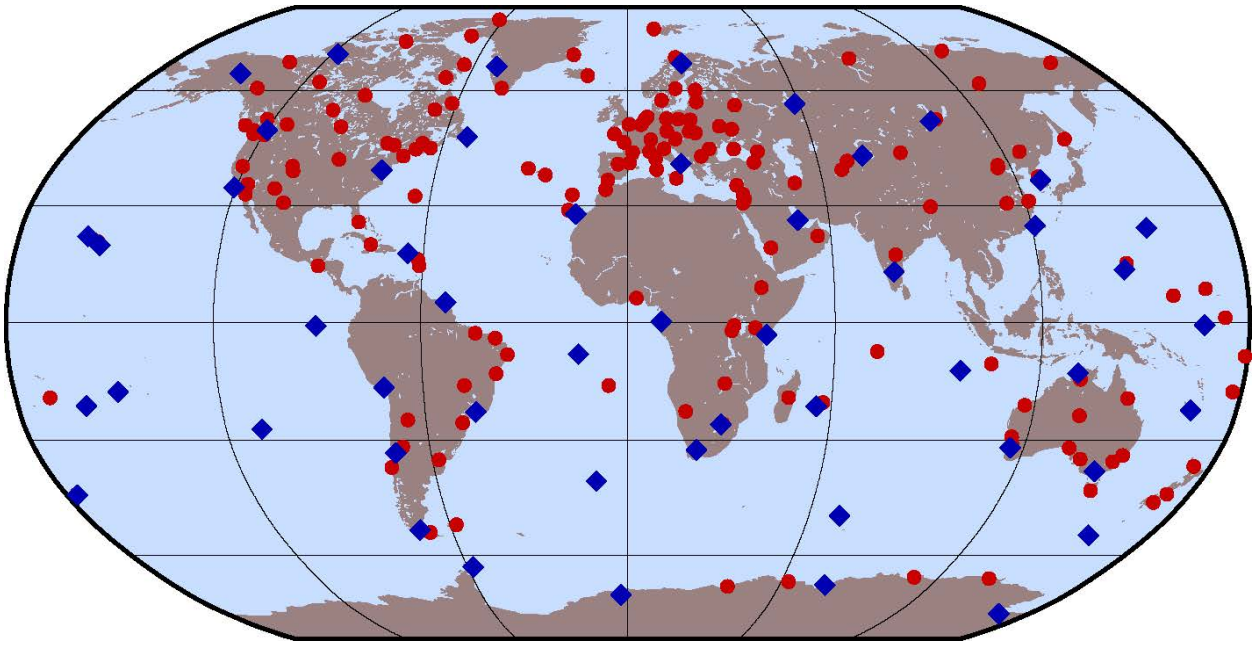

Fig. 1: *Geographical distribution of the stations with given coordinates and velocities in IGS14 realization of the ITRF2014 reference frame. The blue diamonds indicate the location of the 51 core stations that are used for the datum definition when generating the IGS products.*

Network Status

The Central Bureau monitors a globally distributed network of 507 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 GNSS constellations. Approximately 221 IGS stations provide real-time data streams to support the IGS real time activities.

Since GPS week 1934 (29 January 2016), the IGS has been using the IGS14 realization of the ITRF2014 reference frame. It contains the coordinates and velocities for 252 stations, where only a globally well distributed subset of 51 stations are used as so-called core sites for the datum definition when generating the IGS products. For 113 of them the coordinates are affected by the change of the related antenna phase center model why it was decided to update the realization to IGb14 in early 2020. The geographical distribution of the stations is shown in Figure 1 .

Analysis and Core Product Generation

The IGS core products have continued to be operationally combined and delivered to users in a timely manner through 2019. 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 http://acc.igs.org. The ACC also coordinates the 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, and so forth.

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 in the Analysis Center Coordinator Section of the IGS Technical Report.

Installing 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 Real-Time Analysis Centers (RT-AC) and three 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. Three RT-CCs combine orbit and clock corrections to three separate, 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 10 cm 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 http://rts.igs.org.

Multi-GNSS Extension

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

It was decided at the IGS 2014 workshop in Pasadena, California, USA, that the related dataflow of RINEX 3 files with an extended set of observations be 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). Currently about 60% of the IGS stations deliver their data in RINEX 3 format using 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 using different strategies. More information on the current status can be found on the website http://www.igs.org/mgex. This site also contains selected 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 3.04. 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 the MGEX Pilot Project) are currently under discussion.

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) $\times$ 2.5 deg (lat)		hourly	≈2–8 TECU	≈11 days	weekly	99%

Governance

After Allison Craddock became the Director of the IGS Central Bureau in 2018, Mayra Oyola was appointed in February 2019 to fill the role of Deputy Director and Executive Secretary of the Governing Board.

The Governing Board conducted a 6-month-long formal review of the Central Bureau in 2018. A dedicated review panel, consisting of Ignacio Romero, Tom Herring, and Chris Rizos, engaged with Craddock and the JPL Central Bureau Task Manager, Michael “Mick” Connally, via email and telecons over the past six months. A Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis exercise was conducted (in consultation with the 2017 Terms of Reference), which laid the foundation for dialogue between the review panel members and CB, and served to identify areas of concern. Resulting from this dialogue, avenues of potential improvement were identified, providing guidance and direction for the Central Bureau in its future work.

Organizationally, the Terms of Reference were updated in early 2019 to be in alignment with a forward-looking and sustainable organizational vision. This includes the addition of appendix “procedures” documents, which outline such things as Associate Member Engagement, and Governing Board Elections processes, with more to come. The IGS continues to function as a service of the International Association of Geodesy (IAG), and a contributor to the Global Geodetic Observing System (GGOS). Accordingly, a number of the GB members continue to

participate in IAG and GGOS governance, bureaus, commissions and working groups, ensuring the IGS retains its strong level of relevance and impact, and therefore sustainability. Importantly, GB members also participate in the United Nations Global Geospatial Information Management (UN GGIM) efforts on Geodesy, which aims to enhance the sustainability of the global geodetic reference frame through intergovernmental advocacy for geodesy. GB members also routinely invited to present and provide valuable input at the National Space-Based Positioning, Navigation, and Timing (PNT) Advisory Board, providing input and recommendations to the United States government.

The IGS Governing Board met two times in 2019:

7 Apr. 2019	Governing Board Business Meeting, held prior to the 2019 European Geosciences Union meeting Vienna, Austria
8 Dec. 2019	54^{th} Governing Board Meeting, held prior to the 2019 American Geophysical Union meeting, San Francisco, CA, United States

The IGS Executive Committee – consisting of Gary Johnston (Chair of the Governing Board), Felix Perosanz (Vice Chair of the GB), Rolf Dach, Charles Meertens, Chris Rizos, and Allison Craddock, with regular participation by other Governing Board and Central Bureau members as required – met several times via teleconference.

Strategic Planning

The current IGS Strategic Plan covers the period 2017–2020. Drafting and development of the 2021 IGS Strategic Plan is underway, through strategic dialogues at community events (such as the 2019 EGU) as well as a globally-distributed community survey.

Other Developments and Activities

IGS Workshop AC 2019

A dedicated analysis center workshop was held at the GFZ Potsdam (Helmholtz-Zentrum Potsdam; Deutsches GeoForschungsZentrum) from 15 to 17 April 2019. All ACs have been represented. It was discussed and finally agreed on the modeling standards and the schedule for the 3^{rd} reprocessing campaign in order to support the ITRF2020.

Among others it was decided to include Galileo into the solution because of the availability of pre-launch satellite antenna calibrations. Together with an updated set of ground station calibrations GNSS may potentially contribute to the scale of the next ITRF solution for the first time. A series of test solutions have been carried out and analyzed during 2019 in order to prepare the reprocessing campaign.

For the first time, each AC has to submit the solution for one dedicated year for comparison before the data for all 25 years are going to be processed. These test solutions have been discussed at the AC meeting held in December 2019 during the AGU meeting in San Francisco, CA.

Troposphere SINEX Format Update

A new format for exchanging tropospheric and meteorological parameters (SINEX_TRO) was developed by R. Pacione (e-GEOS/ASI-CGS, Italy) and J. Douša (GOP/RIGTC, Czech Republic) within the last years. It considers numerous aspects from the troposphere application side (e.g., troposphere slant delays or long-term series for climatology) but also makes use of the long station identifiers (9 characters) as they are introduced with the naming convention of RINEX 3 standard.

The format was endorsed by the troposphere working group in its December meeting. The ACs are encouraged to use the new format for the troposphere products generated in the frame of the repro3 campaign.

Real Time GNSS Service (RTS)

Currently, IGS combined products are limited to clocks and orbits for GPS, with GPS+GLONASS products still classed as experimental. Some multi-GNSS analysis center solutions are available, notably CNES (France) and GFZ (Germany), with the CNES stream currently disseminating (unmonitored and uncompared) biases. ESA ESOC also plans to generate a multi-GNSS solution, but this is not yet at a stage where it can be disseminated.

IGS real-time orbit products are based on the ultra-rapid predictions. Thus, all information that helps to improve the IGS orbit products are needed, and of this, access to complete and accurate satellite metadata (information pertaining specifically to the physical properties of GNSS satellites) remains an issue.

It was recommended at the 2018 IGS Workshop that the IGS Real-Time Service should prepare for the transition to a true multi-GNSS service. In order to accomplish this, a number of prerequisites need to be fulfilled, such as the availability of predicted orbits for all constellations, the availability of processing, combination and validation capabilities as well as the selection of a suitable transfer format.

IGS Workshop

The next IGS Workshop was scheduled from 10 to 14 August, 2020, in Boulder, Colorado, USA (to be jointly hosted by UNAVCO and UCAR). Due to the COVID-19 situation it was postponed to take place 27 June to 1 July 2022.

Outreach

The IGS is 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. The trial project of ICG Monitoring and Assessment Task Force (IGMA) has been established, co-organized by IGS and ICG. 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.

Official IGS Citation and IGS Library

In response to ever-growing applications for precise GNSS data as a public utility, the work of the IGS and its constituent elements continues to increase in relevance, especially as applications that essentially rely on IGS data and products expand both within and outside of the sciences.

As it enters its second quarter-century, the IGS is evolving into a truly multi-GNSS service. For more than 25 years, IGS data and products have been made openly available to all users for use without restriction, and continue to be offered free of cost or obligation. In turn, users are encouraged to participate within the IGS, or otherwise contribute to its advancement and to include a reference to the IGS in their citations.

The IGS Governing Board recently updated the official citation for acknowledging IGS data, products, and other resources in scholarly publications. The new official citation is the IGS chapter in the 2017 Springer Handbook of Global Navigation Satellite Systems.

The IGS Central Bureau gratefully acknowledges the contributions of IGS Governing Board and Associate members in the drafting of this article, as well as to Geoscience Australia for financially supporting the authorship. Special thanks to the article's authors, Governing Board Chairman Gary Johnston, as well as to Anna Riddell and Grant Hausler.

Johnston, G., Riddell, A., Hausler, G. (2017). The International GNSS Service. In Teunissen, Peter J.G., & Montenbruck, O. (Eds.), Springer Handbook of Global Navigation Satellite Systems (1st ed., pp. 967–982). Cham, Switzerland: Springer International Publishing. DOI: 10.1007/978-3-319-42928-1

The book is currently available for purchase and download on the Springer website: https://www.springer.com/us/book/9783319429267 . A special pre-print version of this document may be found on the IGS Knowledge Base.

The IGS Library function has also transitioned to a Google Scholar-based platform. Please view https://scholar.google.com/scholar?q=International+GNSS+Service or http://bit.ly/IGSlibrary to learn more.

Rolf Dach