3.4 Technique Centres

3.4.1 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 2018 that are of interest to IERS are summarized within this report. The information was compiled from the 2018 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 2018. 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 over the last year by more than 4.2 Tb (30.5 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 into official IGS products on an operational basis including a quality control procedure. Nearly 3.5 Gb IGS Final, Rapid, and Ultra-rapid product files (GPS and GLONASS) as well 28 Mb IGS real-time and 225 Mb 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 (CDDIS statistics). The Central Bureau assumes responsibility for day-to-day management of the service, interaction with station operators, and answering of the order of 150–200 questions and requests from users per month. These activities are performed all year and day-by-day, with high redundancy and reliability, through the pooled resources of more than 200 institutions worldwide.

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. The geographical distribution of the stations is shown in Figure 1 .

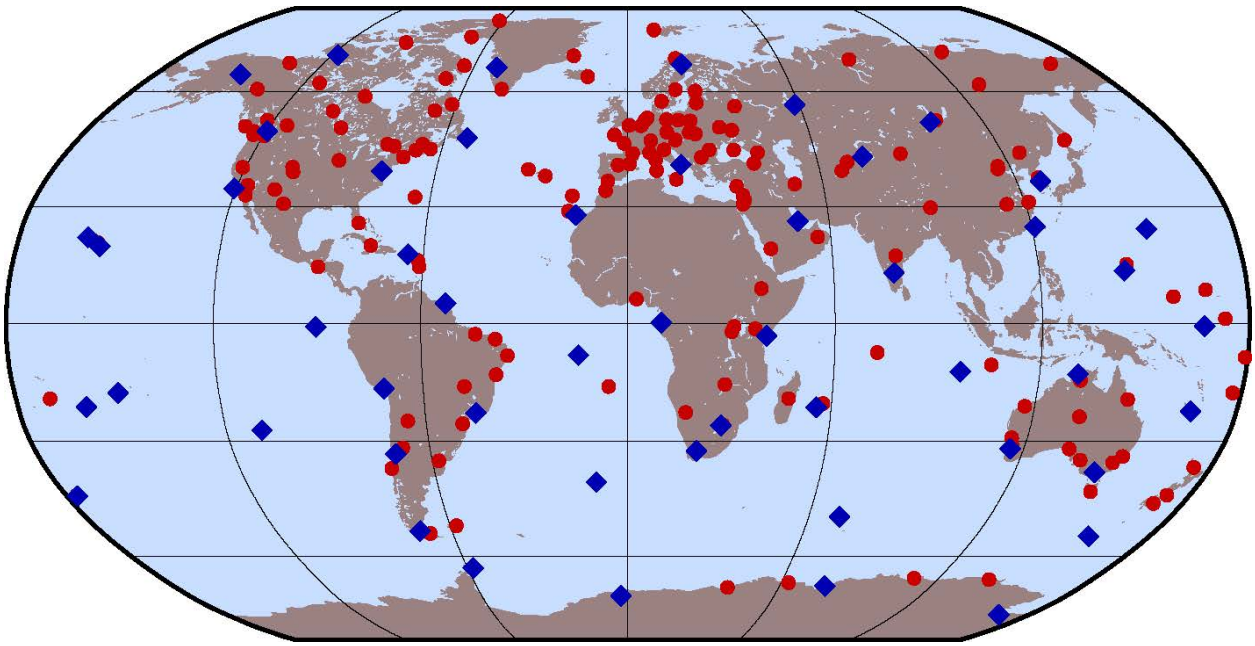

Fig. 1: *Geographical distribution of the stations with given coordinates and velocities in IGS14 realization of the ITRF2014 reference frame. The blue diamonds indicate the location of the 51 core stations that are used for the datum definition when generating the IGS products.*

Analysis and Core Product Generation

The IGS core products have continued to be routinely combined and delivered to users in a timely manner through 2018. 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 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 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 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

The year 2018 signaled a changing of the guard within the IGS Central Bureau, with the long-standing Director of the Central Bureau, Ruth Neilan, moving on to other endeavors after serving the IGS community since its inception, and before. The contribution Ruth has made to science and society through the IGS cannot be underestimated, and the IGS Governing Board wish her well for the future.

Allison Craddock was appointed by NASA JPL to take on the role of Director of the IGS CB in early 2018, and confirmed by the Governing Board at its meeting in April 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.

Additionally, Felix Perosanz of CNES was appointed to serve as the first Vice Chair of the IGS Governing Board. The Vice Chair position has been created as an acknowledgment of the increasing outreach role of the Governing Board, and the increasing diversity of participation in the IGS. The Vice Chair, working closely with the Chair and Executive committee, will assist with the representation of the IGS at the many forums where IGS participation is of value.

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 four times in 2018:

8 Apr. 2018	Governing Board Business Meeting, held prior to the 2018 European Geosciences Union meeting Vienna, Austria
28 Oct. 2018	50^{th} Governing Board Meeting (1 of 2 sessions), held immediately before the 2018 IGS Workshop Wuhan, China
2 Nov. 2018	50^{th} Governing Board Meeting (2 of 2 sessions), held immediately after the 2018 IGS Workshop Wuhan, China
8 Dec. 2018	51^{st} Governing Board Meeting, held prior to the 2018 American Geophysical Union meeting Washington, District of Colombia, United States

The IGS Executive Committee – consisting of Gary Johnston, Rolf Dach, Charles Meertens, Chris Rizos, and Allison Craddock, with regu-

lar 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.

IGS Workshop 2018

The latest IGS Workshop, with the theme of "Multi-GNSS through Global Collaboration" took place 29 October to 2 November, 2018. The workshop was hosted locally by Wuhan University at the East Lake Conference Center in Wuhan, China, and was the first IGS Workshop to be held on the Asian continent. Over 300 individuals participated in the sessions.

This workshop brought together researchers from all over the world, with a very strong contingent from China, to discuss the current work program of the IGS and plans for the future. The geographical location of the workshop also made it appropriate to strongly consider the role of Beidou in the multi-GNSS future that the IGS is embracing.

The workshop featured two keynote presentations:

- "Introduction to BeiDou-3 Navigation Satellite System" presented by Yuanxi Yang of the State Key Laboratory of Geo-Information Engineering, based in Xi'an, China.
- "BeiDou Augmentation and its Future" presented by Liu Jingnan, an Academician of the Chinese Academy of Engineering, based at Wuhan University in Wuhan, China.

The theme of the 2018 workshop – "Multi-GNSS through Global Collaboration" – was echoed through ten plenary sessions, posters, and working group splinter meetings. Underpinning much of this Multi-GNSS momentum was the IGS MGEX White Paper, titled "Satellite and Operations Information for Generation of Precise GNSS Orbit and Clock Products" . The paper discusses the parameters needed to ensure the highest possible performance of IGS products for all constellations and motivates the need for provision of satellite and operations information by the GNSS providers. All information requested by the IGS is considered to be sufficiently abstract such as to neither interfere with the GNSS providers' safety and security interests nor with intellectual property rights. http://bit.ly/MGEXwhitepaper

New IGS Working Group on PPP Ambiguity Resolution Established

It was noted that while current IGS products are high quality, they are not fully compatible with PPP-AR and lack multi-GNSS support. In response to this, a new IGS working group that will focus on PPP with ambiguity resolution (PPP-AR) was established at the Wuhan Workshop. It is Chaired by Simon Banville from NRCan in Canada.

RINEX 3.04 Update

The RINEX GNSS data format is a standard that is jointly managed by the IGS RINEX Working Group and the IGS Governing Board, together with the Radio Technical Commission for Maritime Services (RTCM) Special Committee (SC) 104 on Differential Global Navigation Satellite Systems (DGNSS). This relationship was formed between IGS and RTCM to ensure that RINEX would continue to be freely available.

The release of RINEX 3.04 was officially approved by the IGS Governing Board at the IGS Workshop in Wuhan. It was also recently approved by the RTCM SC-104. Key changes in this version include adjusting for new signals.

Laser Ranging to GNSS

At the request of the International Laser Ranging Service (a sister service within the International Association of Geodesy) the IGS issued two official recommendations. One encouraged the extension of SLR stations supporting high-altitude tracking, specifically in the Asia-Pacific region, and the transition to kHz laser systems enabling shorter normal point duration. The other addressed the increasing load on ILRS stations caused by the increasing number of GNSS satellites equipped with laser retroreflectors by recommending that observatories give priority to dedicated campaigns for tracking of selected GNSS satellites at the expense of a reduced background tracking activity while using remaining tracking resources to select and track the remaining GNSS satellites in a randomized manner – the latter of which to be defined at the discretion of the observatory.

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.

The next IGS Workshop will be held from 10 to 14 August, 2020, in Boulder, Colorado, USA. It will be jointly hosted by UNAVCO and UCAR.

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 Updated

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 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.

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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