The IGS

2000 ANNUAL REPORT

International

GPS

Service

The IGS 2000 Annual Report series contains two volumes — this Annual Report and a companion, more detailed Technical Report. Both are available from the IGS Central Bureau upon request, and are also accessible at the IGS World Wide Web (WWW) site, known as the IGS Central Bureau Information System (CBIS).

The CBIS can be accessed using the WWW or via anonymous File Transfer Protocol (FTP) —

- *WWW — http://igscb.jpl.nasa.gov*
- *FTP — ftp://igscb.jpl.nasa.gov (See pub/IGSCB.DIR for directory and file information.)*

For the IGS Mail archive, please see —

- *http://igscb.jpl.nasa.gov/mail/mailindex.html*

The United States' Global Positioning System (GPS) constellation of satellites plays a major role in regional and global studies of Earth. Data products of the International GPS Service (IGS) may be accessed on the Internet through the Central Bureau, sponsored by the National Aeronautics and Space Administration (NASA) and managed for NASA by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology.

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Introduction

The IGS mission is to support geodetic and geophysical research activities, measurements, and global change studies through GPS data and products. The IGS contributes significantly to the maintenance and extension of the International Terrestrial Reference Frame (ITRF) and is a recognized scientific service of the International Association of Geodesy (IAG) and of the Federation of Astronomical and Geophysical Data Services (FAGS). This 2000 Annual Report of the International GPS Service serves as the executive summary of key annual activities for this unique global organization. For more detailed information on the activities of the IGS, please refer to the companion volume, the 2000 IGS Technical Reports.

IGS Governing Board 2000

Seated: Ivan Mueller, Bill Melbourne, Christoph Reigber, Ruth Neilan, Gerhard Beutler. First row: Jim Ray, Carine Bruyninx, Werner Gurtner, Claude Boucher, Angelyn Moore. Second row: Norm Beck, Carey Noll, Jim Slater, Bjorn Engen, Bob Serafin, Gordon Johnston, Gerd Gendt, Jim Zumberge, John Dow, Geoff Blewitt, Markus Rothacher, Pascal Willis, Haig Bazoian, Mike Bevis.

The year 2000 saw many new developments in the IGS; notably the establishment of two new projects, the Low-Earth Orbiter Pilot Project and the International GLONASS Pilot Project. Throughout the year, the IGS Governing Board was engaged in a strategic planning effort resulting in a renewed mission statement and identified goals and objectives to shape and guide the organization over the next five years. The final plan document will be available by late 2001.

The Analysis Center Coordinator at the University of Bern in Switzerland departed for a new position with very fond farewells from longtime IGS colleagues. The University of Bern succeeded in seamlessly reassigning responsibility for this vital role, and continues to produce the combined IGS products, orbits, clocks, station positions, and velocities. The IGS, through its Analysis Centers, collectively produces the most precise GPS orbit products available anywhere. The IGS network continued to grow, not just in the number of stations and affiliated regional arrays, but in functionality as stations become identified as meeting requirements necessary for one or more of the IGS projects. Data centers are a critical link in the smooth processing abilities of the IGS, and they find themselves responding to an increasing user base with decreasing latencies as many groups and applications push towards real-time availability of data and products. The IGS as an organization continues to leverage the resources of over 100 contributing organizations and fosters the evolution of many GPS applications through projects and working groups.

2000

Contributing Organizations of the IGS

Alfred Wegener Institute, Germany (AWI)

Astronomical Institute, University of Bern, Switzerland (AIUB)

Australian Survey and Land Information Group, Australia (AUSLIG)

Bakosurtanal, Indonesia (BAKO)

Bundesamt für Kartographie und Geodäsie, Germany (BKG)

Bundesamt für Landestopographie (Swiss Federal Office of Topography), Switzerland (L+T)

Bureau International des Poids et Mesures, France (BIPM)

Center for Space Research, University of Texas at Austin, USA (CSR)

Centre National de Études Spatiales, France (CNES)

Centro de Estudios Espaciales, Chile (CEE)

Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico (CICESE)

China Geo-Informatics Center Chinese Academy of Surveying and Mapping, China (CG-IC)

China Seismological Bureau (CSB)

Chinese Academy of Sciences, China (CAS)

Chinese Academy of Sciences, Kunming Astronomical Observatory, China (KAO-CAS)

Crustal Dynamics Data Information System, NASA Goddard Space Flight Center, USA (CDDIS)

CSIR Centre for Mathematical Modeling and Computer Simulation, India (CMMACS)

Delft University of Technology, Netherlands (DUT)

Department of Land, New Caledonia (DITTT)

Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V., Germany (DLR/DFD)

Earthquake Research Institute, University of Tokyo, Japan (ERI)

East-Siberian Research Institute for Physicotechnical and Radiotechnical Measurements, Russia (VS NIIFTRI)

European Space Agency, Germany (ESA)

European Space Operations Center, Germany (ESOC)

Finnish Geodetic Institute, Finland (FGI)

FOMI Satellite Geodetic Observatory, Hungary (FOMI)

Geodetic Survey Division, NRCan, Canada (GSD)

GeoForschungsZentrum Potsdam, Germany (GFZ)

Geographical Survey Institute, Japan (GSI)

Geophysical Institute, University of Alaska, USA (GIUA)

Geosciences Research Division, National Oceanic and Atmospheric Administration/National Geodetic Survey, USA (GRDL)

Goddard Space Flight Center, National Aeronautics and Space Administration, USA (GSFC)

Hartebeesthoek Radio Astronomy Observatory, South Africa (HRAO)

Incorporated Research Institutions for Seismology, USA (IRIS)

Institut Cartografic de Catalunya, Spain (ICC)

Institut Géographique National, France (IGN)

Institute for Metrology of Time and Space, GP VNIIFTRI, Russia (IMVP)

Institute for Space and Astronautic Science, Japan (ISAS)

Institute for Space Research Observatory, Austria (GRAZ)

Institute of Applied Astronomy, Russia (IAA)

Institute of Astronomy, Russian Academy of Sciences, Russia (INASAN)

Institute of Earth Sciences, Academia Sinica, Taiwan (IESAS)

Institute of Geodesy and Geodetical Astronomy, Warsaw University of Technology, Poland (IGGA-WUT)

Institute of Geological and Nuclear Sciences, New Zealand (IGNS)

Instituto Brasileiro de Geografia de Estatistica, Brazil (IBGE)

Instituto Nacional de Estadistica Geografia e Informatica, Mexico (INEGI)

Instituto Nacional de Invetigaciones Geologico Mineras, Colombia (INGEOMINAS)

Instituto Nacional de Pesquisas Espaciais, Brazil (INPE)

International Deployment of Accelerometers / IRIS, Scripps Institution of Oceanography, USA (IDA)

International Earth Rotation Service, Germany (IERS)

International Research Center–Geodynamic Proving Ground, Kyrgyz Republic (IRC-GPG)

Italian Space Agency, Italy (ASI)

Jet Propulsion Laboratory, California Institute of Technology, USA (JPL)

Korean Astronomy Observatory, Korea (KAO)

Kort & Matrikelstyrelsen, National Survey and Cadastre, Denmark (KMS)

Land Information New Zealand (LINZ)

Main Astronomical Observatory of the Ukrainian National Academy, Ukraine (MAO)

Manila Observatory, Philippines (MO)

Marmara Research Center, The Scientific and Technical Research Council of Turkey (TUBITAK)

Massachusetts Institute of Technology, USA (MIT)

Nanyang Technical University, Singapore (NTU)

National Aeronautics and Space Administration, USA (NASA)

National Bureau of Surveying and Mapping, China (NBSM)

National Center for Atmospheric Research, UCAR, USA (NCAR)

National Geodetic Survey, USA (NGS)

National Geography Institute, South Korea (NGI)

National Geophysical Research Institute, India (NGRI)

National Imagery and Mapping Agency, USA (NIMA)

National Institute in Geosciences, Mining, and Chemistry (INGEOMINAS), Colombia (INGM)

National Oceanic and Atmospheric Administration, USA (NOAA)

National Science Foundation, USA (NSF)

Natural Resources of Canada (NRCan)

Observatoire Royal de Belgium, Belgium (ROB)

Olsztyn University of Agriculture and Technology, Poland (OUAT)

Onsala Space Observatory, Sweden (OSO)

Pacific Geoscience Center, Geological Survey of Canada, NRCan, Canada (PGC)

Proudman Oceanographic Laboratory, UK (POL)

Real Instituto y Observatorio de la Armada, Spain (ROA)

Research Institute of Geodesy, Geodetic Observatory Pecny, Czech Republic (RIG)

Royal Greenwich Observatory, UK (RGO)

Royal Jordanian Geographic Center (RJGC)

Russian Academy of Sciences (RAS)

Russian Data Archive and Analysis Center, Russia (RDAAC)

School of Ocean and Earth Science and Technology, University of Hawaii, USA (SOEST)

Scripps Orbit and Permanent Array Center, Scripps Institution of Oceanography, USA (SOPAC)

Shanghai Astronomical Observatory, China (SAO)

Southern California Integrated GPS Network, USA (SCIGN)

Space Research Center of the Astrogeodynamical Observatory, Poland (SRC-PAS)

Statens Kartverk, Norwegian Mapping Authority, Norway (SK)

Survey of Israel (SOI)

Technical University Munich (TUM)

United States Naval Observatory, USA (USNO)

United States Geological Survey, USA (USGS)

University Consortium for Atmospheric Research, USA (UCAR)

University Federal de Parana, Brazil (UFPR)

University Navstar Consortium, USA (UNAVCO)

University of Bonn, Germany (UB)

University of Colorado at Boulder, USA (CU)

University of Nevada at Reno, USA (UNR)

University of Newcastle on Tyne, UK (NCL)

University of Padova, Italy (UPAD)

Western Pacific Integrated Network of GPS, Japan (WING)

Wuhan Technical University, China (WTU)

IGS ANNUAL REPORT

Governing Board

Member	Institution and Country	Functions	Term*
Christoph Reigber	GeoForschungsZentrum Potsdam, Germany	Chair, Appointed (IGS)	1999–2002
Gerhard Beutler	University of Bern, Switzerland	Appointed (IAG)	—
Mike Bevis	University of Hawaii, USA	Appointed (IGS)	1998–2001
Geoff Blewitt	University of Nevada, USA	Analysis Center Representative	1998–2001
Claude Boucher	Institut Géographique National, ITRF, France	IERS Representative to IGS	—
Carine Bruyninx	Royal Observatory, Belgium	IGS Representative to the IERS	2000–2003
John Dow	ESA/European Space Operations Center, Germany	Network Representative	2000–2003
Bjorn Engen	Norwegian Mapping Authority	Network Representative	1998–2001
Joachim Feltens	ESA/European Space Operations Center, Germany	Ionosphere Working Group Chair	1999–2000
Remi Ferland	Natural Resources Canada	IGS Reference Frame Coordinator	1999–2000
Gerd Gendt	GeoForschungsZentrum Potsdam, Germany	Troposphere Working Group Chair	1999–2000
Tom Herring	Massachusetts Institute of Technology, USA	IAG Representative	—
John Manning	Australian Survey and Land Information Group	Appointed (IGS)	2000–2003
Angelyn Moore	Jet Propulsion Laboratory, USA	Secretariat	—
Ruth Neilan	Jet Propulsion Laboratory, USA	Director of IGS Central Bureau	—
Carey Noll	NASA Goddard Space Flight Center, USA	Data Center Representative	1998–2001
Paul Paquet	Royal Observatory of Belgium	FAGS Representative	—
Jim Ray	U. S. Naval Observatory, USA	Precise Time Transfer Project Chair	1999–2001
Markus Rothacher	Technical University of Munich, Germany	Analysis Representative	2000–2003
Robert Serafin	National Center for Atmospheric Research, USA	Appointed (IGS)	1998–2001
Jim Slater	National Imagery and Mapping Agency, USA	GLONASS Pilot Project Chair	2000–2001
Tim Springer	University of Bern, Switzerland	Analysis Center Coordinator	1999–2000
Michael Watkins	Jet Propulsion Laboratory, USA	Low-Earth Orbiter Working Group Chair	1999–2000
Robert Weber	University of Bern, Switzerland	Analysis Center Coordinator	2000–2002
Jim Zumberge	Jet Propulsion Laboratory, USA	Analysis Representative	2000–2003

Former Member	Institution and Country	Service
Yehuda Bock	Scripps Institution of Oceanography, USA	1994–1999
Martine Feissel	International Earth Rotation Service, France	1994–1995
Teruyuki Kato	Earthquake Research Institute, University of Tokyo, Japan	1994–1995
Jan Kouba	Natural Resources Canada	1994–1999
Gerry Mader	National Geodetic Survey, National Oceanic and Atmospheric Administration, USA	1994–1997
Bill Melbourne	Jet Propulsion Laboratory, USA	1994–1999
Ivan Mueller	Ohio State University, USA	1994–1999
David Pugh	Southampton Oceanography Center, UK	1996–1998
Bob Schutz	Center for Space Research, University of Texas–Austin, USA	1994–1997
Pascal Willis	Institut Géographique National, France	1999

* Current terms are four years for elected members and two years for working group or project chairs. Terms are from 1 January–31 December.

2000

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The IGS GOVERNING BOARD 2000

Christoph Reigber

GeoForschungsZentrum Potsdam, Germany

Chair, IGS Governing Board

Over the past year, the IGS again experienced great success in many areas. The IGS continues to thrive as new applications emerge and fundamental IGS systems and processes continually improve. This vitality is due to the concerted efforts; of each of our contributing organizations and individuals. On behalf of the Governing Board, I would like to sincerely thank each contributor.

The year 2000 was also a new experience for the Board, beginning with important changes in membership. December 1999 saw the departure of Ivan Mueller, Bill Melbourne, Jan Kouba, and Yehuda Bock. Each of these individuals had been members of the Board since the inception of the IGS and their collective talents greatly helped to shape the organization.

The main activities this past year addressed by the Governing Board include the development of a strategic plan for the IGS for the coming years and a focus on IGS working group activities.

IGS Strategic Planning Summary

With the tremendous growth of IGS and an increase in demanding applications, the Board appointed a planning committee in June to coordinate a strategic planning process for the IGS. The IGS is mature and diverse enough to warrant a close look at the organization's focus over the next five years, how to achieve the key goals and objectives that are identified, and how best to continue the success and benefits accomplished to date. The Governing Board is committed to completing the IGS strategic plan in 2001.

The planning group approved by the Board includes:

- Norman Beck, Natural Resources Canada
- Gerhard Beutler, University of Bern, Switzerland
- John Manning, Australian Survey and Land Information Group
- Bill Melbourne, Jet Propulsion Laboratory, California Institute of Technology
- Angelyn Moore, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology
- Ivan Mueller, Professor Emeritus, Ohio State University

- Ruth Neilan, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology
- Jim Ray, United States Naval Observatory
- Christoph Reigber, GeoForschungsZentrum Potsdam
- Robert Serafin, National Center for Atmospheric Research

The strategic plan discussions resulted in a broadening of the stated missions of the IGS.

The Central Bureau retained an excellent planning consultant, Haig Bazoian, to facilitate the strategic planning process.

The planning committee was involved in preparation of materials with Bazoian throughout the summer of 2000, and met as a smaller group at Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt during early September. This initial meeting was a two-day session aimed at preparing material for a retreat with the entire Governing Board in December. The main points discussed were the strengths and challenges of the IGS, the three most important strategies that should be adopted, the IGS mission, and long-term objectives. This preliminary material was distributed to the Governing Board in October. Additional input was solicited from each Board member and we met as a large group in Napa Valley, California, on 12–13 December, just prior to the AGU. Additional invitees to this meeting were Werner Gurtner (Astronomical Institute, University of Bern/AIUB), Gordon Johnston (RACAL), David Simpson (Incorporated Research Institutions for Seismology/IRIS), and Pascal Willis (Institut Géographique National/IGN).

This was a very good meeting with refinement of the strategies and identification of actions that need to be taken over the next few years. The next steps are to complete the meeting summary and develop the draft document of the strategic plan by March. The Governing Board plans its next meeting in conjunction with the European Geophysical Society (EGS) in Nice, France, on 25 March 2001. The document will be reviewed and the IGS hopes to make a future presentation to the International Association of Geodesy (IAG) Executive Committee and gain approval of the plan.

The strategic plan discussions resulted in a broadening of the stated missions of the IGS specifying our "long-term commitment to provide the highest quality global navigation satellite systems data and products," reflecting IGS inclusion of GLONASS and future global navigation satellite systems (GNSS) such as Galileo into the IGS GPS infrastructures.

Much discussion centered on consideration of the establishment of the IGS as an "official" or legal international entity, the benefits of such action, and how this could improve the ability of the IGS to conduct its tasks. Recommitment to IGS participation is envisioned and strategies for stabilizing and acquiring agency sponsorships will be explored.

Two key strategies identified by the Board include that the IGS affirms to continuously provide users with the highest quality, reliable data and products in a readily accessible manner and to achieve worldwide acceptance of IGS products as the "world standard" for data and products — the provider of choice.

These two strategies address the vital interest in keeping the IGS on the leading edge of this technology and encouraging broader recognition and use of IGS data products. This is especially important with regards to the global reference systems and the utility of GPS and GLONASS to provide access to the international terrestrial reference frame. Of course, many other issues and considerations were addressed in addition to these topics. The detailed plan will be will be made available in the next few months.

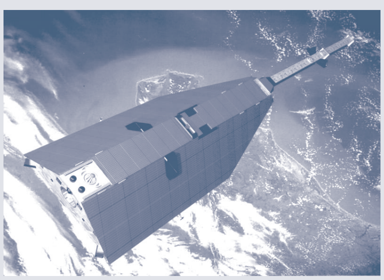
IGS Governing Board Business Meeting Summary

On 14 December, following the two days of strategy meetings, the Governing Board met for its 15th official meeting. The agenda began with a wrap-up of the two-day strategy session, defining the schedule for completing the documents as described above.

A pivotal event this past year was the decision by Tim Springer to resign his position as Analysis Center Coordinator. Tim was able to attend the Governing Board meeting and provided an excellent report on the state of IGS products. He was presented with an IGS certificate of appreciation, noting his long involvement and commitment to the IGS since pre-IGS days. The IGS is most fortunate that Prof. Beutler and his staff at

C H A M P

Challenging Minisatellite Payload



CHAMP is a German small-satellite mission for geoscientific and atmospheric research and applications, managed by Geofor-schungsZentrum (GFZ) Potsdam. Its highly precise, multifunctional, complementary payload elements (magnetometer, accelerometer, star sensor, GPS receiver, laser retroreflector, ion drift meter) and its orbit characteristics (near polar, low altitude, long duration) will generate, for the first time, simultaneous highly precise gravity and magnetic field measurements over a five-year period. The mission will allow detection of the spatial variations of both fields, as well as their variability with time.

The CHAMP mission will open a new era in geopotential research and will become a significant contributor to the Decade of Geopotentials. In addition, with the onboard radio occultation measurements and the infrastructure on the ground, CHAMP will become a pilot mission for the pre-operational use of spaceborne GPS observations for atmospheric and ionospheric research and applications in weather prediction and space weather monitoring. The onboard GPS receiver — the Black Jack or TRSR-2 — was developed by NASA's Jet Propulsion Laboratory.

Missions of importance for new low-Earth orbiting GPS applications include the Argentina–U.S. SAC-C mission (successfully launched from Vandenberg, California, in late November); the U.S.–Germany Gravity Recovery and Climate Experiment (GRACE), scheduled to launch in early 2002; and ESA's Earth Explorer mission, the Gravity Field and Steady-State Ocean Circulation (GOCE) satellite, scheduled to launch in 2006.

the University of Bern were able to provide an excellent candidate as Tim's replacement, Prof. Robert Weber. The Analysis Center representatives and the Governing Board unanimously accepted Robert. This demonstrates Bern's remarkable commitment to complete the next two years of the Analysis Center Coordinator term. Many thanks again to AIUB for this perfect solution. Robert, in his new position, was also welcomed to the Governing Board and will represent the IGS on analysis issues. Tim was congratulated on his new position with wishes for success being expressed by the Board.

The issue concerning data centers for the IGS was also discussed at length, while noting the increased pressure on the data flow and access as a result of IGS sub-daily "ultra" products and moving closer to real-time processes. It was agreed that a solution must be found to ensure redundant capabilities and provide more efficient and timely access by the Analysis Centers to network data. Carey Noll agreed to work with the Analysis Center Coordinator and the Central Bureau to redefine data center requirements and processes. The IGS components and the Governing Board will review this in 2001 in anticipation of acquiring additional data centers and realizing enhancements at our existing data centers.

The remainder of the time was devoted to the IGS working groups and pilot projects. The current projects of the IGS are:

- IGS/BIPM Precise Time and Frequency Project — Jim Ray, U.S. Naval Observatory and Felicitas Arias, Bureau International des Poids et Mesures, Co-Chairs
- LEO Pilot Project — Mike Watkins, Jet Propulsion Laboratory, Chair
- Ionosphere Working Group — Joachim Feltens, European Space Operations Center, Chair
- Atmosphere Working Group — Gerd Gendt, GeoForschungsZentrum, Chair
- Reference Frame Working Group — Remi Ferland, Natural Resources Canada, Chair
- International GLONASS Service Pilot Project (IGLOS PP) — Jim Slater, National Imagery and Mapping Agency, Chair

According to IGS policy, each working group must be reviewed every two years to determine its status and continuance or dissolution of the activity. The IGS/BIPM timing project had been extended through 2001 previously, and the IGLOS-PP was approved at the June meeting of the Governing Board. All groups provided an update and it was decided to continue the working groups, with additional technical and organizational details to be considered at the next Board meetings. Reports on the progress of these groups are contained in the IGS Annual Report and in the Technical Reports. Progress is described generally in the IGS Report series or details may be obtained via the IGS website (*http://igscb.jpl.nasa.gov*). The organizational meeting of the IGS LEO Project will take place on 6–8 February at GFZ Potsdam; for more information, visit *http://op.gfz-potsdam.de/D1/LEOW/LEOW_index.html*.

The Central Bureau noted that, due to budgetary challenges, the finalization of the 1999 report series had been delayed since midsummer, but should be completed very soon, with electronic versions becoming available first.

Mike Bevis and I discussed the formalization of a working group on sea-level monitoring with continuous GPS measurements at tide gauges and tide gauge benchmarks. This has been a "seed" initiative of the IGS since the joint Permanent Service for Mean Sea Level (PSMSL)/IGS "Workshop on Methods for Monitoring Sea Level" in 1997 (see the proceedings, subtitled GPS and Tide Gauge Benchmark Monitoring and GPS Altimeter Calibration, in the "Publications" section at the IGS website). A proposal will be prepared for the next meeting of the IGS Governing Board. Mike is the responsible chair for the International Association for the Physical Sciences of the Ocean (IAPSO) Commission on Mean Sea Level and Tides and has established a website to further discussion of this activity at *http://www.soest.hawaii.edu/cgps_tg*. The Sea Level Change Project (SEAL), carried out by

Important IGS-related events and influences in 1999 and 2000.

1999	9–11 March	Low-Earth Orbiter Workshop, Potsdam, Germany
	8–10 June	Analysis Center Workshop, La Jolla, California
	July	International Union of Geodesy and Geophysics General Assembly, Birmingham, UK
	27 July	12th IGS Governing Board Meeting, Birmingham, UK
	August	IGS Adopts ITRF97
	15 August	GPS Week Roll-over
	13 December	13th IGS Governing Board Meeting
2000	January	Call for Participation in IGS Low-Earth Orbiter Project announced
	20 February	IGS reference frame products initiated
	27 February	IGS final orbits aligned to IGS realization of ITRF
	March	IGS Tutorials in Cape Town and Hartebeesthoek, South Africa
	27 April	AFREF Planning Meeting, Nice, France
	2 May	Selective Availability – removed!
	June	14th IGS Governing Board Meeting, USNO, Washington, DC
	12–14 July	IGS Network Workshop, joint with COST 716: "Towards Operational Meteorology," Oslo, Norway
	15 July	Successful CHAMP launch
	13–14 September	IGS Strategic Planning Committee meets in Frankfurt, Germany
	19–22 September	Institute of Navigation GPS2000 Annual Meeting, Salt Lake City, Utah; IGS User Forum conducted
	25–29 September	IGS Analysis Center Workshop, USNO; two days devoted to the IGS-BIPM Precise Time Transfer Project
	12 October	IGS Presentation and Exhibit at INTERGEO, Berlin, Germany
	November	IGS ultrarapid products initiated; predicted products discontinued
	21 November	Successful SAC-C Launch
	12–13 December	Strategic Planning Meeting, Napa Valley
	14 December	15th IGS Governing Board Meeting

a number of German research institutions — GeoForshungsZentrum Potsdam (GFZ), GKSS Research Center Geesthacht (GKSS), and Alfred Wegener Institute for Polar and Marine Research (AWI). The project will put a concerted effort into GPS monitoring of global tide gauges. An introduction to the complete program can be found at *http://op.gfz-potsdam.de/seal/*. Additional recommendations at the meeting were to form two additional committees, reinstate the Infrastructure Committee, and create a new IGS Real-Time Working Group.

The next meeting of the Governing Board is scheduled for 25 March 2001 in Nice, France, during the 26th General Assembly of the EGS.

One further note — it was decided to plan the next IGS workshop based on a theme as opposed to having separate analysis and network workshops. This is tentatively planned for early in 2002. Proceedings from the Network Workshop in Oslo in July 2000 and the Analysis Center Workshop at U.S. Naval Observatory in September will be published and available in spring 2001. The Network Workshop proceedings will be published by Elsevier in the peer-reviewed journal publication *Physics and Chemistry of the Earth*; the Analysis Center Workshop proceedings will be published by the GPS *Solutions* journal.

Central Bureau STATUS 2000

Ruth E. Neilan

Jet Propulsion Laboratory, California Institute of Technology, USA

Director, IGS Central Bureau

After the quiet and uneventful passage of "Y2K," the year 2000 for the Central Bureau was marked by significant outreach for the IGS organization, as described below. The IGS exhibit display and materials were completely redesigned to reflect the continuous IGS technical advancements and growth of projects. The exhibit is easily transportable and quite cost effective. The IGS tutorial, first developed in 1999 for the International Symposium on GPS (GPS99 Tsukuba) was revised, updated, and integrated into a single document available both as hardcopy and via the IGS website. The tutorial is an important tool for promoting the straightforward use of IGS data and products and outlines the IGS conventions as the accepted international standard.

A key task of the Central Bureau was the support for the organization of the IGS strategic planning committee, as addressed by Christoph Reigber in this Annual Report. The Central Bureau worked to prepare materials with the very experienced facilitator, Haig Bazoian, to organize interim documents, as well as managing the logistics for the various meetings of the planning groups and the Governing Board throughout the year. One of the factors resulting from the planning process is a critical consideration of the organization, staffing, and resources of the Central Bureau, and how this should be structured to properly support the IGS in the future. Resource issues of the Central Bureau delayed the publications of the 1999 and 2000 report series; however, the issues have largely been resolved at present and these important annual records should resume normal preparation and publication schedules.

The Central Bureau was very much involved in the preparation of the Call for Participation in the Low-Earth Orbiter (LEO) Pilot Project, as described in the reports by Christoph Reigber and Mike Watkins (this Annual Report). This is an IGS project with appropriate structure involving every component of the IGS (station, data centers, analysis centers, etc.). This activity is expected to have a significant effect on the IGS and to bring substantial enhancements technically and in terms of broadening partnerships.

IGS Outreach and Tutorial

The new IGS booth was first displayed in March 2000 at Cape Town, South Africa, at the 28th International Symposium on Remote Sensing of the Environment entitled "Information for Sustainable Development." The IGS sponsored a tutorial during the venue of this symposium hosted by Richard Wonnacott, Director of Survey Services, Chief Directorate of Surveys and Mapping, and Prof. Charles Merry, University of Cape Town. The following week, the tutorial was again offered outside of Johannesburg at the Hartebeesthoek Radio Astronomy Observatory (HARTRAO) hosted by Ludwig Combrinck. HARTRAO is recognized as a fundamental station for geodetic positioning, where a number of techniques are collocated: very long baseline interferometry (VLBI), Global Positioning System (GPS), satellite laser ranging (SLR), and precise range and range-rate experiment (PRARE). The tutorial was well received in both locations and there was valuable feedback from attendees for making the IGS products more accessible to the user community. The IGS tutorial and product details were updated after the removal of selective availability on 2 May.

Expanding Partnership of IGS

The Chinese Seismological Bureau (CSB) is the designated project head for the Crustal Motion Observation Network of China (CMONOC), a newly implemented state-of-the-art national GPS network collocated with their existing seismic network. The CMONOC sent a letter to the Governing Board outlining their intention to participate in the IGS. The Governing Board responded very favorably to this with hopes to develop significant collaboration with CMONOC and its contributing organizations, while pursuing an open data policy as advocated by IGS values. Discussions with the CSB took place in China during January, where the U.S. National Science Foundation coordinators delegation negotiated the renewal of the 20-year U.S.–China protocol agreement on earthquake science research.

AFREF

A meeting on developing and implementing an African Reference System (AFREF), was held in Nice, France, organized by Claude Boucher as head of the International Association of Geodesy (IAG) Commission X devoted to Global and Regional Geodetic Networks. About 13 people attended, including representatives from and United Nations Food and Agricultural Organization (UN–FAO), the IGS Central Bureau, the Norwegian Mapping Authority, the European Reference Frame (EUREF), Sistema de Referencia Geocéntrico para América del Sur (SIRGAS), and the U.S. National Imagery and Mapping Agency. Lamentably, none present were African due to the ad hoc nature of the meeting. A meeting is expected to occur in Africa to encourage broad-based African participation in generating a project plan and structure. An e-mail list service was subsequently established by the Central Bureau to facilitate contacts between IAG, IGS, Africans, and people from the global community interested in such an activity. The IGS and International Earth Rotation Service (IERS), as IAG services and with IAG endorsement, have pledged strong support. It was noted that GPS is a truly viable and sustainable technology that can be adopted by the African organizations and maintained in the future for continental and national infrastructures. The Central Bureau has been invited to the Congress on South African Surveyors Meeting (CONSAS) to be held in March 2001 in Cape Town where an AFREF planning meeting will be conducted. A regional realization based on IGS conventions may be the more practical approach given the numerous nations within Africa and the extensive infrastructure of the IGS. A previous activity known as ADOS (African Doppler Survey) was initiated in 1981 and based on the TRANSIT satellite system. This was organized within the IAG International Coordination of Space Techniques of Geodesy and Geodynamics (CSTG), in cooperation with the IAG Commission for Geodesy in Africa.

International Geodynamics Research Center in Kyrgyz Republic

In June 2000, a dedication of the International Research Center–Geodynamic Proving Ground (IRC-GPG), took place in Bishkek, Kyrgyz Republic, followed by a four-day workshop on the geodynamics of the Tien Shan. This occasion was to dedicate new facilities collocated with the scientific station research facility of the Institute of High Temperatures, Russian Academy of Sciences (IVTAN). It was well attended by the international science community. The purpose of the new center is to facilitate not only regional but international collaborative research in geodynamics. Since 1992, a GPS network has been established through collaborations with Indiana University and Massachusetts Institute of Technology, consisting of more than 300 stations in the region and an impressive nine-station permanent GPS network. Two of these stations are recognized as global stations of the IGS and therefore of great importance for analysis and global network stability. One of these is located at IRC-GPG and known as the Poligan GPS station, and one is at Selezaschita, Almaty, Kazakhstan. A subsequent geological field trip included exploring various locations, some measured by GPS, revealing the intriguing geology and spectacular beauty of the Tien Shan region. The facility was the vision of Yuri Trapeznikov, former director of the IVTAN scientific station. The IRC-GPG was presented an IGS certificate of appreciation for outstanding contributions. For more information on this center and its activities, see *http://tiger.gdirc.ru/irc/* or *http://helios.gdirc.ru/*.

Workshops

Network Workshop

The second major IGS Network Workshop was hosted by the Norwegian Mapping Authority, 10–14 July 2000 in Oslo, Norway. The purpose of this workshop was to focus on aspects of the network targeted at improving the infrastructure and network operations in support of the quality and timeliness of IGS products. Angelyn Moore, IGS Network Coordinator and Deputy Director of the IGS Central Bureau at the Jet Propulsion Laboratory in Pasadena, California, convened this workshop, which was considered a great success by all who attended. The local organization and logistics were excellently managed by the Norwegian Mapping Authority's Hans-Peter Plag, within the Geodesy Division under the direction of Bjorn Engen, a member of the IGS Governing Board. The workshop was held at the beautiful Soria Moria Hotel on a hill overlooking Oslo and provided a unique atmosphere enjoyed by all, which will be long remembered.

The new center will faciliate regional and international collaborative research in geodynamics.

This was the first occasion that the IGS Network Workshop was convened as a multidisciplinary meeting. It was co-organized with "COST Action 716"– "European Cooperation in the Field of Scientific and Technical Research." Action 716 is "Exploitation of Ground-Based GPS For Climate and Numerical Weather Prediction Applications." COST is a framework for scientific and technical cooperation, allowing the coordination of national research on a European level. The main objective of COST 716 is assessment on an international scale of the operational potential for exploiting ground-based GPS networks to provide near-real-time observations for numerical weather prediction and climate applications. In parallel, the IGS has a dedicated Troposphere Working Group estimating total zenith path delays (ZPD) and precipitable water vapor (PWV) at a number of the IGS stations (see Gerd Gendt's report in this Annual Report). Also, a number of the IGS agencies and their networks have either implemented or are moving towards real-time processing activities, many pursuing similar applications in terms of ground-based meteorology.

The Network Workshop proceedings were published in the peer-reviewed journal publication *Physics and Chemistry of the Earth* by Elsevier.

Analysis Center Workshop and IGS/BIPM Precise Time and Frequency Project

The IGS Analysis Center Workshop 2000 was held in September at the U.S. Naval Observatory, where Jim Ray and his USNO Earth Orientation Department colleagues did an outstanding job in organizing and hosting this superb workshop. This was a very good occasion for many interesting presentations and fruitful discussions. The first two days were devoted to the IGS/BIPM Timing Project (see Jim Ray's account in this Annual Report). The remaining days focused on IGS near-real-time products and their applications, and the potential interactions between the IGS and various global navigation satellite systems (GNSS), e.g., GPS, Galileo, and GLONASS. A subset of the presented papers was published as a special issue of the journal *GPS Solutions*.

The next IGS workshop will be based on the theme "Towards Real-Time" and will be hosted by the Natural Resources Canada Geodetic Division. This will be a comprehensive IGS workshop addressing all components, projects, and working groups. It is planned for early 2002.

The IGS station at Kellyville (Kangerlussuaq), Greenland. (Photo courtesy of Oivind Ruud, UNAVCO)

Angelyn W. Moore

Jet Propulsion Laboratory, California Institute of Technology, USA

IGS Network Coordinator and Deputy Director, IGS Central Bureau

Growth of the IGS NETWORK in 2000

The IGS network of permanent dual-frequency GPS tracking stations formed by the cooperative efforts of the IGS site-operating agencies welcomed the addition of 25 sites in 2000. This set includes sites that improve coverage in important areas such as Central America, Africa, northern Asia, and the Middle East, as well as desirable collocations with other geodetic techniques.

The complete network distribution at the end of 2000, which totalled 248 stations, is depicted in Figure 1. Stations added to the network in 2000 are emphasized by large circles. Of the stations in the complete network, 92 (shown in Figure 2) earned the "Global" classification for being regularly analyzed by at least three Analysis Centers (one on a continent other than that of the station). The data center report in this Annual Report notes that the number of sites participating in the hourly data subnetwork grew to more than 70.

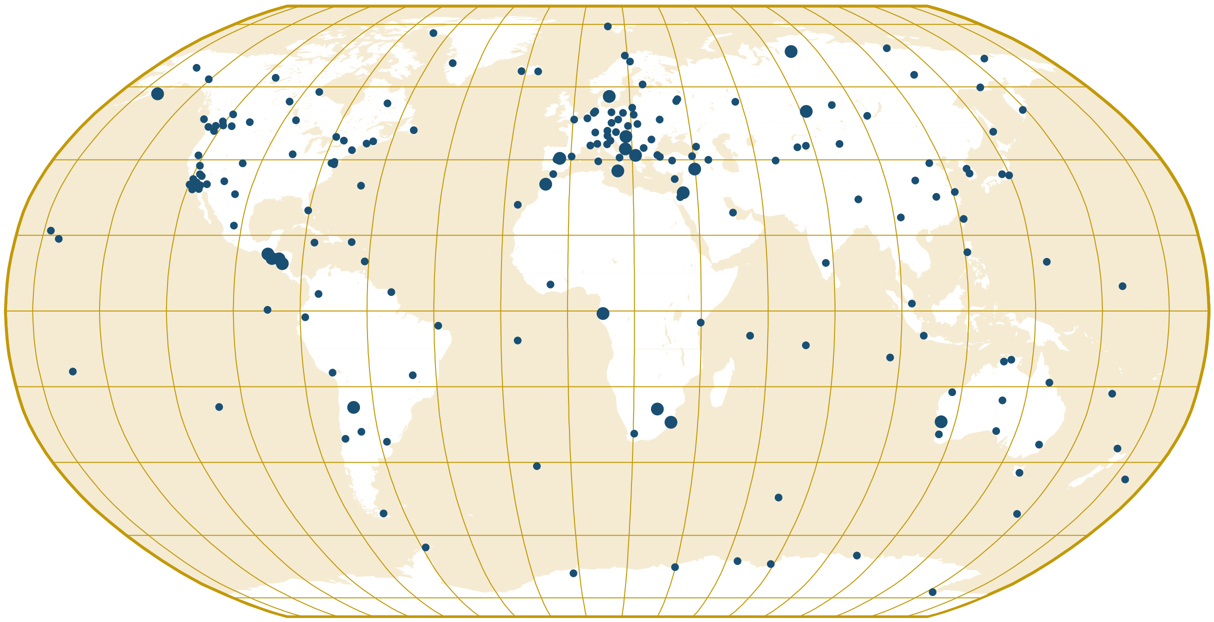


Figure 1. The IGS network at the end of 2000. New stations in 2000 are indicated by the larger circles.

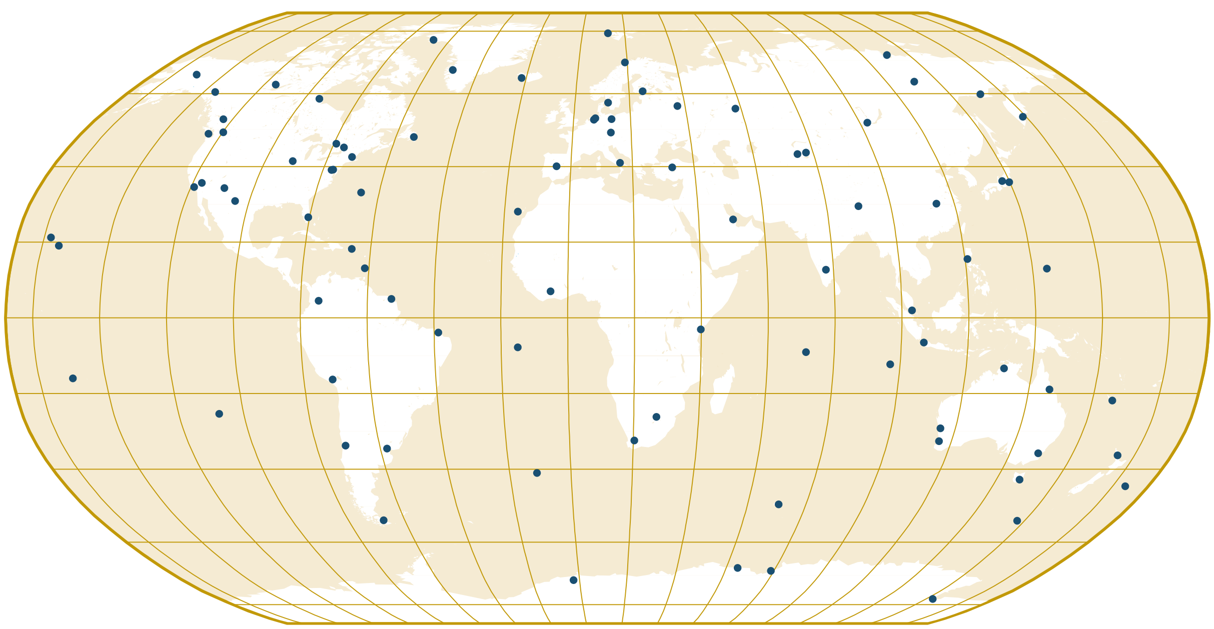


Figure 2. IGS Global stations at the end of 2000.

2000 Oslo Network Workshop

The workshop and its expert local organizers from the Norwegian Mapping Authority have already been lauded in the Central Bureau article in this Annual Report. Another highlight was the selection of “On Hourly Orbit Determination” by Jan Dousa and Leos Mervart of the Research Institute of Geodesy, Topography, and Cartography in the Czech Republic for the best poster of the joint meeting. A committee comprising representatives of the IGS and COST Action 716 considered all the posters and was pleased to see Dousa, as first author, presented with two Locus GPS receivers generously donated by Ashtech as a prize. The productivity of the entire event is apparent in the *Proceedings*, available as a special issue of *Physics and Chemistry of the Earth*, Part A, vol. 26, no. 6–8, published by Elsevier Science. Coordinating editor Hans-Peter Plag, fellow IGS guest editors Mark Caissy and Ludwig Combrinck, the COST Action 716 team, and each author made the production of this document a pleasure and an education. This peer-reviewed, indexed journal probably represents the deepest penetration of a collection of IGS network articles into the world’s libraries to date.

Network Coordination

The well-publicized Y2K rollover was readily handled by the IGS. Indeed, the new Central Bureau server installed to handle the rollover enabled enrichments such as self-service subscription management for the IGS e-mail lists. Many users welcomed a noticeable improvement in response time.

Following the near-eradication of station metadata errors in calendar 1999, automatic quality audits of site logs and Receiver-Independent Exchange (RINEX) observation data file headers were increased to twice weekly. In this maintenance mode, station operators are notified by targeted e-mail should a metadata error be inadvertently introduced by equipment or software changes. This system continues to maintain near-zero metadata error rates with minimal human effort and has enabled the long-envisioned Software-Independent Exchange (SINEX) combination and consistency of all products in the IGS realization of the International Terrestrial Reference Frame (ITRF).

Looking Ahead

The expanding usage of the IGS network into new applications brings requirements for the collection and dissemination of such metadata. In late 2000, a revised site log template supporting global navigation satellite system (GNSS) equipment other than GPS was drafted, in anticipation of incorporating GLONASS stations into the IGS network. This provided an opportunity to also improve the collection of site eccentricity information, describing the spatial relation between a geodetic marker and a GPS antenna, and other geophysical information regarding each site. When reviewed and adopted, the new log format will allow the Central Bureau to provide increased and standardized station information to the user community.

ANALYSIS

Activities

The generation of more frequent IGS products for near-real-time use is an urgent need.

Robert Weber

and

Tim Springer

Astronomical Institute,

University of Bern,

Switzerland

Analysis Center Coordinator

In September 2000, the IGS Analysis Center Workshop was held at the U.S. Naval Observatory in Washington, D.C. Current progress in carrier phase time transfer and the realization of an internal IGS time scale had been identified as major goals for this meeting. Furthermore, as proposed in a position paper by G. Gendt, et al., the year before (1999 IGS Technical Report, Section 7), IGS products have to move towards real-time availability. Thus, this workshop discussed the quality of the recently implemented ultrarapid products as well as their applications; e.g., for the derivation of ground-based GPS meteorological parameters used in numerical weather prediction. Another important session on global navigation satellite system (GNSS) operations considered the potential interactions between the IGS and various GNSS systems (GPS, GLONASS, and Galileo). For more detailed information, see the workshop proceedings or IGS Mail message no. 3057.

Table 1. Quality of the IGS Reference Frame Products as of March 2001. (For details, see http://igscb.jpl.nasa.gov/components/prods.html.)

Products:	Predicted*	Ultrarapid	Rapid	Final	Units
Delay:	Real Time	Real Time	17 hours	13 days	
Orbit	50.0	25.0	5.0	<5.0	centimeters
Clock	150.0	5.0	0.2	0.1	nanoseconds
Polar Motion	—	—	0.2	0.1	milliarcseconds
LOD	—	—	30.0	20.0	microsec/day
Station Position h/v**	—	—	—	3.0 h / 6.0 v	millimeters (mm)
Troposphere	—	—	—	4.0	mm zenith path delay

*Delivery of IGS-predicted (IGP) products terminated in March 2001; the ultrarapid products, available twice daily, include the predicted orbits.
**Horizontal/vertical.

Current IGS and Analysis Center Product Quality

The primary objective of the IGS is to provide a reference system for a wide variety of GPS applications. To fulfill this role, the IGS produces a large number of different combined products that constitute the practical realization of the IGS reference system. Table 1 gives a brief overview of the estimated quality of these different IGS reference frame products at the beginning of the year 2001.

The quality improvement of the IGS products since 1994 is demonstrated in Figure 1, which shows the weighted orbit rms (wrms) for the final Analysis Center solutions with respect to the combined IGS final orbit products. Several Analysis Centers and also the IGS rapid orbit products have reached the 3–4-centimeter orbit precision level. Similar levels of accuracy are indicated by the IGS 7-day arc orbit analysis and by comparisons with satellite laser ranging (SLR) observations of the GPS satellites PRN 5 and 6 equipped with SLR retroreflectors. The enormous efforts and the resulting improvements of the Analysis Center global solutions are also indicated in Table 2, where the yearly averages of weighted orbit RMS values are given for all Analysis Centers and the IGS rapid orbit (IGR).

In October 1999, the first Analysis Center (GFZ) provided the new ultrarapid products. These products, which will be delivered every 12 hours, will contain a 48-hour orbit arc from which 24 hours are real orbit estimates and 24 hours are orbit predictions. The latency of this product is 3 hours. The generation of a combined ultrarapid product (IGU) started in March 2000 based on contributions from up to five different Analysis Centers. This product has been made available for real-time usage, like the IGS predicted orbits (IGP), but the quality is significantly better because the average age of the predictions is reduced from 36 to 9 hours. During the next months, the quality and the reliability of the IGS ultrarapid orbits were compared to the IGS predicted and the IGS rapid products.

Figure 1. Weighted orbit rms (centimeters) of the Analysis Center and IGS rapid (IGR) orbit solutions with respect to the IGS final orbits.

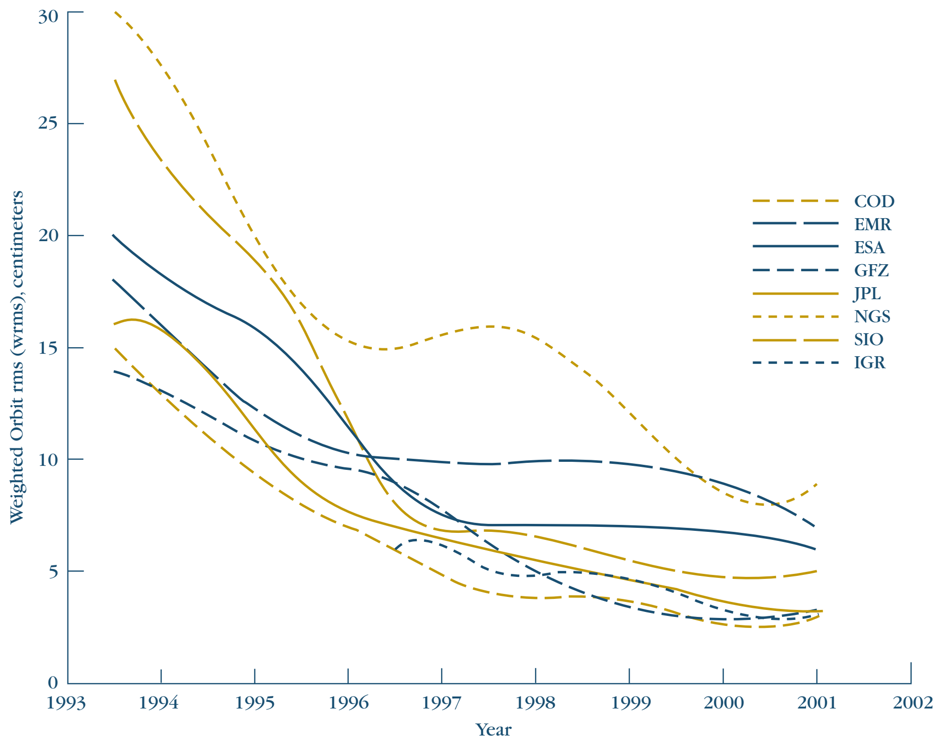


Table 2. Yearly Average Weighted Orbit rms (cm) of the Analysis Center and IGS Rapid (IGR) Orbit Solutions with Respect to the IGS Final Orbits

Year	COD	EMR	ESA	GFZ	JPL	NGS	SIO	IGR
1994	11	14	17	12	14	32	21	—
1995	8	10	14	10	9	17	16	—
1996	6	10	9	9	7	15	8	6
1997	4	10	7	6	6	16	7	5
1998	4	10	7	4	5	14	6	5
1999	3	10	7	3	4	9	5	4
2000	3	7	6	3	3	9	5	3

COD = Center for Orbit Determination in Europe, University of Bern, Switzerland
EMR = Geodetic Resources Division, Natural Resources Canada, Ottawa, Canada
ESA = European Space Operations Center, European Space Agency, Darmstadt, Germany
GFZ = GeoForschungsZentrum Potsdam, Germany
JPL = Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA
NGS = National Oceanic and Atmospheric Administration/National Geodetic Survey, Silver Spring, Maryland, USA
SIO = Scripps Institution of Oceanography, University of California, San Diego, California, USA
IGR = IGS Rapid

Figure 2 shows the consistency of individual orbit submissions at the 25-centimeter level during the second half of 2000. In November 2000, the ultrarapid products became an official IGS product and subsequently the submission of predicted orbits was terminated in March 2001 (Wk 1105). Currently seven different Analysis Centers deliver contributions to the ultrarapid products.

A new station and satellite clock combination, based on the Receiver-Independent Exchange (RINEX) clock format, was implemented in November 2000. This combination provides the normal combined satellite clocks in the orbit (SP3) format and also provides both satellite and station clocks in the RINEX clock format. These clock products have a sampling rate of 5 minutes, compared with 15 minutes in SP3-formatted files. Some Analysis Centers provide even higher sampled clock products; e.g., JPL provides clocks with a sampling rate of 30 seconds. The new clock combination is distinguished by the high quality of the provided clocks and it has improved the robustness of the combination process tremendously.

Outlook

The presently active and upcoming low-Earth orbit (LEO) missions have the potential to fundamentally change the IGS as we know it today. It is therefore necessary that the IGS take an active role in this field in order to maintain its position as the service that delivers the reference system for all GPS applications. In this context, the generation of more frequent IGS products for near-real-time use is an urgent need. Therefore, the IGS workshop, "Towards Real-Time," to be held in Ottawa in early 2002 is dedicated to real-time requirements and IGS real-time products. In addition to these efforts, the workshop will deal with the remarkable progress achieved by the various IGS project groups within the past two years.

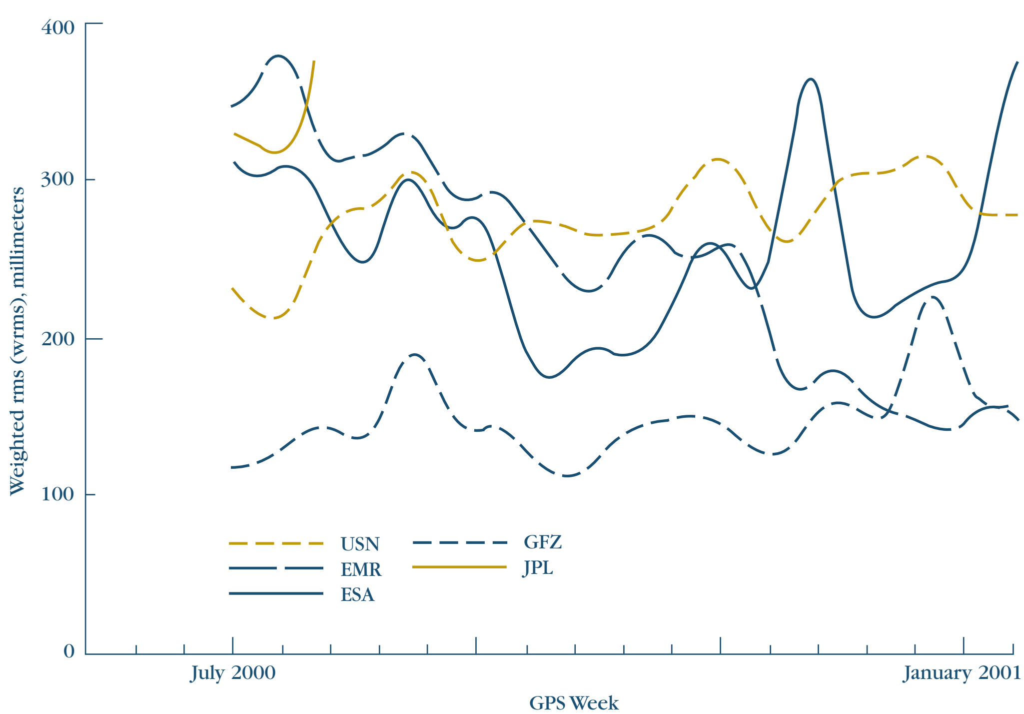


Figure 2. Weighted orbit rms (millimeters) of the individual Analysis Center orbit solutions with respect to the IGS ultrarapid orbits. Values are smoothed, using a 7-day window period: GPS Week 1070–1100 (July 2000–January 2001).

Data Center

ACTIVITIES 2000

Since the inception of the IGS, the archives of the data centers have become increasingly important to a wide range of scientific and research applications. The distributed nature of the data flow supporting the IGS has been key to the successful archive and availability of both IGS data and products. The IGS utilizes a hierarchy of data centers to distribute data from the network of tracking stations: Operational, Regional, and Global Data Centers. This scheme provides for efficient access and storage of GPS data, thus reducing network traffic, as well as a level of redundancy allowing for security of the data holdings.

Carey E. Noll

NASA Goddard Space Flight Center, USA

Manager, Crustal Dynamics Data Information System, IGS Global Data Center

Highlights for 2000 and Plans for 2001

General

The past year was once again a busy time for the IGS data centers. The increased size of the network, both of sites producing daily data sets as well as those capable of generating hourly data sets, challenged the capacities of Global and Regional Data Centers. The timeliness of the hourly data product continued to improve as various levels of the IGS infrastructure reviewed data transmission methods and implemented improvements. However, as the IGS moves more toward supporting near real-time activities, it has become clear that the data centers must take further steps to ensure the reliability of hourly data operations. To achieve this goal, the data centers, particularly the Global Data Centers, will implement schema during early 2001 to ensure timely and redundant availability of the hourly data. Table 1 lists the data centers supporting the IGS in the year 2000; information on how to contact these data centers is available through the IGS Central Bureau website.

Unfortunately, due to personnel reassignments, the Global Data Center at Institut Géographique National (IGN) was not able to fully support IGS activities during 2000. Management at the institute have announced that routine operations, as well as improvements to the data center, can be expected in late 2001.

At the IGS Network Workshop, held in July 2000 in Oslo, Norway, the development and implementation of backup data flow paths were discussed. This workshop focused on identifying areas of improvement in the IGS infrastructure needed to support near real-time operations. Installation of an effective data flow redundancy plan is essential to the current and future directions of the IGS. These plans have yet to be realized within the current IGS infrastructure, but it is hoped that they will be reviewed once IGN is again fully operational.

IGS Data

The IGS data centers continued to expand their archives of data from the IGS network. During the past year, nearly 700 stations were archived daily at Scripps Institution of Oceanography (SIO), supporting both the IGS and other global research activities; nearly 200 at the Crustal Dynamics Data Information System (CDDIS), supporting the IGS, the Southern California Integrated GPS Network (SCIGN), and NASA activities; and over 100 at IGN. GPS data, in both daily and hourly observation, navigation, and meteorological data files, are available from the IGS Regional and Global Data Centers in standard format — compressed Receiver-Independent Exchange (RINEX) format. IGS products, such as precise orbits, station positions, and atmospheric parameters, are also accessible through these data centers.

The global network of IGS sites producing 30-second data on an hourly basis expanded to over 70 sites during 2000, as shown in Figure 1. Hourly files are archived in compressed, compact RINEX format and are retained at the Global Data Centers for 3 days. No validation or checking of data quality is performed on these data in order to provide the files in an immediate fashion to the user community. The daily observation and navigation files from these hourly sites, containing all 24 hours of data, are then transmitted through established data flow paths and archived indefinitely at the data centers. The timeliness of

Figure 1. Subnetwork distribution of IGS stations delivering hourly RINEX data files.

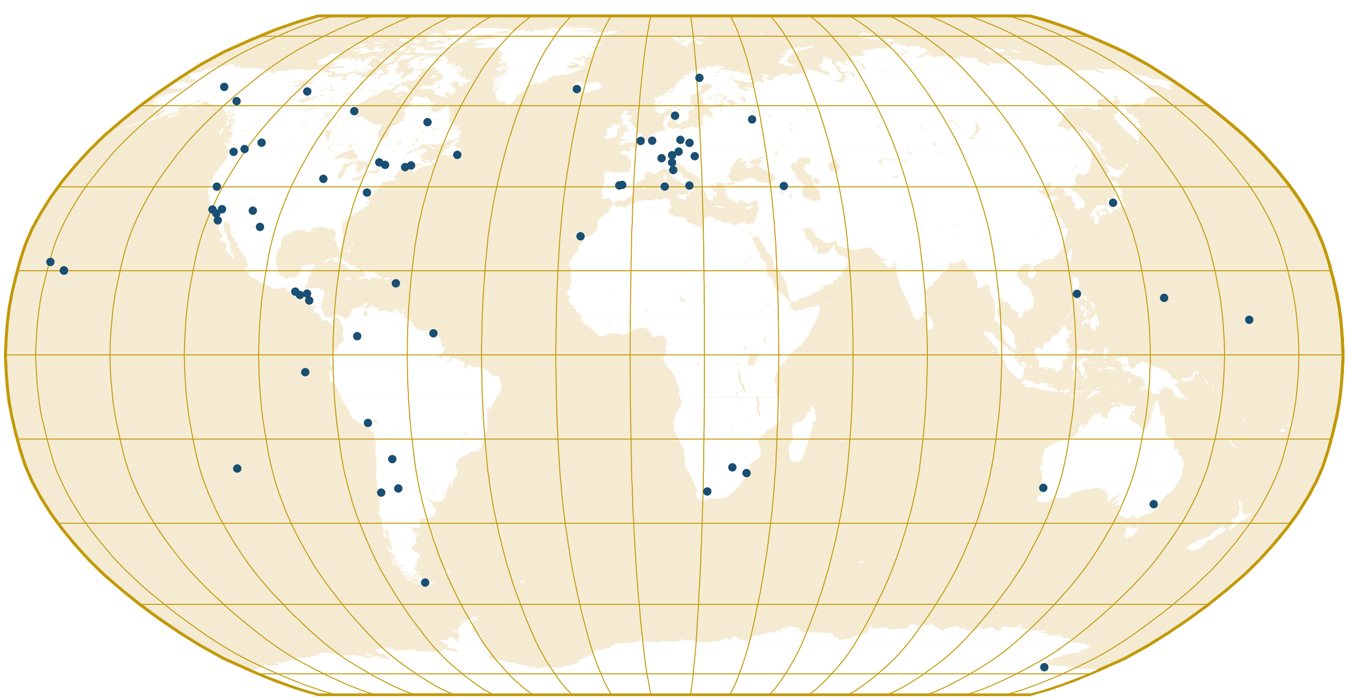


Table 1. Data Centers Supporting the IGS in 2000

	Operational Data Centers
ASI*	Italian Space Agency
AUSLIG	Australian Surveying and Land Information Group
AWI	Alfred Wegener Institute for Polar and Marine Research, Germany
BKG*	Bundesamt für Kartographie und Geodäsie, Germany
CASM	Chinese Academy of Surveying and Mapping
CNES	Centre National d'Études Spatiales, France
DGFI	Deutsches Geodätisches Forschungsinstitut, Germany
DSN*	Deep Space Network, National Aeronautics and Space Administration), USA
DUT	Delft University of Technology, The Netherlands
ESOC*	European Space Agency, Space Operations Center, Germany
GFZ	GeoForschungsZentrum Potsdam, Germany
GSI	Geographical Survey Institute, Japan
ISR	Institute for Space Research, Austria
JPL*	Jet Propulsion Laboratory, California Institute of Technology, USA
KAO	Korean Astronomical Observatory
NGI	National Geography Institute, Korea
NIMA	National Imagery and Mapping Agency, USA
NMA	Statens Kartverk, Norwegian Mapping Authority
NOAA*	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada
PGC*	Pacific Geoscience Center, NRCan, Canada
RDAAC	Regional GPS Data Acquisition and Analysis Center on Northern Eurasia, Russia
SIO	Scripps Institution of Oceanography, USA
UNAVCO	University NAVSTAR Consortium, USA
USGS	United States Geological Survey
	Regional Data Centers
AUSLIG	Australian Surveying and Land Information Group
BKG	Bundesamt für Kartographie und Geodäsie, Germany
JPL	Jet Propulsion Laboratory, California Institute of Technology, USA
NOAA	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada
	Global Data Centers
CDDIS	Crustal Dynamics Data Information System, NASA Goddard Space Flight Center, USA
IGN	Institut Géographique National, France
SIO	Scripps Institution of Oceanography, USA

*Operational Data Center forwarding hourly 30-second data to the IGS.

the hourly data improved during 2000, with 50 percent of the data available within 15 minutes after the end of the previous hour, and 85 percent available within 30 minutes. Efforts to further reduce the time delay of daily and hourly data sets will continue during the coming months.

Not all IGS Global Data Centers had yet begun to provide a timely archive of hourly, 30-second data during 2000. Efforts will begin in 2001 to ensure that these hourly data are available at all IGS Global Data Centers, thus permitting analysts three redundant sources for these critical data sets.

By mid-2001, the International GLONASS Service–Pilot Project (IGLOS-PP) will commence operations. The pilot project is a continuation of the successful 1998–99 International GLONASS Experiment (IGEX-98), the first global GLONASS observation campaign for geodetic and geodynamics applications. IGLOS-PP will see the integration of GLONASS data into the IGS data flow and in the generation of IGS products. Data centers will provide a single point of access for both GPS and GLONASS data sets.

The IGS Pilot Project for Low-Earth Orbiters (LEO) will also begin in mid-2001. Data centers supporting the pilot project will archive data from a network of 30 to 40 high-rate (1-second) sites. These data will be archived in files containing 15 minutes of data. Furthermore, data from GPS flight receivers, particularly Argentina's Satélite de Aplicaciones Cientificas (SAC-C) and the Challenging Mini-Satellite Payload for Geophysical Research and Application (CHAMP), will be made available through IGS data centers supporting the pilot project. An enhanced version of RINEX (version 2.20) will be utilized for the flight receiver data; RINEX version 2.10 will continue to be used for GPS data from the high-rate ground network.

Analysis Centers participating in the LEO-PP will utilize these various data sets to produce orbits for the LEO missions and study the impact on the "classic" IGS products. This pilot project will also help assess the issues involved in future IGS support of occultation analysis.

IGS Products

The products generated by the IGS Analysis Centers, Associate Analysis Centers, and various pilot projects continued to be archived at the IGS data centers and the Central Bureau in 2000. These products include the weekly, standard orbit, clock, station position, and Earth rotation parameters (ERPs) from the seven IGS Analysis Centers and the combined product from the IGS Analysis Coordinator. The accumulated IGR (rapid orbit) and IGP (predicted orbit) products were distributed and archived on a daily basis as well. The Analysis Centers began producing a new ultrarapid analysis product in 2000; the combined product, generated twice daily, is now archived at the IGS data centers. IGS station coordinate and reference frame solutions were routinely provided by seven IGS Associate Analysis Centers as well as a combined solution by the IGS Reference Frame Coordinator. The IGS troposphere product, in the form of combined zenith path delay (ZPD) estimates for over 160 sites, was generated by GeoForschungsZentrum (GFZ) and archived on a weekly basis at the Global Data Centers.

The Analysis Centers began producing a new ultrarapid analysis product in 2000.

Individual ionosphere maps of total electron content (TEC) were derived on a daily basis by five IGS Associate Analysis Centers and archived at the Global Data Centers. A daily file of these data in Ionosphere Map Exchange (IONEX) format includes twelve 2-hour snapshots of the TEC and optional corresponding rms information.

The INTERNATIONAL Terrestrial Reference Frame

Zuheir Altamimi

Institut Géographique National, France

ITRF Section, International Earth Rotation Service

Following its terms of reference, IGS works in close cooperation with the International Earth Rotation Service (IERS). The Product Center of the International Terrestrial Reference System (ITRS) of the IERS, hosted by the Institut Géographique National, cooperates very closely with the different IGS components (Central Bureau, Analysis Centers, and tracking stations) for ITRF station coordinates and analysis of solutions provided by IGS analysis centers as well as site information and local ties of the collocation sites. For more information, see *http://lareg.ensg.ign.fr/ITRF*.

ITRF and IGS Relationship

Since the beginning of the IGS preliminary test activities in 1992, the IGS Analysis Centers have used ITRF coordinates for some subset of stations in their orbit computations. Moreover, the combined IGS ephemerides are expressed in ITRS because the coordinates used by the IGS are based on ITRF91 from the beginning until the end of 1993; ITRF92 during 1994; ITRF93 during 1995 until mid-1996; ITRF94 since mid-1996 until the end of April 1998; ITRF96 starting on March 1, 1998; ITRF97 starting on 1 August 1999, and ITRF2000 in late 2001.

IGS supports the continuous improvement of the ITRF by contributing to the extension of the ITRF network, providing new collocations or by improving position accuracy. The IGS Analysis Centers contribute greatly to ITRF by providing IGS/GPS solutions, which are included in the ITRF combinations.

IGS provides also a very efficient method to densify the ITRF network: one can now obtain millimetric positions directly expressed in ITRS by processing suitable GPS data together with IGS products.

ITRF2000

The ITRF2000 solution is the most dense and accurate frame ever developed, containing about 800 stations located at about 500 sites. It has been achieved by simultaneous combination of positions and velocities using full variance/covariance matrices of the individual solutions provided by the IERS analysis centers. It includes primary core stations observed by very long baseline interferometry (VLBI), lunar laser ranging (LLR), satellite laser ranging (SLR), GPS, and DORIS (usually used in previous ITRF versions), as well as regional GPS networks for its densification (Alaska, Antarctica, Asia, Europe, North and South Americas, and Pacific). Figure 1 shows the distribution of the primary sites of ITRF2000, highlighting the collocated techniques.

The ITRF2000 is intended to have an accurate datum definition, achieved as follows:

- The origin and its rate by a weighted average of most consistent SLR solutions.
- The scale and its rate by a weighted average of VLBI and most consistent SLR solutions. Unlike the ITRF97 scale expressed in the Geocentric Coordinate Time Frame, that of the ITRF2000 is expressed in Terrestrial Time Frame.
- The orientation is aligned to that of ITRF97 at 1997.0 epoch and its rate to be such that there is no-net-rotation rate with respect to NNR-NUVEL-1A. Note that the orientation as well as its rate are defined upon a selection of ITRF sites with high geodetic quality.

The ITRF2000 long-term stability, evaluated over 10 years, is estimated to be better than 4 millimeters in origin and better than 0.5 parts per billion in scale, equivalent to a shift in station heights of approximately 3 millimeters over the Earth's surface.

All the ITRF2000 related files are available at: *http://lareg.ensg.ign.fr/ITRF/ITRF2000*.

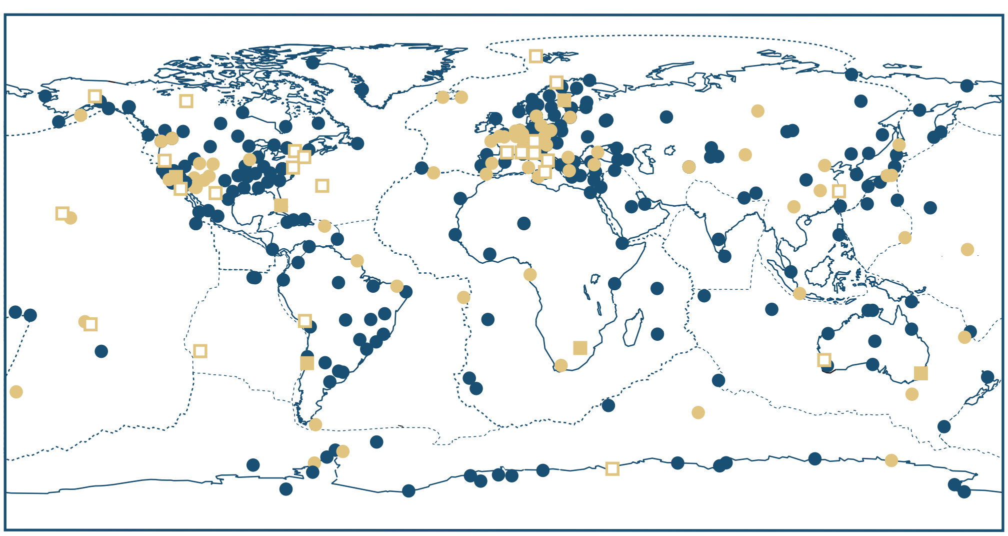


Figure 1. The ITRF2000 primary network. Symbols indicate collocations of space geodetic techniques (GPS, VLBI, SLR, DORIS).

IGS Reference FRAME Coordination and WORKING Group Activities

Remi Ferland

Geodetic Surveys Division, Natural Resources Canada

IGS Reference Frame Coordinator

The need to generate unique IGS station coordinates and velocities, Earth rotation parameters (ERPs), and geocenter products was recognized as early as 1994 by the IGS and is described in a paper entitled "IGS Reference Frame Realization" (Kouba, Ray, and Watkins, 1998). The Reference Frame Working Group (RFWG) was organized to address this need. These products have a direct impact on GPS satellite ephemerides and clock products. Recent activities can be grouped in four distinct but related tasks: First, the generation of the weekly products; second, the contributions made to ITRF2000 in the spring and fall of 2000; third, the proposed IGS realization of ITRF2000, and finally, the reprocessing of the older data.

The IGS reference frame products became official with IGS Governing Board approval starting on 20 February 2000 (GPS week 1050) following several improvements proposed by the RFWG members. These products are available in the Software-Independent Exchange (SINEX) format. Since 27 February 2000 (GPS Week 1051), the orbit products have been aligned by the Analysis Center Coordinator to the weekly SINEX cumulative combinations, to ensure product consistency. This requires that the SINEX combination be available for the final orbit combinations, which is now produced within 12 days after the end of each week. It was agreed to set the deadline at the end of the Thursday (Ottawa local time) of each week for the SINEX weekly combination and submission.

The ERPs are included in the weekly SINEX combination along with the station coordinates with full use of the covariance information. The best Analysis Center pole (and rates) are consistent at 0.05–0.10 milliarcsecond (0.10–0.20 mas/day), while the calibrated length of day (LOD) estimates are consistent at 20–30 microseconds. Similar daily ERPs are also estimated as part of the final GPS orbit combination process "igs95p02" and with the Massachusetts Institute of Technology Global Network Associate Analysis Center (GNAAC) combination. The combined ERPs are consistent with those combinations at about 0.05 milliarcsecond (0.10–0.20 mas/day). Comparison of the combined daily pole positions with IERS Bulletin A shows a noise level at about 0.06 milliarcsecond after a constant bias was removed.

This year, the participation in the realization of ITRF2000 included two cumulative solutions. The first cumulative solution was submitted in early April; it contained about four years of GPS data (21 January 1996–25 March 2000; GPS weeks 0837–1054). Between 25 January 1996 and 3 October 1998 (GPS weeks 0837 and 0977), the weekly SINEX solutions from the GNAACs JPL, MIT, and NCL were used in the cumulative solution. Since 4 October 1998 (GPS week 0978), the seven Analysis Centers' weekly SINEX solutions are used in the combination, while the GNAACs are used to quality control the weekly combination. The AC/GNAAC weekly solutions were unconstrained; their covariance information was rescaled with the estimated variance factor, and they were combined using the standard least-squares technique. AC/GNAAC station coordinates estimates were rejected if they exceeded 5 sigmas or the 50-millimeter threshold. The weekly combination also included daily ERPs (pole position and rate, LOD) since 6 June 1999 (GPS week 1013). The weekly apparent geocenter position was also estimated starting on 4 October 1998 (GPS week 0978). The cumulative combination has been updated every week with the current weekly combination. The submitted cumulative solution included station coordinates and velocity for 177 sites. Several stations were rejected mainly due to unreliable velocity estimates caused by short data span. The cumulative solution was aligned to ITRF97 by applying a 14-parameter transformation estimated using a set of 51 so-called reference frame stations. Inner constraints in origin, orientation, and scale (and their rates) were applied to the solution. The second cumulative solution, made possible by an opportunity to submit updated solutions provided by the ITRF Working Group, was submitted in late November. It included station coordinates and velocity for 167 sites with an extra 34 weeks of data, up to 19 November 2001 (GPS week 1088).

Participation in the realization of ITRF2000 included two cumulative solutions.

The ITRF2000 solution became available in March 2001. After a few iterations amongst the RFWG members, an IGS realization of ITRF2000 was proposed for implementation. It consists of 55 high-quality, well-distributed, global reference frame stations. It is proposed to replace the IGS realization of ITRF97, which contains 51 reference frame stations. All the proposed additions/changes are in the Southern Hemisphere, with the main objective being to improve the reference frame station distribution. Two new stations are proposed in South America, and one is removed. Three other stations are proposed — one on Ascension Island in the Atlantic Ocean, one on Diego Garcia Island in the Indian Ocean, and one in Australia. Based on the 49 common stations between the two IGS realizations, the estimated transformation parameters from IGS (ITRF97) to IGS (ITRF2000) at epoch 1 July 2001 are given in Table 1 (the signs are consistent with IERS convention). The proposed coordinates and velocity for the IGS realization of ITRF2000 RF stations were extracted from the

Table 1. Transformation Parameters from IGS (ITRF97) to IGS (ITRF2000) at 1 July 2001 (Sigmas are in Brackets). See IGS Mail message no. 3605.

	Translations			Rotations			Scale
	TX, mm	TY, mm	TZ, mm	RX, mas	RY, mas	RZ, mas	S, ppb
1 July 2001	–4.7	–2.8	25.6	–0.030	–0.003	–0.14	–1.48
(1 sigma)	(0.5)	(0.6)	(0.8)	(0.025)	(0.021)	(0.021)	(0.09)
Rate per year	0.4	0.8	1.6	0.003	–0.001	-0.030	–0.03
(1 sigma)	(0.3)	(0.3)	(0.4)	(0.012)	(0.011)	(0.011)	(0.05)

mas = microarcseconds **ppb = parts per billion** **S = scale**
mm = millimeters **R = rotation** **T = translation**

cumulative solution for GPS week 1112 (02 May 2001).

The differences in translation parameters, the rotation about the Z axis (RZ), the scale, and the Z translation rate are significant (>3 sigmas). The above transformations are consistent with those derived by using directly the ITRF97 and ITRF2000 and agree with the above at or better than 1.2 sigmas. The weekly estimated IGS geocenter, which currently relies on COD, ESA, and JPL weekly SINEX solutions, is affected by the proposed realization. The apparent geocenter time series between 4 October 1998 and 12 May 2001 (GPS Weeks 0978–1113) show average offsets of 1.6 millimeters, 4.0 millimeters, and –17.4 millimeters for the X, Y, and Z components in ITRF97. The average ITRF2000 geocenter offsets for the same period are 5.2 millimeters, 3.9 millimeters, and –23.3 millimeters. This results in average differences of 3.6 millimeters, 0.1 millimeter, and 5.9 millimeters for each component. From these comparisons, a significant improvement in the alignment of the apparent GPS geocenter is expected with the use of the ITRF2000 origin, especially for the Z-axis. For the beginning of July, the weekly reference frame station coordinate residuals standard deviation between the reference frame realization and the IGS cumulative solution are expected to be at the millimeter level in the north, east, and height components. Using the ITRF2000 coordinates directly would increase the standard deviations for the same stations to about 3 millimeters horizontally and 6 millimeters vertically. This indicates that the internally consistent proposed IGS realization of ITRF2000 is still preferable. The direct use of ITRF2000 would still be superior to ITRF97, where the standard deviation of the vertical component was at 10 millimeters at the best of times.

The rms of the reference frame station coordinates and velocity residuals after aligning the IGS realizations of ITRF97 and ITRF2000, at the reference epoch (1 July 2001), are 1.4 millimeters, 2.1 millimeters, and 5.8 millimeters, and 0.4 millimeter/year, 0.5 millimeter/year, and 1.5 millimeters/year in the north, east, and up directions. This shows the level of consistency of the two consecutive realizations. It also shows the effect of the addition of one more year of data in the cumulative solution for the reference frame stations. The comparison of the estimated velocity of a subset of reference frame stations with the North-

Table 2. Comparison of the ITRF97/ITRF2000/IGS (ITRF97)/IGS (ITRF2000) Estimated Velocity of a Subset of the Reference Frame Stations to NNR–NUVEL-1A

		ITRF			IGS		
Realization	No. of stations	N, mm	E, mm	H, mm	N, mm	E, mm	H, mm
1997	44	2.3	2.7	3.9	2.2	2.5	3.5
2000	48	2.2	2.4	3.8	2.0	2.4	3.0

western University velocity model (NUVEL)-1A plate motion model is summarized in Table 2. For the vertical component, the statistics are with respect to "zero" velocity. It includes the ITRF97 and ITRF2000 station velocity estimates as well as their IGS counterpart. For the ITRF97 realization, stations Arequipa (AREQ), Guam (GUAM), Lahasa (LHAS), MacMurdo (MAC1), O'Higgins (OHIG), Santiago (SANT), and Tsukuba (TSKB) were excluded, and for the ITRF2000 realization, stations AREQ, Diego Garcia (DGAR), GUAM, LHAS, MAC1, SANT, and TSKB were excluded due to poor agreement (>10 millimeters/year) with the plate motion model. Table 1 shows a larger improvement for the vertical component of the IGS realizations. The other components show marginal improvement. They are probably caused by NNR (no net rotation)-NUVEL-1A modeling limitations at some stations.

Finally, two iterations of reprocessing the AC-based SINEX solutions between GPS weeks 0837 (21 January 1996) and 0977 (3 October 1998) have been completed. The improvements are expected to be most significant in the vertical component. This reprocessing is using all the available information provided by the ACs and GNAACs. The AC and GNAAC solutions are considered independent during the processing, although in reality they have significant correlation, mainly because they use the same code and phase observations for all the common stations. The differences between the AC solutions are mainly caused by variations in the processing strategies and the network distribution. Once finalized, the reprocessing will improve the quality of the weekly and cumulative solutions as well as its consistency and tractability by using a consistent strategy. The densification of the IGS reference frame will benefit from the reprocessing of the older data.

The IGS/BIPM TIME & FREQUENCY Pilot Project

The respective roles of the IGS and BIPM are complementary and mutually beneficial.

Jim R. Ray
United States Naval Observatory, USA
Earth Orientation Department

The IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements is sponsored jointly with the Bureau International des Poids et Mesures (BIPM). The project has been underway since early 1998, with the main goal being to investigate and develop operational strategies to exploit geodetic GPS methods for improved global availability of accurate time and frequency comparisons.

The respective roles of the IGS and BIPM are complementary and mutually beneficial. The IGS brings a global GPS tracking network, standards for continuously operating geodetic, dual-frequency receivers, an efficient data delivery system, and state-of-the-art data analysis groups, methods, and products. The BIPM and the timing laboratories contribute expertise in high-accuracy metrological standards and measurements, timing calibration methods, algorithms for maintaining stable time scales, and formation and dissemination of UTC.

Recent activities generally fall into the following areas:

- Workshop — Two days during the "IGS 2000 Analysis Center Workshop," held 25–26 September 2000 at the U.S. Naval Observatory, were devoted to the pilot project.

- Deployment of GPS receivers — The IGS network currently consists of about 250 permanent, continuously operating stations globally distributed. Of these, external frequency standards are used at ~38 with H-masers, ~23 with cesium clocks, and ~17 with rubidium clocks; the remainder use internal crystal oscillators. Table 1 lists the IGS stations currently located at timing laboratories. The former timing lab at the Technical University of Graz, TUG (GRAZ receiver) ended operations in 2000, while the NPLD and SPT0 stations are new. Figure 1 shows the locations of the stations.

- GPS data analysis — A new method to combine satellite and receiver clock estimates, both sampled at 5-minute intervals, was implemented officially by the IGS on 5 November 2000.

Table 1. IGS Stations Located at BIPM Timing Laboratories (in 2000)

IGS Site	Time Lab	GPS Receiver	Frequency Standard	City
AMC2	AMC*	AOA SNR-12 ACT	H-maser	Colorado Springs, Colorado, USA
BOR1	AOS	AOA TurboRogue	Cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-maser	Brussels, Belgium
MDVO	IMVP	Trimble 4000SSE	H-maser	Mendeleevo, Russia
NPLD	NPL*	Ashtech Z-XII3T	H-maser	Teddington, UK
NRC1	NRC*	AOA SNR-12 ACT	H-maser	Ottawa, Canada
NRC2	NRC*	AOA SNR-8100 ACT	H-maser	Ottawa, Canada
OBER	DLR	AOA SNR-8000 ACT	Rubidium	Oberpfaffenhofen, Germany
PENC	SGO	Trimble 4000SSE	Rubidium	Penc, Hungary
SFER	ROA	Trimble 4000SSI	Cesium	San Fernando, Spain
SPT0	SP	JPS Legacy	Cesium	Boras, Sweden
TLSE	CNES	AOA TurboRogue	Cesium	Toulouse, France
USNO	USNO*	AOA SNR-12 ACT	H-maser	Washington, DC, USA
WTZR	IFAG	AOA SNR-8000 ACT	H-maser	Wettzell, Germany

***Participates in two-way satellite time transfer operations.**

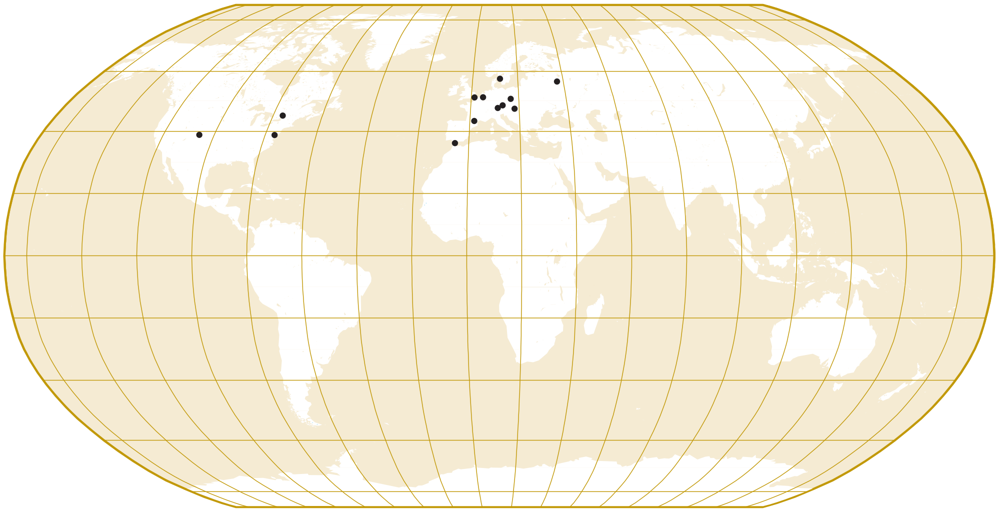


Figure 1. Locations of IGS stations at BIPM timing laboratories.

- Instrumental delays — The BIPM has demonstrated techniques to calibrate the instrumental biases of the Ashtech Z-XII3T receiver. Efforts are underway to measure the biases of similar receivers deployed at timing laboratories.
- Comparison experiments — Studies are underway comparing geodetic timing results with simultaneous, independent measurements using the common-view and two-way satellite techniques.

For further information, please refer to *http://maia.usno.navy.mil/gpst.html*.

Attendees of the USNO Analysis Center workshop 2000. (Photo courtesy of Finn Bo Madsen)

2000 IGS Activities in the Area of the IONOSPHERE

Joachim Feltens

European Space Agency

European Space Operations Center, Germany

The IGS Ionosphere Working Group has been active since June 1998. The working group's most important short-term goal is the routine provision of global ionosphere total electron count (TEC) maps plus GPS spacecraft differential code biases (DCBs) with a delay of several days. The routine delivery of station DCBs is in preparation and will be included soon. In the medium- and long-term, the development of more sophisticated ionosphere models and the establishment of a near-real-time service are the major tasks. The final target is the establishment of an independent IGS ionosphere model.

Five Ionosphere Associate Analysis Centers (IAACs) contribute products to the working group activities:

CODE	Center for Orbit Determination in Europe, Astronomical Institute, University of Bern, Switzerland
ESOC	European Space Operations Center of ESA, Darmstadt, Germany
JPL	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA
NRCan	National Resources Canada, Ottawa, Ontario, Canada
UPC	Universitat Politècnica de Catalunya, Barcelona, Spain

This report gives an overview of the IGS Ionosphere activities in 2000.

Routine Activities

Daily Ionospheric Total Electron Content (TEC) Information

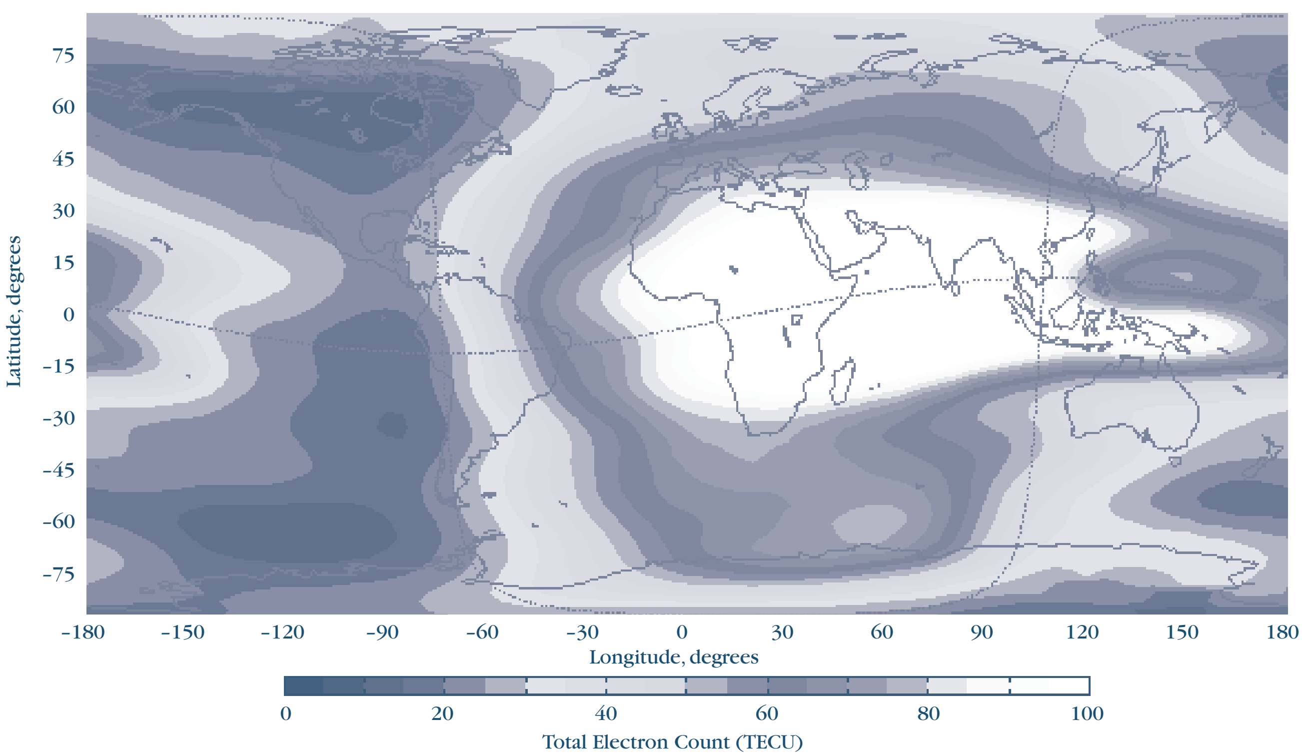
Every 24 hours, each IAAC delivers an Ionosphere Map Exchange (IONEX) file (Schaer et al., 1997) with 12 maps containing global TEC information with 2-hour time resolution and a daily set of GPS satellite DCBs in its header. The inclusion of ground station receivers DCBs is in preparation.

Weekly Comparisons

On Tuesday of each week, the TEC maps from the different Analysis Centers are compared for all days of the week before. These comparisons are done at ESA/ESOC. A weekly comparison summary is distributed via e-mail to working group members. The daily summaries, the daily IONEX files with the mean TEC maps and GPS satellite DCBs, and daily TEC and DCB difference files with respect to the mean for each IAAC, as well as plots of these maps, are made available via ESOC's FTP account. Figure 1 illustrates a weighted mean TEC map of 28 March 2000.

In the northern hemisphere, the deviations of the different IAAC TEC maps from the IGS mean are, under normal conditions, 5 TEC units (TECUs) or less. At the equator and in the southern hemisphere, the situation is more problematic, because of gaps in the station coverage at these latitudes. However, the deployment of new IGS stations in these areas has reduced these gaps since 1999.

Figure 1. The IGS weighted mean TEC map of 28 March 2000 at 11h in total electron count units. On that particular day, the TEC level was very high.



The day-by-day variations of the different IAAC DCB sets are normally less than 0.3 nanosecond, and sometimes 0.5 nanosecond. According to a presentation of S. Schaer at the IGS Analysis Workshop in September 2000 in Washington, mean IAAC satellite DCB series show an agreement of about 0.1 nanosecond.

Improvement of the Comparison Scheme and Validations

The current comparison/combination algorithm is based on a pure statistical approach using weighted means. On the other hand, the methods used by the IAACs to model the ionosphere are very different. In order to achieve an objective weighting for a combination scheme, the existing comparison/combination is currently being upgraded. Based on two self-consistency methods proposed by Natural Resources Canada (NRCan) and Universitat Politècnica de Catalunya (UPC), in which TEC values derived directly from GPS observables are compared with corresponding TEC values interpolated from the IAAC TEC maps, new geographic-dependent weights will be computed. This will replace the current statistical weighting in the comparison/combination algorithm. A detailed description on how these two methods work can be found in these sources (listed in the Bibliography, Appendix A, for this Annual Report): Feltens, 2000a; Feltens, 2000c; Hernandez-Pajares, 2000; Heroux, 1999.

Special Activities

During events of special interest for the ionosphere community and for ionospheric research, the working group organizes dedicated high-rate tracking campaigns with the global IGS ground station network. After the Solar Eclipse Campaign on 11 August 1999, preparations for a new high-rate campaign with the name “HIRAC/SolarMax” in April or May 2001 were initiated by J. Feltens and N. Jakowski. The goal of the HIRAC is to monitor ionospheric behavior under the current solar maximum conditions. For more information, see IGS Mail message no. 3094 (Feltens, 2000b) .

Future Tasks

As soon as the new weighting scheme is implemented into the comparison/combination program, we plan to start the routine delivery of a combined IGS ionosphere product. Preparations are made to attach validations to the weekly comparison program runs by comparing the IAAC model vertical TEC values with vertical TEC values derived from TOPEX/Poseidon satellite (and Envisat, once launched) altimeter data.

Another important aspect will be the reduction of the time deadline for ionosphere products delivery. The ionosphere is a very rapidly changing medium, and it must be the working group’s intention to provide actual ionosphere models in short time frames — especially with regard to the current solar maximum.

For more than four years, IGS has generated a combined tropospheric IGS product. All the contributing IGS components are performing well and the product has reached a high quality — at the level of 3 to 5 millimeters in the zenith total delay, which corresponds to ≥1 millimeter in water vapor. The biases are even smaller. There are no plans for further investigations for a post-processed tropospheric product on a global scale. Therefore, the activities of the Tropospheric Working Group will be finished. The established procedures for regular product generation will be continued, including the combination at GFZ (see *http://op.gfz-potsdam.de/S11/index_GPSS.html*).

IGS Tropospheric PRODUCTS

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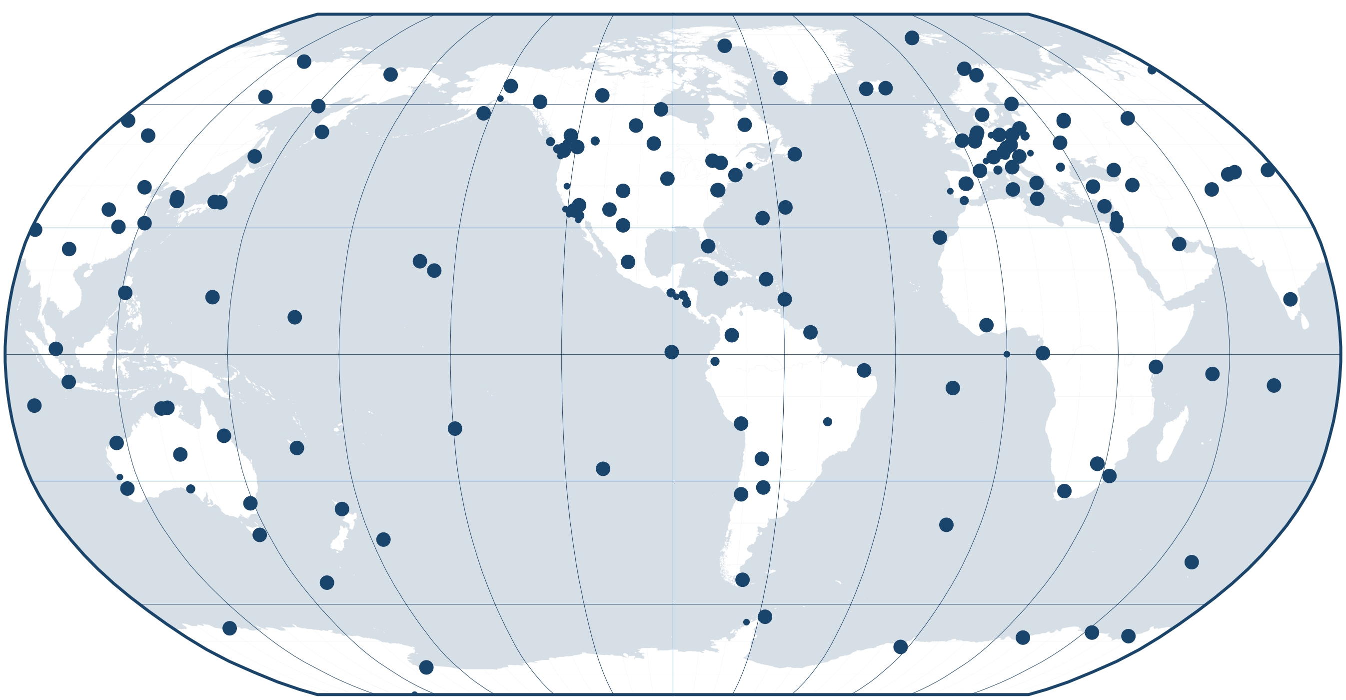
The combined tropospheric IGS product is available now for more than 210 sites.

The product is available now for more than 210 sites (see Figure 1). Nearly 150 sites are used by three or more Analysis Centers, which allows derivation of reasonable quality measures. The number and quality of the meteorological sensors used for conversion into water vapor content is slowly improving. Nowadays 30 to 40 sites report meteorological data. Information on the quality of all sites to support the selection for new installations was compiled. Presently there are tendencies by some meteorological institutions to assimilate the zenith total delay directly into the numerical weather prediction (NWP) models. If this proves to be the final strategy, it will have an impact on the installation of meteorological sensors for the regional applications devoted to NWP. However, for sites used in climate studies, which is the case for the global IGS network, meteorological sensors are important, and the usual daily Receiver-Independent Exchange (RINEX)-met files are sufficient to transmit the information. Therefore, IGS should strive to complete the installation of sensors in its global network.

Presently, near-real-time (NRT) monitoring of water vapor is supported by IGS by providing global data, NRT orbits, and ultrarapid predictions. Although NRT activities are more suited to individual countries or regional organizations, IGS plans to study the feasibility for an ultrarapid or even NRT global tropospheric product where sufficiently dense networks are operated. Such a product, provided for a relative sparse network only, can be used for NRT quality control in regional network applications.

The IGS contribution should be seen in the context of other activities like the establishment of a similar database for Asia and Western Pacific by the Earthquake Research Institute, Tokyo, Japan, and the generation of a combined tropospheric product within the European Reference Frame (EUREF).

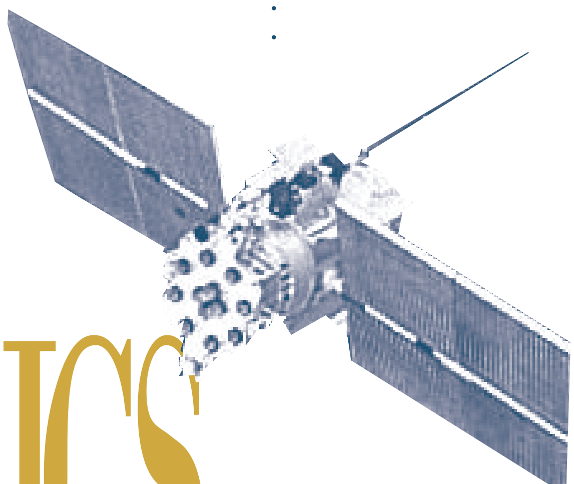
Figure 1. IGS stations with tropospheric estimates.



The IGS initiated IGLOS-PP to benefit from the GLONASS system for as long as it remains viable.

James A. Slater

National Imagery and Mapping Agency, USA



IGS International Glonass Service PILOT PROJECT

Russia launched the first GLONASS satellites in late 1982. However, until the International GLONASS Experiment (IGEX-98) was conducted in 1998–1999, no coordinated international effort had been organized to collect and process GLONASS data. IGEX-98 created a global tracking network of stations with geodetic receivers, obtained increased laser tracking support from the satellite laser ranging community, generated a continuous archive of satellite observations, and produced post-processed precise orbits. As a result of continued interest in GLONASS, the IGS initiated a pilot project, the International GLONASS Service Pilot Project (IGLOS-PP), to benefit from the GLONASS system for as long as it remains viable.

A Call for Participation was issued in May 2000 with the following goals and objectives:

1. Establish and maintain a global GLONASS tracking network.
2. Produce precise (10-centimeter level) orbits, satellite clock estimates, and station coordinates.
3. Monitor and assess GLONASS system performance.
4. Investigate the use of GLONASS to improve Earth orientation parameters.
5. Improve atmospheric products of the IGS.
6. Fully integrate GLONASS into IGS products, operations, and programs.

A pilot project committee was formed consisting of the following individuals:

- Vladimir Glotov, Russian Space Agency
- Ramesh Govind, Australian Survey and Land Information Group
- Werner Gurtner, University of Berne, International Laser Ranging Service liaison
- Arne Jungstand, EC Joint Research Center and DLR
- Angelyn Moore, IGS Central Bureau
- Carey Noll, NASA Goddard Space Flight Center (Data Center Coordinator)
- James Slater, National Imagery and Mapping Agency (Chair)
- Robert Weber, University of Technology, Vienna (IGLOS Analysis Center Coordinator)
- Pascal Willis, Institut Géographique National

In addition, the IGS Central Bureau initiated a new mail service, IGLOSMAIL, on 25 May 2000 for participants in the project.

The pilot service is based on the infrastructure already in place in the IGS for GPS. Tracking stations forward their data to Regional and Global Data Centers where the data are retrieved by Analysis Centers that compute precise orbits and other products. These products are then archived at Global Data Centers for access by the user community.

Tracking Network

As of December 2000, there were 32 operational dual-frequency tracking stations and 13 proposed stations in the IGLOS pilot project global tracking network. Most of the operational receivers are Ashtech Z-18 or JPS Legacy models. The remainder are 3S navigation receivers. In conjunction with this, the International Laser Ranging Service has been coordinating laser tracking of three GLONASS satellites (in slot numbers 1, 15, and 24) as part of its routine schedule. The laser tracking takes advantage of laser retroreflectors that are on every GLONASS satellite.

Analysis Centers and Global Data Centers

Two Analysis Centers, Bundesamt für Kartographie und Geodäsie (BKG) and the European Space Agency/European Space Operations Center (ESA/ESOC), have been computing precise orbits on a weekly basis using the receiver data from the tracking network. The Mission Control Center of the Russian Space Agency and the NERC Space Geodesy Facility in the United Kingdom have been computing orbits from the laser tracking data on an intermittent basis. After the BKG and ESA/ESOC orbits are produced, the IGLOS Analysis Coordinator computes a combined orbit at the University of Technology in Vienna.

Data and precise orbits are stored in the Crustal Dynamics Data Information System (CDDIS) Global Data Center at NASA Goddard Space Flight Center. Between August and November 2000, 28 organizations, primarily from Austria, Germany, Russia and the United States, retrieved IGLOS data from the Global Data Center.

Precise GLONASS Orbits

Precise GLONASS orbits have been computed continuously by BKG and ESA for each day in 2000 for all the operational satellites. BKG uses the Bernese software, while ESA uses its GPSOBS/BAHN software. Orbit repeatability is generally in the 10–20-centimeter range (rms). The Analysis Centers also compute the time offset between GPS and GLONASS times, and estimate datum transformations between the GLONASS PZ-90 reference frame and the International Terrestrial Reference Frame using the GLONASS broadcast message. After the individual center orbits are released, a weighted combination of the two orbits is generated and made available through the CDDIS.

Precise GLONASS orbits have been computed continuously for all the operational satellites.

The Natural Environment Research Council (NERC) has computed GLONASS orbits using satellite laser ranging data alone and compared it with microwave receiver-based orbits. It has also compared laser ranges directly with ranges derived from the microwave receiver–based orbits. The rms differences between the laser and microwave orbits are approximately 10 centimeters radially and 50 centimeters in the along-track and cross-track directions.

Plans

Efforts during 2001 will be focused on integrating the GLONASS receiver sites with the GPS sites in the IGS. Site log forms, data archives, and Analysis Center software will be revised where possible to process combined GPS and GLONASS data. Stations will all have to meet IGS standards. Improved timeliness of orbit products will also be a goal. There is still some uncertainty regarding the GLONASS constellation and its long-term reliability and maintenance. Nine satellites were operational in December, but without a new launch in 2001, this number will probably go down.

IGS LEO

Pilot Project

Michael Watkins

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The Call for Participation in the IGS Low-Earth Orbiter (LEO) Pilot Project was announced in January 2000. It elicited a very strong response evident by the 26 proposals submitted to the Central Bureau. All components were represented (stations, data centers, Associate Analysis Centers, etc.), and the Governing Board accepted all the proposals at the June meeting at the U.S. Naval Observatory. The constitutional meeting to organize the project was planned for January 2001 at GeoForschungsZentrum (GFZ) in Potsdam, Germany. The CHAMP satellite launched successfully on 15 July. In November, after an initial commissioning phase of the satellite, members of the IGS LEO Pilot Project were provided with one day of CHAMP GPS, gravity, and magnetic field sensor data, as well as accelerometer and attitude data plus reference frame and data format descriptions. Data from the U.S.–Argentina mission SAC-C, which successfully launched on 21 November, are also available to the project. The benefits of a common ground-based infrastructure to serve upcoming multimissions cannot be overlooked.

The definition and operation of a robust, high-sampling-rate, low-latency subset of the global tracking network is progressing rapidly, and issues such as data formats, access, products, etc., will be discussed in more detail in 2001 when the project members have had opportunity to examine the space and ground data and produce preliminary results.

One of the key questions is the structure of the project, and in particular, identifying the Associate Analysis Coordinator for the project. Various groups will evaluate the inclusion of LEO data as a core element of the IGS. An assessment of the effects on the traditional IGS analysis products will be performed (GPS ephemerides, clocks, Earth orientation, and troposphere), as well as an assessment of the additional computational and data center burdens. There are clear potential benefits, but these are balanced by additional complexity. In the spirit of the IGS, the pilot project looks to provide a collaborative approach. The data from the satellites are generated by spaceborne, geodetic-quality GPS receivers designed by JPL. In addition to CHAMP and SAC-C, these flight receivers will be flown on board a number of upcoming missions — Jason-1, Gravity Recovery and Climate Experiment (GRACE), and ICESat.

It is clear that the next few years will provide interesting opportunities to explore the enhancement of the IGS through many applications projects. The LEO Pilot Project promises fertile cooperation, noting that by 2003 nearly a half dozen missions will be on orbit and available to the pilot project.

Continuous GPS POSITIONING of Tide Gauges

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Pacific GPS Facility
University of Hawaii, USA

Philip Woodworth
Proudman Oceanographic Laboratory, UK

The working group known as Continuous GPS at Tide Gauges, CGPS@TG, was formed in 1999 in response to an International Union of Geodesy and Geophysics (IUGG) recommendation that the Permanent Service for Mean Sea Level (PSMSL)/Global Sea Level Observing System (GLOSS)/IGS technical committee on continuous GPS (CGPS) positioning of tide gauges merge with a similar committees being planned under the auspices of IAG Special Commission 8 and the International Association for the Physical Sciences of the Ocean (IAPSO) Commission on Mean Sea Level and Tides. This report summarizes the working group's activities to date.

A CGPS@TG website has been set up at the University of Hawaii to serve as an online resource (*http://www.soest.hawaii.edu/cgps_tg*). It also provides contact information for the members of CGPS@TG. The working group has grown to about 33 members, of whom 11 have already contributed to the website. The website's "Introduction" page contains a paper by Bevis, Scherer, and Merrifield that summarizes the technical issues associated with siting, building, and maintaining a CGPS station at a tide gauge, and provides recommendations on technical standards and field procedures. This document is then amplified by a growing collection of articles in the "Case Studies" section. The "Background" section contains a global inventory, compiled by Guy Woppleman and others, of existing CGPS stations that are collocated or nearly-collocated with tide gauges. This set of webpages mirrors the French website *http://sonel.ensg.ign.fr/stations/cgps/surv_update.html*. In the future, the "Background" page of the website will contain links to general position papers on the CGPS@TG agenda. Several members of the working group are currently preparing materials to submit to the CGPS@TG website.

The working group served as an advocate for increased IGS involvement in the processing of CGPS stations located at or near important tide gauges. The IGS has recently announced the GPS Tide Gauge Benchmark Monitoring (TIGA) pilot project to address this important task. TIGA is chaired by Tilo Schoene of GeoForschungs-Zentrum (GFZ), who is also a member of the CGPS@TG working group.

CGPS@TG organized a one-day workshop at the University of Hawaii on 25 April 2001, which was attended by more than 30 participants. Major topics included the need to reanalyze the IGS time series to improve the vertical stability of the International Terrestrial Reference Frame (ITRF), the lessons to be drawn from the project Baseline Inferences for Rebound Observations of Sea Level and Tectonics (BIFROST), field craft and monumentation, the needs of the oceanographic community, several case studies, and the TIGA Call for Participation. A report of the CGPS@TG workshop, together with those of other workshops held at the University of Hawaii during the week 23–27 April, is included in the overall meeting report of the Intergovernmental Oceanographic Commission (IOC) GLOSS Group of Experts 7th Session available via *http://www.pol.ac.uk/psmsl/programmes/gloss.info.html*. IOC also has included information on the use of CGPS at gauge sites, derived from the experiences of the CGPS@TG group, in Volume 3 of its *Manual on Sea Level Measurement and Interpretation* (Manuals and Guides No. 14) available via *http://www.pol.ac.uk/psmsl/training/training.html*.

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These publications, along with brochures, resource package, and the IGS Directory (printed annually), are available on request from the Central Bureau.

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IGS 2000 Annual Report (JPL 400-994) and 2000 Technical Reports, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

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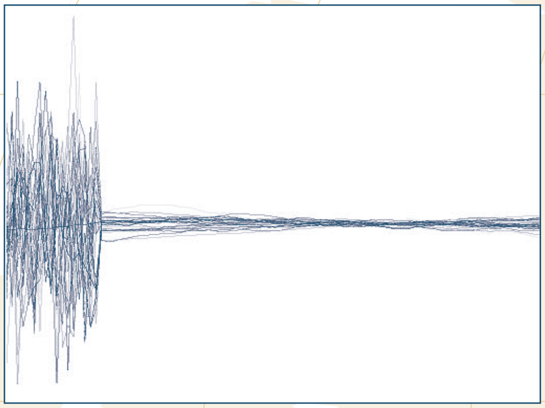
The Impact of Ultra-Rapid Orbits on Precipitable Water Vapor Estimation using Ground GPS Network



Selective Availability (SA) removed, May 2, 2000.

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