IGS Annual Report 2001–2002

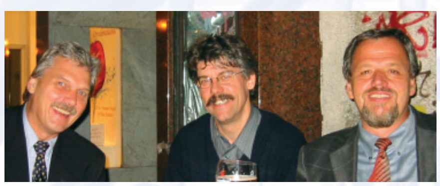
International

GPS

Service







IGS

Annual Report

2001–2002

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The IGS 2001/2002 Annual Report series contains two volumes — this Annual Report spanning two years, 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.

IGS

Contributing Organizations

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Comisión Nacional de Actividades Espaciales (CONAE), Argentine Space Agency
Estación Astronómica Río Grande
Facultao de Cs. Astronómicas y Geofísicas
La Plata National University
Universidad Salta Instituto Geonorte
Armenia
National Survey for Seismic Protection
Australia
Australian Antarctic Division
ESA Perth and New Norcia Ground Stations
Geoscience Australia, National Mapping Division (formerly AUSLIG)
Research School of Earth Sciences
Austria
Institute for Space Research, Observatory Graz
University of Technology Vienna
Barbados
Coastal Zone Management Unit
Belgium
ESA Redu Ground Station
Royal Observatory of Belgium (ROB)
Bermuda
Bermuda Biological Station for Research
Brazil
Instituto Brasileiro de Geografia e Estatística (IBGE)
Instituto Nacional de Pesquisas Espaciais (INPE)/ATSME, Brazilian Space Agency
University Federal de Parana
Bulgaria
Military Topographic Service of Bulgaria
Canada
Geodetic Survey Division, Natural Resources Canada
Natural Resources Canada (NRCan)
Pacific Geoscience Center (PGC), Geological Survey of Canada, Natural Resources Canada
University of New Brunswick
Chile
Centro de Estudios Espaciales, Center for Space Studies
China
China Geo-informatics Center, Chinese Academy of Surveying and Mapping
China Seismological Bureau
Crustal Motion Observation Network of China
Institute of Geology
Kunming Astronomical Observatory
National Bureau of Surveying and Mapping
Shaanxi Observatory Chinese Academy of Science
Shanghai Observatory Chinese Academy of Science
Tibet Autonomous Regional Bureau of Surveying and Mapping
Wuhan Technical University of Surveying and Mapping
Yunnan Observatory
Colombia
Instituto de Investigación e Información Geoscientífica, Minero-Ambiental y Nuclear (INGEOMINAS)
Côte d'Ivoire
Bureau National D'Etudes Techniques (BNETD)
Czech Republic
Research Institute of Geodesy, Topography, and Cartography
Denmark
Kort & Matrikelstyrelsen, National Survey and Cadastre (KMS)
Ecuador
Charles Darwin Research Station, Galápagos Islands
Instituto Geográfico Militar (IGM)
El Salvador
Centro Nacional de Registros
Finland
Finnish Geodetic Institute
France
Bureau International des Poids et Mesures (BIPM)
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Centre National d'Etudes Spatiales (CNES)
Institut Geographique National (IGN)
Observatoire de la Côte d'Azur (OCA)
Territoire des Terres Australes et Antarctiques Francaises
French Guyana
ESA Station Diane, Kourou
Gabon
Universite des Sciences et Techniques de Masuku
Germany
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Bavarian Academy of Sciences
Bundesamt für Kartographie und Geodäsie (BKG)
Deutsche Forschungsanstalt für Luft-und Raumfahrt e.V. (DLR)
Deutsches Geodätisches ForschungsInstitut (DGFI)
European Space Agency/European Space Operations Center (ESA/ESOC)
GeoForschungsZentrum Potsdam (GFZ Potsdam)
Physikalisch-Technische Bundesanstalt (PTB)
Technical University Munich
University of Bonn
University of the Bundeswehr
Greece
Technical University of Crete
Greenland
SRI International
Guam
Guam Seismic Observatory
Guatemala
Instituto Geográfico Nacional
Honduras
Instituto Geográfico Nacional
Hungary
Satellite Geodetic Observatory, Penc
Iceland
Landmaelingar Islands, National Land Survey of Iceland

India
Council of Scientific and Industrial Research (CSIR), Centre for Mathematical Modelling and Computer Simulation (CMMACS)
National Geophysical Research Institute
Indonesia
BAKOSURTANAL National Coordination Agency for Surveys and Mapping
Israel
Survey of Israel (SOI)
Tel-Aviv University (TAU)
Italy
Agenzia Spaziale Italiana (ASI), Italian Space Agency
Nuova Telespazio S.p.A.
Time and Frequency Laboratory, Instituto Electtrotecnico
Nazionale G. Ferraris
Ufficio Geodetico di Bolzano Regione Autonoma Trentino Alto Adige
University of Padova
Jamaica
Jamaica Meteorological Service
Japan
Communications Research Laboratory (CRL)
Earthquake Research Institute, University of Tokyo (ERI)
Geographical Survey Institute (GSI)
Radio Astronomy Applications Group
Usuda Deep Space Tracking Station
Western Pacific Integrated Network of GPS (WINGS)
Jordan
Royal Jordanian Geographic Centre
Kazakhstan
Scientific-Forecast Centre "Prognoz," Emergency Agency
Kenya
San Marco Telemetry Station, Malindi
Kyrgyzstan
Electromagnetic Field Expedition of the Institute of High Temperatures (IVTAN)
International Research Center — Geodynamic Proving Ground (IRC-GPG)
Malaysia
Malaysia Department of Surveying and Mapping
Mexico
Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
Instituto Nacional de Estadistica Geografía e Informatica (INEGI)
Mongolia
Research Centre of Astronomy and Geophysics
Netherlands
Delft Institute for Earth-Oriented Space Research (DEOS)
Delft University of Technology
New Caledonia
Department of Land (DITTT/ST/BGN), Noumea
New Zealand
Institute of Geological and Nuclear Sciences (GNS)
Land Information New Zealand (LINZ)
Nicaragua
Instituto Nicaraguense de Estudios Territoriales
Norway
Nordlysobservatoriet
Norwegian Mapping Authority, Geodetic Institute
Ny-Alesund Geodetiske Observatorium
Papua New Guinea
Department of Surveying and Land Studies
Philippines
Manila Observatory
Poland
Astrogeodynamical Observatory, Space Research Centre, Polish Academy of Sciences
Institute of Geodesy and Geodetic Astronomy, Warsaw
University of Technology
University of Warmia and Mazury in Olsztyn
Republic of Croatia
University of Zagreb
Republic of Cyprus
Department of Lands and Surveys, Survey Branch
Republic of Macedonia
Republica Geodetska Uprava
Romania
Technical University of Civil Engineering Faculty of Geodesy
Russia
Complex Magnetic-Ionospheric Station (CMIS)
Geophysical Observatory Arti
Geophysical Service, Russian Academy of Sciences
Institute for Metrology of Time and Space, GP VNIIFTRI
Institute of Applied Astronomy, Russian Academy of Sciences (IAA)
Institute of Astronomy, Russian Academy of Sciences (INASAN)
Institute of Geophysics, Siberian Branch of Russian Academy of Sciences
Institute of Marine Geology and Geophysics
Mission Control Center, Russian Space Agency (MCC)
OMSP Petropavlovsk
Russian Data Analysis and Archive Center (RDAAC)
Seismic Station Bilibino
Seismic Station Magadan
Seismic Station Tixi
Seismic Station Yakutsk
Technical University of Krasnoyarsk
The Institute of Metrology for Time and Space (IMVP)
East-Siberian Research Institute for Physics, Technical and Radio-Technical Measurements (ES RIPRM), VS NIIFTRI
Seychelles
Seychelles National Oil Company
Singapore
Nanyang Technological University
Slovenia
Slovenian Environmental Agency

South Africa
Chief Directorate Surveys and Mapping, Department of Land Affairs (CDSM)
Council for Scientific and Industrial Research (CSIR)
Hartebeesthoek Radio Astronomy Observatory (HartRAO)
South Korea
Korea Astronomy Observatory
National Geography Institute
Spain
ESA Villafranca Satellite Station
Institut Cartografic de Catalunya
Instituto Geografico Nacional
Instituto Nacional de Técnica Aeroespacial (INTA) / Estacion Espacial de Maspalomas
Real Instituto y Observatorio de la Armada (ROA)
Universitat Politécnica de Catalunya
Sweden
ESA Kiruna Ground Station
National Land Survey of Sweden
Onsala Space Observatory
Swedish National Testing and Research Institute
Switzerland
Astronomical Institute University of Bern (AIUB)
Swiss Federal Office of Metrology and Accreditation (METAS)
Swiss Federal Office of Topography, Bundesamt für Landestopographie (L+T)
Tahiti
Universitié de la Polynésie Française
Taiwan
Institute of Earth Sciences, Academia Sinica
National Standard Time and Frequency, Telecommunication Laboratories, Chunghwa
Turkey
Harita Genel Komutanligi General Command of Mapping
Istanbul Technical University (ITU) Civil Engineering Faculty
Karadeniz Teknik Universitesi
TUBITAK Marmara Research Center Earth Sciences Research Institute
Uganda
Uganda Geological Survey and Mines Dept.
Ukraine
Main Astronomical Observatory of National Academy of Sciences
National University Lviv Polytechnic
Poltava Gravimetric Observatory of the National Academy of Sciences
Science and Research Institute of Geodesy and Cartography
Space Research Laboratory of the Uzhgorod National University
United Kingdom
National Physical Laboratory
Natural Environment Research Council (NERC), Space Geodesy Facility (NSGF)
University of Newcastle upon Tyne
University of Nottingham
Uruguay
Universidad de la República
US Virgin Islands
National Radio Astronomy Observatory (NRAO)
USA
Allen Osborne Associates, Inc. (AOA)
California County of Riverside
Center for Earthquake Research and Information (CERI)
Center for Space Research, University of Texas at Austin (CSR)
County of Riverside, California
Crustal Dynamics Data Information System (CDDIS – NASA Goddard Space Flight Center)
Eastport Elementary School, Maine
Incorporated Research Institutions for Seismology (IRIS)
International Deployment of Accelerometers (IDA)
Intuicom, Incorporated
Jet Propulsion Laboratory (JPL), California Institute of Technology
Long Valley Observatory
Maine College of the Atlantic GIS Laboratory
Massachusetts Institute of Technology (MIT) — Haystack Observatory
MIT Department of Earth, Atmospheric, and Planetary Sciences
NASA Goddard Space Flight Center (NASA/GSFC)
National Aeronautics and Space Administration (NASA)
National Center for Atmospheric Research (NCAR)
National Geodetic Survey (NGS)
National Imagery and Mapping Agency (NIMA)
National Radio Astronomy Observatory (NRAO)
National Science Foundation (NSF)
Naval Research Laboratory (NRL)
NRAO Mauna Kea
NRAO Pie Town
Ohio State University — Laboratory for Space Geodesy and Remote Sensing
Scripps Orbit and Permanent Array Center (SOPAC), Scripps Institution of Oceanography
U.S. Naval Observatory (USNO)
United States Geological Survey (USGS)
University Consortium for Atmospheric Research (UCAR)
University NAVSTAR Consortium (UNAVCO)
University of Alaska — Geophysical Institute
University of Colorado at Boulder
University of Hawaii — School of Ocean and Earth Science and Technology, Pacific GPS Facility
University of Nevada, Reno
University of Texas, McDonald Observatory
Uzbekistan
Ulugh Beg Astronomical Institute of the Uzbekistan Academy of Sciences
Vietnam
Marine Hydrometeorological Center
Zambia
Zambia Survey Dept., Ministry of Lands

Governing Board — 2001–2002

MEMBER	INSTITUTION AND COUNTRY	POSITION	SERVICE*
Christoph Reigber	GeoForschungsZentrum Potsdam, Germany	Chair, Appointed (IGS)	1999–2002
Norman Beck	Natural Resources Canada	Network Representative	2002–2005
Gerhard Beutler	University of Bern, Switzerland	IAG Representative	—
Henno Boomkamp	ESA/European Space Operations Center, Germany	LEO Working Group Chair	2002–2004
Claude Boucher	Institut Geographique National, France	IERS Representative to IGS	—
Carine Bruyninx	Royal Observatory, Belgium	IGS Representative to the IERS	2000–2003
Mark Caissy	Natural Resources Canada	Real-Time Working Group Chair	2001–2002
Loic Daniel	Institut Geographique National, France	Data Center Representative	2002–2005
John Dow	ESA/European Space Operations Center, Germany	Network Representative	2000–2003
Joachim Feltens	ESA/European Space Operations Center, Germany	Ionosphere Working Group Chair	1999–2002
Remi Ferland	Natural Resources Canada	IGS Reference Frame Coordinator	1999–2002
Gerd Gendt	GeoForschungsZentrum Potsdam, Germany	Troposphere Working Group Chair	1999–2002
Tom Herring	Massachusetts Institute of Technology, USA	IAG Representative	1999–2003
John Manning	Australian Survey and Land Information Group	Appointed (IGS)	2000–2003
Angelyn Moore	Jet Propulsion Laboratory, USA	Board Secretariat; Network Coordinator	—
Ruth Neilan	Jet Propulsion Laboratory, USA	Director of IGS Central Bureau	—
David Pugh	Southhampton Oceanography Center, UK	FAGS Representative	—
Carey Noll	NASA Goddard Space Flight Center, USA	Data Center Working Group Chair	2002–2004
Jim Ray	U. S. National Geodetic Survey, USA (U. S. Naval Observatory until September 2002)	Analysis Representative; Precise Time Transfer Project Co-Chair	2002–2005
Markus Rothacher	Technical University of Munich, Germany	Analysis Representative	2000–2003
Tilo Schöne	GeoForschungsZentrum Potsdam, Germany	TIGA Pilot Project Chair	2001–2003
Robert Serafin	National Center for Atmospheric Research, USA	Appointed (IGS)	1998–2005
Jim Slater	National Imagery and Mapping Agency, USA	GLONASS Pilot Project Chair	2000–2002
Robert Weber	University of Bern, Switzerland; Technical Univ. of Vienna	Analysis Center Coordinator	2001–2002
Peizhen Zhang	China Seismological Bureau, Institute of Geology	Appointed (IGS)	2002–2005
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
Mike Bevis	University of Hawaii, USA	1998–2001
Geoff Blewitt	University of Nevada, Reno, USA	1996–2001
Bjorn Engen	Norwegian Mapping Authority	1994–2001
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
Paul Paquet	Royal Observatory of Belgium	1999–2002
Bob Schutz	Center for Space Research, University of Texas–Austin, USA	1994–1997
Tim Springer	University of Bern, Switzerland	1999–2000
Mike Watkins	Jet Propulsion Laboratory, USA	1999–2001
Pascal Willis	Institut Geographique 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.

IGS

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IGS Introduction

Tim Dixon

University of Miami

Tim Dixon received his B.Sc from the University of Western Ontario in London, Ontario, Canada, in 1974, and his PhD from Scripps Institution of Oceanography in San Diego, California, in 1979. He worked at the Jet Propulsion Laboratory from 1979–1992, then moved to the University of Miami, where he is currently Professor of Marine Geology and Geophysics at the Rosenstiel School of Marine and Atmospheric Sciences.

It is a somewhat humbling experience to be a user of IGS products. A moment's consideration reveals the huge global enterprise that goes into constructing a product such as the IGS precise ephemeris, so critical to achieving high-precision scientific results with GPS. These results are now considered routine, but were difficult or impossible to achieve 10 or 15 years ago. The main difference is IGS.

While the reader of a typical scientific article employing GPS data may be unaware of IGS' contribution, the author of that article is (or should be) fully aware of the key role played by IGS in the generation of his or her scientific results. In most scientific research articles, space does not permit the proper acknowledgment of the full scope of those contributions. My guess is that, on average, a minimum of several hundred people around the world who are affiliated with IGS have made key (but largely unsung) contributions to the work described in a typical geophysical research paper, including station installation and maintenance; maintaining Internet connections; archiving activities, data analysis at several facilities for production of satellite ephemerides, satellite clocks, and other products; improvement of geophysical models; development of new algorithms and software for data analysis; and comparison and validation of results. Without all these contributions by members of IGS, we simply could not do modern geodetic research.

Members of IGS have a shared global vision. They realize that by pooling data and ideas, the sum is much greater than the parts. IGS serves as a model of unselfish global cooperation, exploiting the Internet to bypass political and institutional boundaries, pumping vast amounts of data around the world in record time, and generating something important with it, to amazingly high technical standards. The goal of all this activity is to generate data products of unprecedented accuracy that facilitate a wide range of scientific and environmental applications. As we survey the state of the world in 2004, with its host of problems, the answer to at least a few of them seems obvious: act more like IGS.

IGS is a remarkable organization, and its members can be justly proud of their accomplishments on this 10th anniversary of its founding.

IGS

Executive Overview

These two years continue to realize the collective success of the IGS. A key focus of both years has been the IGS Strategic Plan and the process for implementing actions to accomplish the objectives. The key parts of this plan refine the mission, long-term goals, and objectives of the IGS, which are included here. The directions of the IGS as formulated in this plan promise productive and rewarding years to come in this unique global federation of the IGS.

Mission

The International GPS Service is committed to providing the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. These activities aim to advance scientific understanding of the Earth system components and their interactions, as well as to facilitate other applications benefiting society.

Long-Term Goals and Objectives

The IGS strives to:

- Provide the highest quality, reliable GNSS data and products, openly and readily available to all user communities.
- Promote universal acceptance of IGS products and conventions as the world standard.
- Continuously innovate by attracting leading-edge expertise and pursuing challenging projects and ideas.
- Seek and implement new growth opportunities while responding to changing user needs.
- Sustain and nurture the IGS culture of collegiality, openness, inclusiveness, and cooperation.
- Maintain a voluntary organization with effective leadership, governance, and management.

The final document was approved by the Board in late 2001 and published in March of 2002. Separate copies are available from the Central Bureau.

Highlights

The table on page 5 indicates the significant events of the IGS and more are described in the submissions to this document and in the Technical Reports.

2001 Key Events

A major challenge to the IGS was met by Prof. R. Weber, who succeeded Dr. T. Springer as IGS Analysis Center Coordinator mid-term. This demonstrated the University of Bern's deep commitment to this task through 2002 and was greatly respected by everyone. In February 2001, *A new project called TIGA was established within the IGS to use GPS observations at tide gauge benchmark stations in order to assess long-term sea level change*

GeoForschungsZentrum organized a Low Earth Orbiter Workshop in Potsdam, Germany, which was co-hosted by the IGS. This was well attended and provided a venue to discuss the end-to-end aspects of LEO missions, particularly CHAMP, and their applications which include precision orbit determination, gravity, atmospheric occultation, and ionospheric tomography. Following the workshop, the first meeting of the IGS Real-Time Working Group was held in Potsdam to develop the charter and technical approach to building a real-time IGS subnetwork and related processes. The IGS supported a campaign of the Ionosphere Working Group to collect and analyze high-rate data during the period of the total eclipse of the Sun during April.

A new project called TIGA (Tide Gauge Monitoring Pilot Project) was established within the IGS to use GPS observations at tide gauge benchmark stations in order to assess long-term sea-level change. GPS observations will be used to remove the signals from coastal crustal deformation or subsidence from the long-term sea-level records. The TIGA has very challenging vertical measurement requirements that will span decades. The project has facilitated analyzing data from stations with high latency data availability — some collected only once per year from remote locations with no access to the Internet.

The need for a continental reference system in Africa — termed AFREF — has been increasingly underscored. Discussions were held in Capetown, South Africa, with Surveying and Mapping representatives from most of the southern African nations to discuss and plan a regional realization of AFREF and included representatives from the Central Bureau (see the report by Wonnacott in this Annual Report).

2002 Key Events

A true highlight of the year was a full workshop of the IGS in April titled “Towards Real-Time,” skillfully managed by Natural Resources Canada, host and local organizer. This was the first workshop in many years that brought all components of the IGS together and it was agreed that this was an excellent meeting. Proceedings of this Ottawa workshop are available at the IGS website. A workshop of the Ionosphere Working Group was held in January at ESA/ESOC in Darmstadt.

IGS became a member of a United Nations Action Team on Global Navigation Satellite Systems (GNSS) with the Central Bureau Director as the designated representative. This team focuses on the use of GNSS, especially in developing countries, and is chartered by the UN

Office of Outer Space Affairs in Vienna to address various GNSS-related issues. More progress is expected as the team prepares its report for the 2004 UNISPACE conference.

The LEO mission GRACE launched successfully in March 2002, promising additional data for the LEO Working Group. At the December Governing Board meeting, my term as Chair of the IGS Governing Board was completed and Prof. John Dow of ESA/ESOC was elected to lead the Board and the IGS. A proposal for the next Analysis Center Coordinator was also approved by the Board with Dr. Gerd Gendt, GFZ, to succeed Prof. Robert Weber, AIUB and Technical University of Vienna. This was unanimously approved based on technical expertise and committed support of GFZ. The expected transition period is set to be complete by mid-2003. A GNSS Working Group is set up with plans to position the IGS to take advantage of the future Galileo and modernized GPS. Due to all of these increasing demands on the data and product access, a Data Center Working Group was approved in April 2002. IGS timescale activities moved seamlessly from USNO to Naval Research Laboratory with continued expertise.

IGS Governing Board Meeting, September 10, 2002. From left: Gerhard Beutler, Tilo Schöne, Henno Boomkamp, Manuel Hernandez-Pajares, Markus Rothacher, Gerd Gendt. Front row: Ruth Neilan, Carine Bruyninx, Angelyn Moore, Felicitas Arias. Back row: Christoph Reigber, Norman Beck, Zuheir Altamimi, John Dow, Loic Daniel, Jim Zumberge.

I have very much enjoyed working with the Board and the people of the IGS, and am convinced that the IGS will continue to flourish. I will remain on the Board until 2004, working on the strategic issues and the new program of the International Association of Geodesy: Global Geodetic Observing System (GGOS).

Christoph Reigber

GeoForschungsZentrum Potsdam
Germany

Chair, IGS Governing Board
1999–2002

IGS Significant Events

2001

January	*R. Weber replaces T. A. Springer as IGS Analysis Coordinator, University of Bern*
February	*LEO workshop, GeoForschungsZentrum Potsdam*
	First meeting of the IGS Real-Time Working Group, Co-Chairs named: M. Caissy, NRCan; R. Mullerschoen, JPL
March	*IGS Board establishes the International GLONASS Service Pilot Project, IGLOS-PP*
March 9-17	*CONSAS and AFREF meeting in Capetown supported by the Central Bureau*
March 25	*IGS Governing Board 16th Meeting, Nice, France*
	TIGA Project established by the Governing Board, chaired by T. Schoene, GFZ
April	*High-rate tracking campaign for ionospheric research during solar eclipse*
May	*Release of CHAMP data for LEO Pilot Project*
April 23–27	*GLOSS meeting in Hawaii — joint with TIGA project*
Mid-2001	*IGS Workshop Proceedings published externally*
	• GPS Solutions: Analysis Center Workshop, September 2000, US Naval Observatory
	• Physics and Chemistry of the Earth: Network Workshop of the IGS, Oslo, Norway, Norwegian Mapping Authority
September 1	*IGS Governing Board 17th Meeting, Budapest, Hungary, at the IAG Scientific Assembly 2001*
December 9	*IGS Governing Board 18th Meeting, San Francisco, California*

2002

January	*Ionosphere Workshop, ESA/ESOC, Darmstadt, Germany*
Early 2002	*IGS Strategic Plan 2002–2007 completed and published*
March	*GRACE successfully launched*
April	*Ottawa Workshop — "Towards Real-Time," Natural Resources Canada*
April 11	*IGS Governing Board 19th Meeting, Ottawa, Canada*
	Data Center Working Group established naming C. Noll as Chair
June	*IGS representation on the UN GNSS Action Team, Vienna*
June 21	*Marks ten years since IGS Pilot Project initiated*
July	*UN Regional GNSS Workshop, Lusaka, Zambia: AFREF meeting*
September 10	*IGS Governing Board 20th Meeting, Potsdam, Germany*
December 10	*IGS Governing Board 21st Meeting, San Francisco, California*
	• J. Dow elected to succeed C. Reigber as IGS Governing Board Chair
	• GNSS Working Group established with R. Weber as Chair
	• IGS/BIPM Pilot Project dissolved as timing activities become part of IGS official suite of products; K. Senior, US Naval Research Lab, named Timing Coordinator

ACTIVITIES

Robert Weber

Astronomical Institute, University of Bern, Switzerland, and Technical University of Vienna, Austria

Analysis Center Coordinator

The International GPS Service is committed to providing the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. In this context, the IGS offers a large number of consistent products that constitute the practical realization of the International Reference System and allow for easy access to the most recent International Terrestrial Reference Frame (ITRF). To ensure enhanced reliability, all products are the outcome of a combination of the individual IGS Analysis Center solutions.

Table 1 shows the estimated quality of the IGS combined data products at the end of 2002.

Table 1. Quality of the IGS Reference Frame Products as of December 2002. (For details, see *http://igscb.jpl.nasa.gov/components/prods.html*.)

Products / Delay	Ultrarapid/ Real Time	Rapid/ 17 hours	Final/ 13 days	Units
Orbit (GPS)	15.0	5.0	3.0	centimeters
Satellite Clocks	5.0 (predicted)	0.1	0.05	nanoseconds
Station Clocks	—	0.1	0.05	nanoseconds
Polar Motion	—	0.1	0.05	milliarcseconds
Length of Day	—	30.0	20.0	microsec/day
Stations h/v*	—	—	3.0/6.0	millimeters (mm)
Troposphere	—	—	4.0	mm zenith path delay

*Horizontal/vertical

Figure 1 shows the weighted orbit rms for the Analysis Center solutions with respect to the combined final orbit products.

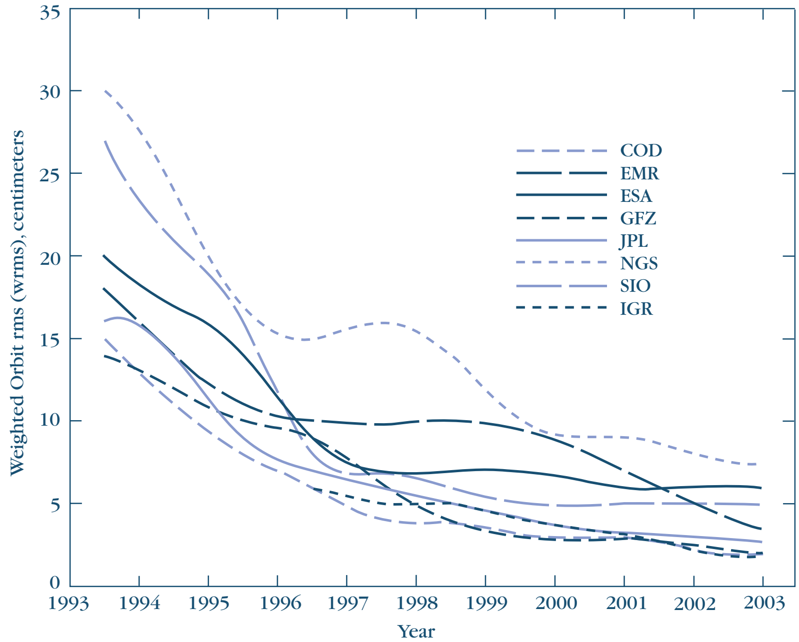


Figure 1. Weighted orbit rms of the Analysis Center and IGS rapid (IGR) orbit solutions.

Reference Frame

Since December 2001 (GPS-Week 1143), all IGS products have been based consistently on the IGS Reference Frame realization (IGS00) of the ITRF2000. To perform this task, the unconstrained weekly combined IGS-SINEX solution of station coordinates/velocities and Earth rotation parameters is aligned by minimum datum constraints to IGS00, based on a list of 54 reference stations with high-quality positions/velocities in ITRF2000. Rotations of the individual SINEX solutions with respect to the SINEX combination are subsequently applied to the Analysis Center orbit solutions by means of a spatial similarity transformation in order to align orbits to the common IGS00 frame.

Ultrarapid Products

In order to support real-time applications, the IGS has been providing combined ultrarapid satellite orbits (IGU) in standard SP3 format since November 2000. An updated version of this format, labelled SP3c, was developed in 2002. The new format offers a significant enhanced flexibility, e.g., in characterizing the variable accuracy of the given data points within the IGU-orbits. Since December 2002, the ultrarapid as well as the IGS rapid orbit products have been available in both formats.

The average percentage of satellites provided in the IGU-orbits with an accuracy of better than 20 centimeters could be enhanced to over 90 percent in 2002. Satellites with reduced accuracy were rejected from the combination. Furthermore, a graphic tool has been developed that demonstrates on a weekly basis the quality of the observed and predicted clock estimates within the IGU-orbit combination and within the relevant submissions of the individual Analysis Centers — see *http://lwww.hg.tuwien.ac.at/forschung/satellitenverfahren/igs_ultrarapids_products.htm*.

To shorten the predicted periods and thus to improve the orbit and clock quality significantly, it is envisaged that more frequent updates of the ultrarapid products (every 6 hours) will be issued very soon.

Central Bureau

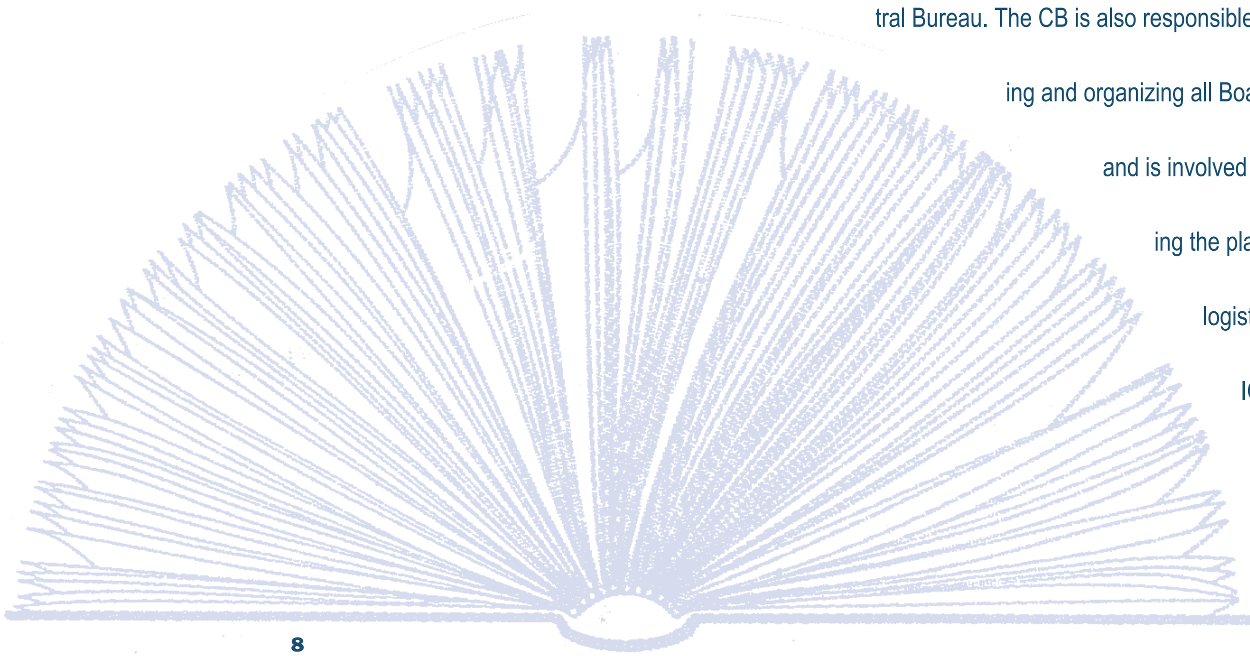
STATUS and PERSPECTIVE

Ruth E. Neilan

Jet Propulsion Laboratory, California Institute of Technology, USA

Director, IGS Central Bureau

As we enter another year, the Central Bureau continues to promote the IGS organization, data, and data products as setting the world standard for GPS/GNSS geodetic applications as outlined in the IGS Strategic Plan. The Central Bureau was responsible for the organization of the strategic planning process, preparation of all documents, and the editing and publication of the plan. This was a major activity and the Board's consensus on the plan is a significant milestone in the evolution of the IGS. The Central Bureau is responsible for the day-to-day management of the Service. With 200 organizations in over 80 countries and a ground network of 242 stations, this requires daily interfaces on many different levels globally. The separate summary of the IGS Network Coordinator is included in this Annual Report and demonstrates the vital technical tasks of the Central Bureau. The CB is also responsible for arranging and organizing all Board activities and is involved in supporting the planning and logistics of all IGS workshops and meetings.



In 2001–2002, the CB focused its efforts on outreach to other nations to encourage participation in the IGS for mutual benefit. Continued discussions with principals of China's Crustal Motion Observation Network of China (CMONOC) at the China Seismological Bureau (CSB) demonstrate their deep interest in becoming more involved with the IGS. Similarly in Africa, the CB has been active in 2000 and 2001 to further the concept of a continental reference system for Africa, called AFREF, taking part in meetings and discussions in Capetown. The initiative is being embraced by principal people within Africa, a key requirement for the long-term viability of a reference frame realization.

The CB began working with the United Nations Office of Outer Space Affairs (UN/OOSA) to assist in the planning of the regional series of UN/GNSS workshops, with the objective of obtaining broader international participation in these meetings. In particular, a key workshop took place in Lusaka, Zambia, in July 2002 where many people from throughout Africa were present. One of the sessions of the workshop was devoted to unifying the African continental reference frame (AFREF) and was very well attended. The IGS exhibit was displayed and nearly all handout materials quickly disappeared due to keen interest. One of the main problems facing Africans is the ability to interface with the international community and this was seen as an opportunity for them to make connections that help to build up their base of sustainable technology.

This year the IGS published workshop proceedings in conjunction with outside publishing companies as a variant on CB publications: GPS Solutions published the proceedings from the 2000 Analysis Center Workshop (some copies are available from the CB); and Physics and Chemistry of the Earth published the IGS Network Workshop proceedings joint with "Towards Operational Meteorology," the European COST 716 Action "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications." These are excellent proceedings; however, copyright issues preclude their posting to the IGS website, which limits the availability of information, especially to the wider global community.

The CB continues to improve efficiencies with very limited resources and staff and looks forward to working with the GB to accomplish one of the objectives of the strategic plan — to strengthen and stabilize the Central Bureau.

The IGS NETWORK 2001–2002

Angelyn W. Moore

Jet Propulsion Laboratory, California Institute of Technology, USA

IGS Network Coordinator and Deputy Director, IGS Central Bureau

The IGS network is a set of permanent, continuously operating, dual-frequency GPS stations operated by over 100 worldwide agencies. The data set is pooled at IGS Data Centers for routine use by IGS Analysis Centers in creating precise IGS products, as well as free access by other analysts around the world. The IGS Central Bureau hosts the IGS Network Coordinator, who assures adherence to standards and provides information regarding the IGS network via the Central Bureau Information System website.

Typical IGS stations contribute data sampled at 30 seconds on a daily basis; a growing and increasingly well-distributed subset contributes similar data hourly and/or 1-second data subhourly (Figure 1). Some stations feature ancillary sensors or functionality relevant to new studies emerging in IGS Working Groups and Pilot Projects, such as meteorological sensors, high-rate data, tide gauges, precise frequency standards, or data from other satellite navigation systems (presently GLONASS). In total, 348 stations form the IGS network (Figure 2).

In 2001–2002, the IGS station operators and other IGS participants collaborated with the Network Coordinator to realize several improvements to the network element. An overhaul of the station logs that record the history of each site (crucial to the maintenance of the IGS realization of the International Terrestrial Reference Frame and the consistency of IGS products) started with a proposal of a form allowing the structured collection of information on more types of ancillary and geophysical data. After review and revision by a small yet representative group, final suggestions were collected from the IGS at large in typical IGS collaborative fashion. The changeover was handled at the Central Bureau, with significant and timely assistance from site operators when apparent discrepancies arose.

This revised station metadata allowed stations participating in the International GLONASS Service Pilot Project (IGLOS-PP) to be fully

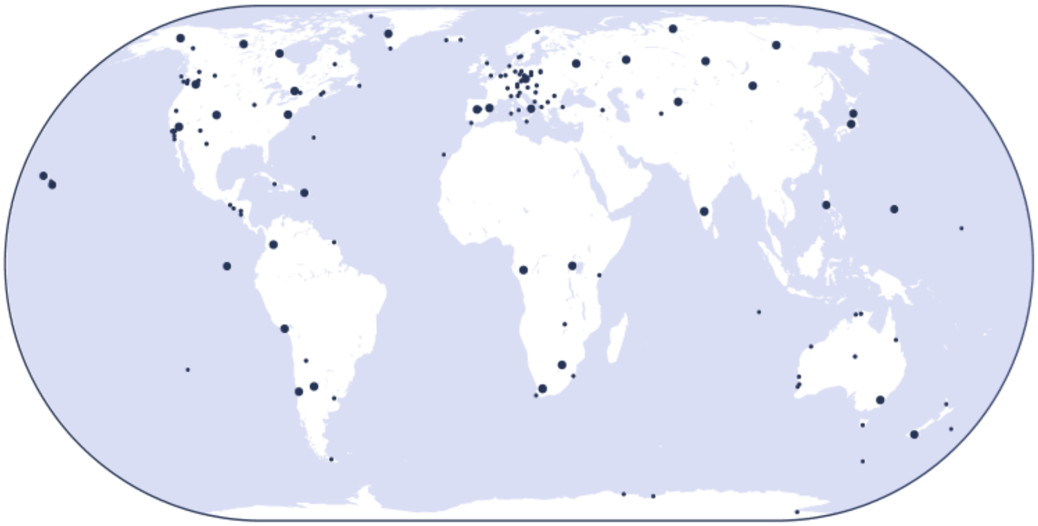


Figure 1.
IGS stations providing hourly (small circles) or subhourly (large circles) data during 2001–2002.

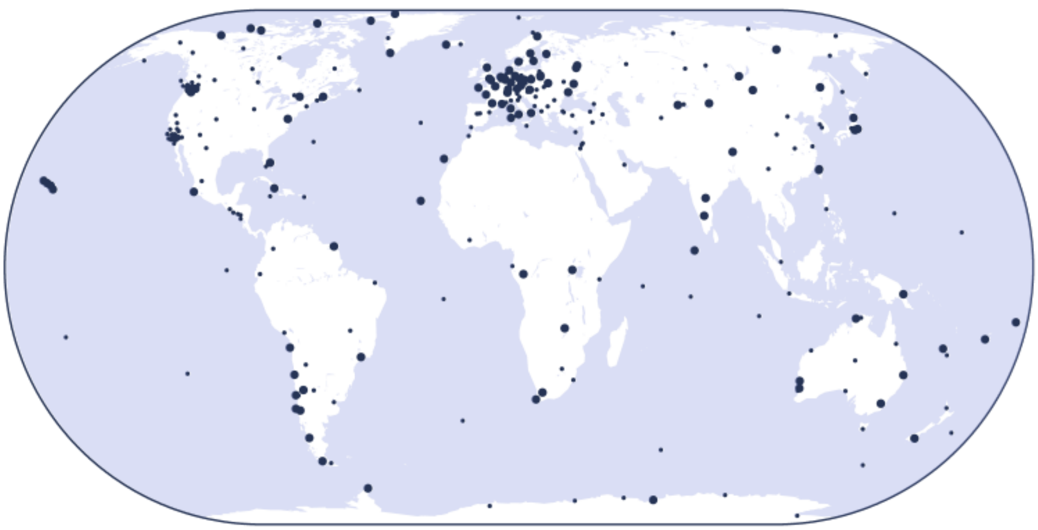


Figure 2.
The IGS network at the end of 2002. Large circles indicate sites added in 2002.

integrated into the IGS network. Combined GPS/GLONASS data and stations now appear side by side with the GPS-only IGS stations (Figure 3). This accounts for many of the large number of sites (112) added to the IGS network between 2001 and 2002. In addition to augmenting the IGS network and providing convenience for IGLOS-PP analysts, this serves as a significant demonstration of the IGS' capability to integrate data from other Global Navigation Satellite Systems (GNSS) into the IGS organization and information flow. The new sites also include some participating in other IGS Working Groups and Pilot Projects, such as timing activities and Tide Gauge Benchmarks. Notable coverage improvements came to the Arctic and southern Africa, as is evident from the large circles in Figure 2.

The IGS CBIS began to provide convenient downloadable maps of the IGS network and

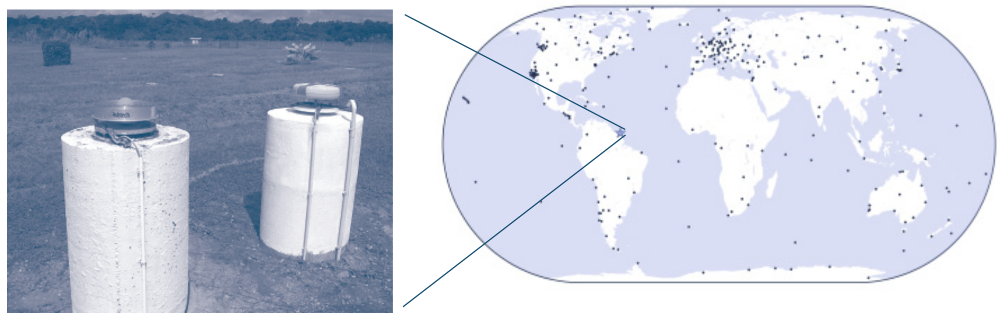


Figure 3. The IGS station at Kourou, French Guyana, gained dual GPS/GLONASS capability in 2002, in support of the International GLONASS Service Pilot Project. (Photo courtesy of ESA/ESOC)

subnetworks, as well as recent data quality metrics for each IGS site. The latter are helpful in identifying sudden changes in data character that can identify a site disturbance or equipment failure (Figure 4).

These examples of network-wide improvements in themselves do not adequately reflect the complete picture of activity within the IGS network. All the while, the stations' operating agencies are planning new stations, arranging for equipment repair and upgrade, maintaining the integrity of station information, and improving communications and automation. It is this significant commitment to contribute to the global data set that fundamentally makes the IGS possible.

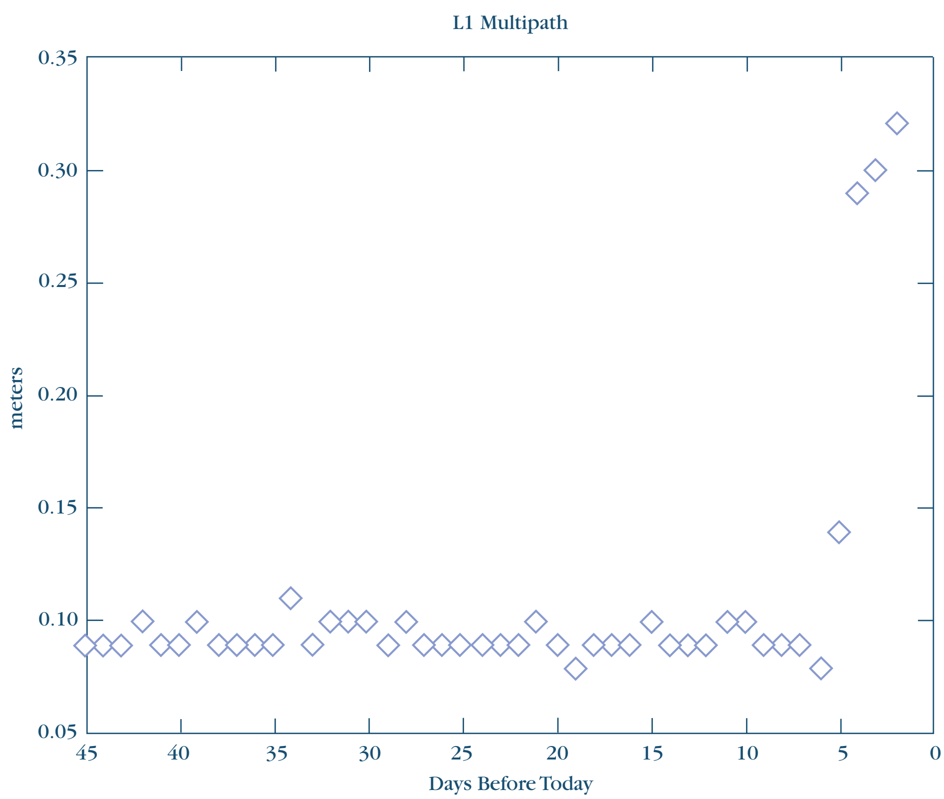


Figure 4. The IGS Central Bureau monitors data quality indicators that can point to an event at a station. Here, a discontinuity in multipath indicates a potential incident about 5 days prior.

Table 1. Site Additions During 2001–2002.

AJAC	Ajaccio, Corsica, France
ALRT	Alert, Nunavut, Canada
ANTC	Los Angeles, Chile
BAN2	Bangalore, India
BOGI	Borowa Gora, Poland
BREW	Brewster, Washington, USA
BRST	Brest, France
CAGS	Gatineau, Quebec, Canada
CAGZ	Capoterra, Italy
CFAG	Caucete, Argentina
CHPI	Cachoeira Paulista, Brazil
CHUM	Chumysh, Kazakhstan
CONZ	Concepcion, Chile
COPO	Copiapo, Chile
COYQ	Coyhaique, Chile
DARR	Darwin, Australia
DAVR	Davis, Antarctica
DLFT	Delft, the Netherlands
DREJ	Dresden, Germany
DWH1	Woodinville, Washington, USA
FALE	Faleolo, Samoa
FFMJ	Frankfurt/Main, Germany
FREE	Freeport, the Bahamas
GMAS	Mas Palomas, Gran Canaria, Spain
GUAO	Urumqi, China
HELJ	Helgoland Island, Germany
HERP	Hailsham, England
HILO	Hilo, Hawaii, USA
HNLC	Honolulu, Hawaii, USA
HOLM	Holman, Northwest Territories, Canada
HUEG	Huegelheim, Germany
HYDE	Hyderabad, India
INVK	Inuvik, Northwest Territories, Canada
IQQE	Iquique, Chile
IRKJ	Irkutsk, Russia
JOZ2	Josefoslaw, Poland
KGN0	Koganei, Japan
KGNI	Koganei, Japan
KHAJ	Khabarovsk, Russia
KOU1	Kourou, French Guyana
KOUC	Koumac, New Caledonia
KR0G	Kiruna, Sweden
KSMV	Kashima, Japan
LAE1	Lae, Papua New Guinea
LEIJ	Leipzig, Germany
LHAZ	Lhasa, Tibet, China
LHUE	Lihue, Hawaii, USA
LIND	Ellensburg, Washington, USA
LROC	La Rochelle, France
MALD	Male, Maldives
MANZ	Manzanillo, Mexico
MARS	Marseille, France
MAT1	Matera, Italy
MAUI	Haleakala, Hawaii, USA
MBAR	Mbarara, Uganda
MDVJ	Mendeleevo, Russia
METZ	Kirkkonummi, Finland
MIKL	Mykolaiv, Ukraine
MIZU	Mizusawa, Japan
MOBN	Obninsk, Russian Federation
MORP	Morpeth, UK
MR6G	Maartsbo, Sweden
MSKU	Franceville, Gabon

MTBG	Mattersburg, Austria
MTKA	Mitaka, Japan
NAIN	Nain, Newfoundland, Canada
NNOR	New Norcia, Australia
NPLD	Teddington, UK
OBE2	Oberpfaffenhofen, Germany (replacing OBER)
OBET	Oberpfaffenhofen, Germany
OHI2	O'Higgins, Antarctica (replacing OHIG)
OHIZ	O'Higgins, Antarctica
OPMT	Paris, France
OS0G	Onsala, Sweden
OUS2	Dunedin, New Zealand
PADO	Padova, Italy (replacing UPAD)
PARC	Puntas Arenas, Chile
POLV	Poltava, Ukraine
PTBB	Braunschweig, Germany
QAQ1	Qaqortoq, Greenland
RESO	Resolute, Nunavut, Canada
REYZ	Reykjavik, Iceland
SACH	Sachs Harbour, Northwest Territories, Canada
SCUB	Santiago de Cuba, Cuba
SIMO	Simonstown, South Africa
STR2	Stromlo, Australia
SULP	Lviv, Ukraine
SUNM	Brisbane, Australia
SUTM	Sutherland, South Africa
SUVA	Suva, Fiji
TCMS	Hsinchu, Taiwan, Republic of China
TGCV	Palmeira, Republic of Cape Verde
THU2	Thule, Greenland
THU3	Thule, Greenland
TITZ	Titz, Germany
TLSE	Toulouse, France (replacing TOUL)
TNML	Hsinchu, Taiwan, Republic of China
TWTF	Taoyuan, Taiwan, Republic of China
ULAB	Ulaanbataar, Mongolia
UNB1	Fredericton, New Brunswick, Canada
USN1	Washington, D.C., USA
VALP	Valparaiso, Chile
VS0G	Visby, Sweden
WROC	Wroclaw, Poland
WTZA	Koetzting, Germany
WTZJ	Wettzell, Germany
WTZZ	Koetzting, Germany
YAKT	Yakutsk, Russian Federation
YARR	Dongara, Australia
ZAMB	Lusaka, Zambia
ZIMJ	Zimmerwald, Switzerland
ZIMZ	Zimmerwald, Switzerland

The data flow supporting the International GPS Service (IGS) is structured in a distributed fashion, allowing for redundant flow and archive of data and products, thus providing the international GPS/GNSS user community with a robust data archiving system to support scientific research. The IGS uses a hierarchy of data centers to distribute data from the tracking station network: 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. The structure has been a key aspect to the success of the IGS within the user community.

2001/2002 Data Center ACTIVITIES

Carey E. Noll

NASA Goddard Space Flight Center, USA

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

GPS data, in both daily and hourly observation, navigation, and meteorological data files, are available from the IGS Regional and Global Data Centers in compressed Receiver-Independent Exchange (RINEX) format. IGS products, such as precise orbits, station positions, and atmospheric parameters are also accessible through these data centers. Table 1 lists the data centers supporting the IGS in 2001 and 2002; information on how to contact these data centers is available through the IGS Central Bureau website at *http://igscb.jpl.nasa.gov*.

Highlights for 2001-2002 and Plans for 2003

General

The past two years have been a busy time for the IGS data centers. The Global Data Center at Institut Géographique National (IGN) was upgraded and once again became a fully operational archive supporting the IGS in mid-2002. 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. In 2001, the data centers Crustal Dynamics Data Information System (CDDIS), IGN, Scripps Orbit and Permanent Array Center (SOPAC), and Bundesamt für Kartographie und Geodäsie (BKG) established a global redundancy of hourly observation files by maintaining identical archives.

In April 2002, the IGS Governing Board approved the establishment of the IGS Data Center Working Group, formed to address data center issues. Among the topics to be addressed by this group are an effective data flow redundancy/backup plan, reliability, security, and consistency at data centers, and timely archive and dissemination of data as the IGS moves into a real-time mode for selected products. Efforts will continue in these areas during 2003. A new database-driven system is in development at BKG to manage its archive of regional GPS data and to generate dynamic Web pages for user query of data holdings; the staff hopes to have this system operational in late 2003.

IGS Data

The archives of the IGS Global Data Centers continued to expand in support of the global network. By the end of 2002, SOPAC archived data from nearly 1,000 sites (supporting both the IGS Southern California Integrated GPS Network [SCIGN] and other global research activities), CDDIS archived data from over 260 sites (supporting both the IGS and NASA activities), and IGN archived data from approximately 170 sites. The global network of IGS sites producing 30-second data on an hourly basis expanded to over 130 sites by the end of 2002. These hourly files are archived in compressed, compact RINEX format and are retained at the Global Data Centers for 3 days. 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 the hourly data improved during the past two years with 60 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 both daily and hourly data sets will continue during the coming months.

During 2001, data centers began supporting the IGS Pilot Project for Low-Earth Orbiters (LEO-PP). The CDDIS provided access to data from a network of over 50 sites providing high-rate (1-second) RINEX observation data in 15-minute files. Analysis Centers participating in the LEO-PP, as well as the general IGS user community, will utilize these various data sets to produce orbits for the LEO missions and study the impact on the "classic" IGS products. Additional support of the LEO-PP consists of the archive of spaceborne receiver data, including SAC-C, Challenging Minisatellite Payload (CHAMP), Jason, and ICESat. The CDDIS began archiving data from these missions in January 2002 to enable IGS access. Agencies sponsoring the mission archive and maintain the complete data sets.

Also starting in 2001, data supporting the IGS GPS Tide Gauge (TIGA) Benchmark Monitoring Pilot Project began to flow to the IGS data centers. The primary goal of the pilot project is to provide height coordinates and velocities of the vertical motion for the TIGA Observing Stations (TOS). The latency of the data flow for these stations is often much greater (up to one year) than that for the typical IGS station. Therefore, data centers must retrieve data from participating stations using a flexible schedule.

The transition to operational status for the International GLONASS Service Pilot Project (IGLOS-PP) includes the incorporation of data from GPS+GLONASS receivers into the flow of IGS data and in the generation of IGS products. Starting in April 2002, the archive of these data was merged with existing GPS data structures at the IGS data centers.

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 in 2001 and 2002. 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 combined IGU (ultrarapid orbit) products were distributed and archived on a daily basis as well. 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 180 sites, was generated by GFZ and archived on a weekly basis at the Global Data Centers. Individual ionosphere maps of total electron content (TEC) were derived on a daily basis by five IGS Associate Analysis Centers and were also 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.

Table 1. Data Centers Supporting the IGS in 2001 and 2002.

Operational Data Centers and Other Station Operations Agencies	
ASI	Italian Space Agency*†
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'Etudes Spatiales, France
CRL	Communications Research Laboratory, Japan
DGFI	Deutsches Geodätisches ForschungsInstitut, Germany
DUT	Delft University of Technology, The Netherlands
ESOC	European Space Agency (ESA) European Space Operations Center, Germany*
GA	Geoscience Australia (formerly Australian Surveying and Land Information Group)*

GFZ	GeoForschungsZentrum Potsdam, Germany*†‡
GOP	Geodetic Observatory Pecny, Czech Republic*†
GSI	Geographical Survey Institute, Japan
HartRAO	Hartebeesthoek Radio Astronomy Observatory, South Africa*
ISR	Institute for Space Research, Austria
JPL	Jet Propulsion Laboratory, California Institute of Technology, USA*†‡
KAO	Korean Astronomical Observatory
KMS	National Survey & Cadastre, Denmark
NGI	National Geography Institute, Korea
NIMA	National Imagery and Mapping Agency, USA
NMA	Norwegian Mapping Authority
NOAA	National Oceanic and Atmospheric Administration, USA*
NRCan	Natural Resources Canada*†
PGC	Pacific Geoscience Centre, 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

BKG	Bundesamt für Kartographie und Geodäsie, Germany
GA	Geoscience Australia
HartRAO	Hartebeesthoek Radio Astronomy Observatory, South Africa
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 GSFC, USA‡
IGN	Institut Géographique National, France
SIO	Scripps Institution of Oceanography, USA

* Operational Data Center forwarding hourly 30-second data to the IGS.
† Operational Data Center forwarding 15-minute files of 1-second data to the IGS.
‡ Organization providing space receiver data.

IGS Reference Frame Working Group ACTIVITIES

Remi Ferland

Geodetic Surveys Division, Natural Resources Canada

IGS Reference Frame Coordinator

The requirement to generate unique IGS station coordinates and velocities, Earth rotation parameters (ERPs), and geocenter products was recognized as early as 1994 by the IGS. The requirement was described in a position paper (Kouba et al., 1998). The Reference Frame Working Group (RFWG) was organized to address this requirement. These products have a direct impact on the GPS satellite ephemerides and clock products.

Recent activities of the working group can be summarized in three distinct categories:

- Generation of the weekly products.
- Implementation of the IGS realization of International Terrestrial Reference Frame 2000 (ITRF2000).
- Participation in International Earth Rotation Service (IERS) activities, such as the definition of the Software-Independent Exchange (SINEX) version 2.0 and the analysis campaign to align the Earth rotation parameters (ERPs) to ITRF2000/International Celestial Reference Frame (ICRF).

Generation of the Weekly Products

To ensure the consistency of all IGS combined products, since 27 February 2000 (GPS Week 1051), the combined orbit products, generated by the Analysis Center Coordinator, have been aligned to the weekly SINEX cumulative combinations. The SINEX combination is available within 12 days (Thursday) after the end of each GPS week. The Earth rotation parameters (ERPs) are included in the weekly SINEX combination along with the station coordinates, with a full variance-covariance information. The increase in the number of stations is contained in the weekly IGS combined SINEX solutions of the Analysis Centers, and Global Network Associate Analysis Centers (GNAACs). The Analysis Centers currently process between 40 and 140 stations weekly. The IGS weekly combined solution now contains in excess of 180 stations that meet the quality control tests. The complete cumulative solution currently includes over 340 stations. Of those, 215 stations containing reliable information are released in the weekly combined SINEX solutions, which are considered sufficient to form a basis for any ITRF densification requirements. A comparison between the Analysis Center, GNAACs, and IGS weekly solutions, and the cumulative IGS solution of the epoch, indicates that the Analysis Center noise level is 3–8 millimeters horizontally and 8–15 millimeters vertically; while the GNAAC and IGS weekly noise levels are 3–4 millimeters horizontally and 5–8 millimeters vertically. The IGS weekly and GNAAC consistency is approaching 3 millimeters, which reflects the processing noise level. The best Analysis Center pole (and rates) are consistent at the 0.05–0.10 milliarcsecond (mas) (0.10–0.20 mas/day), while the calibrated lengths of day (LOD) are consistent at 20–30 microseconds. The combined ERPs are consistent with the GNAAC combinations at about 0.05 mas (0.10–0.20 mas/day). Comparison of the combined daily pole positions with Bulletin A published by the IERS shows a noise level at about 0.06 mas after removing a constant bias.

IGS Realization of ITRF2000/IGS00

In 2001, IGS00 — the IGS realization of ITRF2000 — was also made available. The IGS97/ITRF97 realization, which was in use until then, was updated to IGS00. The IGS00 is a 54-station subset of the cumulative solution IGS01P37.snx (GPS week 1131, 9 September 2001) aligned to ITRF2000. 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 were added in South America, while two stations were removed. Three new stations were also added: Ascension Island in the Atlantic Ocean, Diego Garcia Island in the Indian Ocean, and one station in Australia. Although ITRF97 and ITRF2000 are supposed to be aligned, there are some small transformation parameters between their IGS realizations, due mainly to network effects. Based on the 49 common refer-

Table 1. Transformation Parameters from IGS97 (ITRF97) to IGS00 (ITRF2000) at 2 December 2001 (Sigmas Are in Brackets).

	Translations			Rotations			Scale
02 December 2001	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	S (ppb)
(1 sigma)	–4.5 (4.1)	–2.4 (5.0)	26.0 (7.5)	–0.024 (0.092)	–0.004 (0.099)	–0.159 (0.076)	–1.451 (0.27)
Rate (/y) (1 sigma)	0.4 (1.7)	0.8 (1.9)	1.6 (2.8)	0.003 (0.038)	–0.001 (0.040)	–0.003 (0.034)	–0.03 (0.12)

mas = milliarcsecond
ppb = parts per billion
S = scale
mm = millimeter
R = rotation
T = translation

ence frame stations between the two IGS realizations, the estimated transformation parameters from IGS (ITRF97) to IGS (ITRF2000) are given in Table 1 (the signs are consistent with the IERS convention). The IGS00 reference frame change was made on GPS week 1143 (2 December 2001).

Participation in IERS Analysis Campaign

The objective of the IERS analysis campaign was to better understand the stability, consistency, and limitations of the ERPs alignment when using ITRF2000, with the ERP accuracy goal of 0.1 mas. The test included all the IGS weekly solutions between 27 February 2000 and 23 February 2002. Those solutions contain weekly station coordinates estimates as well as daily ERPs. The weekly solutions were constrained using the ITRF2000 as well as its IGS realization (IGS00). Tests were made using different networks — the reference network containing the 54 reference frame stations mentioned above and a network of all available and acceptable IGS stations. The tests also included various types of constraints on the network, namely minimal, formal, and heavy position weights. Heavy weights are 100 times the formal weights. In the case of minimal constraints, the weekly solutions were aligned to the reference frame realization of the epoch using a weighted 7-parameters Helmert transformation. Inner constraints were also applied in this instance to produce meaningful statistics. Note that in this procedure, the application of the inner constraints had no effect on the estimated parameters. In all cases, the noise level of the X and Y pole position differences with respect to the official IGS ERP time series igs00p02.erp remained below 0.03 mas.

AFREF A Continental Reference Frame for AFRICA

Richard T. Wonnacott

Department of Land Affairs, South Africa

Director, Survey Services

A uniform coordinate reference system is fundamental to any project, application, service, or product that requires some form of georeferencing. Most countries in the world have established such reference systems, which are used for national surveying, mapping, photogrammetry, remote sensing, Geographical Information Systems (GIS), development programs, and hazard mitigation (earthquake studies, fault motion, volcano monitoring, severe storms).

Many of these national coordinate systems are based on reference figures of the Earth that are somewhat outdated and, when based on a local origin or datum point, are restricted to a particular country, making cross-border or regional mapping, development, and planning projects very difficult indeed. In some instances, more than one datum has been used within a country, thus adding to the confusion. The objectives set out by African Heads of Government in the New Partnership for Africa's Development (NEPAD) cannot be achieved because the priority areas such as agricultural development, improved transport and power infrastructure, disease control, and so on require adequate geographic information products. The need to establish a unified African geodetic reference framework, upon which all geospatial information is to be based, is therefore urgent.

The concept of a unified reference frame has been recognized since the 1980s, and the African Doppler Survey (ADOS) project was intended to provide such a frame. However, the ADOS project ended in 1986 without fully achieving its objectives. Several factors were responsible for the failure of ADOS, including the difficulty in satisfying the simultaneous observations required by the Doppler satellite technology used at the time.

The explosive growth of GPS applications over the past 10 years and the economics of GPS make it the technique of choice for sustainable geodetic operations, a particularly positive aspect within the developing nations of Africa and elsewhere. The existing global infrastructure of permanent GPS stations, operated and maintained by the IGS, provides high-quality GPS data, products, and information resources that can advance the realization of an African continental reference system.

Other regions of the world have also embarked on unified reference frames, notably EUREF in Europe and SIRGAS for South America. These reference frames are based on establishing a network of permanent GPS stations, tied to the global network of the International GPS Service. Adopting the same technology and standards will be of great benefit to Africa. In line with the objectives of NEPAD, Africa will be fully integrated into the world network, allowing it to tap into several global data and information resources, especially in the area of geographic information.

The AFREF concept is, therefore, to establish a network of permanent GPS stations such that a user anywhere in Africa would have free access to the data and would be at most, within 1000 kilometers from such stations. This network will be the fundamental basis for the national three-dimensional reference networks fully consistent and homogeneous with the International Terrestrial Reference Frame (ITRF). The approach to be adopted is that of continental coordination with national implementation. For practical effectiveness, an intermediate coordinating structure is proposed at the subregional level, resulting in subregional reference frames: NAFREF (for North Africa), SAFREF (for Southern Africa), CAFREF (for Central Africa), EAFREF (for East Africa), and WAFREF (for West Africa) — all still conforming and compatible with IGS/ITRF specifications. Following the principle of national implementation, countries will be expected to maintain and secure the stations, undertake field campaigns, and submit the data to designated regional data centres. Already, the Hartebeesthoek Radio Astronomy Observatory (HartRAO), a national facility of the National Research Foundation (NRF) of South Africa, is an IGS data center and will play a key role in the implementation of AFREF. It is noted that countries may not be fully self-sufficient in terms of the resources required to establish and maintain permanent GPS stations, so assistance may therefore be sought for such countries from other African countries that have more capacity or from the international community.

The IGS/BIPM TIME TRANSFER Pilot Project

Jim R. Ray

United States Naval Observatory, USA

The IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements has been sponsored jointly with the Bureau International des Poids et Mesures (BIPM). The project began in 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. Recent activities mostly fall into the areas described below.

Consultative Committee for Time and Frequency (CCTF

At its 15th meeting, held 20–21 June 2001 at the BIPM (Sevres, France), the CCTF adopted Recommendation 2 (2001), which supports the Pilot Project and encourages full participation by the timing labs contributing to UTC.

Deployment of GPS Receivers

The IGS network currently consists of about 350 permanent, globally distributed, continuously operating tracking stations. Of these stations, external frequency standards are used at approximately 40 with H-masers, about 25 with cesium clocks, and about 15 with rubidium clocks; the remainder use internal crystal oscillators. There are about 18 IGS stations currently (March 2002) co-located at timing laboratories, half of which also participate in two-way satellite time transfer operations.

Common-View Files from RINEX data

The Observatoire Royal de Belgium (ROB) has developed a procedure to use Receiver-Independent Exchange (RINEX) data from geodetic GPS receivers to form common-view observation files, the current standard for international time comparisons, as recognized by the Consultative Committee on Time and Frequency, GPS, and GLONASS Time Transfer Standards. This method aims to permit common-view time links using calibrated geodetic receivers to be introduced into BIPM's UTC computation. The BIPM initiated a pilot experiment (TAIP3) using this method in June 2002 among 12 time labs. The experiment is expected to transition to operational use in 2003.

GPS Data Analysis

The IGS implemented a new method developed by Natural Resources Canada (NRCan) and the Astronomical Institute, University of Bern (AIUB) to combine satellite and receiver clock estimates from the Analysis Centers. The clock values are sampled at 5-minute intervals and exchanged using the clock RINEX format, starting with GPS week 1086 (29 October 2000). Figure 1 shows the locations of the stations included in the IGS clock products.

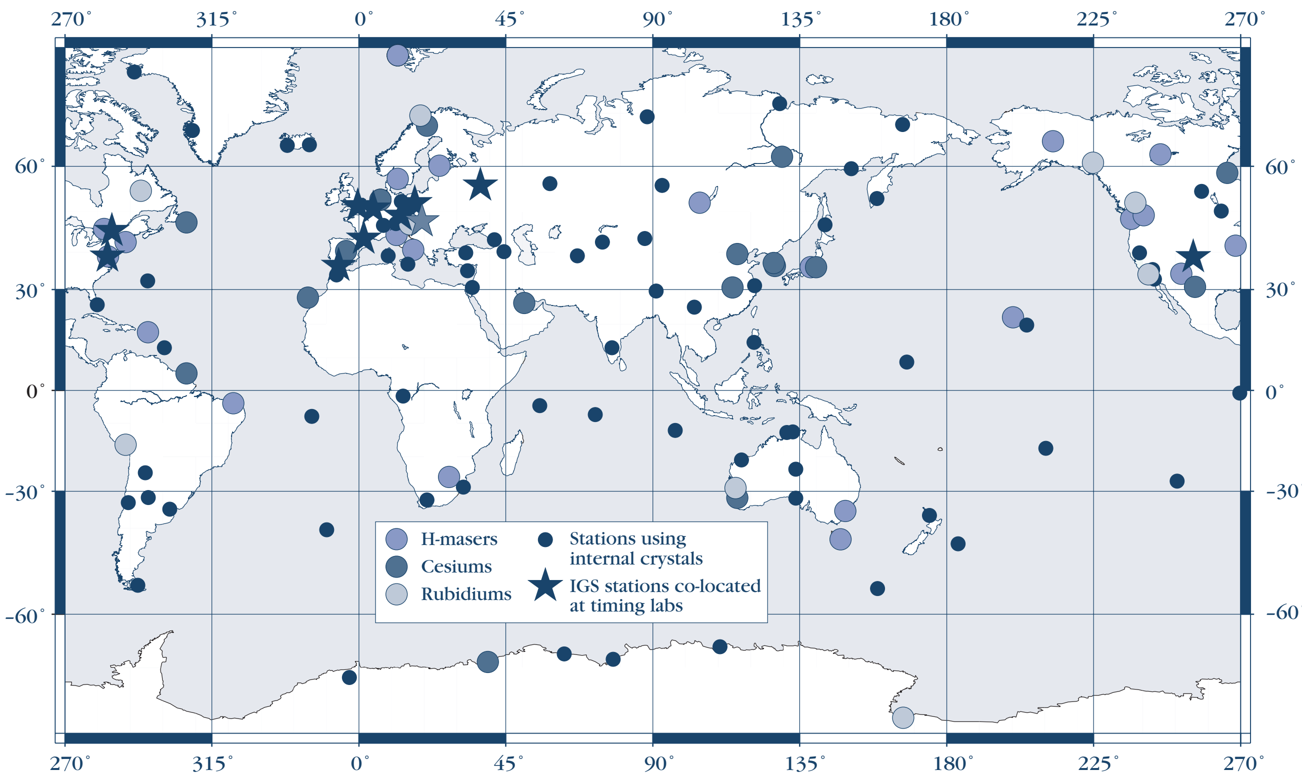


Figure 1. Geographical distribution of IGS stations included in the IGS combined clock products (March 2002). The larger, colored symbols denote stations equipped with external frequency standards.

New IGS Time Scale

A new internally realized time scale was developed by the U.S. Naval Research Laboratory (NRL) to improve the stability of the IGS clock products, which are otherwise limited at about one day and longer by the large instability of GPS time. The consistency of the original IGS clock and orbit products is fully preserved in the new re-referenced clocks, which were released on 15 August 2001. Official adoption of the new time scale by the IGS is expected in the near future.

Clock "Densification"

It was agreed that Analysis Centers may augment their IGS submissions by using the precise point positioning method to determine clocks for receivers not used in their orbit solutions. In this way it is expected that all stations equipped with external frequency standards, especially all timing labs, can be included in the IGS clock products.

Assessment of Accuracy and Precision

Colleagues at NRL, National Geodetic Survey, and the U.S. Naval Observatory (USNO) have studied the realigned IGS clock products for 30 receivers and found that the time transfer performances vary greatly, depending on a variety of local station factors. In the best cases, the timing transfer accuracy is roughly consistent with the formal errors and is adequate for frequency comparisons among the best standards in current use. However, the quality can sometimes be an order of magnitude worse and the next generation of standards will probably require improved stability performance.

GPS Clock Predictions

Four Analysis Centers (USNO, GeoForschungs-Zentrum Potsdam [GFZ], European Space Agency [ESA], and NRCan) provide predictions of the GPS satellite clocks. These are combined and added to the IGS ultrarapid products, together with the orbit predictions, starting in 2000. The twice-daily clock predictions are only about 25 percent better than the broadcast clocks due to the stochastic nature of the satellite clock variations. However, more frequent ultrarapid updates, which are planned for the future, can significantly improve the clock prediction performance for real-time users.

Instrumental Delays

The BIPM and others have developed and demonstrated techniques to calibrate the instrumental biases of the Ashtech Z-XII3T receiver, in both absolute and relative modes. In 2001, the BIPM began a campaign to circulate an absolutely calibrated Ashtech receiver to differentially measure the biases of similar receivers deployed at timing laboratories. Some 12 such receivers have been differentially calibrated during 2001–2002 and the campaign is continuing. The first repeated measurements indicate an agreement at the level of 1 nanosecond between two independent calibrations of the same receiver.

Future Activities

The IGS/BIPM Pilot Project will transition to permanent operational status within the IGS after 2002 in the form of a new clock products activity that augments IGS classic products. A longer period will be required to evaluate the usefulness of the IGS clock products in the work of the BIPM.

IGS ACTIVITIES in the Area of the Ionosphere 2002

Joachim Feltens

European Space Agency

European Space Operations Center, Germany

Manuel Hernandez-Pajares

Polytechnical University of Catalunya, Spain

The IGS Ionosphere Working Group (Iono WG) has been active since June 1998. The working group's most important short-term goal is the routine provision of global ionosphere total electron content (TEC) maps plus differential (P1-P2) code biases with a delay of some days. In the medium- and long-term, the working group intends to develop more sophisticated algorithms for deducing mappings of ionospheric parameters from GPS measurements and to realize near-real-time availability of IGS ionosphere products. The final target is the establishment of an independent IGS ionosphere model.

Five Ionosphere Associate Analysis Centers (IAACs) contribute with their 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 — Natural Resources Canada, Ottawa, Ontario, Canada

UPC — Polytechnical University of Catalunya, Barcelona, Spain

On 10 December 2002, the Iono WG chairmanship was handed over from J. Feltens to M. Hernandez-Pajares at the Polytechnical University of Catalunya (UPC). This article gives an overview of the Iono WG activities in 2002.

Routine Activities

Daily Ionospheric TEC Information

Every 24 hours, each IAAC delivers an Ionosphere Map Exchange (IONEX) file with 13 TEC maps containing global TEC information with a 2-hour time resolution and a daily set of GPS satellite and station differential code biases (DCBs) in its header.

Weekly Comparisons

On Wednesday of each week, the TEC maps from the different IAACs are compared for all days of the last available week (two weeks before). These comparisons are done at the IGS Ionosphere Associate Combination Center (IACC). At the beginning of 2003, the duties for the IACC responsibility were delivered from ESOC to UPC. A weekly comparison summary is e-mailed to the Iono WG members via Iono WG mail hosted at the University of New Brunswick. Additionally, the daily summaries, the daily IONEX files with the mean TEC maps and GPS satellite and station DCBs, and daily TEC and DCB difference files with respect to the mean for each IAAC, and also plots of these maps, are made available to the Iono WG members on UPCs FTP account, which can be found at *ftp anonymous@gage.upc.es* (directory *pub/gps_data/GPS_IONO/cmpcmb*).

Since August 2001, the weekly comparisons are done with weights derived from external validations. These external validations are routinely run by the Ionosphere Associate Validation Centers (IAVCs) UPC and NRCan prior to the weekly comparisons.

On 17–18 January 2002, an IGS/IAACs Ionosphere Workshop was held at Darmstadt, Germany. The essential aim of this workshop was the identification of actions that needed to be undertaken before the routine delivery of a combined IGS ionosphere product could be started. At the IGS Network, Data, and Analysis Center Workshop, 8–11 April 2002, in Ottawa, Canada, a dedicated Iono WG position paper was presented. Based on the outcome of the Darmstadt workshop and on the discussions at Ottawa, five recommendations were formulated in this position paper, which were the guidelines for the Iono WG members on how to progress — particularly the steps toward starting the routine delivery of an official IGS ionosphere product.

The decisions made at Darmstadt and at Ottawa required also several modifications in the comparison/combination program, which were implemented into the software during 2002. The modifications were:

- Inclusion of ground station DCBs into the comparisons/combinations.
- Re-scaling of UPC and NRCan validation values to an equivalent level and norming the resulting weights.
- Derivation of global weights from the regional ones to avoid “chessboard”-like patterns in the combined RMS and TEC maps.
- Change of the IONEX files TEC- and RMS-maps reference epochs from the odd hours 1h,3h,5h, ..., 23h to the even hours 0h,2h,4h, ..., 24h. With this change, an IONEX file now contains now 13 TEC and RMS maps per day. The major reason for this modification is to allow users an easier interpolation when transiting from one day to the next, i.e., from one IONEX file to the successive one.

After all these modifications were made, the complete comparison/combination software was delivered from the IACC at ESOC to the new IACC at UPC at the end of 2002 and implemented at UPC. The weekly comparisons/combinations have been running at UPC since January 2003.

TOPEX Validations

Since July 2001, JPL has been providing vertical TEC data derived from TOPEX altimeter observables to the working group to enable validations. A dedicated TOPEX validation program is attached to the comparison/combination software to run these TOPEX validations together with the weekly comparisons.

Two additional statistics were attached in 2002 to the TOPEX validations output:

- sf/rms — estimate of the scale factor of the RMS values obtained from the TOPEX validation in relation to the corresponding IAAC RMS values, which should theoretically be close to one, especially for the combined IGS TEC maps.
- wrms — mean RMS as indicator for a TEC map's quality.

The TOPEX validation program was also delivered from ESOC to UPC, together with the comparison/combination software, i.e., the weekly TOPEX validations are now made at the new IACC at UPC.

The TOPEX validations show that an essential criterion for the start of the delivery of an official IGS ionosphere product is now fulfilled, thus confirming the upgrades made in the comparison/combination algorithm: the routine validations with TOPEX since July 2001 show an agreement of the combined IGS TEC maps with the TOPEX data on the same order as the best IAACs TEC maps.

Future Tasks

As of March 2003, final actions are being undertaken by UPC to commence with the routine delivery of an official combined IGS ionosphere product to the Crustal Dynamics Data Information System (CDDIS).

Plans are underway to study further improvements in the combination algorithm as follows:

- IAACs weights per IONEX file reference epoch, i.e., weights per 2 hours, instead of daily weights.
- Possibility of downweighting only of those parts of an IAAC's TEC maps that are bad in the combination, instead of excluding TEC maps completely in such cases.

In addition to the TOPEX validations, there are plans to implement routine validations with the ENVISAT and Jason satellite altimeters.

Beyond these short-term targets, further future aims and activities were discussed at the workshops in Darmstadt and Ottawa, of which the most important are:

- A pilot project to reduce the time resolution of TEC and RMS maps in the IONEX files from 2 hours to 1 hour or less.
- A pilot project for “short-term processing” is in preparation for the realization of a new rapid ionosphere product. The critical point here is the number of available ground stations for short-term ultrarapid processing.
- Identification of possible new working areas and products.
- An extension to use of data other than GPS, e.g., Champ, Galileo, and ionosonde.
- Three-dimensional ionosphere models.

IGS

Tropospheric

ACTIVITIES

Gerd Gendt

GeoForschungsZentrum

Potsdam, Germany

Division Geodesy and

Remote Sensing

The quality and consistency of the IGS Final weekly combined tropospheric product has steadily improved during its more than 6-year history. The comparisons between the individual Analysis Center (AC) solutions and the IGS official combined solution are shown in Figure 1. All but one AC agree within 3 mm standard deviation since week 1180 (August 2002) — for most ACs even at the 2 mm level. This corresponds to a quality of better than 0.5 mm in the precipitable water vapor.

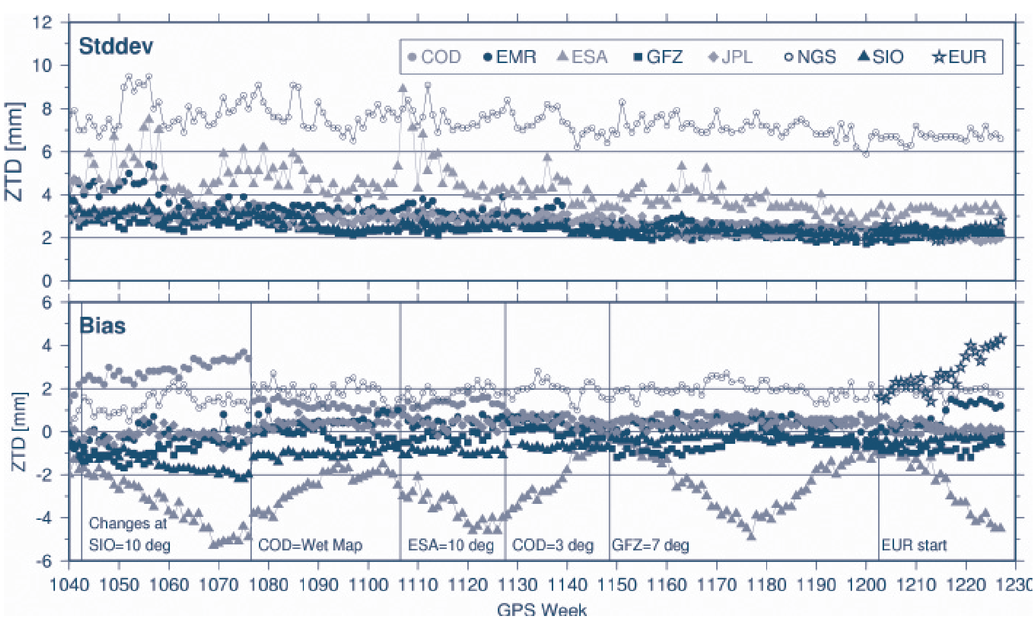


Figure 1. Standard deviation and bias in the neutral zenith total delay between the individual Analysis Center estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center. (GPS Week 1042.6 = 2000.0)

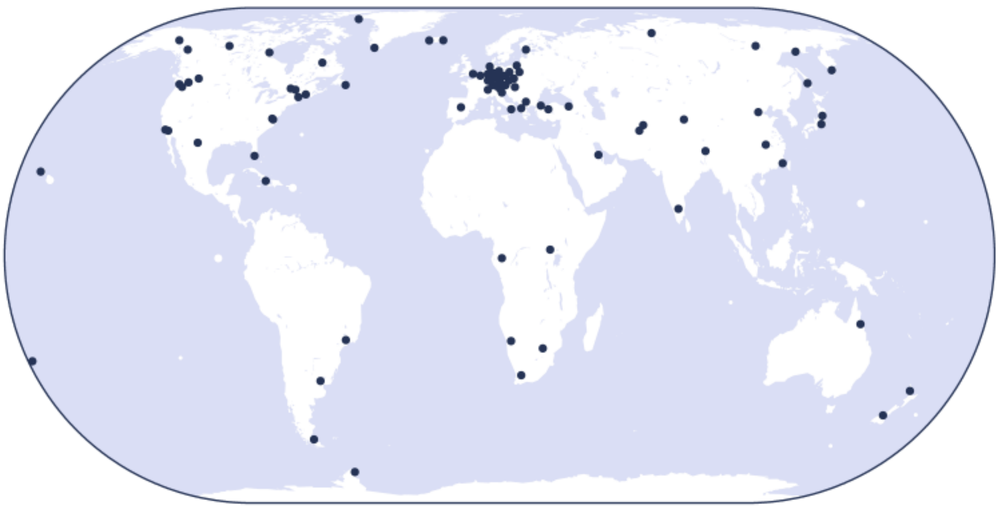


Figure 2.
Network of collocated meteorological sensors.

The bias changes at individual ACs caused by changes in their analysis strategy are even smaller, and in total they are usually in the ±2 mm band. The consistency between the ACs having the smallest standard deviations agrees best. It is during the last years even at the ±1 mm level. Those good ACs have the highest weight in the combination so that the expected bias changes in the combined solution are smaller than ±1 mm.

Tropospheric Products

In June 2001, the EUREF community started a pilot experiment for the generation of tropospheric products. The solution is a combination of 15 individual EUREF ACs and comprises a European network of about 150 sites. After a short test phase in 2001–2002, an official EUREF (abbreviation: EUR) submission was included in the IGS combination starting in February 2002 (GPS week 1203). The standard deviation of the EUREF solution has the same level as seen for the best single IGS ACs. The bias seems to change with time; however, the time interval is still too short for a final assessment. Through this regional densification, the number of sites included in the IGS tropospheric product has grown from 180 to 280.

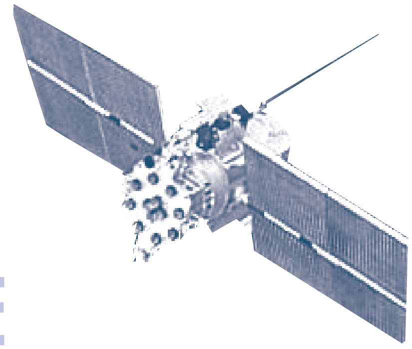
During the last one and a half years, the number of collocated meteorological sensors has improved significantly, to a current total of about 75 stations. However, especially in the tropical region, where the water vapor in the atmosphere is most interesting to monitor, a need for additional sensors is obvious (see Figure 2).

Near-Real-Time Products

After a pilot experiment starting in June 2001, the IGS is generating a near-real-time (NRT) tropospheric product using the global hourly station network. Every 3 hours, a product for the last 12 hours is combined by all individual submissions of up to 8 ACs. Statistics for the contributing ACs are in the IGS Technical Report series. The product is available with a delay of about 2.5 hours and comprises more than 140 stations. The consistency of the product is at the level of ±2 to 4 mm ZTD, as demonstrated in 2001.

In summary, the quality of the IGS combined products — both the final and the near-real-time — corresponds to better than 1 mm in the water vapor content.

IGS International GLONASS Service Pilot Project



James A. Slater

National Imagery and Mapping Agency, USA

Since its inception in 2000, the IGLOS Pilot Project (IGLOS-PP) has maintained a global network of 32–46 continuously operating tracking stations and has also arranged for the collection by the International Laser Ranging Service (ILRS) of satellite laser ranging (SLR) data for three Global Navigation Satellite System (GNSS) satellites. Russia restored part of the depleted GLONASS constellation with satellite launches in 2001 and 2002, but at the end of 2002 there were only seven healthy satellites broadcasting signals. Three organizations have computed precise satellite orbits for this entire period. From these, the IGLOS Analysis Center Coordinator generated a combined orbit product similar to the combined GPS orbits. All the tracking data and precise orbits continue to be archived at the IGS Global Data Center at NASA's Goddard Space Flight Center (GSFC). After keeping the GLONASS data separate from the GPS data in the IGS for the first two years of the project, revisions were made to the IGS Site Logs, Analysis Center software, and archival procedures at the Global Data Centers such that the IGLOS tracking data could be merged with the other IGS tracking data in routine operations. The accomplishment of this was a significant milestone (see A. Moore's report, this volume).

GLONASS Constellation Status

Russia launched three new satellites into orbit plane 1 (slots 3, 5, and 6) in January 2001. One of these satellites, the first GLONASS-M model, was never set to healthy, although it transmits a signal. Thus, for most of this period, there were six to seven operational satellites. In December 2002, Russia launched three more satellites, this time into orbit plan 3 (slots 21, 22, and 23). This brought the total number of operational GLONASS satellites to 10.

Tracking Network

In coordination with the IGS GPS stations, all IGLOS stations were requested to submit new site log forms to become "official" IGS stations. These new site logs were designed to accommodate global navigation satellites in general, rather than just GPS. Only dual-frequency receivers capable of tracking at least four GLONASS satellites simultaneously were sanctioned as official IGS stations. As of December 2002, the IGLOS tracking network consisted of 46 stations, although six of these were still unofficial. All the operational stations use either Ashtech or Javad Positioning Systems receivers.

The ILRS has provided continuous support for SLR tracking of three GLONASS satellites. In 2001, one GLONASS satellite in each of the three orbit planes was tracked (plane 1/slot 7, plane 2/slot 15, plane 3/slot 24). During 2002, the targeted satellites were changed to slots 3 and 6 of plane 1, along with slot 24 of plane 3.

Precise Orbit Computation

Bundesamt für Kartographie und Geodäsie (BKG) and the European Space Agency (ESA) produced precise orbits from the receiver network tracking data for all the operational GLONASS satellites. The Russian Mission Control Center (MCC) computes precise orbits based on the SLR observations alone. These individual orbits are combined in a weighted average computation by the IGLOS Analysis Center Coordinator to produce the final IGLOS precise orbits. SLR orbit accuracies are probably at the 1–2 decimeter level while the receiver-based orbit accuracies are at the 2–3 decimeter level, depending upon the satellite. GLONASS orbit comparisons done at the Natural Environment Research Council (UK) have indicated that some long-term systematic biases may be present in the GLONASS receiver-based orbits compared to the SLR orbits.

GLONASS Data and Product Usage

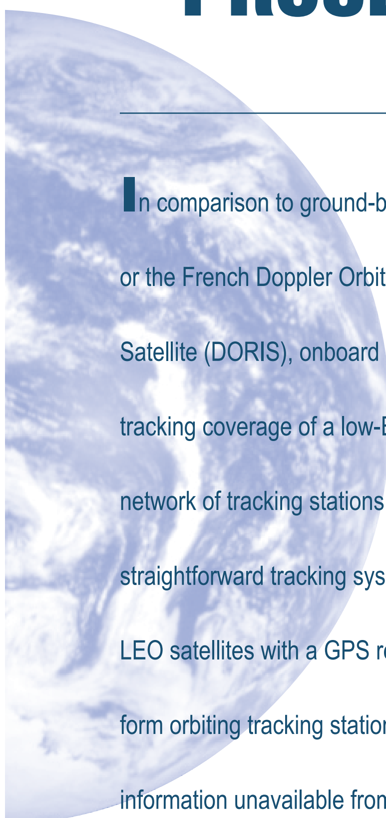
All receiver tracking data, including the satellite broadcast messages, and the precise orbit products are stored and retrievable at the IGS Global Data Center, CDDIS, at NASA GSFC. Over an 11-month period from January–November 2002, 9,475 orbit products were downloaded from the Data Center. Two-thirds or more of these probably relate to the actual production of the precise orbits by the Analysis Centers in Austria, Germany, and Russia, but at least 1,560 downloads are attributable to other users of the data products. These figures do not include downloads of the actual tracking data. It is not clear at this time what applications these products are being used for. This is definitely of interest and will be pursued in the coming year.

IGS LEO PILOT PROJECT

Henno Boomkamp

European Space Agency

European Space Operations Center, Germany



In comparison to ground-based tracking systems like satellite laser ranging (SLR) or the French Doppler Orbitography Doppler and Radiopositioning Integrated by Satellite (DORIS), onboard GPS offers the important advantages of continuous tracking coverage of a low-Earth orbit (LEO) satellite without the need for a complex network of tracking stations. For the LEO missions, GPS has become an attractive, straightforward tracking system, so that in 2002 there were already five operational LEO satellites with a GPS receiver on board. To the IGS, these LEO satellites can form orbiting tracking stations for the GPS constellation itself, which may provide information unavailable from Earth-based stations. The goals of the IGS LEO Pilot Project are to explore the ways in which this LEO GPS data may enhance the IGS products and how the IGS may support LEO missions now and in the future.

The orbital period of most LEO satellites ranges from 90 to 120 minutes. A single LEO satellite might produce up to seven tracking passes per orbit for every GPS satellite, and even a small constellation of LEO satellites can then provide a tracking data set that is equivalent to the data provided by the land-based IGS stations. Apart from differences in data quantities, the LEO data offers qualitative differences like long-baseline tracking geometries, independence of Earth rotation parameters, or direct links to other LEO data sets like SLR or DORIS. It is clear that LEO satellites have the potential to produce a revolution in GPS data processing, but they also bring additional complexity, and many technical problems need to be solved.

The IGS LEO Working Group has existed since 1999, but by May 2001, when ESOC took on the role of IGS LEO Associated Analysis Center coordinator, there had not yet been concrete activities other than initiating an IGS LEO Pilot Project. The obvious reason for this situation was the lack of usable LEO GPS data at that time. The first substantial LEO GPS data set was released for the German Challenging Minisatellite Payload (CHAMP) satellite in May 2001. While the IGS technical difficulties of incorporating LEO data were being assessed, it became clear that the maturity of LEO data processing differs widely among the Analysis Centers. To analyze the impact of LEO data on IGS product generation, a center needs to combine the capability of generating IGS-like products with expertise in processing LEO data at precision levels compatible with land-based GPS data. Seven centers were identified as potentially developing this combination of expertise, four of which are IGS Analysis Centers. Ten further centers can provide LEO expertise without generating IGS-like products themselves.

Although it is not obvious what precision orbit determination (POD) level is required before the LEO data can have some positive impact on IGS products, the initial orbit precision for CHAMP was around 25 centimeters RMS, which is much worse than the typical precision for which Earth-based IGS station coordinates are known. This was generally considered insufficient for analyzing LEO data in IGS context, and for some time the main interest of IGS LEO became to improve LEO POD quality. To address this, a CHAMP Orbit Comparison Campaign was initiated, in which 13 different centers participated. The campaign has helped to clarify many typical LEO problems, and provides good reference solutions for assessing precision levels. It also forms a useful platform to exchange knowledge between typical GPS centers and typical LEO centers. Similar campaigns will therefore be held for future LEO GPS satellites of interest, as soon as data become available.

From a single LEO satellite and two centers with combined GPS and LEO processing capability in early 2001, the working basis of the IGS LEO Pilot Project is expected to develop into a set of six LEO satellites and five to seven mature Analysis Centers 2003. This will be sufficient for comprehensive analysis of the potential use of LEO GPS data by the IGS. For the latest developments in the IGS LEO Pilot Project, see the IGS LEO website at *http://nng.esoc.esa.de/gps/igsleo.html*.

The TIGA PILOT Project

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GPS Tide Gauge Benchmark Monitoring - Pilot Project
IGS - TIGA Site Information Log for Continuous GPS Station @ Tide Gauge
Help for filling the TOS form

IGS - TIGA Site Information Log
Continuous GPS Station @ Tide Gauge

0. Form

Prepared by (full name)          :
Date Prepared                    : (CCYY-MM-DD)
Report Type                      : (NEW/UPDATE)
If Update
 Section Updated                 : (e.g. 2.4) (multiple entries)

1. GNSS Information

1.1 … Information

Station Name                     :
Four Character ID                : (A4)
WWW site for the site log        : http://igscb.jpl.nasa.gov/
Country of station location      :
Station in operation since       :
Approx. Station coordinates
 Latitude                        :
 Longitude                       :
Additional Information           : (multiple lines)

1.2 Contact Information
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Tilo Schöne

GeoForschungsZentrum

Potsdam, Germany

In 2001, the Tide Gauge Benchmark Monitoring Pilot Project (TIGA) was initiated by the IGS in response to the demanding need for highly precise and reliable estimates of the position and the vertical motion of tide gauge benchmarks. This service will facilitate the distinction between absolute and relative sea-level changes by accounting especially for the vertical uplift of the station, and is, therefore, an important contribution to climate-change studies.

A Call for Participation was issued in June 2001, identifying the following goals and objectives:

1. Establish, maintain, and expand a global Continuous GPS at Tide Gauges (CGPS@TG) network.

2. Contribute to the procedures through which IGS realizes a global reference frame in order to improve its utility for global vertical geodesy. This may involve reprocessing a significant subset of the (past and present) IGS global tracking data set.

3. Compute precise station coordinates and velocities for the CGPS@TG stations using a processing stream that runs months behind real-time in order to include the largest possible number of stations. This effort will incorporate all previously collected GPS data at each CGPS@TG station. Later on, the combined solution will have a maximum latency of one year.

4. Establish a secondary processing stream with much reduced latency in order to support operational activities that cannot tolerate large processing delays.

5. Monitor the stability of the network.

A Pilot Project Committee was formed, consisting of the following individuals:

- Trevor Baker, Proudman Oceanographic Laboratory, Bidston Observatory, UK

- Mike Bevis, University of Hawaii, USA
- Claude Boucher, Institut Geographique National, France
- Remi Ferland, Natural Resources Canada
- Bruce Haines, Jet Propulsion Laboratory, California Institute of Technology, USA
- John Manning, Australian Survey and Land Information Group
- Gary Mitchum, University of South Florida, USA
- Angelyn Moore, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, USA
- Ruth Neilan, IGS Central Bureau (Director), Jet Propulsion Laboratory, California Institute of Technology, USA
- Steve Nerem, University of Colorado, USA
- Christoph Reigber, GeoForschungsZentrum Potsdam, Germany (Chairman, IGS Governing Board)
- Wolfgang Scherer, National Tidal Facility, Australia
- Tilo Schöne, GeoForschungsZentrum Potsdam, Germany (Chair, TIGA-PP)
- C. K. Shum, Ohio State University, USA
- Guy Wöppelmann, University La Rochelle, France
- Philip Woodworth, Bidston Observatory, Proudman Oceanographic Laboratory, UK

TIGA will not only make use of existing GPS stations but will also include stations that are not previously known to the IGS. During the initial phase of TIGA, it was agreed to process GPS data with a very high latency. This allows also the very remote stations, e.g., from Antarctica, to provide their data.

TIGA Components

TIGA observing stations (TOS) are primarily, but not exclusively, existing IGS and European Reference Frame (EUREF) stations. Some agencies are also providing their GPS data previously not part of the IGS. Due to the higher latency of the processing, data from remote stations can also be included into the routine analysis. A site information log for TOS was developed, displaying necessary additional information for each tide gauge. This log sheet supplements the standard IGS log. A map of current TOS is given in Figure 1. TOS forms are available at the TIGA website — *http://op.gfz-potsdam.de/tiga*.

TIGA Analysis Centers (TAC) will process data in different chains. The primary chain will have a latency of 460 days. A secondary chain will provide solutions with a very short latency to support operational aspects. In addition a few processing centers have agreed to re-compute a selected subset of the IGS and other network data (including a retro-processing of IGS station data for CGPS@TG) for an improved long-term stability of the reference frame since the inception of the IGS.

TIGA Associate Analysis Centers (TAAC) will facilitate TIGA in two ways. These centers will process a selected regional subset of CGPS@TG stations and analyze the results of the TACs in various ways, including comparisons with other space techniques or absolute gravity measurements.

As a new component, TIGA Data Centers (TDC) will store and redistribute GPS data as well as metadata. They will fulfill three functions:

- Store GPS data sent by different media (FTP, computer tapes, CD-ROM, diskettes, etc.) with high and changing latency.
- Store metadata (e.g., leveling data, sketch maps of the TG) of any kind (e.g., computerized, handwritten, microfiches, etc.).
- Establish links to Tide Gauge Data Centers for easy and convenient data access.

Plans

A regular service was established in 2002 for continuous processing of CGPS@TG data. Starting with a high-latency processing chain, the reprocessing of older data was also initiated. After a significant number of TACs begin to provide solutions, a combined solution will be provided. Also in 2002, more TIGA observing stations became available to complement the existing network. An important task is the constant effort for the establishment of more leveling ties to tide gauge benchmarks.

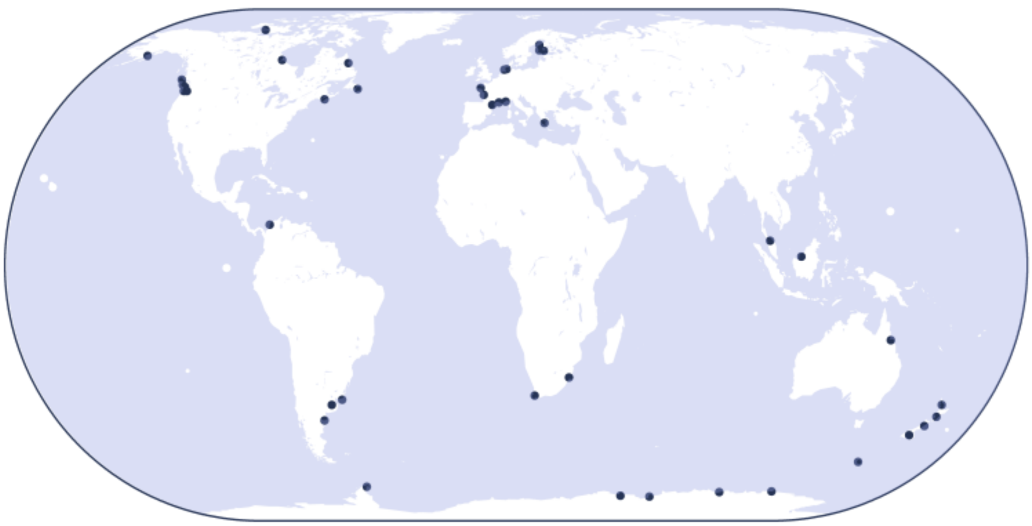


Figure 1. GPS stations fully contributing to TIGA (i.e., GPS and tide gauge data).

ESTABLISHING The IGS REAL-TIME Working Group

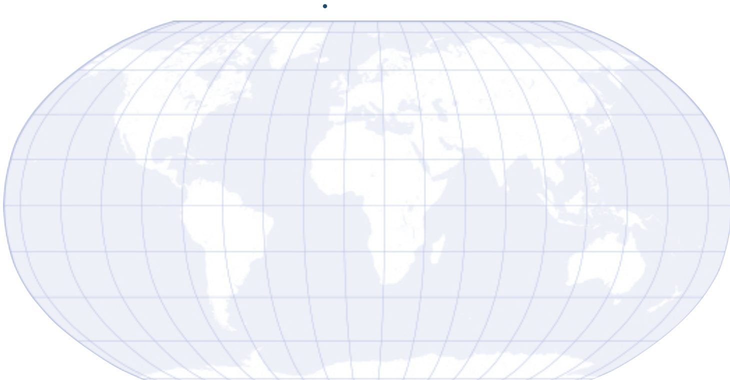
Mark Caissy

Natural Resources of Canada

Ron Muellerschoen

Jet Propulsion Laboratory, California Institute of Technology, USA

Many very demanding applications and systems now require GPS raw data and products with greatly reduced delays. The requirement for real-time data and products is inevitable and it now seems prudent for the IGS to establish real-time systems to insure compatibility, integration, access, and sharing. To fully serve the multidisciplinary scientific user community, the IGS must work towards enhancing its standards for infrastructure and data and product availability. This will place the IGS in a position to serve real-time user's needs as soon as it is practical.



Having a real-time vision is not new to the IGS. Members have been discussing for several years the creation of an IGS real-time component. For example, the Annapolis Network Workshop held in 1998 included a number of presentations on the topic, which was further discussed in 2000 at Oslo. Also, the IGS community does not lack real-time experience, as demonstrated by the existence of specialized real-time GPS networks operated by several member agencies in Europe, Asia, and North America. The IGS Governing Board showed a strong consensus to establish a Real-time Working Group (RTWG) to assess and address issues involved as the IGS moving towards real-time infrastructure and processes.

IGS Real-Time Working Group Charter

The IGS Real-Time Working Group (RTWG) will assess and address issues that pertain to the IGS developing real-time infrastructure and processes. In addressing these issues, the RTWG will cooperatively work towards a functional and scaleable model that demonstrates the real-time delivery of raw data and the dissemination of products to real-time Analysis Centers and simulated or actual real-time users, respectively. The activities of the RTWG will consist of the required planning, designing, and implementing stages necessary for a prototype infrastructure and processes. A pilot project will be recommended following the completion of activities.

The RTWG will plan, design, and implement a prototype system for the support of precise real-time positioning guided by the principles of robustness, sustainability, and acceptance. The primary products of such a system will be GPS/GNSS station data and satellite orbits and clocks, made available to the user by Internet and other economical and available streaming technologies. Potential user groups include those from, among others, geodetic agencies mandated to provide access to a globally consistent reference frame for all position applications; precision navigation users (LEO); agencies involved in natural hazards monitoring, prediction, warning, and response; structural engineering monitoring; near/real-time atmospheric monitoring for weather prediction; real-time earthquake seismology (simultaneously with seismological analysis); and time transfer and dissemination.

The requirements for the system will impact all components of the IGS and it will therefore be imperative that the RTWG receive cooperation and participation from all components with frequent and ongoing communication and meetings as required.

Progress in 2002

The IGS Workshop titled "Towards Real-Time" was a key event for the entire IGS and brings the focus of all components of the IGS onto real-time activities of the working group. Natural Resources Canada hosted and organized this meeting in early April, and the general reaction of the attendees was quite favorable. This was the first workshop in many years that brought all parts of the IGS together — station operators, network managers, data centers, analysis centers, other projects and working groups, and the Governing Board. One of the key issues discussed by the real-time working group was the schedule of work, with a long discussion on the pros and cons of the various protocols and what is most suitable for IGS purposes. The proceedings document available at the IGS website (and also as a CD version by request to the Central Bureau) is a full record of the presentations and recommendations from this workshop.

IGS Publications

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

STRATEGIC PLAN

IGS 2002–2007 Strategic Plan, March 2002, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, JPL 400-1000.

IGS WORKSHOP PROCEEDINGS

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Proceedings of the 2000 IGS Network Workshop, 12–14 July 2000, Statens Kartverk, Norway, joint with COST Action 716 Workshop, "Towards Operational Meteorology," Physics and Chemistry of the Earth (A), Vol. 26, No. 6–8, Pergamon/Elsevier Science Ltd., 2001.

Proceedings of the 2000 IGS Analysis Center Workshop, 12–14 July 2000, U.S. Naval Observatory, Washington, D.C., GPS Solutions, The IGS Special Issue, Vol. 4, Number 4, Spring 2001, John Wiley & Sons, Inc.

Proceedings of the International GLONASS Experiment (IGEX-98) Workshop, 13–14 September 1999, Nashville, Tennessee, USA, J. A. Slater, C. Noll, and K. Gowey, editors, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

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International GPS Service (GPS): An Interdisciplinary Service in Support of Earth Services, G. Beutler, M. Rothacher, T. Springer, J. Kouba, R. E. Neilan, 32nd COSPAR Scientific Assembly, Nagoya, Japan, 12–19 July, 1998.

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Proceedings of the 1997 Workshop on Methods for Monitoring Sea Level, 17–18 March 1997, R. E. Neilan, P. A. Van Scoy, and P. L. Woodworth, editors, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, JPL Publication 97-17.

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Proceedings of the IGS Workshop on Special Topics and New Directions, 15–18 May 1995, G. Gendt and G. Dick, editors, GeoForschungsZentrum, Potsdam, Germany.

Proceedings of the Workshop on Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks, 30 November–2 December 1994, J. F. Zumberge and R. Liu, editors, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, JPL Publication 95-11.

Proceedings of the 1993 IGS Analysis Center Workshop, 12–14 October 1993, J. Kouba, editor, Geodetic Survey Division, Natural Resources Canada, Ottawa, Canada.

Proceedings of the 1993 IGS Workshop, 25–26 March 1993, G. Beutler and E. Brockmann, editors, Astronomical Institute, University of Bern, Switzerland.

IGS ANNUAL REPORTS

IGS 2000 Annual Report (JPL 400-994) and 2000 Technical Reports (JPL Publication 02-012), IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

IGS Annual Reports: 1999 (JPL 400-978); 1998 (JPL 400-839); 1997 (JPL 400-786); IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

IGS Technical Reports: 1999; 1998 (JPL Publication 00-002); IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California.

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Inside Front Cover Photographs

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1. *Lusaka, Zambia, Ezigbalike, UN GNSS Regional Workshop, July 2002: Richard Wonnacott, Charles Merry, Dozie Ezigbalike*
2. *San Francisco, December 2001: John Dow, Ruth Neilan, Carey Noll, Angie Moore*
3. *GFZ, Potsdam, Germany, March 2001: "School of Rock," CHAMP Science Meeting and First IGS LEO Pilot Project Meeting*
4. *GFZ, Potsdam, Germany, March 2001: Jan Dousa, Hans Van der Marel*
5. *GFZ, Potsdam, Germany, September 2002: 20th IGS Governing Board meeting in the historic Helmert Library*
6. *Budapest, Hungary, September 2001: Bernd Richter, Markus Rothacher, Wolfgang Schlüter*
7. *Potsdam, Germany, January 2002: Bill Melbourne, Katrin Weisse, Tom Yunck*

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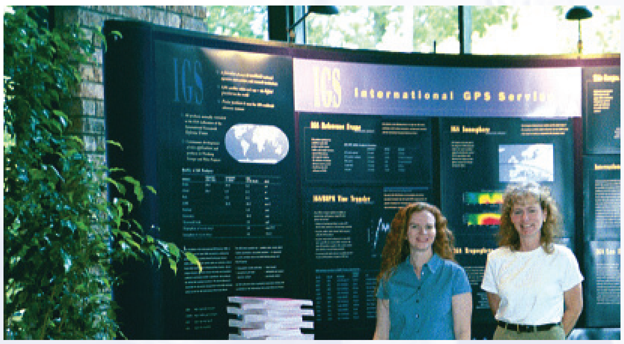
1. *San Francisco, Governing Board dinner, December 2001: Hans-Peter Plag, Bjorn Engen, Jim Slater*
2. *DGFI, Munich, Germany, IAG Planning Committee leading to the Global Geodetic Observing System, November 2002: Suzana Zerbini, Veronique Dehant, Chopo Ma, Rene Forsberg, Claude Boucher, Reiner Rummel, John Manning, Ruth Neilan, Hermann Drewes, Jim Ray, Tom Yunck, Christoph Reigber, Gerhard Beutler, Phil Woodworth, Wolfgang Schlüter*
3. *Nice, France, Analysis Center Antipodes, March 2001: Norm Beck, Jim Ray, John Dow, Markus Rothacher, Daniel Ineichen, Gerd Gendt, Robert Weber*
4. *GFZ, Potsdam, Germany, March 2001: Christoph Reigber, IGS Governing Board Chair; and Ruth Neilan, Director of the Central Bureau*
5. *GFZ, Potsdam, Germany, March 2001: Internet hub, Ron Muellerschoen and Werner Gurtner*
6. *Ottawa, Canada, IGS Workshop "Towards Real-Time," April 2002: Pierre Tetreault and Norm Beck, Geodetic Survey, Natural Resources Canada hosts*
7. *Ottawa, Canada, IGS Workshop "Towards Real-Time," April 2002: Markus Rothacher, Remi Ferland (seated), Martin Schmitz, Jim Ray, Ralf Schmid*
8. *Department of Land Affairs, Surveys and Mapping, Capetown, South Africa, AFREF organizational meeting for Southern Africa, March 2001: Front row — Ruth Neilan, IGS Central Bureau, NASA/JPL; Angelyn Moore, International GPS Service, NASA/JPL; Jose Luis Quemb, DINAGECA, Mozambique; Raynald Moyo, Zambia Survey Dept.; Greshan Gunda, Surveys Dept., Malawi; Charles Merry, Univ. Cape Town. Back row — Ludwig Combrinck, HartRAO, Georg Weber, BKG, German Cartographic and Geodetic Agency, Frankfurt; Sydney Simelane, Surveyor General–Swaziland; Shaibu Y. Juma, Directorate of Surveys and Mapping–Namibia; Rodwick Chigumete, DSG–Zimbabwe; James S. Broadwater, NIMA; Jose Elias Mucombo, DINAGECA, Mozambique; Per Backman, DINAGECA, Mozambique; Godfrey Biki Habana, Dept. Surveys and Mapping–Botswana; Muneendra Kumar, NIMA, Richard Wonnacott, CDSM–South Africa.*
9. *International GPS Service Display: Ruth Neilan, IGS Central Bureau, NASA/JPL; Angelyn Moore, International GPS Service, NASA/JPL*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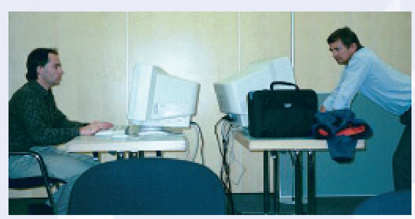

International GPS Service

International Association
of Geodesy

International Union of Geodesy
and Geophysics

Federation of Astronomical
and Geophysical Data
Analysis Services

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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