International GNSS Service (IGS)

http://www.igs.org

Chair of the Governing Board: Gary Johnston (Australia)

Director of the Central Bureau: Ruth Neilan (USA)

Applications of the Global Navigation Satellite Systems (GNSS) to Earth Sciences and technology are numerous and growing. The International GNSS Service (IGS), a voluntary federation of government agencies, universities and research institutions, combines GNSS resources and expertise to provide the highest–quality GNSS data, products, and services in order to support high–precision applications for GNSS–related research and engineering activities. The IGS has been a service of the IAG since 1994.

Overview

The IGS has continued to support scientific and other GNSS users through the 2015-2017 reporting period. The IGS provides essential products that contribute to the realization of ITRF and enable very high accuracy positioning using GNSS technologies for scientific, and a wide variety of other uses. The Service also provides a number of experimental products, in a continuous effort to encourage technological and analytical improvement. IGS continues to refine the accuracy and consistency of its products by an ongoing process of both technique improvement and reprocessing of past data sets in order to achieve the highest quality results.

The IGS continues to adapt and contribute to advances in technology, including ongoing and increased efforts for transitioning to a multi-GNSS service, as well as advancing real-time applications. Re-tooling and modernization of capabilities, as well as developing and extending relevant standards, have also been significant efforts within the IGS.

In addition to many technical achievements, the IGS continues with proactive efforts to sustainably maintain and develop the IGS organization and improve its management. Starting where the 2013-2016 Strategic Plan ended, a comprehensive user survey and strategic planning process took place in late 2016 and early 2017. The resulting 2017 Strategic Plan has been developed in response to both the user

and community survey responses as well as continuing key elements of the previous strategic plan's goals and objectives. It also aims to recognize the extensive contribution of the IGS participants, and to encourage strong engagement with a broader stakeholder set that now rely implicitly on IGS products and services.

The IGS Terms of Reference, as well as the associate membership, have been reviewed annually by the Governing Board and relevant committees since 2011, with updates to both in the last year. All current IGS organizational documents and component membership rosters are maintained in the IGS Knowledge Base website: http://kb.igs.org/.

By working within the science community through (IAG/IUGG/ICSU) and the inter-governmental community through ICG / UN GGIM / US PNT AB and others, the IGS GB is ensuring the IGS retains its strong level of relevance and impact, and therefore sustainability.

Events and Milestones

MGEX Experiment Transition to Service and Pilot Project

The success of the MGEX experiment has demonstrated the inevitability of a transition of the IGS to a full multi–GNSS Service. Accordingly, the Governing Board decided to acknowledge this by terminating the "experiment" status and move MGEX to the status of a Pilot Project. Continued efforts are required to negotiate access to satellite specific information for new satellites from system providers, allowing for more realistic models of satellite behavior to be developed and utilized by the IGS AC's.

Wuhan Data Center

In 2015 the Governing Board endorsed the proposal by Wuhan University, China, to become an IGS Global Data Center. The Wuhan Data Center offers access to the full collection of IGS data and products to any user globally, especially those within the Asia Pacific Region. Importantly the data center gives direct access to the IGS data holdings to the very large research sector within China.

New Analysis Center Coordinator

IGS has continued with a very exciting work program and list of achievements from the IGS participants and contributing organizations. The role of Analysis Centre Coordinator (ACC) is now distributed across two centers, Geoscience Australia and MIT, in two continents, hemispheres apart, using combination software operating on Cloud computing services (Amazon Web Services).

IGS 2016 Workshop in Sydney, Australia

In 2016, the IGS had its first workshop to be held outside of North America or Europe, with the Sydney Workshop held in February 2016 at the University of New South Wales. This workshop, the first in South East Asia, and the first in the southern hemisphere, signaled the stronger involvement of BeiDou and QZSS into the IGS's GNSS futures and featured keynote presentations from Todd Humphreys (University of Texas at Austin), Jan Weiss (UCAR), and John Church (CSIRO), as well as over 50 plenary presentations and 57 posters. Keynotes, presentations, and posters may be viewed on the IGS website: http://www.igs.org/presents/workshop2016.

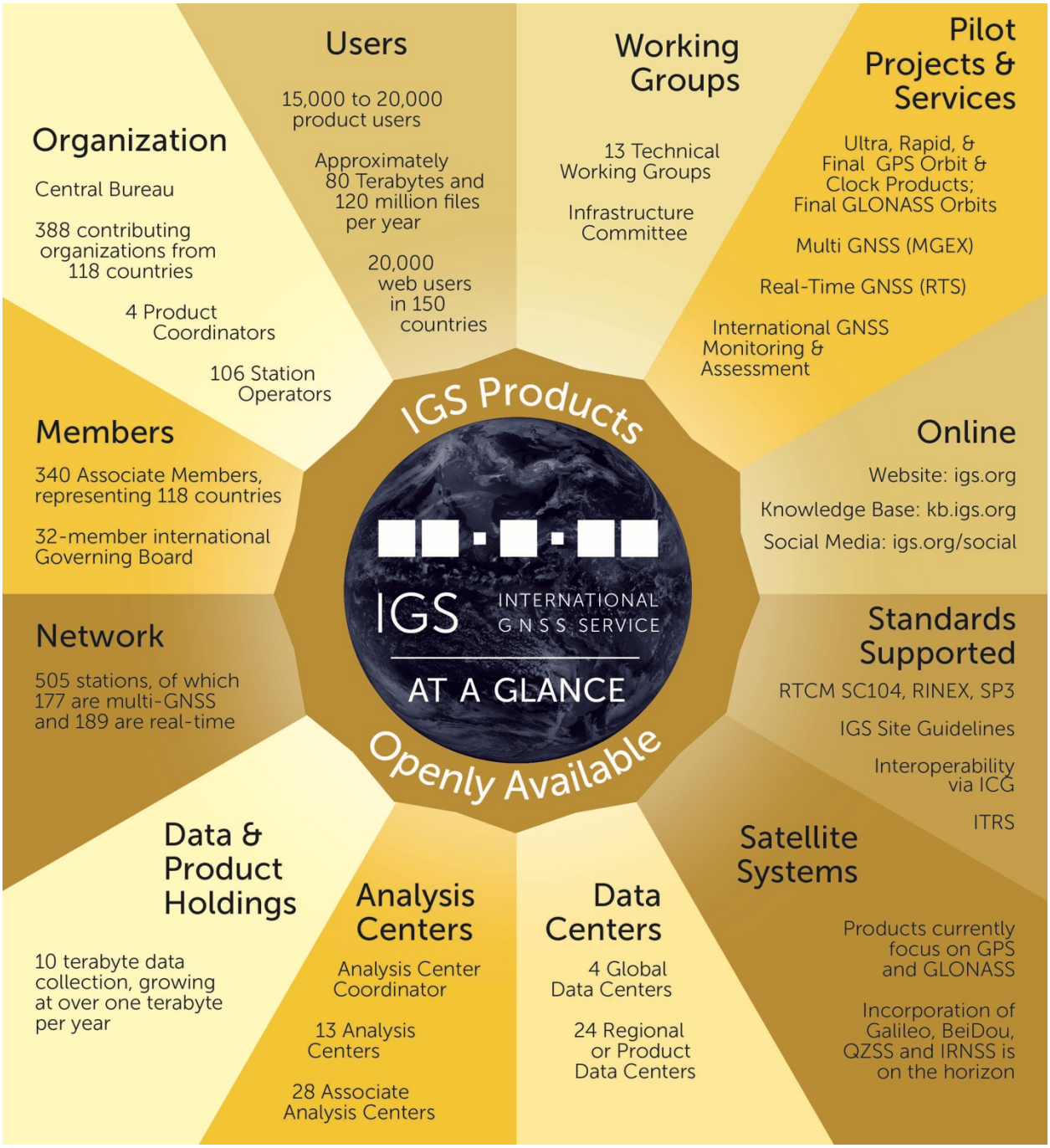
IGS-UN ICG Collaboration on GNSS Monitoring and Assessment

IGS played a key role in forming the United Nations International Committee on GNSS (ICG) International GNSS Monitoring and Assessment (IGMA) Task Force, and International GNSS Service (IGS) Joint GNSS Monitoring Working Group met concurrent to the Sydney workshop. The Call for Proposals for participation in the IGS / ICG joint Monitoring and Assessment project is a pragmatic example of the IGS being flexible enough to respond to stakeholder requirements. That project aims to utilize existing skills within the IGS community to service a new user community as an extension to our current role of providing world class GNSS expertise. The Call for Participation had a strong response including a proposal from ESA to undertake the Monitoring and Assessment ACC function. Importantly this new joint project ensures the IGS continues to have strong influence with GNSS system providers. This strong relationship has been developed over many years by IGS participation in the ICG.

Publications, Presentations, Outreach

Comprehensive lists of IGS publications since 2015, as well as publications referencing IGS in that timeframe, may be found, organized according to IGS component, in the 2015 Technical Report as well as the 2016 Technical Report.

Figure 1: The IGS At-a-Glance



IGS Structure

The IGS is a self-governed federation of 388 contributing organizations from 118 countries around the world that collectively operate a global infrastructure of tracking stations, data centers and analysis centers to provide high quality GNSS data products. The IGS products are provided openly for the benefit of all scientific, educational, and commercial users. The IGS is governed by an international

Governing Board (Table 1) that is elected by designated Associate Members who represent the principal IGS participants. Executive management of the IGS is carried out by the Central Bureau, as is coordination of the IGS Tracking Network and management of the IGS web portal that provides centralized access to IGS products and information. IGS products are generated by combining results from different Analysis Centers under the direction of the Analysis Coordinator and specific Product Coordinators. Introduction of new products and specific technical issues are addressed through Pilot Projects and Working Groups of technical experts (Table 2). The IGS organization is depicted in Figure 2.

Status	First	Last	Affiliation	Country	Role	Service Years
EC-V	Gary	Johnston	Geoscience Australia	Australia	Board Chair	2010-2018
	Michael	Moore	Geoscience Australia	Australia	Analysis Center Co-Coordinators	2016-2019
EC-V	Chris	Rizos	University of New South Wales	Australia	IAG appointed	2004-2019
V	Carine	Bruyninx	Royal Observatory of Belgium Observatoire Royal de Belgique (ORB)	Belgium	IGS Network Representative	2011-2017
	Ken	MacLeod	Natural Resources Canada / Ressources naturelles Canada	Canada	RINEX-RTCM Working Group Chair	2012-2019
V	Felicitas	Arias	Bureau International des Poids et Mesures	France	BIPM/CCTF Representative	2005-Present
V	Zuheir	Altamimi	Institut National de l'Information Géographique et Forestière	France	IAG Representative	2011-2019
V	Paul	Rebischung	Institut National de l'Information Géographique et Forestière	France	IGS Reference Frame Coordinator	2017-2020
V	Laura	Sanchez	Deutsches Geodätisches Forschungsinstitut	Germany	Network Representative	2014-2017
V	Mathias	Fritsche	Deutsches GeoForschungsZentrum (GFZ)	Germany	Analysis Center Representative	2015-2019
	Oliver	Montenbruck	Deutsches Zentrum für Luft- und Raumfahrt e. V.	Germany	Multi-GNSS Working Group Chair	2012-2020
	Tilo	Schöne	DeutschesGeoForschungsZentrum Potsdam	Germany	TIGA Working Group Chair	2001-2020
V	Loukis	Agrotis	ESA/European Space Operations Centre	Germany	Real-time Analysis Coordinator	2014-2017
V	Werner	Enderle	ESA/European Space Operations Centre	Germany	Appointed (IGS)	2016-2017
	Ignacio	Romero	ESA/European Space Operations Centre	Germany	Infrastructure Committee Chair	2010-2017
	Axel	Ruelke	Federal Agency for Cartography and Geodesy (BKG)	Germany	Real-time Working Group, Chair	2016-2019
V	Satoshi	Kogure	Japan Aerospace Exploration Agency (JAXA)	Japan	Appointed (IGS)	2014-2017
	Andrzej	Krankowski	University of Warmia and Mazury in Olsztyn	Poland	Ionosphere Working Group Chair	2007-2020
EC-V, IR	Rolf	Dach	Astronomical Institute, University of Bern	Switzerland	Analysis Center Representative	2015-2018
	Arturo	Villiger	Astronomical Institute, University of Bern	Switzerland	Antenna Working Group Chair	2017-2020
	Stefan	Schaer	Federal Office of Topography - swisstopo	Switzerland	Calibration & Bias Working Group Chair	2007-2020
	Marek	Ziebart	University College London	UK	Analysis Center Coordinator	2011-2020
EC-V	Ruth	Neilan	IGS Central Bureau, Jet Propulsion Laboratory	USA	Director of IGS Central Bureau	1994-Present

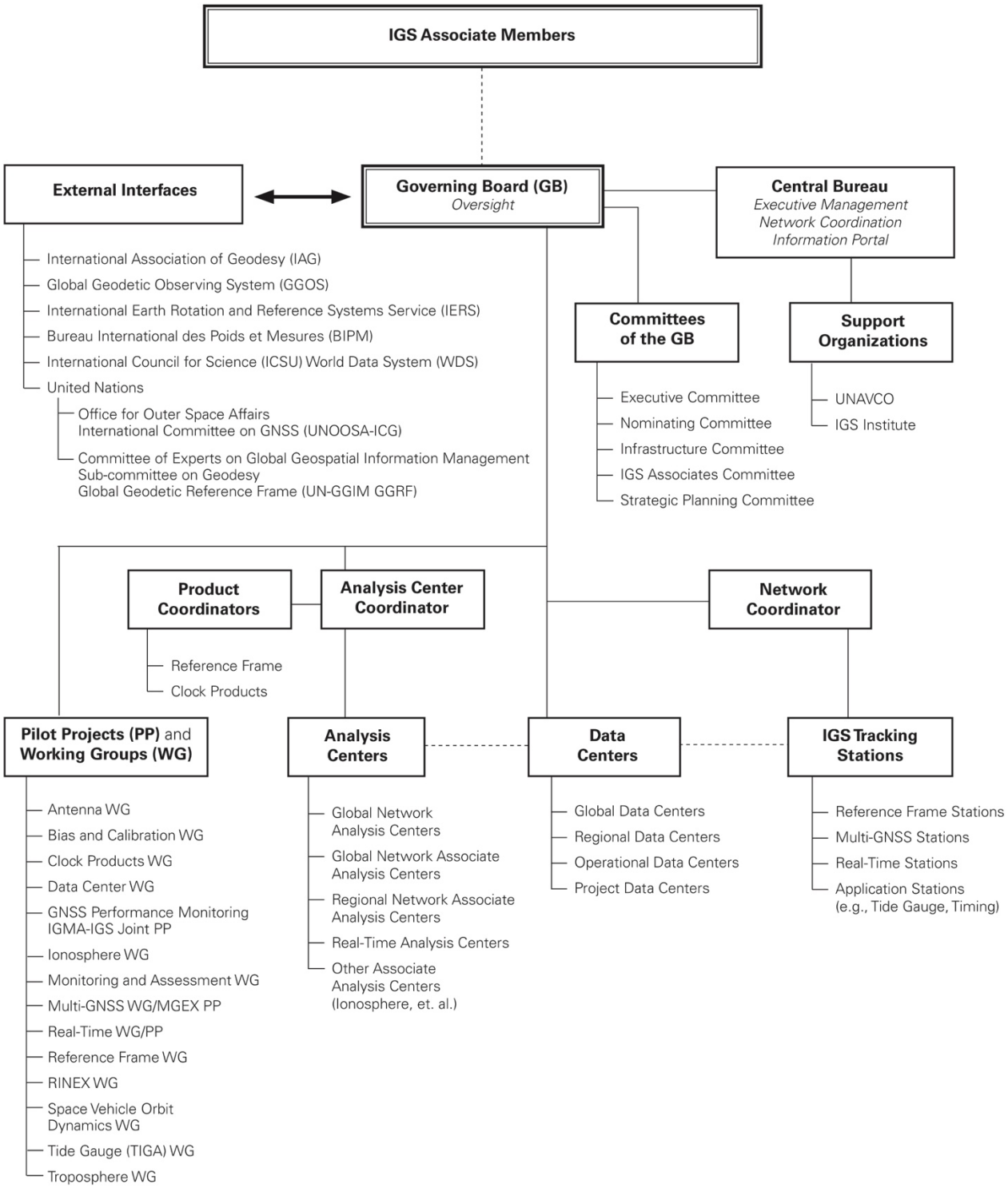
V	Shailen	Desai	Jet Propulsion Laboratory	USA	Analysis Center Representative	2012-2019
V	Richard	Gross	Jet Propulsion Laboratory	USA	IERS Representative	2015-2019
V	Thomas	Herring	Massachusetts Institute of Technology (MIT)	USA	Analysis Center Coordinator	2016-2019
	Carey	Noll	NASA Goddard Space Flight Center	USA	Data Center Working Group Chair	2006-2019
V	Michael	Coleman	Naval Research Laboratory	USA	IGS Clock Products Coordinator	2014-2017
V	Fran	Boler	UNAVCO	USA	Data Center Representative	2014-2017
	David	Maggert	UNAVCO	USA	Network Coordinator	2015-2019
EC-V, IR	Charles	Meertens	UNAVCO	USA	Appointed (IGS)	2011-2018
	Sharyl	Byram	United States Naval Observatory	USA	Troposphere Working Group, Chair	2016-2019

Table 2: IGS Working Groups and Projects

Antenna	Coordinates research in the field of GNSS receiver and satellite antenna phase center determination Arturo Villiger, Chair
Bias and Calibration	Updates various bias values and related auxiliary information for consistent GNSS analysis (product generation), e.g., differential code biases; defines standards and data exchange formats in the field of GNSS biases Stefan Schaer, Chair
Clock Products	Global sub-nanosecond time transfer, and IGS time-scale, jointly with the Bureau International des Poids et Mesures (BIPM) Michael Coleman, Chair
Data Center	Coordination among IGS data centers and support for increasing number of products and real-time Carey Noll, Chair
IGMA Monitoring	United Nations International Committee on GNSS (ICG) International GNSS Monitoring and Assessment (IGMA) Task Force and International GNSS Service (IGS) Joint GNSS Monitoring Working Group Urs Hugentobler, Chair
Ionosphere	Ionospheric science research, global ionospheric maps Andrzej Krankowski, Chair

Multi-GNSS WG and Multi-GNSS Extension (MGEX) Project	Determine actions necessary for IGS to co-opt new GNSS systems, European Union's Galileo system, China's BeiDou, and GPS modernization Oliver Montenbruck, Chair
Real-time WG and Real-Time Service	Demonstrate for IGS real-time network and applications Axel Rülke, Chair
Reference Frame	Global reference frame, Earth orientation, station positions and velocities determined by GNSS Paul Rebischung, Chair
RINEX	Coordinates the development of GNSS observation, navigation and meta data formats Ken MacLeod, Chair
Space Vehicle Orbit Dynamics	Improved understanding and modeling of satellite dynamics towards further improvement of precise orbit determination Marek Ziebart, Chair
Tide Gauge (TIGA)	Monitor long-term sea-level change, attempt to de-couple crustal motion/subsidence at coastal sites from their tide gauge records Tilo Schöne, Chair
Troposphere	Estimate water vapor in atmosphere from the GPS signal delay Sharyl Byram, Chair
IGMA Joint Performance Monitoring	Aimed at creating an authoritative international GNSS monitoring and assessment system to benchmark the performance of available GNSSs Tim Springer, Chair

Figure 2: IGS Organization


IGS Associate Members
External Interfaces
Governing Board (GB)
Oversight
Central Bureau
Executive Management
Network Coordination
Information Portal
International Association of Geodesy (IAG)
Global Geodetic Observing System (GGOS)
International Earth Rotation and Reference Systems Service (IERS)
Bureau International des Poids et Mesures (BIPM)
International Council for Science (ICSU) World Data System (WDS)
United Nations
Office for Outer Space Affairs
International Committee on GNSS (UNOOSA-ICG)
Committee of Experts on Global Geospatial Information Management
Sub-committee on Geodesy
Global Geodetic Reference Frame (UN-GGIM GGRF)
Committees of the GB
Executive Committee
Nominating Committee
Infrastructure Committee
IGS Associates Committee
Strategic Planning Committee
Support Organizations
UNAVCO
IGS Institute
Product Coordinators
Reference Frame
Clock Products
Analysis Center Coordinator
Network Coordinator
Pilot Projects (PP) and Working Groups (WG)
Antenna WG
Bias and Calibration WG
Clock Products WG
Data Center WG
GNSS Performance Monitoring
IGMA-IGS Joint PP
Ionosphere WG
Monitoring and Assessment WG
Multi-GNSS WG/MGEX PP
Real-Time WG/PP
Reference Frame WG
RINEX WG
Space Vehicle Orbit
Dynamics WG
Tide Gauge (TIGA) WG
Troposphere WG
Analysis Centers
Global Network
Analysis Centers
Global Network Associate
Analysis Centers
Regional Network Associate
Analysis Centers
Real-Time Analysis Centers
Other Associate
Analysis Centers
(Ionosphere, et. al.)
Data Centers
Global Data Centers
Regional Data Centers
Operational Data Centers
Project Data Centers
IGS Tracking Stations
Reference Frame Stations
Multi-GNSS Stations
Real-Time Stations
Application Stations
(e.g., Tide Gauge, Timing)

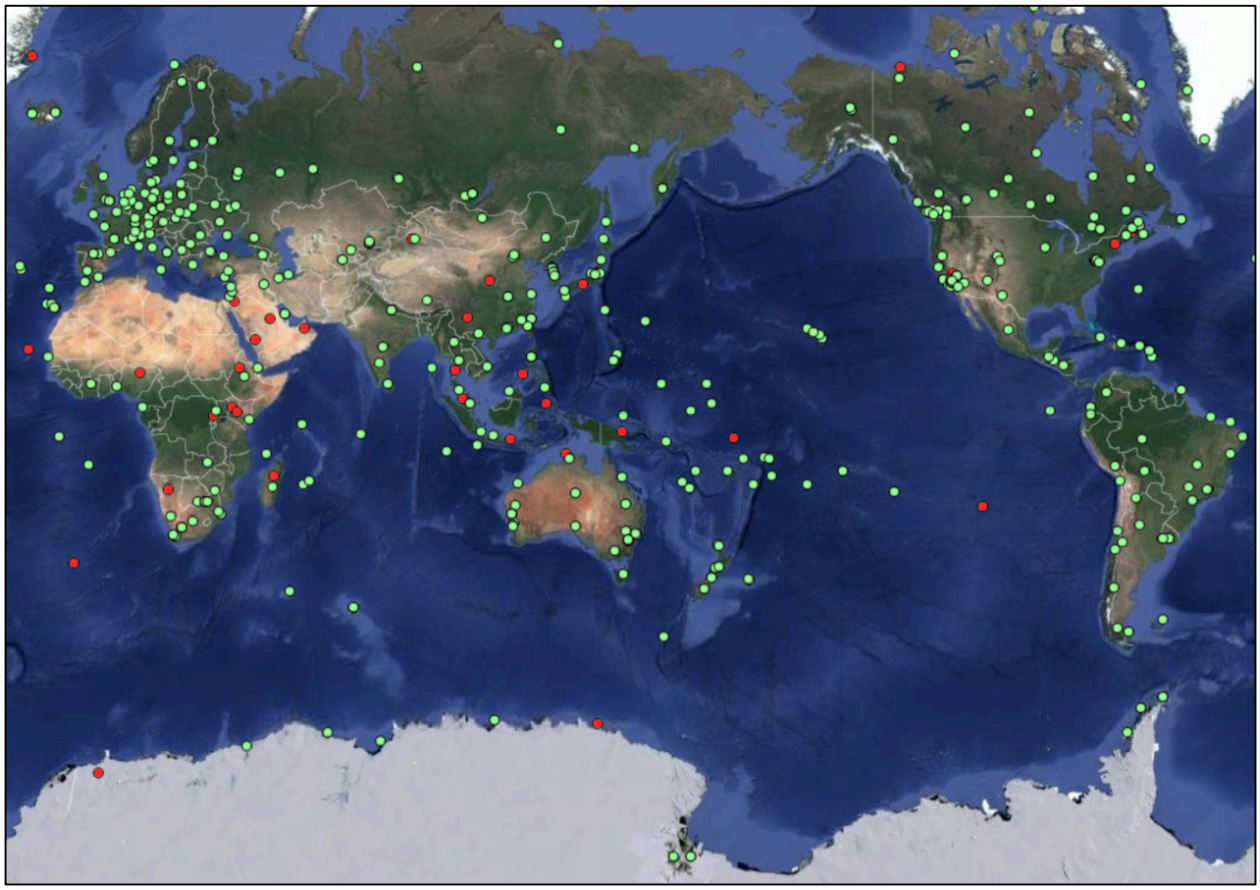
Operational Activities

Delivery of core reference frame, orbit, clock and atmospheric products continued strongly, with further refinement of the Real-Time Service and considerable efforts being targeted towards development of standards. The transition to multi-GNSS also continued, with additional Galileo and BeiDou satellite launches bringing those constellations closer to operational status.

Over 500 IGS Network stations are maintained and operated globally by many institutions and station operators, making tracking data available at latencies ranging from daily RINEX files to real-time streams available for free public use (Figure 2). The development of a multi-GNSS sub-network with the greater IGS network is led by the MGEX project, which develops the IGS's capability to operate with multiple GNSS constellations, and has 177 multi-GNSS capable (GPS + GLONASS + one other) stations. Within the network, 189 IGS stations are now capable of real-time data streaming in support of the IGS Real-Time Service.

The Central Bureau assumes responsibility for day-to-day management, interaction with station operators, and answering user questions and requests. The quantity of IGS tracking data held on permanently accessible servers at each of the four global data centers increased at almost 2 Terabytes per year to what is now approximately 10 Terabyte (over 100 million files). Significant additional storage capabilities are provided by regional data centers. It is estimated that approximately 20,000 users visit the IGS website and related resources each month.

Figure 3: IGS Tracking Network



Thirteen analysis centers and 21 associate analysis centers utilize tracking data from between 70 and 350 stations, four times per day, to generate and verify the quality of highest precision products. Product coordinators combine these products on an operational basis and assure the quality of the products made available to the users. IGS product user activity documentation, courtesy of CDDIS, reveals that in 2017 (January-August), an average 106M GNSS files/12TB were downloaded per month; this includes GNSS data and product files. Focusing on IGNS product files only, then those totals are 26M GNSS product files/4.5TB on average per month. For Tropospheric downloads, CDDIS reports over 46M files totaling over 125 GB in 2016 from 500K unique hosts each month.

All these activities are performed on a daily basis, year-round, with high redundancy and reliability based on the pooled resources of more than 200 institutions worldwide. Only the daily contributions of a large number of engaged individuals makes this significant undertaking possible.

Product Quality

The IGS Analysis Centers have continued to improve product precision, consistency and availability. IGS "final" orbits now agree at a level of approximately 2 cm, and final satellite clock solutions agree at approximately 75 ps RMS with 20 ps standard deviation. The final X- and Y-pole solutions agree at approximately 0.03 mas, and the final length of day solutions agree at approximately 0.01 µs. Products have continued to be available to users, continuously meeting or exceeding the specified availability thresholds (Table 3).

Table 3: IGS Product Quality and Availability

GPS Satellite Ephemerides / Satellite and Station Clocks		Sample Interval	Accuracy	Latency	Continuity	Availability
Broadcast (for comparison)	Orbits	Daily	~100 cm	real time	Continuous	99.99%
	Sat. Clocks		~5 ns RMS; ~2.5 ns Sdev			
Ultra-Rapid (predicted half)	Orbits	15 min	~5 cm	predicted	4x daily, at 03, 09, 15, 21 UTC	99.70%
	Sat. Clocks		~3 ns RMS; ~1.5 Sdev			
Ultra-Rapid (observed half)	Orbits	15 min	~3 cm	3-9 hours	4x daily, at 03, 09, 15, 21 UTC	99.40%
	Sat. Clocks		~150 ps RMS; ~50 ps Sdev			
Rapid	Orbits	15 min	~2.5 cm	17-41 hours	daily, at 17 UTC	99.70%
	Sat. & Stn. Clocks	5 min	~75 ps RMS; ~25 ps Sdev			
Final	Orbits	15 min	~2 cm	12-18 days	weekly, every Thursday	100%
	Sat. & Stn. Clocks	Sat: 30 s; Stn.: 5 min	75 ps RMS; 20 ps Sdev			
Real-time	Orbits	5-60 s	~5 cm	25 seconds	Continuous	100.00%
	Sat. Clocks	5 s	300 ps RMS; 120 ps Sdev			

Note 1: Orbit accuracies are 1D mean RMS values over the three XYZ geocentric components. IGS accuracy limits, except for predicted orbits, are based on comparisons with independent laser ranging results and discontinuities between consecutive days. The precision is better.

Note 2: The accuracy (neglecting any contributions from internal instrumental delays, which must be calibrated separately) of all clocks is expressed relative to the IGS timescale, which is linearly aligned to GPS time in one-day segments. The standard deviation (SDev) values are computed by removing a separate bias for each satellite and station clock, whereas this is not done for the RMS values.

Note 3: Availability is the percentage of time that accuracy and continuity of service meet stated specification.

GLONASS Satellite Ephemerides	Sample Interval	Accuracy	Latency	Continuity	Availability
Final	15 min	~3 cm	12-18 days	weekly, every Thursday	100%

Geocentric Coordinates of IGS Tracking Stations *(over 250 Sites)*		Sample Interval	Accuracy	Latency	Continuity	Availability
Positions of Real-time Stations	Horizontal	daily	3 mm	1-2 hours	daily	100%
	Vertical		6 mm			
Final Positions	Horizontal	weekly	3 mm	11-17 days	weekly, every Wednesday	100%
	Vertical		6 mm			
Final Velocities	Horizontal	weekly	2 mm/yr	11-17 days	weekly, every Wednesday	100%
	Vertical		3 mm/yr			

Earth Rotation Parameters						
Ultra-Rapid (predicted half)	Polar Motion	daily integrations at 00, 06 12, 18 UTC	~200 µas	real time	4x daily, at 03, 09, 15, 21 UTC	99.70%
	Polar Motion Rate		~300 µas/day			
	Length-of-day		~50 µs			
Ultra-Rapid (observed half)	Polar Motion	daily integrations at 00, 06, 12, 18 UTC	~50 µas	3-9 hours	4x daily, at 03, 09, 15, 21 UTC	99.70%
	Polar Motion Rate		~250 µas/day			
	Length-of-day		~10 µs			
Rapid	Polar Motion	daily integrations at 12 UTC	~40 µas	17-41 hours	daily at 17 UTC	100%
	Polar Motion Rate		~200 µas/day			
	Length-of-day		~10 µs			
Final	Polar Motion	daily integrations at 12 UTC	0.03 mas	~11-17 days	weekly, every Wednesday	100%
	Polar Motion Rate		~150 µas/day			
	Length-of-day		0.01 ms			

Note 1: 100 µas = 3.1 mm of equatorial rotation; 10 µs = 4.6 mm of equatorial rotation.
Note 2: The IGS uses VLBI results from IERS Bulletin A to partially calibrate for LOD biases over 21-day sliding window, but residual time-correlated LOD errors remain.

Atmospheric Parameters	Sample Interval	Accuracy	Latency	Continuity	Availability

IGS Final Tropospheric Delay: zenith path delay (ZPD) plus north, east gradients	5 min	~4 mm for ZPD	~ 3 weeks	daily	100%
Ionosphere TEC Grid	2 hours; 5 deg (Lon.) x 2.5 deg (Lat.)	2-8 TECU	~11 days	weekly	100%
Rapid ionosphere TEC Grid	2 hours; 5 deg (Lon.) x 2.5 deg (Lat.)	2-9 TECU	<24 hours	daily	100%

Governance

The IGS has been proactive in advancing its organization and management. The IGS has taken these actions, among others, to improve governance and organizational performance:

Working Group charters and membership

All Working Group charters and membership rosters have been reviewed for relevancy and to assure the appropriate technical experts remain involved. Working Groups are also now invited to give updates on their respective workshop recommendations at regular Associate Member Open Meetings, held at least once between workshops.

Associate Membership Roster

The process for selecting associate members has been reviewed and updated by the IGS Governing Board, resulting in the formation of the Associate Membership Committee. The constituency of associate members is now reviewed continuously throughout the year on a case-by-case basis.

Performance Benchmark and Revised Strategic Plan

Throughout mid-2016, the Central Bureau led the development and distribution of strategic planning-themed surveys to both the IGS community as well as the broader IGS stakeholder community. Feedback was collected and analyzed by the CB and GB during the strategic plan development process, and used to shape the goals and objectives of the 2017 Strategic Plan.

External Coordination

The IGS coordinates extensively with many external organizations to promote the IGS and develop key partnerships with participants and users:

International Association of Geodesy/Global Geodetic Observing System (IAG/GGOS)

The IGS coordinates extensively with GGOS, including membership of the Coordinating Board, Consortium, Science Panel and within the Bureaus. As a service of the IAG, IGS also coordinates with the IAG and its administration.

United Nations Office for Outer Space Affairs (UNOOSA) International Committee on GNSS (ICG)

The ICG Working Group D on Reference Frames, Timing and Applications is co-chaired by the IGS CB Director, as is the International GNSS Monitoring and Assessment System (IGMAS) Task Force. The annual ICG Meeting is typically attended by several IGS participants. Significant progress was made in supporting the development of a cooperative plan with the ICG to monitor performance and interoperability metrics between the different GNSSs, which is now embodied by a joint IGS-ICG Working Group on Monitoring and Assessment.

United Nations GGIM Sub-Committee on Geodesy (formerly Global Geodetic Reference Frame Working Group)

At the most recent session of the GGIM in New York (August 2017), the working group was officially established as a permanent Sub-Committee on Geodesy, to provide stability and long-term planning for the Global Geodetic Reference Frame (GGRF). Previously, the Committee of Experts also endorsed the GGRF Roadmap, which addresses each of the key areas of action described in the operational paragraphs of the 2015 UN General Assembly resolution. These efforts are anticipated to open additional avenues for international cooperation for the IGS and geodesy in general. For more information, please visit the UN-GGIM website: http://ggim.un.org/UN_GGIM_wg1.html.

International Earth Rotation and Reference Systems Service (IERS)

IGS and IERS have continued to extensively cooperate in the realization of ITRF, as well as reciprocally participating on each other's boards.

Radio Technical Commission for Maritime Services, Subcommittee on Differential GNSS (RTCM-SC104)

The IGS holds voting membership on this international standards organization for Differential GNSS, and chairs the RINEX WG.

International Federation of Surveyors (FIG)

FIG represents the single largest user community of IGS products, and is also a potential channel for extending the IGS network. IGS and FIG are coordinating to reach out to users, to conduct joint workshops, as well as to advocate for precision geodesy within organizations such as the ICG.

Regional Reference Frames

The IGS coordinates extensively at multiple levels with regional reference frame activities, such as AFREF, SIRGAS, APREF, NAREF, and EUREF.

Sea Level Activities

Through the Tide Gauge Working Group, IGS participates within the Global Sea Level Observing System (GLOSS) to precisely locate tide gauges within the ITRF.

Additionally, IGS has engaged with many user communities representing different regions and disciplines by participating in scientific workshops and conferences with presentations and chairing of sessions. Examples of conference and workshops attended include: International Council of Science/World Data System (WDS), the American Geophysical Union (AGU) and European Geosciences Union (EGU), the International Union of Geodesy and Geophysics (IUGG), the International Association of Geodesy (IAG), the Asia Oceania Geosciences Society, the U.S. Institute of Navigation, the China Satellite Navigation Conference, the Colloquium on Scientific Applications of Galileo, and others.

Working Group and Project Highlights

Adoption of the New IGS14/igs14.atx Framework

The IGS adopted a new reference frame, called IGS14, on 29 January 2017 (GPS Week 1934). At the same time, an updated set of satellite and ground antenna calibrations, igs14.atx, was implemented. IGS14 is the latest in a series of GNSS reference frames adopted by the IGS. These reference frames form the basis of the IGS products, and are derived from each new version of the International Terrestrial Reference Frame. Updating to IGS14 will align IGS products to ITRF2014, and increase precision of that alignment by integrating additional available reference frame stations with more precise and up-to-date coordinates. For more information, please see [IGSMAIL-7399] “Upcoming switch to IGS14/igs14.atx.”and “IGS14/igs14.atx: a new framework for the IGS products.”

Coincident with the IGS14 Reference Frame release, IGS adopted antenna calibration updates in igs14.atx. These updates include robot calibrations for additional ground antenna types, increasing the

percentage of ground stations in the IGS network with absolute calibrations to over 90%. This will result in increased coordinate accuracy for stations equipped with these antennas. SINEX and ANTEX files, as well as network maps, post-seismic deformation models, and offsets are available for download via ftp from Institut National de l'Information Géographique et Forestière (National Institute of Geographic and Forestry Information, IGN) and École Nationale des Sciences Géographiques (National School of Geographic Sciences, ENSG

Reprocessing Campaigns: repro2

Following the first reprocessing campaign performed by the IGS in 2008, a second reprocessing campaign (repro2) was finalized in 2015. Nine different ACs reanalyzed the history of GNSS data collected by a global tracking network back to 1994 using the latest available models and methodology. Besides supplying an improved consistent set of GNSS geodetic products, one major goal of the repro2 campaign was to provide the IGS input to the latest release of the International Terrestrial Reference Frame (ITRF2014). The individual AC products were combined into official IGS repro2 products called "ig2". Results from the repro2 terrestrial frame combinations are described in Rebischung et al. (2016; https://doi.org/10.1007/s00190-016-0897-6), while results from the repro2 orbit and clock combinations are summarized in IGSMAIL-7411 (https://igscb.jpl.nasa.gov/pipermail/igsmail/2017/008601.html). Troposphere repro2 results are currently being processed and evaluated.

Multi-GNSS Global Experiment (MGEX)

In the beginning of 2016, the status of the Multi-GNSS Experiment (MGEX) of the IGS was changed to a Pilot Project by the IGS Governing Board. In 2016, the number of IGS multi-GNSS stations increased from almost 130 to about 180, see Figure 1. About half of the stations also provide real-time streams, mainly via the dedicated MGEX caster (http://mgex.igs-ip.net/) but also via the IGS-IP caster (http://igs-ip.net). Both casters are operated by BKG and provide the real-time streams in different versions of the RTCM-3 MSM format. Six analysis centers (ACs) contribute orbit and clock products to MGEX: CNES, CODE, GFZ, JAXA, TUM, and Wuhan University. MGEX includes the new GPS signals, new Russian GLONASS signals, the Japanese QZSS, the Chinese BeiDou, and the European Union's Galileo.

Real-Time Service

The IGS-RTS is based on a global network of IGS stations providing data streams to the RTS observation broadcasters. There are several observation broadcasters in operation including the first level global casters at BKG, CDDIS and IGS Central Bureau. There are eight real time Analysis Centres (AC) which use different software packages to compute epoch-wise orbit and clock products. The large number of ACs ensures a high redundancy of the service on the one hand and a strong quality control

Thanks to the contributions from a large number of partners, the IGS RTS operates a dense high quality

real time GNSS network. The observation data is used to derive orbit and clock products which allow user PPP at decimeter accuracy. A limitation is the convergence time of about 30 minutes and the latency of the combined products of 20-30s. The IGS RTS ensures open access to its data and products and supports open standards and data formats. Data and products are provided via TCP/IP connections. The range of applications is focused on scientific and educational topics, such as positioning, navigation and timing, Earth observations and research; and other applications that benefit the scientific community and society.

Infrastructure Improvements <<Nacho has promised to provide an update>>
The Infrastructure Committee (IC) has focused on improving the IGS network, as well as planning the changeover of the IGS infrastructure to support Multi-GNSS and real-time efforts, while maintaining integrity of core products. The IC has led efforts to revise the IGS site guidelines to promote proper practice in operating GNSS stations. The most recent revision in 2012 added new procedures for upgrading station equipment designed to minimize disruption to the IGS reference frame, as well operating standards for stations participating within the Real-time Service. The IC has also led an experiment to assess the effects of 21 IGS stations that are co-located with SLR or VLBI sites where radomes have not been calibrated to IGS standards. This will aid in mapping any discontinuities that may arise as equipment is upgraded at these stations. Analysis is currently in progress for a number of the participating stations.

Data Center Coordination

During the reporting period, the IGS Data Center Working Group (DCWG) worked with the Infrastructure Committee (IC) to integrate multi-GNSS data in RINEX Version 3 format into the operational directory structure at the Global Data Centers in order to promote the use of multi-GNSS data and the new RINEX format. The WG also coordinated a site metadata activity for managing the information contained in IGS site logs and to promote the use of the GeodesyML application schema for managing GNSS site metadata in general.

Receiver Independent Exchange Format (RINEX)

The RINEX Working Group has assumed leadership in maintenance and further development of the RINEX data exchange standard, in cooperation with RTCM-SC104, and has led the recent release of RINEX 3.03. The RINEX Working Group has worked in cooperation with the IC to prepare a plan to transition from RINEX 2.x to RINEX 3.x. Additionally, the RWG has encouraged and supported the development of open software tools for RINEX 3.x data handling and quality control.

Tide Gauge Benchmark Monitoring

The Tide Gauge Benchmark Monitoring Working Group (TIGA) of the IGS continues its support for climate and sea level related studies and organizations concerned herewith (e.g., GGOS, OSTST, UNESCO/IOC). The TIGA WG provides vertical geocentric positions, vertical motion and displacements of

GNSS stations at or near a global network of tide gauges and works towards establishing local geodetic ties between the GNSS stations and tide gauges

TIGA Network operator works with Tide Gauge and GNSS station operators to make existing stations available to TIGA, a main (ongoing) task is to update the current database of existing local ties between GNSS and tide gauge benchmarks. By the end of 2016 about 173 local ties information were made available at http://www.sonel.org/-Stability-of-the-datums.html?lang=en. The number stations directly committed to TIGA the number of ties has risen to 76, with 820 GNSS@TG stations (with 119 stations were decommissioned).

The TIGA-WG carried forward the GLOSS-Task "Priorities for installation of continuous Global Navigation Satellite System (GNSS) near to tide gauges. Report to Global Sea Level Observing System (GLOSS)" by King, M.A. (2014) for the densification and extension of the TIGA Observing Network to GGOS. The response by the GGOS Coordinating Board was received early 2017.

Improved Satellite Force Models *<no response from Marek regarding update. Please advise if the following should be modified, or if this subtopic should be deleted from this travaux>>*
The Satellite Orbit and Dynamics Working Group has developed improved satellite radiation pressure models, which are available to IGS through the University College London website. These models are expected to improve the quality of the IGS orbit products once implemented by the IGS analysis centers.

Bias and Calibration Research

The Bias and Calibration Working Group continues coordinating research activities related to bias retrieval, analysis, and monitoring. Presently, the group is considering C1W–C1C, C2W–C2C, and C1W–C2W differential code biases (DCB). Potential quarter-cycle biases between different phase observables (specifically between GPS L2W and L2C) are another issue to be dealt with. In the face of GPS and GLONASS modernization programs and upcoming GNSS, such as the European Galileo and the Chinese BeiDou, careful treatment of measurement biases in legacy and new signals becomes more and more crucial for combined analysis of multiple GNSS.

In 2016 and 2017, a GNSS bias reprocessing (for GPS/GLONASS) using the recently implemented observable-specific signal bias (OSB) parameterization was carried out at CODE for 1994-2016 RINEX data. The outcomes of this reprocessing effort are daily normal-equation (NEQ) files for GPS and GLONASS code bias parameters that are conform to both global ionosphere and clock analysis.

The combination of these daily bias results into a coherent long-term (1994-present) GPS/GLONASS bias product is another key achievement. Such a bias product is particularly useful for applications where calibration in the absolute sense are crucial (e.g., for GPS timing, or atomic clock comparisons). Additionally, CODE's classic GPS DCB product and the most resent GNSS bias results are made available using the Bias-SINEX Format Version 1.00.

Troposphere Product

The goal of the IGS Troposphere Working Group is to improve the accuracy and usability of GNSS-derived troposphere estimates. It does this by coordinating (a) working group projects and (b) technical sessions at the IGS Analysis Workshops. The Working Group is currently focusing on: automating comparisons of troposphere estimates obtained using different measurement or analysis techniques, standardization of the tropo_sinex format, and automated Analysis Center Estimate Comparisons.

Dr. Christine Hackman chaired the IGS TWG through December 2015. Dr. Sharyl Byram has chaired it since then and also oversees production of the IGS FTEs. IGS FTEs are produced within the USNO Earth Orientation Department GPS Analysis Division, which also hosts the USNO IGS Analysis Center. The United States Naval Observatory produces IGS Final Troposphere Estimates for nearly all of the stations of the IGS network. Each 24-hr site result file provides five-minute-spaced estimates of total troposphere zenith path delay (ZPD), north, and east gradient components, with the gradient components used to compensate for tropospheric asymmetry.

Daily zenith path delay estimates are being generated with an approximate three-week latency for all active IGS sites, based on Precise Point Positioning techniques. IGS Final Troposphere estimates are used by scientists worldwide to support climate-change and meteorological studies, and 46.3 million estimates files from over 1000 distinct hosts were downloaded in 2012 alone.

Ionosphere Product

Following the IGS Workshop 2014 in Pasadena, ionospheric fluctuation map products were established as a pilot project of the IGS service. The current product roster includes: final GIM (please note that GIMs also include GPS and GLONASS stations' and satellites' DCBs); rapid GIM; predicted GIM for 1 and 2 days ahead (pilot product).

Recent key accomplishments include:

- IGS Global ionosphere predicted products for 1 and 2 days ahead (pilot product). This new IGS products are currently based on predicted ionosphere maps prepared by UPC and ESA.
- IGS Global ionosphere maps with 1 hour time resolution. This new IGS products are currently based on ionosphere maps prepared by UPC, ESA and CODE.

- IGS Global Ionosphere Maps (GIMs) now include differential code biases (DCBs) for GLONASS satellites.
- The pilot phase of the new IGS ionospheric product - TEC fluctuations maps

More Information

For greater detail about the aforementioned activities, efforts, and components, please refer to the IGS Technical Reports, available for download on the IGS Knowledge Base.