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The International GPS Service tracking network: Enabling diverse studies and projects through international cooperation

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Abstract

The International GPS Service (IGS), formulated beginning in 1989 and formalized in 1994, was founded on the collaborative operation of approximately 30 permanent GPS stations to benefit global geodynamics. The same cooperative principles, today applied to a network of over 300 stations, still serve to maximize global benefit without unnecessary duplication of investment in global infrastructure. The scope of applications of the dataset has grown to include atmospheric, oceanographic, subdaily, and low-earth orbiter activities through working groups and pilot projects fostered within the IGS in the now traditional IGS spirit of collaboration. These activities and the IGS infrastructure are viewed as critical elements to the Global Geodetic Observing System. This presentation will review the present nature of the IGS tracking network and its ability to support new applications.
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1. Introduction to the IGS network

The 348 stations of the IGS network, shown in Fig. 1, are operated by over 100 worldwide agencies, including government research agencies, national geodetic and mapping agencies, and universities, which agree to adhere to IGS station guidelines and contribute the collected data to IGS data centers. The IGS Network Coordinator at the Central Bureau ensures compliance to standards, collects and provides standardized station configuration metadata, monitors data quality and data usage in IGS products, leads planning of future improvements, and provides feedback to the station operators. The Central Bureau, which is sponsored by the National Aeronautics and Space Administration and managed for NASA by the Jet Propulsion Laboratory, California Institute of Technology, is responsible for the general management of the IGS consistent with directives, policies and priorities set by an international Governing Board, and hosts the IGS Network Coordinator (IGS, 2003).

All stations meet basic IGS requirements which enable calculation of precise satellite orbits and clocks:

- Permanent,
- Continuously operating,
- Dual frequency,
- Data publicly available daily.

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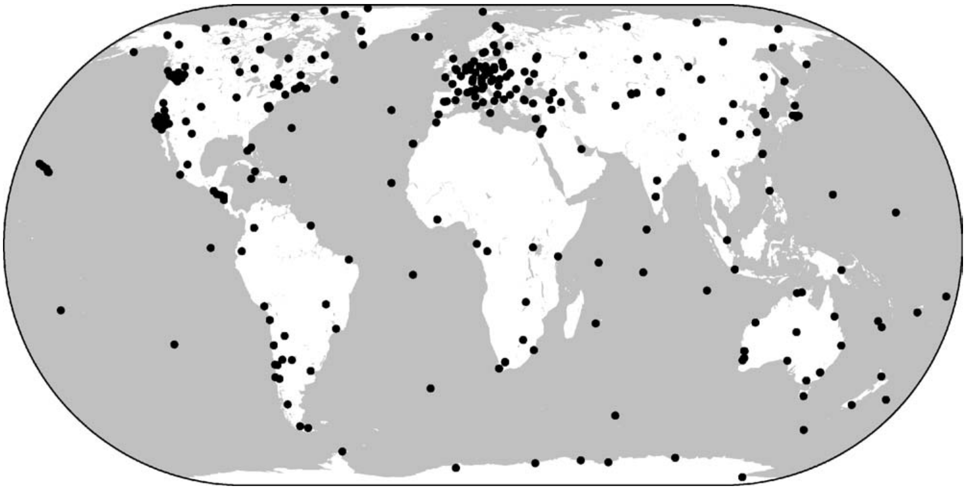

Fig. 1. The stations of the IGS network as of mid 2003.

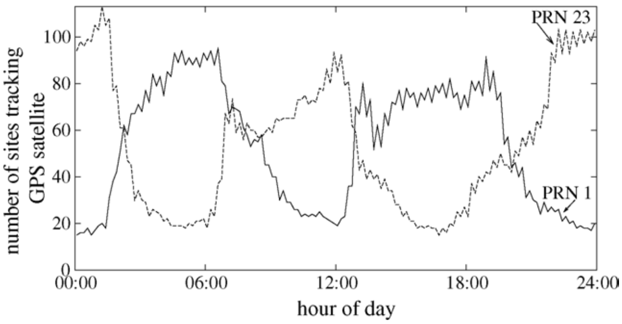

Fig. 2. The IGS network has considerable redundancy protecting against final orbit degradation due to failure of any single station. The traces show the number of IGS stations receiving signals from two representative GPS satellites on a typical day (day 129 of year 2003).

These characteristics enable the original IGS product: the final GPS orbits, generated by seven analysis centers in four countries, and combined into a single product with a precision of less than 5 cm at a latency of 13 days by the IGS Analysis Coordinator (currently hosted by GeoForschungsZentrum Potsdam, Germany).

The number and distribution of IGS sites allow the IGS network to effectively sample the GPS constellation for final orbit generation. On a typical day, at least 15 IGS stations were tracking each active satellite at any time (minima occurring when a satellite passes near the south pole), as shown in Fig. 2. This redundancy provides the final orbit products acceptable tolerance to single-station failures.

Subsets of IGS stations feature additional instrumentation or capability that allows them to contribute to other IGS products and projects, which do not yet enjoy the comfortable spatiotemporal coverage of the final orbits. This article highlights IGS support to a few of these:

- International GLONASS Service Pilot Project (IGLOS-PP),
- Tide Gauge Benchmark Monitoring Pilot Project (TIGA-PP),
- Reference frame,
- Troposphere products,
- Low-latency products.

2. International GLONASS Service Pilot Project (IGLOS-PP)

This pilot project achieves 30-cm precision orbits of the Russian GLONASS satellites through a subnetwork whose receivers record GLONASS data as well as GPS (Weber and Slater, 2001; Weber and Springer, 2001). Analogous

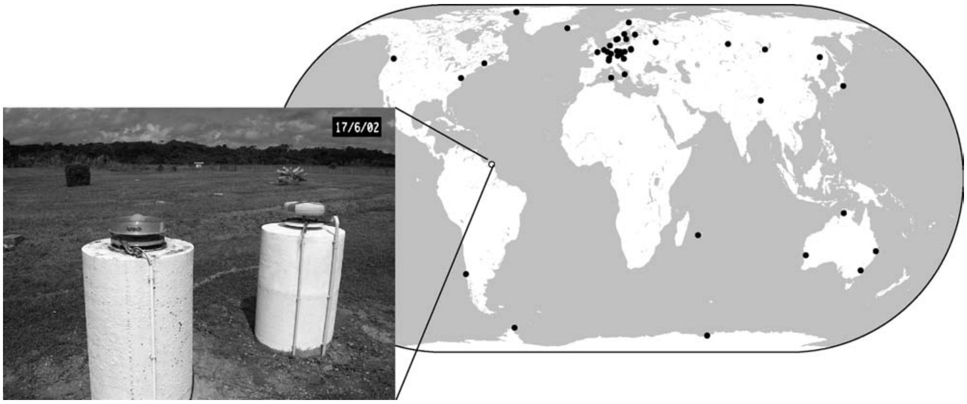

Fig. 3. Forty-five IGS stations have tracked GLONASS satellites in addition to GPS in the recent period, including the Kourou, French Guyana station operated by the European Space Agency. Photo courtesy ESA/ESOC.

to the GPS orbit creation process, four analysis centers in three countries independently produce GLONASS orbits, which are combined into a single IGS product by a coordinator currently hosted by the Technical University of Vienna, Austria. Perhaps most importantly, the IGLOS-PP serves as a demonstration of the ability to integrate GNSS systems other than GPS into the IGS data flow and framework. Thus far, however, the GLONASS data set lacks the global coverage and redundancy of the GPS final orbit data set (see Fig. 3).

3. Tide Gauge Benchmark Monitoring Pilot Project (TIGA-PP)

TIGA-PP is a pilot study to analyze data from GPS stations at or near tide gauges (TGs) on a continuous basis (see Fig. 4). In particular, products will distinguish between absolute and relative sea level changes by accounting for vertical uplift at the stations (Bevis et al., 2002). More than 30 IGS (or associated) sites presently participate as TIGA

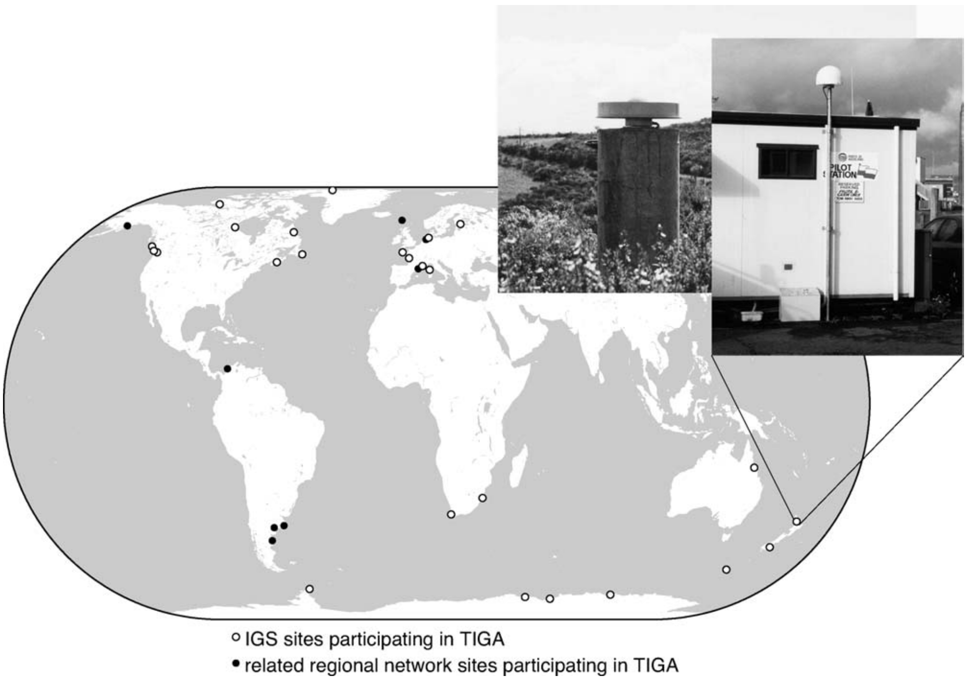

Fig. 4. In some cases, TIGA stations are “paired” with a geodetically monumented station inland. This allows further isolation of motions when the pair is analyzed together. Photos of Auckland, New Zealand sites (AUCK, TAKL) courtesy of J. Beavan, GNS.

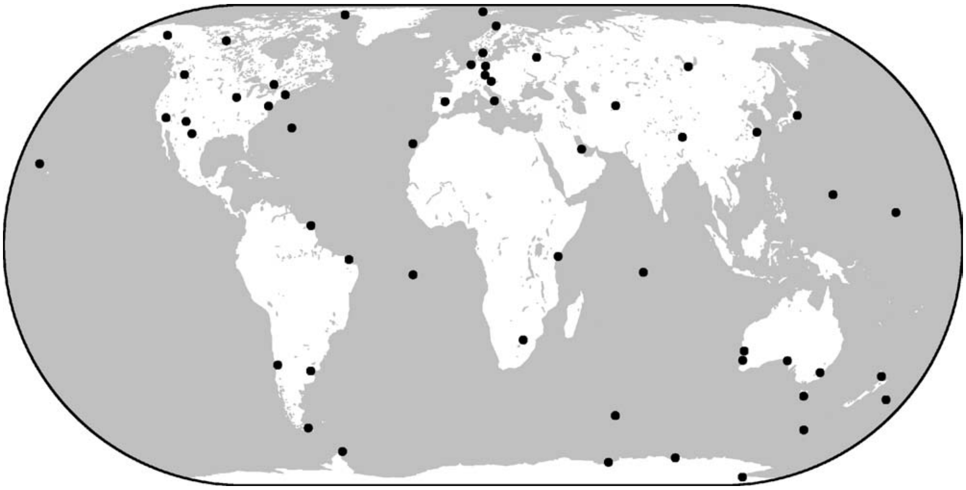

Fig. 5. The current set of IGS reference frame sites.

Observing Stations. Due to challenging infrastructure at many TG stations, TIGA data latency can greatly exceed that of other sites. In view of this, TIGA analysis runs months behind real time. Seven TIGA analysis centers in six countries have planned to participate in this effort, with several more associated analysis centers performing particular studies.

The TIGA-PP chair is hosted by GeoForschungsZentrum Potsdam, Germany.

4. Reference frame

A terrestrial reference frame is an accurate, stable set of positions and velocities providing a coordinate system which allows measurements to be linked over space and time (Torge, 2001).

Geodetic networks such as the IGS provide data for reference frame determination. The IGS' products use a GPS-only reference frame closely aligned with the International Terrestrial Reference Frame (ITRF). The IGS Reference Frame Working Group, whose chair is hosted by Geodetic Survey Division, Natural Resources Canada, periodically selects a set of globally distributed, stable sites for determination of this frame. Presently 54 stations are so designated (see Fig. 5), based on geographic location and operational qualities. The IGS Reference Frame products are combined by the chair from independent analyses by the same analysis centers which perform GPS final orbit analyses.

All IGS products, such as the station velocity map shown in Fig. 6, depend on the reference frame stations and products to be accurate, reliable, and stable.

5. Troposphere products

Many (200+) IGS stations contribute to the IGS tropospheric zenith path delay (ZPD) products (see Fig. 7), which are precise to about 4mm. These can be directly utilized for meteorology.

Computation of precipitable water vapor (PWV), necessary for climatological studies, requires precise meteorological data alongside the GPS data (Bevis et al., 1994) (see Fig. 8). The IGS recommends installation of such equipment measuring pressure, temperature, and humidity wherever possible. Recently approximately 70 IGS stations have contributed meteorological data. The seven IGS final orbit analysis centers produce independent tropospheric analyses, which are combined by the Troposphere Working Group Chair, currently hosted by GeoForschungsZentrum Potsdam, Germany (but under transition to Jet Propulsion Laboratory, California Institute of Technology, USA).

6. Low-latency products

The set of IGS stations which contribute data on an hourly (rather than daily) basis enables the IGS ultrarapid products (Feng et al., 2001), which are updated twice daily and include 24 h of post-processed orbits and 24 h of predicted orbits. Although the distribution of hourly sites is much improved compared to a few years ago, sev-

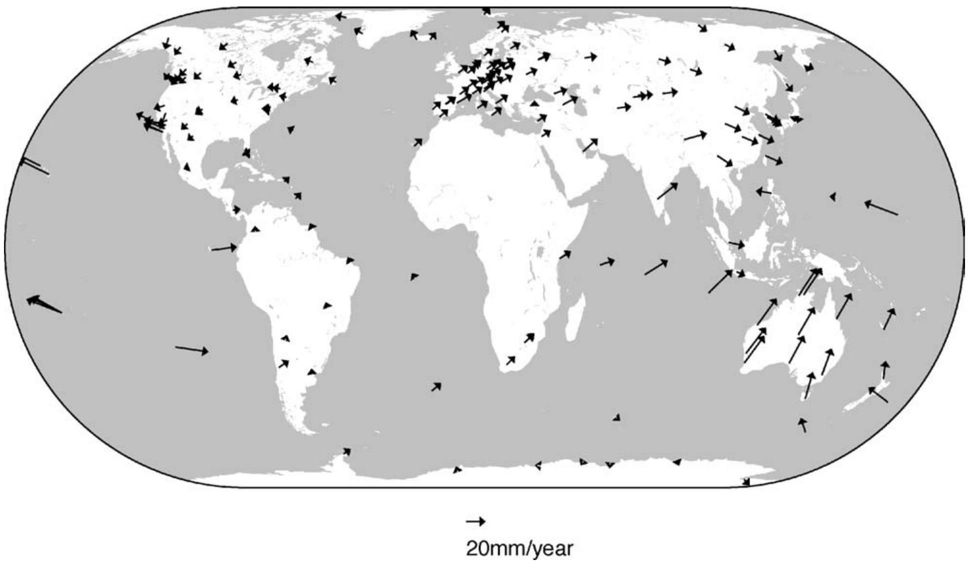

Fig. 6. Calculated velocities of the IGS stations. The plotted values are from the IGS weekly Reference Frame product.

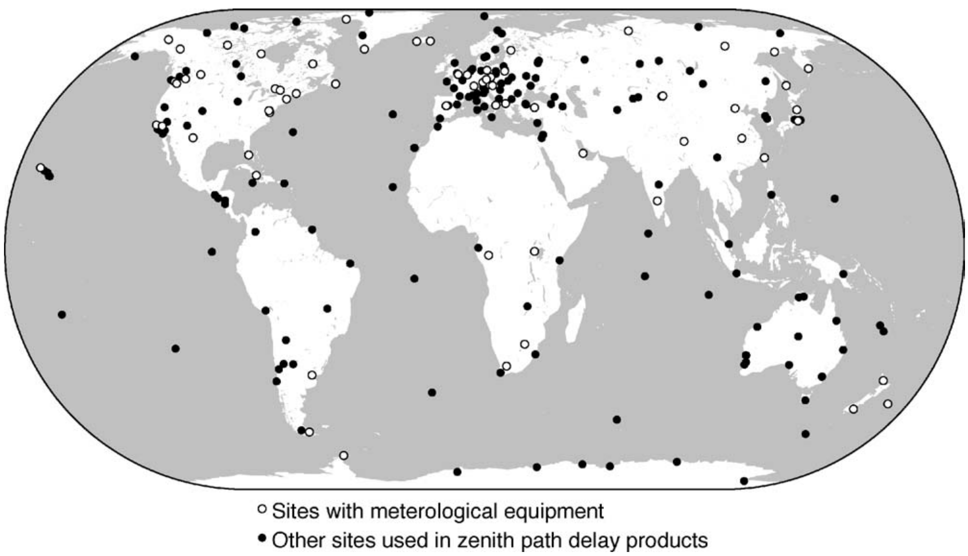

Fig. 7. Stations contributing to troposphere products.

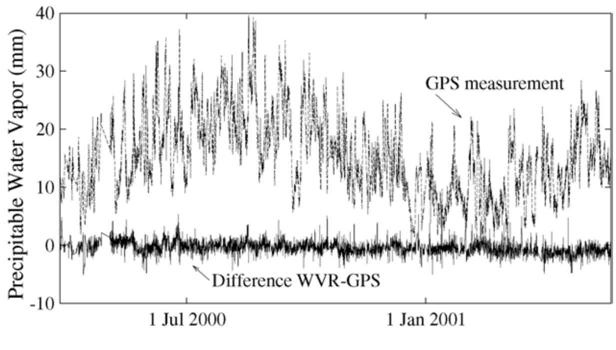

Fig. 8. Comparisons of precipitable water vapor computed from GPS data against a co-located water vapor radiometer at Potsdam, Germany are favorable. Data provided by G. Gendt, GFZ Potsdam.

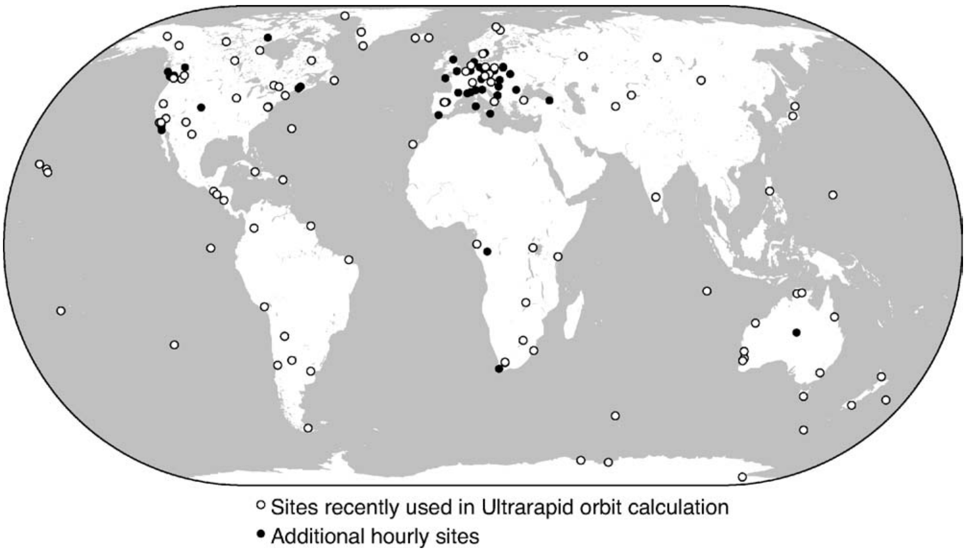

Fig. 9. Stations recently available to ultrarapid orbit products.

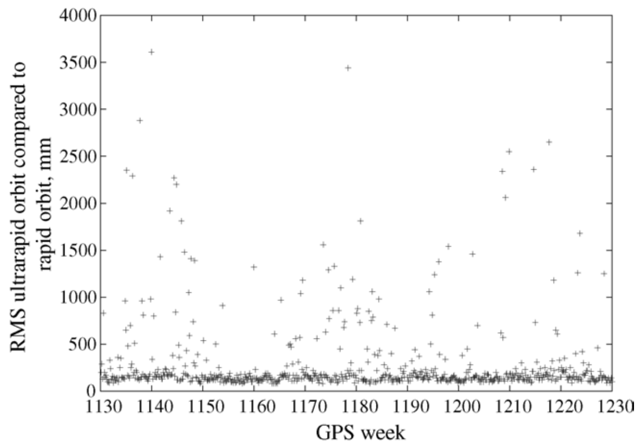

Fig. 10. Comparison of IGS ultrarapid orbit vs. IGS rapid orbit. Data provided by R. Weber, TU Wien.

eral areas still lack sufficient hourly stations to provide adequate redundancy against station outages, as seen in Fig. 9.

Consistency between IGS analysis centers' ultrarapid orbit analyses, produced by six of the final orbit centers + 1 additional analysis center and combined by the same coordinator as the final orbits, is about 25 cm. Recent comparisons to the IGS rapid orbit, which is post-processed and whose latency is 17 h, yield RMS differences most frequently 15–20 cm, although larger differences do occur (see Fig. 10).

7. Looking ahead

The IGS network (and the IGS itself) has proven able to support many new types of analysis not envisioned at the outset of the IGS. It is the agencies which operate IGS sites which fundamentally enable the IGS. The wide range, both spatial and organizational, of agencies solely or cooperatively operating stations supporting the products discussed here, is evident in Table 1. The IGS model embodies the IGGOS vision to integrate different approaches to achieve consistency and reliability (Rummel et al., 1998).

The increase in number and types of stations has also increased the complexity of the network. In view of this, IGS station guidelines are undergoing a full revision to reflect new equipment types and specialized applications. Also,

Table 1
Agencies operating stations for the projects or products detailed in this article

Dirección de Catastro de la Prov. del Chubut, Argentina			TG		
Comisión Nacional de Actividades Espaciales, Argentina					LL
Estación Astronomica Rio Grande, Argentina		Met.		Rf.Fm.	LL
Observatorio Astronómico del Bosque, Argentina		Met.	TG	Rf.Fm.	LL
Universidad Salta Instituto Geonorte, Argentina					LL
Geoscience Australia, Australia	G/G		TG	Rf.Fm.	LL
Department of Natural Resources, Queensland, Australia	G/G				
TU Wien, Austria	G/G				
Institute for Space Research, Austria		Met.		Rf.Fm.	LL
Royal Observatory of Belgium, Belgium		Met.			LL
Bermuda Biological Station for Research, Bermuda				Rf.Fm.	LL
Instituto Nacional de Pesquisas Espaciais, Brazil				Rf.Fm.	LL
Geological Survey of Canada, Natural Resources Canada, Canada		Met.	TG	Rf.Fm.	LL
Geodetic Survey Division, Natural Resources Canada, Canada		Met.	TG	Rf.Fm.	LL
University of New Brunswick, Canada	G/G				
University of Chile, Chile					LL
Universidad de Concepción, Chile	G/G				
China Geo-informatics Center, China		Met.			
Wuhan University, China		Met.			
Shanghai Observatory, Chinese Academy Of Science, China				Rf.Fm.	
State Bureau of Surveying and Mapping, China		Met.			
Chinese Academy of Surveying and Mapping, China		Met.			
Urumqi Astronomical Observatory, China		Met.			
Tibet Autonomous Regional Bureau of Surveying and Mapping, China	G/G	Met.		Rf.Fm.	
Instituto Geográfico Agustín Codazzi, Colombia			TG		
Centro Nacional de Investigaciones, Cuba		Met.			LL
Geodetic Observatory Pecny, Czech Republic	G/G	Met.			LL
National Survey and Cadastre, Denmark	G/G	Met.			LL
Centro Nacional de Registros, El Salvador					LL
Radiosondestation Torshavn, Faroe Islands			TG		
Finnish Geodetic Institute, Finland	G/G	Met.	TG		
Université de la Rochelle, France			TG		
Observatoire volcanologique du Piton de la Fournaise, La Reunion, France	G/G				
Institut Géographique National, France	G/G		TG		
Centre National d'Etudes Spatiales, France				Rf.Fm.	LL
Université de la Polynésie Française, French Polynesia					LL
Université des Sciences et Techniques de Masuku, Gabon		Met.			
Landesvermessung und Geobasisinformation Niedersachsen, Germany			TG		
Bundesamt für Kartographie und Geodäsie, Germany	G/G	Met.	TG	Rf.Fm.	LL
ESA European Space Operations Center, Germany	G/G	Met.		Rf.Fm.	LL
GeoForschungsZentrum Potsdam, Germany	G/G	Met.	TG	Rf.Fm.	LL
Deutsches Geodätisches Forschungsinstitut, Germany			TG		
SRI International, Greenland					LL
Instituto Geográfico Nacional, Guatemala					LL
National Land Survey of Iceland, Iceland	G/G	Met.			LL
ISRO Telemetry, Tracking and Command Network, India		Met.			LL
CSIR Center for Mathematical Modeling and Computer Simulation, India					LL
Universita' di Cagliari, Italy	G/G				
Astronomical Observatory of Cagliari, Italy	G/G				
Agenzia Spaziale Italiana, Italy	G/G	Met.		Rf.Fm.	LL
Geographical Survey Institute, Japan				Rf.Fm.	
National Astronomical Observatory, Mizusawa, Japan		Met.			LL
Electronic Navigation Research Institute, Japan	G/G				
Usuda Deep Space Tracking Center, Japan					LL
Communications Research Laboratory, Japan		Met.			
IVTAN, Kyrgyz Republic					LL
Drzaven Zavod za Geodetski Raboti, Macedonia		Met.			
Mongolian Academy of Sciences, Mongolia					LL
University of Otago, New Zealand		Met.	TG		LL

Table 1 (*Continued*)

Institute of Geological and Nuclear Sciences, New Zealand		Met.	TG	Rf.Fm.	LL
Instituto Nicaraguense de Estudios Territoriales, Nicaragua					LL
Universitetet i Tromsoe, Norway				Rf.Fm.	LL
Ny-Ålesund Geodetiske Observatorium, Norway				Rf.Fm.	
Norwegian Mapping Authority, Norway				Rf.Fm.	LL
Manila Observatory, Phillipines					LL
Agricultural University of Wroclaw, Poland	G/G				
Institute of Geodesy and Cartography, Poland	G/G	Met.			
Warsaw University of Technology, Poland	G/G	Met.			
Russian Research Institute for Phisicotechnical Measurement “Dalstandart”, Russia	G/G				
East-Siberian Research Institute for Physics-Technical and Radio-Technical measurements, Russia	G/G				
Institute of Marine Geology and Geophysics, Russia		Met.			
Russian Data Analysis and Archive Center, Russia		Met.			LL
Krasnoyarsk State Technical University, Russia					LL
INASAN, Russia				Rf.Fm.	
Institute of Metrology For Time and Space, Russia	G/G			Rf.Fm.	
Seismic Station Magadan, Russia		Met.			
Seismic Station Yakutsk, Russia		Met.			
Complex Magnetic-Ionospheric Station, Russia		Met.			
Hartebeesthoek Radio Astronomy Observatory, South Africa		Met.	TG		LL
CSIR, South Africa					LL
South African Astronomical Observatory, South Africa		Met.			LL
Estación Espacial de Maspalomas, Spain				Rf.Fm.	LL
Institut Cartogriàfic de Catalunya, Spain			TG		
National Land Survey, Sweden	G/G			Rf.Fm.	LL
Onsala Space Observatory/Chalmers, Sweden	G/G			Rf.Fm.	LL
SP Swedish National Testing and Research Institute, Sweden	G/G				
Swiss Federal Office of Topography, Switzerland	G/G	Met.			LL
Astronomical Institute, University of Berne, Switzerland	G/G	Met.			LL
National Standard Time and Frequency, Taiwan		Met.			
Delft University of Technology, The Netherlands	G/G			Rf.Fm.	LL
Istanbul Technical University, Turkey					LL
General Command of Mapping, Turkey		Met.			
Natural Environment Research Council, UK	G/G	Met.			
University of Texas McDonald Observatory, USA		Met.		Rf.Fm.	LL
Douglas W. Hogarth, USA	G/G	Met.			
National Imagery and Mapping Agency, USA		Met.		Rf.Fm.	
Jet Propulsion Laboratory, California Institute of Technology, USA		Met.	TG	Rf.Fm.	LL
Pacific GPS Facility, USA					LL
Guam Seismic Observatory, United States Geological Survey, USA				Rf.Fm.	LL
College of the Atlantic GIS Laboratory, USA		Met.			
NASA Goddard Space Flight Center, USA	G/G			Rf.Fm.	LL
University NAVSTAR Consortium, USA			TG		
University of Alaska, USA			TG		
Incorporated Research Institutions for Seismology, USA		Met.			LL
National Radio Astronomy Observatory, USA				Rf.Fm.	LL
National Geodetic Survey, National Oceanic and Atmospheric Administration, USA		Met.		Rf.Fm.	LL
U.S. Naval Observatory, USA		Met.			LL
Haystack Observatory, USA		Met.		Rf.Fm.	LL
Geological Survey and Mines Dept., Uganda		Met.			LL
Ulugh Beg Astron. Inst./Uzbek Academy of Sci., Uzbekistan				Rf.Fm.	LL

G/G = GPS/GLONASS capability; Met. = Meteorological instruments; TG = Tide Gauge Pilot Project; Rf.Fm. = Reference Frame station; LL = Low-Latency station.

station usage in the various product types is being studied closely. These developments will aid in station operation and network planning by recognizing how various types of stations contribute to the IGS.

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