International GPS Service

The Global Positioning System (GPS) provides unprecedented potential for precise ground- and space-based positioning, timing, and navigation anywhere in the world. Extremely precise use of GPS, particularly for earth sciences applications, stems largely from activities of the International GPS Service (IGS). More than 200 organizations in 75 countries contribute daily to the IGS, which is dependent upon a cooperative global tracking network of over 300 GPS stations. Data are collected continuously and archived at distributed data centers. Analysis centers retrieve the data and produce the most accurate GPS data products available anywhere. IGS data and data products are made accessible to users, reflecting the organization's open data policy. The IGS, a scientific service of the International Association of Geodesy, is a highly successful scientific federation and a model of international cooperation.

History. A number of factors led to the formation of the IGS. By the late 1980s many geodynamics and geodetic organizations recognized the potential uses of this affordable technology for scientific research (such as earthquake studies, fault motion, and plate tectonics) as well as other applications. The motivating goal for the earth sciences was millimeter-level positioning anywhere in the world. However, a single civil organization could not assume the capital investment and recurring operations costs to install and maintain a globally based system. At this point, international groups considered entering into joint partnerships for collecting data, making observations, developing cooperative approaches, and defining standards to ensure that future activities would be driven by science requirements.

The idea for an international GPS service began to crystallize at the 1989 International Association of Geodesy (IAG) Scientific Assembly in Edinburgh, United Kingdom. It was here that people recognized that a standardized civilian system for using GPS would be universally beneficial. Subsequently, a planning committee was established within IAG to transform this recognition into action.

In 1991 a Call for Participation was organized by this IAG Planning Committee, seeking participants to form a demonstration campaign to help develop the "proof of concept" for an international service. It requested interested groups to assume the roles of station operators, networks, data centers, analysis centers, and a Central Bureau for coordination. The pilot activity took place from June to September 1992 and was highly successful, demonstrating IGS viability. The IGS was officially established as an IAG international service on January 1, 1994.

The IGS, as a completely voluntary organization, continues to operate the global civilian GPS tracking system for science and research. Since the pilot project in 1992, the network has grown from approximately 30 permanent GPS stations to more than 300 and the accuracy of the IGS orbits has improved an order of magnitude, from 50 cm (20 in.) to less than 5 cm (2 in.). The IGS continues developing and improving traditional products such as orbits, clocks, station positions, and velocities, as well as fostering projects and working groups that produce additional data products, such as precipitable water vapor (a valuable input into weather forecasting), and total electron content (useful for ionospheric space weather research). Some current IGS projects and working groups are shown in the **table**.

How the IGS works. The IGS functions via a global complex of tracking stations, data analysis centers, working (research) groups, projects, and administrators.

Network of tracking stations. All components of the IGS are critically dependent on the global network of precise GPS tracking stations. Recognizing the fundamental requirement for consistent, coordinated, and high-quality network operations, where different receivers are fielded by more than 100 organizations, a Network Coordinator position resides within the Central Bureau. The IGS network includes over 300 stations that operate continuously, delivering data

IGS science applications

Projects and groups	Purpose
Precise Time and Frequency Transfer Project	Global subnanosecond time transfer; joint with the Bureau International des Poids et Mésures (BIPM)
Low Earth Orbiter (LEO) Pilot Project	Orbit determination of LEO satellites that carry on-board precise GPS receivers (CHAMP, SAC-C, GRACE, Jason, etc.)
International GLONASS Service Pilot Project (IGLOS-PP)	Includes data from the Russian GLONASS system into the IGS processes, producing GLONASS orbits, clocks, station positions, etc.
Tide Gauge Benchmark Monitoring Project	Monitors long-term sea-level change; attempt to decouple crustal motion/subsidence at coastal sites from tide gauge records
IGS Reference Frame Working Group	Global reference frame; Earth orientation; station positions and velocities determined by GPS
Ionospheric Working Group	Ionospheric science research; global ionospheric maps
Atmospheric Working Group	Water vapor in the atmosphere can be estimated from the propagation delay encountered by the GPS signal; useful parameters for weather forecasting
Real-Time Working Group	Investigates methods for IGS real-time network operations
Global Navigation Satellite Systems (GNSS)	Determine actions necessary for IGS to incorporate new GNSS. European Union Galileo system

hourly or daily to the data centers. After a lengthy test and validation period initiated in 1999, in early 2002 the IGS network was expanded to include over 30 GLONASS tracking stations.

Data centers. Since the inception of the IGS, the archives of the data centers have been increasingly important to a wide range of scientific and research applications. The distributed nature of the data flow supporting the IGS has been the key to the successful archiving and availability of both IGS data and products. A hierarchy of data centers (operational, regional, and global) exchanges data from the network of tracking stations. This scheme provides for efficient access and storage of GPS and ancillary data, thus reducing network traffic and providing a level of redundancy for security of the data holdings. There are three global data centers, five regional data centers, and 23 operational data centers.

Analysis centers, analysis coordinator, and associate analysis centers. The eight analysis centers are the scientific backbone of the IGS. They provide, based on the available tracking data of the whole IGS network, a consistent set of high-quality products such as precise satellite orbits, station and satellite clock information, station coordinates, Earth rotation parameters, and atmospheric information. Besides their routine work, the analysis centers are asked to continue developing improved models for GPS observations, and these activities are the driving forces of the success of the IGS.

Analysis center personnel work with the analysis coordinator, who ensures that the IGS objectives are carried out. Specific responsibilities of the coordinator include quality control, performance evaluation, and continued development of appropriate analysis standards. The coordinator is also responsible for the appropriate combination of the analysis centers products into a single set of official IGS products.

Associate analysis centers are organizations that produce specialized products, such as ionospheric information or station coordinates and velocities for a global or regional subnetwork, and are generally linked to an IGS pilot project or working group. There are more than 20 associated centers.

Working groups and pilot projects. Working groups focus on selected topics related to the IGS components according to goals and a schedule specified in a charter. Pilot projects aim to develop particular products or services relying on the IGS infrastructure.

Central Bureau. The Central Bureau is the executive arm of the IGS Governing Board and is responsible for the general management, coordination, and communications of IGS activities and external affairs consistent with the directives, policies, and priorities set by the Governing Board.

Governing Board. The principal roles of the Governing Board are to set policy and to exercise broad oversight of all IGS functions and components. It also controls general activities of the IGS that are appropriate to maintain efficiency and reliability, while taking full advantage of advances in technology and theory.

Summary. Through the IGS contributing organizations, its associate members, hundreds of participating scientists and engineers, and the many respective sponsoring agencies, the IGS operates a collective system that has provided geodetic reference data and related products of enormous benefit to earth science research. The IGS has accomplished much as a fully voluntary, global, decentralized, self-governing organization, without any central source of funding. Financial support is provided through the various member organizations and the agencies around the world that sponsor them.

Building upon its record of achievement, the IGS continues to establish objectives consonant with emerging technological and scientific trends. Technological advances will include improvements to GPS in the form of next-generation GPS and other next-generation Global Navigation Satellite Systems (GNSS), such as Galileo and modernized GPS. For science and research, there will be a host of next-generation low earth orbiting (LEO) satellite missions driven by a broad range of scientific objectives such as weather forecasting, climate monitoring, upper atmosphere monitoring, space weather prediction, and interdisciplinary Earth system studies such as the relationships between ultrasensitive gravity measurements in space and hydrological parameters at the Earth's surface. Use of GPS technology is expanding rapidly and is playing an increasing role in many arenas, including transportation, navigation, agriculture, and geographical information systems. Users of a wide variety of scientific as well as civilian applications have a need for increasingly accurate, reliable, and timely GPS data and products from existing and, in some cases, specialized networks. The IGS, with its breadth of expertise and geographic diversity, is well positioned to serve many of these users. The IGS will respond to these needs and opportunities by broadening its range of services to science and will seek to serve society better through establishing appropriate strategic alliances and collaborations.

[The success of the IGS is solely due to the dedicated contributors and their sponsors worldwide. This article was provided through the courtesy of NASA/Jet Propulsion Laboratory, home of the IGS Central Bureau.]

For background information *see* GEODESY; GEOGRAPHIC INFORMATION SYSTEMS; NAVIGATION; SATELLITE; SATELLITE NAVIGATION SYSTEMS in the McGraw-Hill Encyclopedia of Science & Technology.

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