IGS

INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

1994 ANNUAL REPORT

SEPTEMBER 1, 1995

IGS Central Bureau

Jet Propulsion laboratory
California Institute of Technology
Pasadena, California U.S.A.

Edited by
J. F. Zumberge
R. Liu
R. E. Neilan

Preface

John L. LaBrecque
Program Scientist for Geodynamics and Geopotential Fields
NASA's Mission to Planet Earth
NASA Headquarters
Washington, D.C.

This volume is a report and a celebration of the first operational year of the International GPS Service for Geodynamics. The IGS developed quickly in its first year through the successful incorporation of several developing GPS facilities. These facilities have provided a nearly global network of GPS receiving stations, analysis centers which continue to improve GPS analysis technology, and data centers which maintain the acquired data set. The challenge ahead is to determine the proper direction for future development of the IGS. Certainly a homogeneous distribution of the global network of receivers is a necessary step to achieve the initial objectives of IGS, but what is the optimum density of this network? What are the priorities for the future development of the IGS? Should the IGS focus on the development of dense local networks or should it strive to improve the services of a more dispersed global network? For example, as the accuracy of the IGS network approaches the sub-centimeter level, should we focus on the reliability and the accuracy of the individual stations? Should we strive for a real time reference network? Should the stations be collocated with other instruments which might be synergistic with GPS observations such as meteorological sensors, magnetometers, and other geodetic and atmospheric sensors? How should the IGS respond to civilian, commercial, and governmental requirements? As the navigational and positioning capabilities of GPS become more accepted worldwide, should the IGS with its worldwide capabilities explore a new relationship as a service not only to geodynamics, as its name indicates, but also to the civilian, government, and commercial sectors as well?

Borne out of necessity and nourished by the enthusiasm of a broad science community, the IGS has achieved a great success. No one country and no one agency could have developed such a rich and deeply endowed service. IGS has developed from mutual need and consensus. Each group takes from the IGS what is needed and provides to the Service what it can. We can all find something to be proud of in our contributions to this fast growing service and we all benefit from its success. The many articles in this volume testify to the international contributions and successes of the IGS during its first year. Initially supported for its ability to accurately track the GPS satellites, the IGS network has served to densify the terrestrial reference frame servicing a myriad of requirements from long-term monitoring of sea level to the accurate navigation of orbiting satellites. The IGS also provides for the temporal densification of Earth orientation data as a service to many, including the civilian and global change science communities. Most recently, the spectacular success of the GPS/MET orbiting GPS experiment for atmospheric research depended strongly on the global network both for navigation and as a monitor of the GPS satellite clocks.

As GPS technology continues its rapid development, the IGS will be needed to facilitate and apply this new technology. Congratulations to all who have worked so hard to achieve this very successful first year!

Contents

Section 5—Data Centers

Section 5-Analysis Centers

Section 7—Other Contributions

Section 8—Stations

Introduction to the 1994 IGS Annual Report

James F. Zumberge
IGS Central Bureau, Jet Propulsion Laboratory
Pasadena, California

The International GPS Service for Geodynamics (IGS) began formal operation on January 1, 1994. This, its first annual report, describes the many facets of the service. We hope it will prove useful to both those who area part of the IGS and those who use data and products provided by the IGS.

The report is divided into several sections, which more or less mirror the different aspects of the service. Section 1 contains general information, including the history of the IGS, its organization, and the global network of GPS tracking sites. Section 2 contains a report from the IGS Central Bureau, and includes information on the Central Bureau Information System.

Included in Section 3 is the contribution from the International Earth Rotation Service (IERS). Cooperation and collaboration between the IERS and IGS has been and continues to be excellent.

Readers who are interested in IGS products should take note of the detailed contribution in Section 4 from the IGS Analysis Coordinator.

A better understanding of all of the effort that goes into collecting and distributing IGS data can be found in Section 5 on Data Center Reports. Similarly, contributions in Section 6 describe how the IGS Analysis Centers generate their products. Section 7 contains miscellaneous contributions from other organizations that share common interests with the IGS.

Finally, in Section 8 one can find information on many of the IGS tracking stations.

We hope that you will learn as much from reading this annual report as we have in assembling it, We look forward to providing others in the years to come.

Development of the IGS

Gerhard Beutler
Astronomic/ Institute, University of Beme
Berne, Switzerland

According to Mueller (1993), the primary motivation in planning the IGS was the recognition in 1989 that the most demanding users of the GPS satellites, the geophysical community, were purchasing receivers in exceedingly large numbers and using them as more or less black boxes, using software packages which they did not completely understand, mainly for relative positioning. The observations as well as the subsequent data analyses were not based on common standards; thus the geodynamic interpretation of the results could not be trusted. The other motivation was the generation of precise ephemerides for the satellites together with by-products such as earth orientation parameters and GPS clock information.

These ideas were first discussed in 1989 at the IAG General Meeting in Edinburgh (Neilan, Melbourne and Mader, 1990) and led soon thereafter to the 'IGS Planning Committee' with Ivan I. Mueller, then President of the IAG, as chairman. After several meetings the 'Call for Participation' was issued by this group on February 1, 1991. More than 100 scientific organizations and governmental survey institutions announced their participation either as an observatory (part of the IGS network), as an analysis center, or as a data center. The Jet Propulsion Laboratory (JPL) proposed that they serve as the Central Bureau, and the Ohio State University as the Analysis Center Coordinator. At the 20th General Assembly of the IUGG in Vienna, August 1991 the IGS planning group was restructured and renamed as 'IGS Campaign Oversight Committee' (see next section), This committee started organizing the 1992 events, namely the '1992 IGS Test Campaign' and 'Epoch'92'. Two IGS Workshops (the first at the Goddard Space Flight Center in October 1991, the second in Columbus, Ohio in March 1992) were necessary to organize the 1992 activities. The essential events of this first phase of the IGS development are summarized in Table 1.

The 1992 IGS Test Campaign, scheduled from June 21 to September 22, 1992, focused on the routine determination of high accuracy orbits and ERPs; it was to serve as the proof of concept for the future IGS. Epoch'92 on the other hand was scheduled as a two-week campaign in the middle of the three-month IGS Campaign for the purpose of serving as a first extension of the relatively sparse IGS Core Network analyzed on a daily basis by the IGS Analysis Centers. More background information about this early phase of IGS may be found in Mueller (1993) and Mueller and Beutler (1992).

TWO events prior to the campaign have to be mentioned: (1) the communications test, organized by Peter Morgan of the University of Canberra, Australia, demonstrated that data transmission using the scientific Internet facility had sufficient capacity for the daily data transfer from the IGS stations to the Regional, Operational and Global Data Centers then to the Analysis Centers. (2) The establishment of the 'IGS Mailbox' and the 'IGS Report' series based on e-mail proved to be very important as information resources and as a tool to insure a close cooperation between the IGS participants. This e-mail service, initially located at the University of Berne, was transferred to the Central Bureau (JPL) by January 1, 1994.

Table 1. Chronicle of IGS Events 7989-7991.

Date	Event
Aug-89	IAG General Meeting in Edinburgh. Initial Plans developed by G. Mader, W. G. Melbourne, R. E. Neilan
16-Mar-90	IAG Executive Committee Meeting decides to establish a working group to explore the feasibility of an IGS under IAG auspices, with 1. Mueller as chairman of the Planning Committee of the IAG.
02-Sep-90	Planning Committee Meeting in Ottawa. Preparation of the Call for Participation (CFP)
01-Feb-91	CFP mailed. Letters of Intent due 1 April 1991
01-Apr-91	CFP Attachments mailed to those whose letters of intent were received
01-May-91	Proposals due
24-Jun-91	Proposals evaluated and accepted
17-Aug-91	Planning Committee dissolved and IGS Oversight Committee (OSC) established at the 20th IUGG General Assembly
24-Oct-91	First Campaign Oversight Committee Meeting. Preparation of the 1992 IGS Test Campaign scheduled for 21 June-23 September 1992 and for a two weeks intensive campaign called Epoch 92.

The 1992 IGS Campaign started as scheduled on June 21, 1992. About two weeks later the first results of the IGS Analysis Centers started to flow into the IGS Global Data Centers, which made these results available to the user community. The ERP series were regularly analyzed by the IERS Central Bureau and by the IERS Rapid Service Sub-bureau.

Data collection and transmission as well as data analysis continued on a 'best effort basis' after the official end of the 1992 IGS Test Campaign on September 23, 1992. At the third IGS Oversight Committee meeting on October 15, 1992 at Goddard Space Flight Center (Table 2) it was decided to formally establish the IGS Pilot Service to bridge the gap between the 1992 IGS Test Campaign and the start of the official service. Since November 1, 1992 the orbits of the individual processing centers were regularly compared by the IGS Analysis Center Coordinator (Goad, 1993). An overview of the 1992 IGS events maybe found in Beutler (1993), and a full description maybe extracted from the Proceedings of the 1993 IGS Workshop (Brockmann and Beutler, 1993).

TWO workshops, the Analysis Center Workshop in Ottawa (Kouba, 1993) and the Network Operations Workshop in Silver Spring, MD, and the first Governing Board (GB) Meeting (also in Silver Spring) took place in October 1993. One important outcome of IGS meetings in October 1993 was the decision to produce an official IGS orbit. This responsibility was given to the IGS Analysis Center Coordinator, who, according to the Terms of Reference must be an analysis centers' representative. For more information we refer to chapter IV of this report.

In view of the success of the 1992 IGS Test Campaign and of the IGS Pilot Service the IGS Oversight Committee at its fourth meeting in March 1993 in Berne decided to take the necessary steps towards the establishment of the official IGS on January 1, 1994. In particular the Terms of Reference for this new service were written (see Section I, R. Neilan, "The Organization of the IGS," Appendix, this volume), the organizations active in the 1992 IGS campaigns were asked to confirm their participation in the future service, and last but not least the IAG approval for the establishment of the IGS for January 1, 1994 was

Date	Event
17-Mar-92	2nd IGS O S C Meeting at OSU, Columbus, Ohio
04-May-92	Communication Tests
21-May-92	IGS e-mailbox installed by University of Berne
21-Jun-92	Start of IGS Test Campaign
01-Jul-92	First results, about 2 weeks after beginning of campaign
27-Jul-92	Start of Epoch-92(2 weeks)
23-Sep-92	Official end of campaign, but not of data collection, processing
15-oct-92	3rd IGS O S C Meeting at GSFC, Greenbelt, MD
01-Nov-92	Start of IGS PILOT Service. Start of routine orbit comparisons by IGS Analysis Center Coordinator
24-Mar-93	1993 IGS Workshop and 4th IGS O S C Meeting at the University of Berne
27-May-93	5th IGS O S C Meeting, AGU, Baltimore, MD
09-Aug-93	IAG-Symposium in Beijing. Approval of the Service by the IAG
12-oct-93	Analysis Center Workshop, Ottawa
18-Ott-93	Network Operations Workshop and 1st IGS Governing Board Meeting in Silver Spring, MD
08-Dec-93	GB Business Meeting in San Francisco

Table 2. Chronicle of IGS Events 1992-7993.

requested. It was encouraging that most of the key organizations reconfirmed their participation in the official service: the Central Bureau stayed at JPL, the three Global Data Centers and all but one Analysis Centers continued contributing to the IGS. In view of this encouraging development it was gratifying that the preliminary IAG approval (to be confirmed at the 21st IUGG General Assembly in Boulder, 1995) was given in August 1993.

A key element of the new Service is the Governing Board (GB) consisting of 15 members (see next section). Another key element is the interface between the IGS and the IERS both being IAG services with many common interests. In practice the IERS relies on the IGS for all GPS operations, the IGS in turn relies on the IERS for the continuous maintenance of the terrestrial reference frame.

Table 3 contains the essential events since the start of the official IGS on January 1, 1994. It was of greatest importance that the Central Bureau Information System (CBIS) (Liu *et al.,* 1994) and the combined IGS orbit (Beutler, Kouba, Springer, 1995) became available with the start of the new service. Both the CBIS and the combined orbit are of greatest importance to the user of our service. More information concerning the CBIS may be found in Liu *et* al. (1994); the combined orbit is discussed in detail in chapter IV of this report.

The densification of the ITRF through regional GPS analyses was a key issue in 1994. The guidelines for such a densification were defined at the IGS workshop in December 1994. The topic will continue to be in the center of IGS activities in 1995 and in the years to come. See Neilan on networks in this section for more information.

Table 3 does not contain all the IGS related activities in 1994. It was of particular importance that papers concerning the IGS were presented at numerous international conferences, at GPS seminars, etc. Table 4 summarizes these activities. The bibliography concerning the IGS gives an impression of the

Table 3. Chronicle of IGS Events 1994-mid-1995.

Date	Event
01-Jan-94	Start of official IGS Production of Combined IGS Orbit, Central Bureau Information System (CBIS) established
21-Mar-94	Combined workshop IERS/IGS in Paris (1 week)
25-Mar-94	2nd IGS Governing Board Meeting
30-Nov-94	IGS Workshop Densification of the ITRF through regional GPS Analyses
06-Dec-94	3rd IGS Governing Board Meeting in San Francisco
15-May-95	IGS Workshop on Special Topics and New Directions
06-Jul-95	4th IGS Governing Board Meeting in Boulder

number of papers that was published on behalf of the IGS Oversight Committee responding to the Governing Board.

Let me conclude this overview with a few general remarks. Undoubtedly the progress made since the 20th IUGG General Assembly in Vienna is far beyond any expectations. Only three years after the first plans, the IGS (an IAG service in support of geodesy and geodynamics) became fully operational on January 1, 1994. In view of the complexity of this task such a rapid development is an achievement in itself. It was made possible through the experience, the expertise, and the pioneer spirit in the IGS Oversight Committee and its working groups. The IGS Oversight Committee was dissolved by the end of 1993. We should acknowledge its important contribution to the creation of the IGS.

The first one and a half years of the official IGS service were extremely successful, too: the official IGS orbit has become the accepted standard for a

Table 4. Presentations on behalf of the IGS Governing Board in 1994.

Date	Event	Presented by
Jan	Collegium Generale, University of Berne	G. Beutler
Mar	FIG General Assembly, Melbourne	1.1. Mueller
Mar	Univ. Otago, Dunedin, New Zealand	1.1, Mueller
Mar	Dept. of Surveys and Land Info. (DOSLI), Wellington	1.1. Mueller
Mar	Univ. of New Zealand, Wellington	1.1. Mueller
Apr	UNAVCO/IRIS Workshop, San Diego	G. Beutler
Apr	Tech. Univ. of Budapest, Hungary	1.1. Mueller
May	Warsaw University of Technology	G. Beutler
May	Tech. Univ. of Graz, Austria	1.1. Mueller
May	Hotine/Marussi IAG Symposium, l'Aquila, Italy	1.1. Mueller
May	DOSE Meeting in Baltimore	G. Beutler
May	AGU Baltimore	J. Zumberge
Jun	Technical University Vienna, O G fur Vermessung	G. Beutler
Jul	Univ. of Calgary, Alberta	1.1. Mueller
Jul	Western Pacific Geophysical Union, Hong Kong	R. Neilan
Sep	Symp. on Crustal Deformation, Istanbul, Turkey	1.1. Mueller
Ott	DVW Fortbildungsseminar	G. Beutler
Dec	AGU San Francisco (Splinter Session)	R. Neilan

highly accurate GPS orbit. The Central Bureau Information System (CBIS) developed into the reliable source of information about the IGS for a growing user community.

The IGS workshops in December 1994 and in May 1995 (Table 3) prove that the IGS still is in full development. The activities concerning the densification of the ITRF using the GPS underline this fact.

Let us finally not forget that the IGS is an International Service funded by many Scientific and Government Institutions. Let us keep in mind that without their continued support, the IGS could not exist.

References

Beutler, G. (1993). "The 1992 IGS Test Campaign, Epoch'92, and the IGS Pilot Service." Proceedings of the 1993 IGS Workshop, pp. 3–9, Druckerei der Universität Berne, available through IGS Central Bureau.

Beutler, G. and E. Brockmann (1993). "International GPS Service for Geodynamics." Proceedings of the 1993 IGS Workshop, 369 pages, Druckerei der Universitat Berne, available through IGS Central Bureau.

Beutler, G., J. Kouba, T. Springer (1993). "Combining the Orbits of IGS Processing Centers." Proceedings of the IGS Analysis Center Workshop, October 12–14, 1993, Ottawa.

Goad, C. C. (1993). "IGS Orbit Comparisons." Proceedings of the 1993 IGS Workshop, pp. 21 8–225, Druckerei der Universität Berne, available through IGS Central Bureau.

IGS Central Bureau (1994). IGS Colleague Directory. IGS Central Bureau, Jet Propulsion Laboratory, Pasadena, December 1994.

Kouba, J. (1993). "Proceedings of the IGS Analysis Center Workshop, October 12–14, 1993, Ottawa, Canada," 114 pages, Geodetic Survey Division, Surveys, Mapping and Remote Sensing Sector, NR Can, Ottawa, Canada.

Liu, R., W. Gurtner, (1994). "Introducing the Central Bureau Information System of the International GPS Service for Geodynamics." IGS Colleague Directory, IGS Central Bureau, JPL, Pasadena, December 1994.

Mueller I. I. (1993). "Planning an International Service using the Global Positioning System (GPS) for Geodynamic Applications." Proc. IAG Symp. No. 109 on Permanent Satellite Tracking Networks for Geodesy and Geodynamics, Vienna, Aug. 1991 (G. L. Mader, Ed.), Springer Verlag.

Mueller, I. I., G. Beutler (1992). "The International GPS Service for Geodynamics —Development and Current Structure." Proceedings of the 6th Symposium on Satellite Positioning, Ohio State University, Columbus, Ohio.

Neilan, R. E., W. Melbourne, G. Mader (1990) "The Development of a Global GPS Tracking System in Support of Space and Ground-based GPS Programs." Proc. IAG Symposia No. 102: Global Positioning System: An Overview, Edinburgh, Aug. 1989, (Y. Bock and N. Leppard, Ed.), Springer-Verlag.

Bibliography of Publications about the IGS in Journals and Proceedings of International Meetings

Beutler, G. (1992). "The Impact of 'The International GPS Geodynamics Service (IGS)' on the Surveying and Mapping Community." Proceedings of the XVII ISPRS Congress, Washington, August 8-12, 1992. International Union for Surveying and Mapping (IUSM); American Society of Photogrammetry and Remote Sensing, Washington, D. C., pp. 89-94.

Beutler, G. (1992). "The 1992 Activities of the International GPS Geodynamics Service (IGS)." IAG-Symposium No. 112, Potsdam 1992, pp 9-13.

Beutler, G. and E. Brockmann (1993). "International GPS Service for Geodynamics." Proceedings of the 1993 IGS Workshop, 369 pages, Druckerei der Universitaet Berne, available through IGS Central Bureau.

Beutler, G. (1993). "The International GPS Geodynamics Service (IGS): Progress Report March 1993." Proceedings of the 2nd International Seminar in 'GPS in Central Europe', Pent, Hungary, April 27-29, 1993, pp. 59-67. Institute of Geodesy, Cartography and Remote Sensing, Satellite Geodetic Observatory, Budapest.

Beutler, G., I. I. Mueller, R. E. Neilan (1994). "The International GPS Service for Geodynamics (IGS): Development and Start of Official Service on January 1, 1994." Bulletin Géodésique, Vol. 68, 1, pp. 39-70.

Beutler, G., I. I. Mueller, R. E. Neilan (1994). "IGS - Der International GPS-Dienst fur Geodynamik." Zeitschrift fur Vermessungswesen, Deutscher Verein fur Vermessungswesen (DVW) Jahrgang: 119, Mai, Heft 5, S. 221-232.

Beutler, G., P. Morgan, R. E. Neilan (1993). "Geodynamics: Tracking Satellites to Monitor Global Change." GPS-World, Vol. 4, pp. 40-46. Advanstar Communication, Salem, USA,

Beutler, G., R. E. Neilan, 1.1. Mueller (1993) "Operations of the International GPS Service for Geodynamics (IGS)." International Association of Geodesy General Meeting, Beijing, China, August 8-13, 1993, Book of Abstracts, pp. 123. Chinese Society for Geodesy, Photogrammetry and Cartography.

Beutler, G., W. Gurtner (1993). "The Impact of the International GPS Geodynamics Service (IGS) on Control Networks." International Association of Geodesy General Meeting, Beijing, China, August 8-13, 1993, Book of Abstracts, pp. 110. Chinese Society for Geodesy, Photogrammetry & Cartography.

Beutler, G., R. Weber (1994). "Der International GPS Dienst für Geodynamik (IGS)." 34. DVW-Seminar "GPS-Leistungsbilanz 1994", Karlsruhe, Oktober 1994.

Feissel, M., G. Beutler (1992). "Future Cooperation between the International Earth Rotation Service and the International GPS Service for Geodynamics." EOS, Vol. 74, No. 16, p. 104.

Mueller, 1. I., G. Beutler (1992). "The International GPS Service for Geodynamics - Development and Current Structure." Proceedings of the 6th International Geodetic Symposium on Satellite Positioning, March 17-20, 1992, Weigel Hall, Columbus, Ohio, Vol. 2, pp. 823-835.

The Organization of the IGS

Ruth Neilan
IGS *Central Bureau, Jet Propulsion Laboratory*
Pasadena, California

Overview

The history and development of the IGS demonstrate the unique capability of international groups and agencies to work successfully together for a common goal. In the organization of the IGS, each component has specific responsibilities, and each is dependent on the others to meet performance standards in order for the whole system to operate smoothly and effectively. We are all interdependent and actively work together to maintain and improve the system. This unique situation is achieved by continued focus on the common goal of operating a Global Positioning *System* (GPS) ground tracking system of the highest quality.

The organization of the IGS is depicted in Figure 1. The Navigation Satellite Timing And Ranging (NAVSTAR) GPS was developed by the U.S. Department of Defense as an all weather, satellite-based navigation system, for both military and civilian use. The satellites of the beautifully designed space segment are shown in the upper left corner of the figure. They are clearly a key enabling element of the IGS. The GPS stations shown below the satellites are permanently installed and operate continuously, receiving and recording the L-band, dual-frequency signals transmitted by the 24 NAVSTAR GPS satellites. The station data are accessed by operational data centers through various communication schemes, and the operational centers monitor and validate the data, format it according to standards, and forward the data sets to the regional or global data centers. The analysis centers retrieve the data sets from the global data centers and each produces GPS ephemerides, station coordinates, and Earth rotation parameters. These products are then sent to the analysis center coordinator who uses an orbit combination technique (see Section IV, J. Kouba, this volume) to produce the official IGS orbit. The products are sent to the global data centers

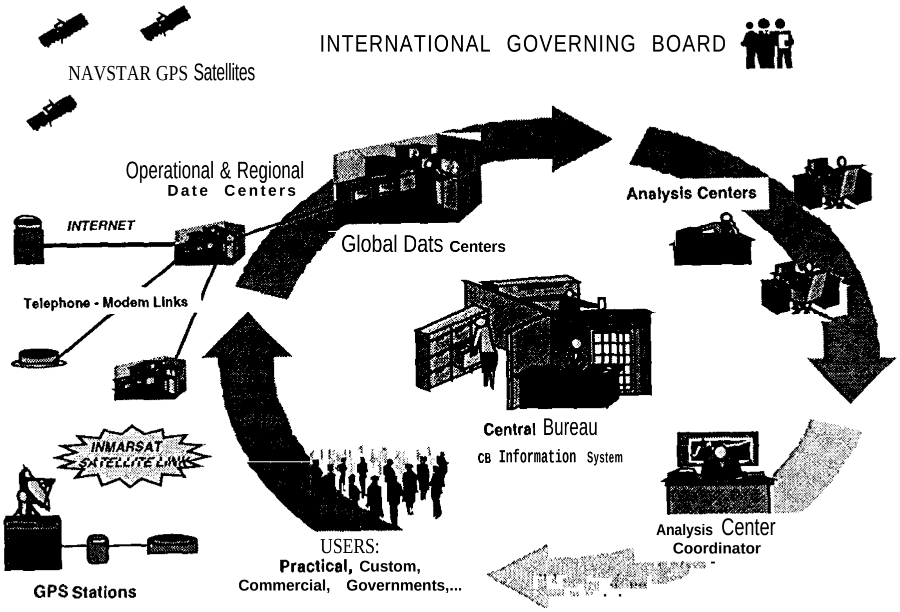


Figure 1. The organization of the International GPS Service for Geodynamics.

and the Central Bureau for archival and access by users. The Central Bureau is responsible for the overall coordination and management of the service, while the International Governing Board is the oversight body that actively makes decisions and determines the activities and direction of the IGS.

Each of these components is described in more detail below. More information on the formal relations can be found in the appendix of this chapter, the IGS Terms of Reference.

Network Stations

The IGS network consists of GPS stations that observe the GPS satellites on a continuous, 24-hour basis. These globally distributed stations are funded, implemented, and operated by one of the IGS participating agencies shown in Table 1. At the close of 1994, 75 stations were listed as part of the IGS network.

Table 1. Contributing agencies of the International GPS Service for Geodynamics.

AIUB	Astronomical Institute, University of Bern, Switzerland
ALO	Astronomical Latitude Observatory, Poland
ASI	Italian Soace Agency, Matera, Italy
AUSLIG	Australian Survey and Land Information Group, Australia
BfL	Bundesamt für Landestopographie (Federal Topography), Switzerland
CAS	Chinese Academy of Sciences, China
CDDIS	Crustal Dynamics Data Information System, USA
CEE	Centro de Estudios Espaciales, Chile
CMMACS	CSI R Centre for Mathematical Modeling and Computer Simulation, Bangalore, India
CNES	Centre National de Etudes, Toulouse, France
CSR	Center for Space Research, University of Texas at Austin, USA
CU	University of Colorado at Boulder, Boulder, CO, USA
DMA	Defense Mapping Agency, USA
DOSLI	Department of Survey and Land Information, Wellington, New Zealand
DUT	Delft University of Technology, Netherlands
ERI	Earthquake Research Institute, University of Tokyo, Japan
ESA	European Space Agency, Germany
ESOC	European Space Operations Center, Germany
FGI	Finnish Geodetic Institute, Finland
GOPE	Geodetic Observatory Pecny, Ondrejov, Czech Republic
GFZ	GeoforschungsZentrum, Potsdam, Germany
GRDL	Geosciences Research and Development Laboratory, NOAA, Silver Spring, MD, USA
GSC	Geological Survey of Canada, NRCan, Canada
GSD	Geodetic Survey Division, NRCan, Canada
GSFC	Goddard Space Flight Center, USA
GSI	Geographical Survey Institute, Tsukuba, Japan
IAA	Institute of Applied Astronomy, St. Petersburg , Russia
IBGE	Instituto Brasileiro de Geografia de Estatistica, Brazil
ICC	Institut Cartografic de Catalunya, Barcelona, Spain
IDA	International Deployment of Accelerometers, USA
IESAS	Academia Sinica, Institute of Earth Sciences, Taiwan
IfAG	Institut fur Angewandte Geodasie, Frankfurt, Germany
IGN	Institut Geographique National, Paris, France
IMVP	The Institute of Metrology for Time and Space, GP VNIIFTRI, Mendeleevo, Russia
INASAN	institute of Astronomy, Russian Academy of Sciences, Moscow, Russia
INPE	Instituto National de Pesquisas Espaciais, Brazil
IRIS	Incorporated Research Institutions for Seismology, USA
ISAS	Institute for Space and Astronautic Science, Sagamihara, Japan
ISRO	Institute for Space Research Observatory, Graz, Austria
JPL	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
NASA	National Aeronautics and Space Administration, USA
NBSM	National Bureau of Surveying and Mapping, China
NOAA	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources of Canada (formerly EMR), Ottawa, Canada
OSO	Onsala Space Observatory, Sweden
OUAT	Olsztyn University of Agriculture and Technology, Poland
PGGA	Permanent GPS Geodetic Array of Southern California, USA
POL	Proudman Oceanographic Laboratory, UK
RGO	Royal Greenwich Observatory, UK
ROB	Observatoire Royal de Belgium, Brussels, Belgium
SAO	Shanghai Astronomical Observatory, China
SIO	Scripps Institution of Oceanography, San Diego, CA, USA
SK	Statens Kartverk, Norwegian Mapping Authority, Norway
UB	University of Bonn, Germany
UFPR	University Federal de Parana, Brazil
UNAVCO	University Navstar Consortium, Boulder, CO, USA
LINT	University of Newcastle-on-Tyne, United Kingdom
U PAD	University of Padova, Italy
USNO	United States Naval Observatory, USA
WING	Western Pacific Integrated Network of GPS, Japan
WTU	Wuhan Technical University, China
WUT	Warsaw University of Technology, Poland

These stations have precision geodetic-quality dual-frequency GPS receivers and ancillary equipment that enable transmission of the data set within a few hours. Currently, the data files span a 24-hour period, although the IGS is considering near real-time to real-time data transmission in the future. Figure 2 shows the current status of the network.

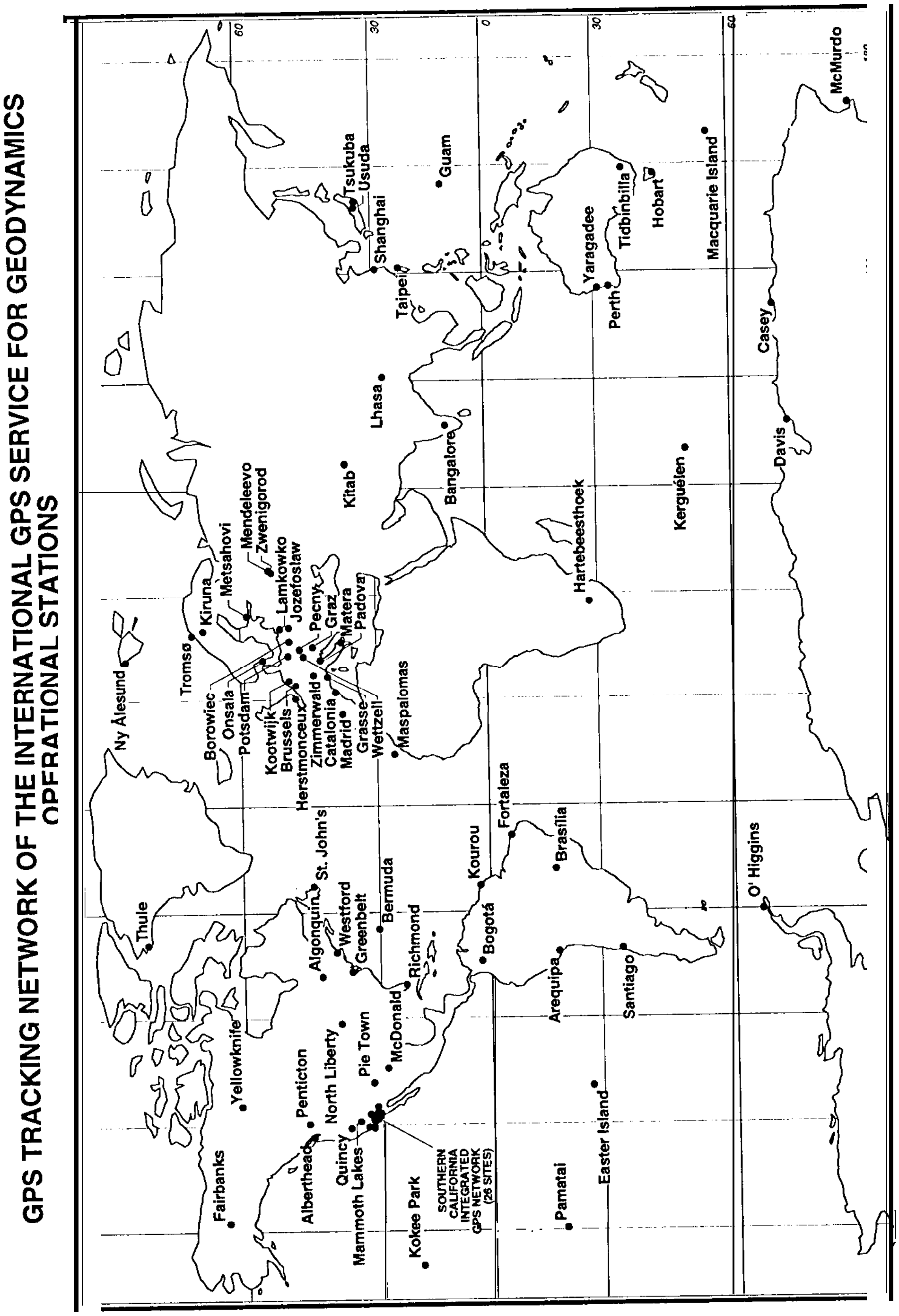


Figure 2. The operational stations of the IGS network, July 1995.

Data Centers

Data centers fall into three categories: operational, regional, and global, and this classification is based on the data-handling or archiving function. The operational centers directly manage and operate the stations, the regional centers have data holdings of specific interest only at the regional level, while the global data centers act as the long-term archive of data and products for the IGS. There is an additional category similar to the regional data center designated a local data center. Local data centers usually store GPS data and products at a very localized level for specific scientific studies or applications, such as the Southern California Earthquake Center or the dense GPS array in Japan (Zumberge and Liu, 1995).

Operational Centers

The operational center receives or collects the data from all stations for which it is responsible. The data transmission between the stations and the center may use dial-up lines, permanently switched telephone lines, Internet, satellite communications, etc. In most cases, the transmitted data are in their receiver-dependent raw form, either in records in a near-real-time mode or as files accumulated several times to once per day.

The operational center checks the data, samples the data to the standard 30-second epochs if necessary, reformats the data into RINEX (Receiver Independent Exchange format) files and sends the data as compressed RINEX files through the Internet to the nearest regional data center, or in some cases to a local data center. Most of the operational centers have automated these procedures so that the data are ready for transmitting a few hours after midnight UTC. Some stations perform the tasks of the operational center for themselves.

Regional Centers

The regional data center is responsible for collecting all data of interest to people in a particular region. The regional center receives or collects the data from local or operational data centers or directly from the stations in some cases.

The data from the Global Network, which are the data used by several analysis centers or users in various parts of the world, are forwarded by these regional data centers to one of the three global data centers.

Table 2. IGS regional data centers.

Australian Land Information Group	Canberra	Australia
Jet Propulsion Laboratory	Pasadena	USA
Institut für Angewandte Geodäsie	Frankfurt	Germany
Statens Kartverk	Honefoss	Norway
Natural Resources of Canada	Ottawa	Canada
Scripps Institution of Oceanography	San Diego	USA
Geosciences Research Lab /NOAA	Silver Spring	USA

Global Data Centers

The global data center is the primary access point for IGS data and products. The three global data centers equalize their IGS data holdings among themselves in order to have the same global data sets available to all international users.

The IGS products generated by the analysis centers and the analysis center coordinator are also deposited at the global data centers and are available on-line for at least 12 months. Station data are available on-line for a minimum of 30 days. These files are openly accessible through anonymous ftp or through ftp by user account/password.

Crustal Dynamics Data Information System, NASA Goddard Space Flight Center	Greenbelt	USA
Institut Geographique National (IGS)	Paris	France
Scripps Institution of Oceanography, University of California	San Diego	USA

Table 3. IGS global data centers.

Analysis Centers

The analysis center performs the fundamental daily task of receiving and processing the tracking data to produce its estimates of the GPS satellite orbits, Earth rotation parameters, and station coordinates and velocities. The analysis centers have committed to produce these without interruption, and forward them to the analysis center coordinator in a timely fashion.

CODE Astronomical Institut-University of Bern	Switzerland
European Space Operations Center/European Space Agency	Germany
FLINN Analysis Center, Jet Propulsion Laboratory	USA
GeoForschungsZentrum	Germany
Geosciences Research Lab, National Oceanic and Atmospheric Administration	USA
Natural Resources Canada	Canada
Scripps Institution of Oceanography	USA

Table 4. The seven analysis centers of the IGS.

Associate Analysis Centers

The associate analysis center produces unique products within the IGS. The recent initiative for the densification of the reference frame using the IGS network (Zumberge and Liu, 1995) has resulted in three proposals for associate analysis centers that are engaging in a pilot project in September 1995 (see Section 1, I. I. Mueller, this volume). This project is designed as a proof of concept for distributed processing of GPS data from many stations, and relies on the associate analysis centers for a rigorous combination of results submitted by IGS analysis centers, or others, to produce precise station locations and velocities in a consistent reference frame.

University of Newcastle-on-Tyne	UK
FLINN Analysis Center, Jet Propulsion Laboratory	USA
Scripps Institution of Oceanography	USA

Table 5. Associate analysis centers for the densification of the global reference frame.

Other types of associate analysis centers are envisioned, which may support the use of GPS data and products as required by other research areas, such ionospheric and atmospheric applications.

Analysis Center Coordinator

The responsibility of the analysis center coordinator is to interface actively with the IGS analysis centers to ensure that the IGS objectives are achieved. The analysis coordinator is primarily responsible for the appropriate combination of the analysis centers products into a single set of official IGS products (see Section IV, J. Kouba, Appendix, this volume). The analysis center coordinator also works with the IERS for the production of IGS-derived ITRF station coordinates, velocities, and Earth rotation parameters to be used with the IGS orbits.

The current IGS analysis center coordinator is Jan Kouba, Natural Resources Canada, Ottawa, Canada.

Central Bureau

The Central Bureau is responsible for the general coordination and management of the International GPS Service. These responsibilities are consistent with the directives and policies set by the IGS Governing Board. The primary functions of the Central Bureau are to facilitate communications, coordinate day-to-day IGS activities, coordinate the establishment of IGS standards, promote compliance with the standards, monitor quality assurance of the data and products, maintain documentation, and organize reports, meetings, and workshops.

A key activity of the Central Bureau is the maintenance and operation of the Central Bureau Information System, an on-line repository for all information pertinent to the IGS. (See Section II, Gurtner and Liu, this volume.)

The Central Bureau is located at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA.

Governing Board

The Governing Board of the IGS is an international body which exercises general oversight and control over the activities of the service. The members of the Governing Board fill a combination of elected, appointed, and *ex-officio* positions. The Governing Board is intended to meet at least once annually. However, since the service is still quite young, two Governing Board meetings, as well as a Governing Board Business meeting, were held in 1994.

Name	Country Institution	Functions	Term
Gerhard Beutler	Switzerland University of Bern	Chair, Analysis Center	4 years
Yehuda Bock	USA Scripps Institution of Oceanography	Analysis Center Rep.	2 years
Claude Boucher	France Institut Geographique National	Appointed (IGS)	2 years
John Dow	Germany ESA/European Operations Center	Network Rep.	2 years
Bjorn Engen	Norway Statens Kartverk	Network Rep.	4 years
Martine Feissel	France International Earth Rotation Service	IERS Rep.	—
Teruyuki Kato	Japan ERI, University of Tokyo	Appointed (IGS)	2 years
Jan Kouba	Canada Natural Resources Canada	Analysis Coordinator	2 years
Gerry Mader	USA GRDL, National Oceanic and Atmospheric Administration	Appointed (IGS)	2 years
Bill Melbourne	USA Jet Propulsion Laboratory	IGS Rep. to IERS	—
Ivan Mueller	USA Ohio State University	IAG Rep.	—
Ruth Neilan	USA Jet Propulsion Laboratory	Director, Central Bureau	—
Carey Nell	USA Goddard Space Flight Center	Data Center Rep.	4 years
Christoph Reigber	Germany GeoForschungsZentrum	Appointed (IGS)	2 years
Bob Schutz	USA CSR, University of Texas-Austin	Appointed (IAG)	4 years

Table 6. The IGS Governing Board members. Terms beginning January 1, 1994.

Users

The consistent users of the IGS are mostly those participating agencies who gain so much from the leveraged cooperation of each component. But as the IGS has expanded and improved, there is increasing interest in the IGS data and products by other government agencies, university groups, research institutions, and commercial and private businesses. The IGS is beginning to assess the use and value of the service to other groups and multi-disciplinary applications in order to improve the service and user base.

References

Zumberge, J., and R. Liu, editors, 1995, “Proceedings of the IGS Workshop on the Densification of the ITRF through Regional GPS Networks”

Appendix

International GPS Service for Geodynamics
Terms of Reference

A proof of concept for the International Global Positioning System Service for Geodynamics (IGS) was conducted with a three-month campaign during June through September 1992, and was continued through a pilot service until the formal establishment of the IGS in 1993 by the International Association of Geodesy (IAG). The routine IGS started on January 1, 1994. IGS is a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) and it operates in close cooperation with the International Earth Rotation Service (IERS).

The primary objective of the IGS is to provide a service to support, through GPS data products, geodetic and geophysical research activities. Cognizant of the immense growth in GPS applications, the secondary objective of the IGS is to support a broad spectrum of operational activities performed by governmental or selected commercial organizations. The service also develops the necessary standards/specifications and encourages international adherence to its conventions.

IGS collects, archives, and distributes GPS observation data sets of sufficient accuracy to satisfy the objectives of a wide range of applications and experimentation. These data sets are used by the IGS to generate the following data products:

- high accuracy GPS satellite ephemerides
- earth rotation parameters
- coordinates and velocities of the IGS tracking stations
- GPS satellite and tracking station clock information
- ionospheric information.

The accuracies of these products are sufficient to support current scientific objectives including

- realization of global accessibility to and the improvement of the International Terrestrial Reference Frame (ITRF)
- monitoring deformations of the solid earth
- monitoring earth rotation
- monitoring variations in the liquid earth (sea level, ice-sheets, etc.)
- scientific satellite orbit determinations
- ionosphere monitoring.

The IGS accomplishes its mission through the following components:

- networks of tracking stations
- data centers
- analysis and associate analysis centers
- the Analysis Coordinator
- the Central Bureau
- the Governing Board.

Networks of Tracking Stations

The networks consists of 30 to 40 core stations and 150 to 200 fiducial stations. The core stations provide continuous tracking for the primary purposes of computing satellite ephemerides, monitoring the terrestrial reference frame and determining earth rotation parameters. The fiducial stations may be occupied intermittently and repeatedly at certain epochs for the purposes of extending the terrestrial reference frame to all parts of the globe and to monitor the deformation of a polyhedron (designated as the IGS Polyhedron) defined by the core and fiducial stations located at the vertices.

Data Centers

The data centers required fall into three categories: operational, regional, and global.

The operational data centers are in direct contact with the tracking sites. Their tasks include suitable data reformatting into a uniform format, compression of data files, maintenance of a local archive of the tracking data in its original receiver and in its reformatted format, and the electronic transmission of data to a regional or global data center. The operational data center must down load data from the receivers located at the core sites on a timely (e.g., daily) basis, without interruption.

The regional data centers reduce traffic on electronic networks. They collect reformatted tracking data from several operational data centers, maintain a local archive of the data received and transmit these data to the global data centers. Regional data centers may also meet the operational requirements (as defined in the above paragraph) of strictly regional network operations.

The global data centers are the main interfaces to the analysis centers and the outside user community. Their primary tasks include the following:

- receive/retrieve, archive and provide on line access to tracking data received from the operational/regional data centers
- provide on-line access to ancillary information, such as site information, occupation histories, etc.,
- receive/retrieve, archive and provide on-line access to IGS products received from the analysis centers
- backup and secure IGS data and products.

Analysis Centers

The analysis centers fall into two categories: analysis centers and associate analysis centers.

The analysis centers receive and process tracking data from one or more data centers for the purpose of producing IGS products. The analysis centers are committed to produce daily products, without interruption, and at a specified time lag to meet IGS requirements. The products are delivered to the global data centers and to the IERS (as per bilateral agreements), and to other bodies, using designated standards.

The analysis centers provide, as a minimum, ephemeris information and earth rotation parameters on a weekly basis, as well as other products, such as coordinates, on a quarterly basis. The analysis centers forward their products to the global data centers.

Associate analysis centers are organizations that produce unique products, e.g., ionospheric information or fiducial station coordinates and velocities within a certain geographic region. Organizations with the desire of becoming analysis centers may also be designated as associate analysis centers by the Governing Board until they are ready for full scale operation.

Analysis Coordinator

The analysis centers are assisted by the Analysis Coordinator.

The responsibility of the Analysis Coordinator is to monitor the analysis centers activities to ensure that the IGS objectives are carried out. Specific expectations include quality control, performance evaluation, and continued development of appropriate analysis standards. The analysis coordinator is also responsible for the appropriate combination of the analysis centers products into a single set of products. As a minimum a single IGS ephemeris for each GPS satellite is to be produced. In addition, IERS will produce ITRF station coordinates/velocities and earth rotation parameters to be used with the IGS orbits.

The Analysis Coordinator is to fully interact with the Central Bureau and the IERS. Generally the responsibilities for the Analysis Coordinator shall rotate between the analysis centers with appointments and terms specified by the Governing Board.

Central Bureau

The Central Bureau (CB) is responsible for the general management of the IGS consistent with the directives and policies set by the Governing Board. The primary functions of the CB are to facilitate communications, coordinate IGS activities, establish and promote compliance to IGS network standards, monitor network operations and quality assurance of data, maintain documentation, and organize reports, meetings and workshops, and insure the compability of IGS and IERS by continuous interfacing with the IERS. To accomplish these tasks the CB fully interacts with the independent Analysis Coordinator described above.

Although the chairperson of the Governing Board is the official representative of the IGS at external organizations, the CB, consonant with the directives established by the Governing Board, is responsible for the day-to-day liaison with such organizations.

Through the existing reciprocity agreement between IGS and IERS the CB serves as the GPS coordinating center for IERS, and as such its designated representative, subject to Governing Board approval, is a member of the IERS Directing Board. Such a representative will become a non-voting member of the Governing Board. In turn, the IERS Directing Board designates a representative to the IGS Governing Board. This arrangement is to assure full cooperation between the two services.

The CB coordinates and publishes all documents required for the satisfactory planning and operation of the service, including standards/speci fications regarding the performance, functionality and configuration requirements of all elements of the service including user interface functions.

The CB operates the communication center for the IGS. It maintains a hierarchy of documents and reports, both hard copy and electronic, including network information, standards, newsletters, electronic bulletin board, directories, summaries of IGS performance and products, and an annual report.

In summary, the Central Bureau performs primarily a long-term coordination and communication role to ensure that IGS participants contribute to the service in a consistent and continuous manner and adhere to IGS standards.

Governing Board

The Governing Board (GB) consists of nine voting and six non-voting members. The voting members are distributed as follows:

Analysis centers' representatives	3
Data centers' representative	1
Networks' representatives	2
Director of the CB	1
IERS representative	1
IAG representative	1

The last three members are considered *ex officio* and are not subject to institutional restrictions. The other six persons must be members of different organizations and are nominated for each position by the IGS components they represent as listed above for a staggered four-year term renewable once. (Initially one representative of each component is elected for a full term, the other three for half a term.)

The election for each position is by the number of nominations received from the relevant IGS component: i.e., from the networks (for this purpose organizations operating two or more core stations are considered a network), from the analysis centers, and from the data centers. In case of a tie, the election is by the members of the Governing Board and the IGS associate members (see below) by a simple majority of votes received.

The Chairperson is one of the members of the GB elected by the Board for a term of four years with the possibility of reelection for one additional term. The Chairperson does not vote, except in case of a tie. He or she is the official representative of IGS to external organizations.

The IAG representative is appointed by the IAG Bureau for a maximum of two four-year terms. The IAG representative is responsible to initiate and conduct the elections for the Governing Board membership at the appropriate times. Members of the GB become IAG Fellows with the appropriate rights and privileges after an initial two-year period.

The non-voting members of the GB are distributed as follows:

Representatives of analysis centers, data centers or networks without voting representation on the GB	2
Members at large	2
Representative to the IERS	1
President of IAG Section II (or of Comm.VIII)	1

The last two members are *ex officio* and generally serve a four-year period. The other non-voting members are appointed by the GB upon recommendation by the CB for a two-year period and are subject of the institutional restrictions mentioned above. Both four- and two-year terms are renewable if necessary. The GB membership should be properly balanced with regard to supporting organizations as well as to geography.

The GB exercises general control over the activities of the service including modifications to the organization that would be appropriate to maintain efficiency and reliability, while taking full advantage of the advances in technology and theory.

Most GB decisions are to be made by consensus or by a simple majority vote of the voting members present, provided that there is a quorum consisting of at least six voting members of the GB. In case of lack of a quorum the voting is by mail. Changes in the structure, membership and Chairperson of the GB can be made by a 2/3 majority of the voting members of the GB, i.e., by six or more votes.

The secretariat of the GB is provided by the Central Bureau.

The Board shall meet at least annually and at such other times as shall be considered appropriate by the Chairperson or at the request of three voting members.

IGS Associate Members

Persons representing organizations which participate in any of the IGS components and who are not members of the Governing Board are considered IGS associate members. They are generally invited to attend non-executive sessions of the GB meetings with voice but without vote.

IGS associate members together with the GB vote for the incoming members of the GB every two years, unless the membership has already been determined on the basis of the number of nominations received for each vacant position as described above.

IGS associate members are considered IAG affiliates with the appropriate rights and privileges.

IGS Correspondents

IGS Correspondents are persons on a mailing list maintained by the Central Bureau, who do not actively participate in the IGS but express interest in receiving IGS publications, wish to participate in workshops or scientific meetings organized by the IGS, or generally are interested in IGS activities. *Ex-officio* IGS Correspondents are the following persons:

- IAG General Secretary
- President of IAG Section II or of Commission VIII
- President of IAG Section V
- Representative of FAGS

18 Oct. 1993 (IIM)

The Evolution of the IGS Global Network, Current Status, and Future Prospects

Ruth Neilan
IGS Central Bureau, Jet Propulsion Laboratory
Pasadena, California

Why Global GPS Networks?

A globally distributed network of GPS ground receivers can provide a comprehensive and robust source of tracking data which yield precise, high accuracy orbital solutions for the GPS satellite constellation. From this, one can determine positions of other independent receivers on the ground or even on-board spacecraft.

The first operational GPS tracking network was installed as part of the Global Positioning System by the Department of Defense, with proof of concept tests as early as 1980. This network, a combination of U.S. Air Force and Defense Mapping Agency stations, comprises the ground segment of the GPS as shown in Figure 1. This ten-station tracking network produces data for the command and control of the satellites, as well as for other military uses.

The Historical 'Fiducial Concept' Influence on the IGS Network

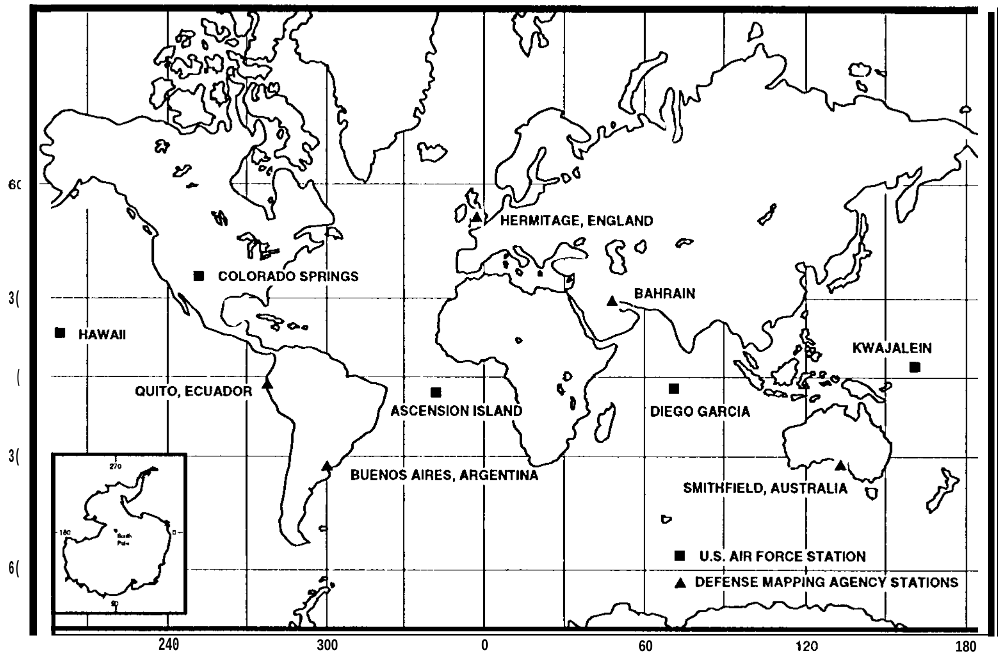
While the orbits produced from the U.S. DoD GPS ground segment were available to certain groups in the early 1980s, the simulations and post-processing of GPS data by civilian groups indicated a need for increasing precision, especially as scientific groups began to look at the GPS as a way to monitor crustal deformation, and as a cheaper, more mobile system to augment the Very Long Baseline Interferometry (VLBI) measurements. An historic test of civilian use of GPS data took place in March 1985, called the High Precision Baseline Test (HPBT '85). This was a test conducted at ten stations in the US, many collocated with VLBI, using 15 dual-frequency geodetic GPS receivers. The data set that was generated was analyzed by a number of analysis groups to demonstrate the 'Fiducial Concept' (Davidson, *et* al., 1985). This technique constrained the GPS positions to VLBI locations at three stations in order to determine the precise orbits and define a terrestrial GPS reference frame aligned with prior VLBI results. Today, within the IGS network, a number of stations are collocated with the VLBI stations and other space geodetic techniques, such as Satellite Laser Ranging (SLR), Precise Range and Range Rate (PRARE), and Doppler Orbit determination and Radiopositioning Integrated on Satellite (DORIS).

Scientific Demand for Precise Global GPS Tracking

The applications of GPS to study the dynamics of the Earth led to an increasing demand for GPS receivers and experiment support. Regional campaigns began to mushroom. An early international experiment was CASA Uno '88 (the First Central and South America GPS Experiment, 1988). This experiment brought together nearly 30 different international agencies participating in an effort to perform the first-epoch geodetic measurements for

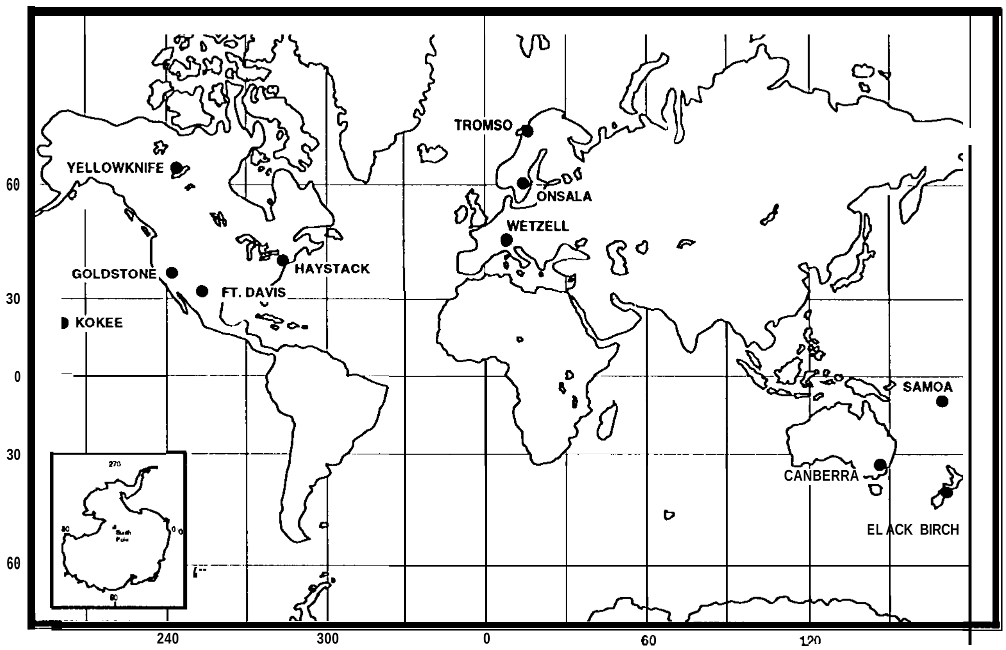
Figure 1. U.S. Air Force and Defense Mapping Agency GPS Tracking Network. The Operational Control Segment of the Global Positioning System. The operational capability was established in May 1985.

GPS TRACKING NETWORK
OPERATIONAL CONTROL SEGMENT
DEFENSE MAPPING AGENCY TRACKING NETWORK



monitoring Central and South American crustal deformation. Nearly 45 receivers were deployed in 13 different countries. This was the first experiment that used a nearly global distribution of tracking stations in order to generate the precise orbits necessary to reduce the scientific dataset (Figure 2). CASA Uno proved to be successful from the scientific aspect as well as for demonstrating the benefits

Figure 2. Extended Global Tracking Network to support the 1988 international geodynamics campaign 'First Central And South American GPS Experiment— CASA Uno *'88,' instrumented with P-code receivers.*



Extended Global Tracking Network for CASA Uno 1988
. GPS stations Mailed for Global Tracking Support, January. February 1988

of a robust global tracking network, The conclusions and results from CASA Uno '88 underlined the fact that the geodynamics community was ready for a continuous, standardized, precise tracking network. It was too costly to deploy receivers to remote tracking locations solely for one particular experiment. The preferred solution was to provide a tracking system that would be a continuous resource for all geodynamics applications, and to develop capabilities for near-real-time data retrieval and accessibility.

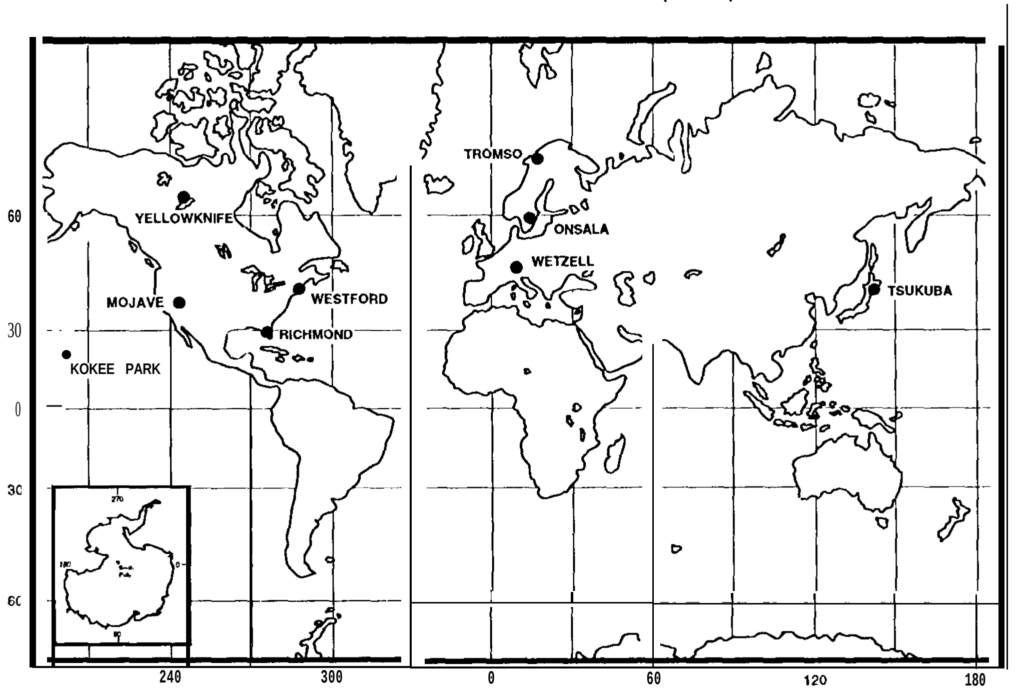
Tracking Network Development

The Coordinated International GPS Network (CIGNET) was an important early activity coordinated by the U.S. National Geodetic Survey for the GPS Subcommission of the International Association of Geodesy's Commission VIII, the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG). The 1989 network shown in Figure 3 was soon augmented by other international partners (Mader, *et al.*, ***1989)***, and efforts focusing on implementing a standard, precision P-code tracking network helped to form the core of the initial IGS Network (Neilan, *et al.*, 1990).

Another major international experiment in 1989 was European Reference Frame (EUREF '89), the first campaign for the determination of transformation parameters between the national geodetic networks of all countries on a subcontinent. It involved more than 60 receivers from four different manufacturers and about 90 sites in 17 Western European countries; 25 of these stations were collocated with VLBI or SLR.

Throughout these activities, it was increasingly apparent that the pivotal point was the standardization of the network infrastructure. Coordinated international network operations for the timely availability of quality data was essential. This was the consensus of the geodetic community and eventually led

COOPERATIVE INTERNATIONAL GPS NETWORK (CIGNET) -1989



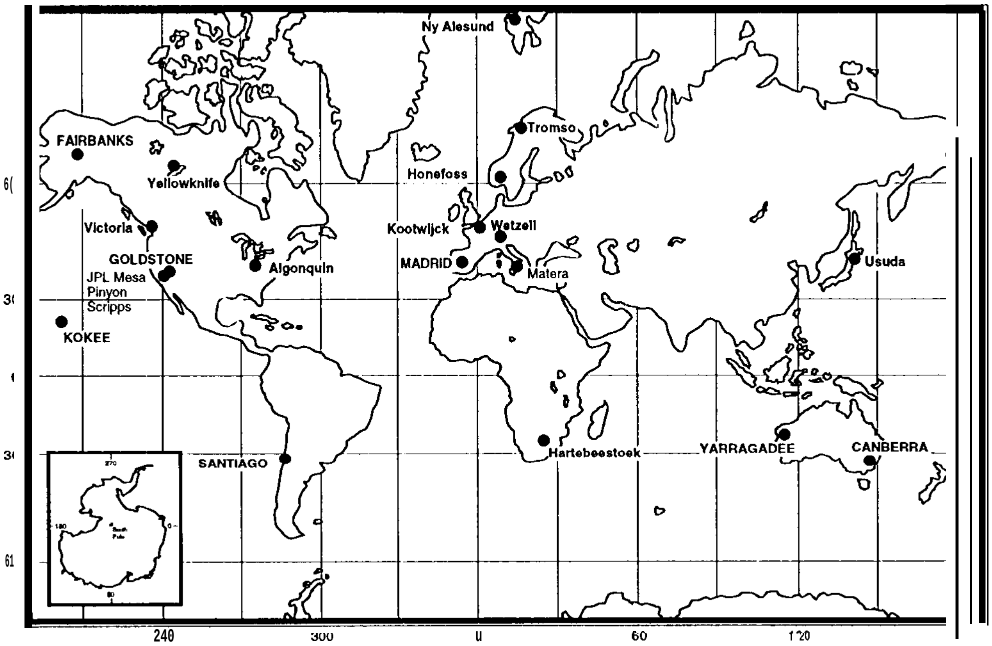
● CIGNET Tracking Sites, January 1989

Figure 3. Cooperative International GPS Network (CIGNET) in** 1989. **Operated by the U.S. National Geodetic Survey.

to the establishment of what would later be called the IGS Planning Committee in 1990.

The 1991 GPS Experiment for the IERS and Geodynamics (GIG'91) campaign was purely a tracking network experiment that was coordinated by JPL for the International Earth Rotation Service and served as the prototype for the current network of the IGS (Melbourne, *et al,, **1993)*** (Figure 4). This experiment had broad international participation and a distributed tracking network of 23 stations (only 13 were permanent in early 1991). During this experiment, the first near-real-time baseline results at the global scale were produced in only 36 hours after data collection. It was noted that during GIG, only six stations were located in the Southern Hemisphere, limiting the achievable accuracies. Feedback from the analysis groups sparked increased implementation south of the equator, particularly in South America and Australia.

Figure 4. The Tracking Network for the GPS Experiment for IERS and Geodynamics 1997-GIG '91. This 27-station, precision P-code network became the operational prototype for the IGS Campaign in 1992.



GPS EXPERIMENT FOR **IERS** AND GEODYNAMICS 1991- ***GIG'91***

● GPS Precision P-Code continuous stations Installed for GIG'91

As described above in the Development of the IGS (See Section I, G. Beutler, this volume), 1991 was a key year for the global tracking network with the distribution of the Call for Participation in the International GPS Service for Geodynamics. The IGS successfully demonstrated the service during the three-month campaign of 1992, the IGS Demonstration Campaign, with data from tracking stations being accessed by the seven Analysis Centers within three days. Precise orbits were made available electronically on the Internet to users within two to three weeks.

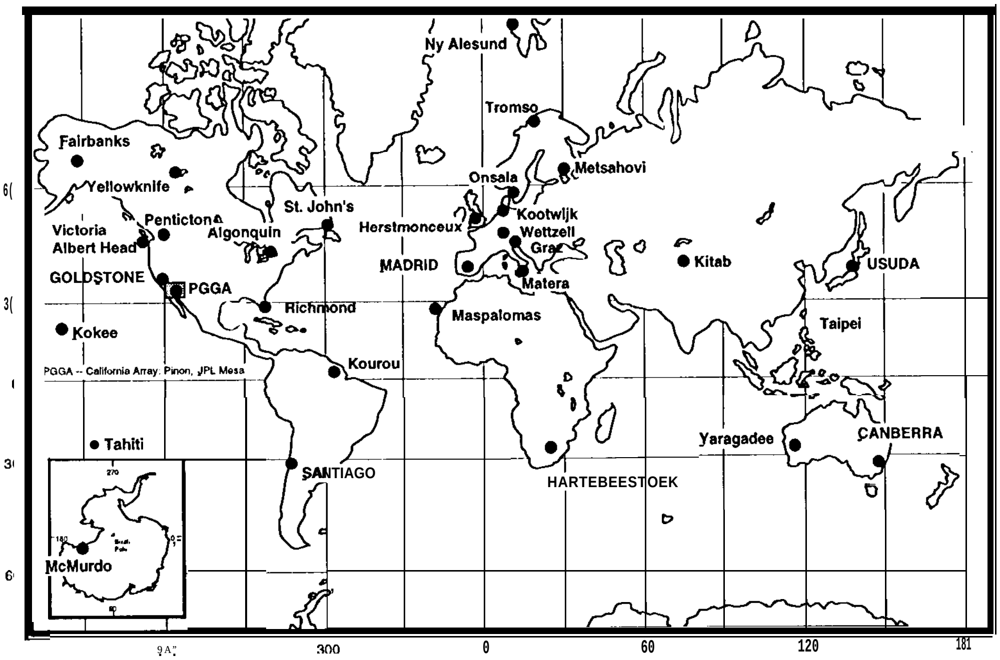


Figure 5. Tracking Network Configuration during the IGS Demonstration Campaign, June 211992- September 22, 1992. All precision P-code instrumentation.

Current IGS Network

The configuration of the IGS network at the close of 1994 is shown in Figure 6, and the status as of July 1995 is included in the previous chapter. Just by comparing the maps, one can see that there are generally one to two new GPS stations per month. There has been incredible growth of the network over the past years, with the network nearly doubling in size each year!

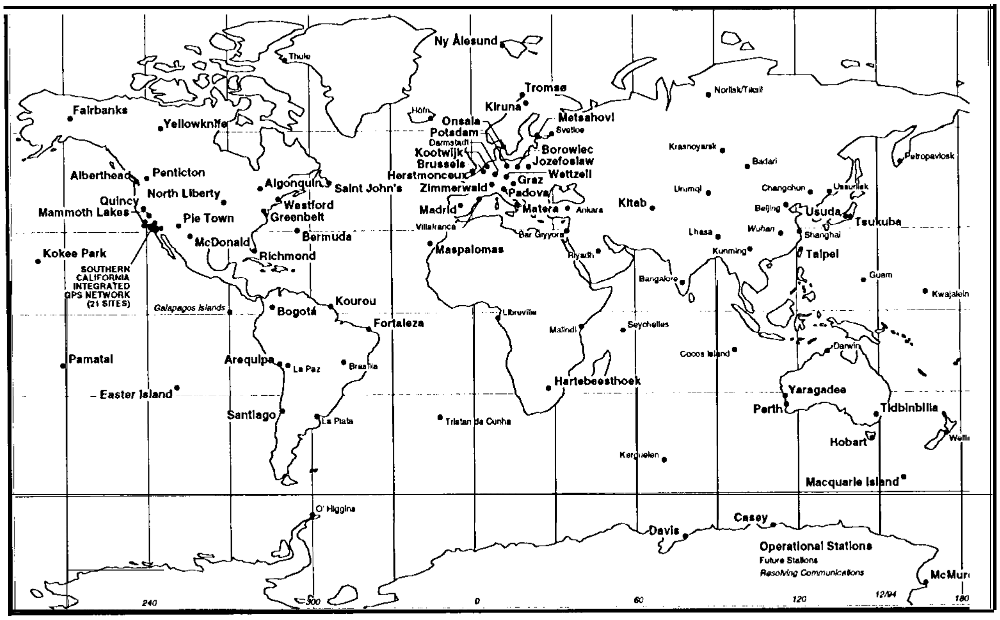


Figure 6. GPS Network at the close of 1994, the first fully operational year of the IGS.

Table 1 lists the current operational stations of the network, and Table 2 lists the future proposed IGS stations. Although this latter list is complete as of June 1995, it is important to note that the GPS stations become available as the implementation opportunity arrives; the future station list changes with time as the different agencies attempt to fill in the gaps in coverage as shown in Figure 7.

Table 1. Operational GPS Stations of the IGS.

PERMANENTLY OPERATING STATIONS OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

	STATION		COUNTRY	GPS Receiver	Lon (E)	Lat (N)	AGENCY
1	Albberthead		Canada	R SNR-8000	- 123.48	48.38	NRCan/GSC
2	Algonquin	•	Canada	R SNR-8000	- 78.07	45.95	NRCan/GSD
3	AOA Westlake†		USA	R SNR-8000	- 118.83	34.16	NASNJPL
4	Arequipa	•	Peru	R SNR-8000	71.48	- 16.45	NASA/JPL-GSFC
5	Bangalore		India	R SNR-8000	77.57	13.02	CMMACS/JPL/CU
6	Bermuda	•	United Kingdom (Is.)	R SNR-8000	64.65	32.35	NOAA/NGS
7	Blythe†		USA	A ZX-II3	- 114.71	33.43	PGGA
8	Bogotá	·	Colombia	R SNR-8000	- 74.08	4.64	NASNJPL
9	Bommer Canyon†		USA	A ZX-II3	- 117.80	33.44	PGGA
10	Borowiec		Poland	R SNR-8000	17.07	52.09	ALO
11	Brandt†		USA	R SNR-8000	- 118.28	34.19	PGGA
12	Brasflia	·	Brazil	R SNR-8000	- 47.88	- 15.94	IBGE/NASA/JPL
13	Brussels		Belgium	R SNR-8000	4.36	50.80	ROB
14	Caltech Pasadena†		USA	R SNR-8000	- 118.13	34.14	NASA/JPL
15	Carrhill†		USA	R SNR-8000	- 120.43	35.71	NASA/JPL
16	Casey	•	Antarctica	R SNR-8100	110.53	- 66.27	AUSLIG
17	Catalonia		Spain	T 4000 SST	2.00	42.00	ICC
18	Chatsworth†		USA	R SNR-8000	- 118.64	.34.08	PGGA
19	Chilao Flats†		USA	A ZX-II3	- 118.03	34.33	PGGA
20	Davis	•	Antarctica	R SNR-8100	77.97	- 68.57	AUSLIG
21	Easter Island	•	Chile	R SNR-8000	- 109.38	- 26.99	NASA/JPL
22	Fairbanks	·	USA	R SNR-8	- 147.48	64.97	NASNJPL-GSFC
23	Fortaleza	·	Brazil	R SNR-8000	- 38.58	- 3.75	NOANNGS
24	Goldstone†	·	USA	R SNR-8	- 116.78	35.23	NASA/JPL
25	Grasse		France	R SNR-8100	6.85	43.73	CNES
26	Graz		Austria	R SNR-8C	15.4~	47.07	ISRO
27	Greenbelt		USA	R SNR-8000	- 76.82	39.02	NASA/JPL-GSFC
28	Guam	·	USA (Mariana Is.)	R SNR-8000	144.87	13.59	NASA/JPL/IRIS
29	Hartebeesthoek	•	South Africa	R SNR-8	27.7C	- 25.88	CNES
30	Harvest†		USA	R SNR-8000	- 120.68	34.29	NASA/JPL
31	Herstmonceux		United Kingdom	R SNR-8C	0.33	50.87	RGO
32	Hobart	·	Australia	RSNR-81OCI	147.43	- 42.80	AUSLIG
33	Holcomb Ridge†		USA	A ZX-II3	- 117.85	34.46	PGGA
34	Jozefoslaw		Poland	T 4000 SSE	21.03	52.08	WUT
35	JPL Mesa Pasadena†		USA	R SNR-8100	- 118.17	.3-4.2	NASNJPL
36	Kerguélen	·	France (Is.)	R SNR-8C	70.26	- 49.35	CNES
37	Kiruna		Sweden	R SNR-81OO	20.25	67.88	ESOC
38	Kitab	·	Uzbekistan	R SNR-8000	66.89	39.13	GFZ
39	Kokee Park	·	USA (Hawaiian Is.)	R SNR-8	- 159.67	22.17	NASA/JPL
40	Kootwijk	·	Netherlands	R SNR-8	5.80	52.17	DUT
41	Kourou	·	French Guiana	R SNR-8C	- 52.62	5.13	ESOC
42	Lake Matthews†		USA	T 4000 SSE	- 117.44	33.68	PGGA
43	Lamkowko		Poland	R SNR-8000	20.67	53.89	OUAT
44	Lhasa		China	R SNR-8000	91.12!	29.41	IfAG
45	Long Beach†		USA	R SNR-8100	- 118.20	33.79	NASA/JPL
46	Longdon Yard†		USA	A ZX-II3	- 118.00	34.02	PGGA
47	Macquarie Island		Australia	R SNR-8100	158.94	- .54.50	AUSLIG
48	Madrid	·	Spain	R SNR-8	4.25	40.42	NASA/JPL
49	Mammoth Lakes		USA	R SNR-8000	- 118.95	37.64	NASA/JPL
50	Maspalomas	•	Canary Islands	R SNR-8100	15.63	27.77	ESoc
51	Matera	•	Ital y	R SNR-8	16.7C	40.63	AS I
52	McDonald	•	USA	R SNR-8000	- 10$.O2	30.67	NASA/JPL
53	McMurdo	•	Antarctica	R SNR-8000	166.67	- 77.85	NASA/JPL
54	Mendeleevo		Russia	T 4000 SSE	37.22	56.03	IMVP/DUT
55	Metsahovi	•	Finland	R SNR-8C	24.38	60.22	FGI

Table 1. (Cont.)

	STATION		COUNTRY	GPS Receiver	Lon (E)	Lat (N)	AGENCY
56	Monument Peak†		USA	A ZX-II3	- 116.42	32.72	PGGA
57	Mount Wilson†		USA	R SNR-81OO	- 118.06	34.23	NASA/JPL
58	North Liberty		USA	R SNR-8000	- 91.50	41.80	NASA/JPL-GSFC
59	Ny Ålesund	•	Norway	R SNR-8	11.85	78.92	SK
60	Oat Mountain†			R SNR-8100	- 118.60	34.33	NASA/JPL
61	O'Higgins	•	Antarctica	R SNR-8000	59.90	- 63.32	IfAG
62	Onsala	•	Sweden	R SNR-8000	11.92	57.38	0s0
63	Padova		Italy	T 4000 SSE	I 1.88	45.41	UPAO
64	Palos Verdes†		USA	T 4000 SSE	- 118.40	33.57	PGGA
65	Pamatai	•	Tahiti	R SNR-800	- 149,57	- 17.57	CNES
66	Pecny		Czech Republic	T 4000 SST	14.79	49.9 I	GOPE
67	Penticton	·	Canada	R SNR-8000	- 119.62	49.32	NRCan/GSC
68	Perth		Australia	R SNR.81OO	11s.82	- 31,97	ESOC
69	Pie Town		USA	R SNR-8000	- 108. I2	34.3c1	NASA/JPL-GSFC
70	Pinemeadow†		USA	T 4000 SST	- 116.61	33.61	PGGA
71	Pinyon Flat†		USA	A ZX-II3	- 116.45	33.60	PGGA
72	Potsdam	•	Germany	R SNR-8000	13.07	52,38	GFZ
73	Quincy		USA	R SNR-8000	- 120.93	39.97	NASA/JPL
74	Richmond	•	USA	R SNR-8000	80.38	25.60	NOAA/NGS
75	Saint John's	•	Canada	R SNR-8000	52.68	47.60	NRCan/GSD
76	Santiago	•	Chile	R SNR-8	70.67	- 33.15	NASA/JPL/CEE
77	Scripps†		USA	A ZX-II3	- 117.25	32.87	PGGA
78	Shanghai	·	China	R SNR-8100	121.20	31.10	SAO/NASA/JPL
79	Taipei	•	Taiwan	R SNR-800	121.63	25.03	IESAS
80	Thule		Greenland	R SNR-8000	68,73	76.S6	NASAfGSFC-JPL
81	Tidbinbilla	•	Australia	R SNR-8	148.97	- 35.38	NASA/JPL
82	Tromsø	•	Norway	R SNR-8	18.93	69.67	SK
83	Tsukuba	•	Japan	R SNR-8100	140.08	36.10	GSI
84	UCLA Los Angeles†		USA	R SNR-8000	- 118.44	34.07	NASA/JPL
85	USC Los Angeles†		USA	R SNR-8000	- 118.29	34.02	NASA/JPL
86	Usuda	•	Japan	R SNR-8000	138.37	36.13	ISAS
87	Vandenberg†		USA	A ZX-II3	- 120.48	34.55	PGGA
88	Villafranca		Spain	R SNR-8100	- 3.95	40.44	ESOC
89	Westford	•	USA	R SNR-8000	- 71.48	42.62	NOAA/NGS
9C	Wettzell	·	Germany	R SNR-800	12.87	49.13	IfAG
91	Yaragadee	·	Australia	R SNR-8	115.33	- 29.03	NASA/JPL
92	Yellowknife	·	Canada	R SNR-8000	- 114.47	62.47	NRCan/GSD
93	Yucaipa†		USA	A ZX-II3	- 117.10	34.04	PGGA
94	Zimmerwald		Switzerland	T 4000 SSE	7.45	46.87	BfL
95	Zwenigorod		Russia	R SNR-8000	36.S4	55.46	GFZ

. Global site: processed by three or more IGS Analysis Centers, one of which is nn another continent
† SCIGN site (Southern California Integrated GPS Network)

R: Rogue, A: Ashtech, T Trimble
All locations given in decimal degrees.

Table 2. Planned Future Stations of the IGS. Note that some of these stations are currently installed and operating, but the communications links for the daily retrieval of data are still being resolved.

PLANNED OR PROPOSED FUTURE STATIONS OF THE INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

	STATION		COUNTRY	GPS Receiver	Lon (E)		Lat (N)	AGENCY
1	Alma-Ata		Kazakhstan		77.08		43.19	UNAVCO
2	Ankara		Turkey		32.83		39.92	IfAG
3	Ascension		United Kingdom (1s.)		14.22	-	7.57	NASA/JPL/IDA
4	Bandung		Indonesia		107.22	-	7.00	DUT
5	Bar Giyyora		Israel	R SNR-8000	35.08		31.72	NASA/JPL-GSFC
6	Beijing		China	R SNR-8000	116.38		39.92	GFZ/NBSM
7	Changchun		China		125.42		43.92	SAO/NASA/JPL
8	Chatham Island		New Zealand		176.70	-	44.00	UNAVCO
9	Cocos Island		Australia		96.83	-	12.20	AUSLIG
10	Darwin		Australia		131.13	-	12.85	AUSLIG
11	Darmstadt		Germany		8.67		49,85	ESOC
12	Diego Garcia		Island		72.25	-	7.20	NASA/JPL/IDA
13	Dudinka		Russia	R SNR-8000	85.42		69.15	GFZ
14	Ensenada	*	Mexico		- 116.30		32.00	NASAIJPL-UNAVCO
15	Galapagos Islands	*	Ecuador	R SNR-8000	89.62		0.90	NASA/JPL
16	Höfn		Iceland		15.00		64.50	SK
17	Hyderabad		India		79.28		17.29	UB
18	Irkutsk/ Badari		Russia		104.00		52.16	NASA/JPL/IAA
19	Ishigaki		Japan		125.00		24.2S	WJNG
20	Kunming		China		102.83		25.17	CAS/NASA/JPL
21	Krasnoyarsk	*	Russia	R SNR-8000	93.12		56.13	GFZ
22	Kwajalein		USA (Marshall Is.)		167.47		9.38	NASAJJPL
23	La Paz		Bolivia		68.50	-	17.00	NASA/JPL
24	La Plata	*	Argentina	R SNR-8000	.57.95	-	34.9C	GFZ
25	Libreville		Gabon		9.27		0.23	CNES
26	Limón		Costa Rica		83.02		10.00	NASAIJPL-UNAVCO
27	Malindi		Kenya		40.13	-	3.23	ESOC
28	Manila		Philippines		121.00		14.37	WING
29	Marcus		Japan		155.00		24.00	WING
30	Mauna Kea		USA (Hawaiian 1s.)		- 1s5.30		19.52	NASA/JPL
31	Mbarara		Uganda		?,0.70	-	0.60	IDA/NASA-JPL
32	Petropavlosk-Kam.		Russia	R SNR-8000	158.65		53.13	GFZ
33	Riyadh		Saudi Arabia		46.70		24.68	NASA/others
34	Saint Croix		USA (Virgin 1s.)		64.43		17.40	NASA/JPL
35	Seychelles	*	Seychelles	R SNR-8000	55.50	-	4.68	NASA/JPL/IDA
3	Simeiz		Ukraine		34.00		44.40	IAA
37	Svetloe		Russia		29.79		60.53	IAA/JPL
38	Taejon		South Korea		127.26		36.20	WJNG
39	Tristan da Cunha		United Kingdom (1s.)		12.50	-	35.50	NASA/JPL/POL
40	Urumqi		China	R SNR-8000	87.72		43.82	GFZ/NBSM
41	Villafranca		Spain		2.67		42.25	ESOC
42	Vladivostok		Russia		131.47		43.06	WING
43	Wellington		New Zealand		174.78	-	41.27	DOSLI/AUSLIG
44	Whangarapoa		New Zealand		174.19	-	35.43	UNAVCO
45	Wuhan	*	China		114.25		30.5	WTU/NGS
46	Xi'an		China		109.00		34.20	CAS/JPL-UNAVCO

* Resolving communications and data retrieval paths.

R: Rogue, A: Ashtech, T Trimble
All locations given in decimal degrees.

Future Network

The future growth of the IGS global network will address improving the global distribution. It can be seen from the operational map shown in the previous chapter, as well as in Figure 7, that to reach a more uniform geographic distribution for global products, a few additional stations are needed in Africa, Russia, China, Asia and the remote ocean island areas.

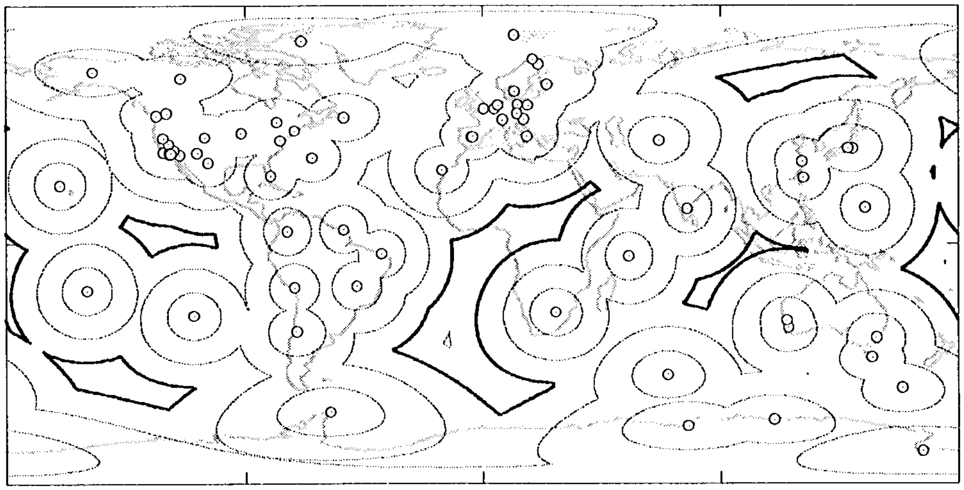


Figure 7. This map depicts the 1000-km contour isolation interval, and helps to indicate where increased GPS coverage would greatly enhance the global network **(from Zumberge, 1995).**

Densification of the ITRF

The new IGS initiative addressed in the December 1994 workshop 'Densification of the International Terrestrial Reference Frame through Regional GPS Networks' is meant to improve access to the global reference frame. The IGS is developing the logistics and techniques to include up to 250 well-distributed GPS stations for the purpose of determining station coordinates and velocities as part of the ITRF. In addition to using the IGS official orbit, these densification stations will ensure that most users will also be within about 1000 km of a precise reference point on which to precisely link their local or regional studies.

Another service which the IGS will begin is the cataloging of all active GPS stations meeting IGS standards, their locations, and points of contacts, even for the local arrays. This should help with redundancy at all levels of the network, and also ensure that there are no duplicate efforts in the same area.

References

Davidson, J., C. L. Thornton, C. Vegos, L. E. Young, T. P. Yunck, (1985) "The March 1985 Demonstration of the Fiducial Network Concept for GPS Geodesy: A Preliminary Report," Proceedings of the First International Symposium on Precise Positioning with the Global Positioning System, Rockville, Maryland.

Neilan, R. E., W. G. Melbourne, G. Mader, (1990) "The Development of a Global GPS Tracking System in Support of Space and Ground-based GPS programs," International Association of Geodesy Symposia, Global Positioning System: An Overview, Symposium No. 102, Springer Verlag; New York

Melbourne, W. G., S. S. Fisher, R. E. Neilan, T. P. Yunck, B. Engen, C. Reigber, S. Tatevian (1993), "The First IERS and Geodynamics Experiment—1991," International Association of Geodesy Symposia, Permanent Satellite Tracking Networks for Geodesy and Geodynamics, Symposium No. 109, Springer Verlag; New York.

Mader, G., W. E. Strange, L. D. Hothem (1989) "GPS Programs at the National Geodetic Survey," Proceedings 5th International Geodetic Symposium on Satellite Positioning, Las Cruces, New Mexico.

Zumberge, J., and R. Liu, editors, 1995, "Proceedings of the IGS Workshop on the Densification of the ITRF through Regional GPS Networks."

Status of the IGS Regional Initiative

Ivan L Mueller
The Ohio State University
Columbus, Ohio

Progress made by the IGS is truly remarkable. High accuracy GPS ephemerides, earth rotation parameters, etc., are routinely generated and made available to users in a short time. One of the primary area of emphasis of the IGS is on the completion of a global, geographically well-distributed network. Inspection of the set of IGS stations at the end of 1993 showed that we continued to be limited in the areas of Russia, China, India, and Africa.

Both the IGS Governing Board and the International Association of Geodesy agreed that the next step for IGS to accomplish (together with IERS) was the extension and densification of the IERS Terrestrial Reference Frame (ITRF) so that a large number of globally distributed GPS reference stations be available to the users at, say, every few (l–3) thousand kilometers.

One way to accomplish this was to solicit cooperation with groups which have been involved in GPS surveys in certain geographic regions where IGS core stations are not yet available.

The questions are (i) how can one integrate geodetic solutions from the growing number of regional GPS campaigns into the ITRF for the above purpose and (ii) how can such cooperation best be organized?

The IERS/IGS Workshops March 21–26, 1994 in Paris started to address the first question and it was addressed again at the IGS Workshop November 30–December 1, 1994 in Pasadena entitled "Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks".

The second question was addressed at a special organizational meeting on March 24, 1994 in Paris (and again in Pasadena), where it became clear that the most practical way to collaborate to densify and extend the ITRF through IGS/IERS is to utilize some of the observations made or to be made at certain selected locations within regional networks, especially in geographic areas where IGS currently does not have core stations. Such utilization of the observations would be mutually beneficial for reasons which do not have to be repeated here.

As a first step it was decided to prepare a map with all currently feasible or seemingly feasible station locations indicated. After assessing what may become available in the near future in terms of stations a decision will have to be made on the best approach on how the observations be best utilized to extend the ITRF.

Such a map was prepared and is shown (Figure Al) in the Proceedings of the Workshop in Pasadena (Zumberge, Neilan, and Mueller, 1995) and is based on information solicited from and provided by various organizations engaged in regional GPS surveys, the Doris tracking network, and tide gauge networks. Stations have been selected from the map as candidates for the densification of the global ITRF.

Action was also needed to provide for geographic areas which still appeared to be "stationless" on the map. The final goal remained to provide ITRF reference at every few thousand kilometers over the globe.

A rigorous and dependable network of ITRF stations is best served through continuously operating stations where this is economically feasible. A number of the regional campaign areas are in the process of making the transition from conventional "campaign" projects to investigations that install permanent stations in the area of interest. The remainder of the network observations are then obtained by a roving set of field GPS receivers.

For example, a standard regional network might have contained 30 points observed in three four-day bursts or phases with 12 receivers, three at fixed locations and nine moving to the next set of stations after each burst. This method of operation can be very costly and requires careful planning and execution for a once-per-year measurement. In many cases the principal investigators would now prefer the temporal resolution and resulting precision provided by a continuous network of stations. Program sponsors are also reviewing this method as being an extremely cost-effective way to provide high-quality scientific data.

Some agencies (e.g., NASA, NSF, and GFZ) are in the process of considering a mix of GPS observations (continuous/fixed/semi-permanent), and are beginning to implement continuous stations in certain project areas. By implementing one to three receivers in an area, two to three additional receivers can be used to occupy the remaining network stations, requiring less resources and enabling a flexible schedule. Note that this method is not being touted for all types of GPS investigations. It is very unlikely that continuous networks would ever completely replace the need for episodic or point measurements. However, the IGS will benefit from incorporating the regional stations at the appropriate spacing into the reference frame dataset, and the scientific investigator will profit by having at least one station in their locally dense network tied into the IGS framework.

Similar network operations have been undertaken by various national agencies, including the Natural Resources of Canada's Active Control Network, the Norwegian Mapping Authority's SATREF network, the Swedish control network, and the Australia Surveying and Land Information Group (AUSLIG) network. These are prime examples of a larger scale regional framework accessible to local users. These operational networks would be very good test cases for the IGS combination process in terms of reference frame extension.

There are certain to be some areas of interest, however, where the lack of basic facilities would not permit or support continuous station operation (e.g., lack of power, communications, etc.). In these cases, it is conceivable that episodic GPS data collected at least once per year could be folded into the process for determination of the reference frame, station coordinates and velocities.

A partial list of projected stations that have a high probability for installation (or resolved communications) before the end of calendar 1995 is given in Table 1.

The Workshop in Pasadena (1995) was held at the IGS Central Bureau, Jet Propulsion Laboratory (JPL). The purpose of the workshop was to discuss how the IGS could best accommodate the rapidly growing number of Global Positioning System (GPS) terrestrial sites.

The Agenda was centered around the following four position papers, which were prepared and distributed in advance to the attendees:

1) "Densification of the IGS Global Network" J. F. Zumberge, R. E. Neilan, I. 1. Mueller

2) "Constructing the IGS Polyhedron by Distributed Processing" G. Blewitt, Y. Bock, J. Kouba

3) "Network Operations, Standards and Data Flow Issues" W. Gurtner and R. E. Neilan

Site	Region	Agency
Bangalore	India	CM MACS/UNAVCO/NASA
Bar Giyyora	Israel	NASA
Brasilia	Brazil	IBGE/NASA
Ensenada	Baja Mexico	NASA
Galapagos Islands	Ecuador	NASA
Guam	Eq. Pacif. Ocean	NASA
Hyderabad	India	Univ. of Bonn
Lhasa	Tibet	IfAG
Mauna Kea	Hawaii	NASA
O'Higgins	Antarctica	IfAG
Shanghai	China	SAO/NASA
St. Croix	Virgin Islands	NASA
Thule	Greenland	NASA
Tian Shari Mountains	Central Asia	NSF/NASA
Xian	China	Xian Observatory

Table 1. Planned Expansion of the IGS Network in 1995.

4) "Densification of the ITRF through Regional GPS Networks: Organizational Aspects" G. Beutler, J. Kouba, R. E. Neilan

The concluding session chaired by Geoffrey Blewitt focused on highlighting issues which needed resolution as soon as possible. Then a post-meeting working group, chaired by Ivan Mueller, discussed the issues in detail. This working group then provided recommendations to the IGS Governing Board (IGSGB), which met the following week in San Francisco.

The following topics were noted to be in need of resolution:

(1) The "IGS Network" needs to be defined, particularly our vision of how it might look in the future.
- Specify those regions where IGS would welcome densification initiatives.
- Should we have a call for participation to install new IGS stations? Which agencies might be able to respond?

(2) Should we have a "pilot phase" to assess the distributed processing approach proposed by Position Paper 3?
- What period of time? one year?
- Should we start by just analyzing global network solutions produced by the current Analysis Centers?
- Who is interested in participating (Associate Analysis Centers of Type 2)?
- We need to define a software independent exchange format for solutions (SINEX).
- We need guidelines for participation.

(3) How are we to organize regional analysis (Associate Analysis Centers of Type 1)?
- Call for participation?
- Should it be delayed until Type 2 activities are underway?
- Who might be able to participate?
- We need guidelines for participation.

(4) To improve clarity, we should agree on conventional terminology. For example, what exactly do the following terms mean?

- Global Network
- IGS Network
- Core Network
- Regional Network

The first major conclusion from the workshop was that at least one, and ideally two Associate Analysis Centers (AAC's) should perform weekly comparisons and combinations of the coordinate solutions of all IGS Analysis Centers (AC's) and of future AAC'S that may analyze parts of the densified IGS network.

In view of the fact that the seven existing IGS AC's are in principle ready to produce weekly free-network coordinate solutions, and considering that the Department of Surveying of the University of Newcastle, represented at the workshop by Geoffrey Blewitt, and the Institute of Geophysics and Planetary Physics of Scripps Institution of Oceanography, represented at the workshop by Yehuda Bock expressed their interest to act as AAC'S during such a pilot phase, it was decided to establish a pilot phase for AAC'S as early as possible in 1995. The ITRF section of the IERS, represented by Claude Boucher, Pascal Willis, and Zuheir Altamimi, promised to accompany this pilot phase by regularly analyzing the products of these AAC'S.

The second major conclusion of the workshop was that IGS stations should be permanent stations wherever possible. (Although near real-time data transmission is desirable, permanent receivers with less-than-real-time data communications would be acceptable, too.) In order to obtain the necessary global coverage, which is currently sparse in several regions, it was recommended that the Central Bureau write a Call for Participation (CFP) identifying regions for the IGS network densification. This CFP shall be sent out in March 1995.

Although not all problems concerning the densification of the IGS network could be addressed at the workshop, the workshop will be remembered as the principal milestone of this ambitious project.

Reference

Zumberge, J., R. Neilan, and I. I. Mueller: "Densification of the IGS Global Network," Proceedings of the 1994 IGS Workshop: Densification of the ITRF through Regional GPS Networks, Position Paper 1, November 30–December 1, 1994, Jet Propulsion Laboratory, Pasadena, CA, 1995.

Status and Activities of the Central Bureau

Ruth Neilan
IGS Central Bureau, Jet Propulsion Laboratory
Pasadena, California

What is the IGS Central Bureau?

The Central Bureau of the International GPS Service is responsible for the overall management and coordination of the Service. The Central Bureau is sponsored by the U.S. National Aeronautics and Space Administration and is located at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. During the Call for Participation to join the IGS in 1991, JPL proposed to assume the responsibilities of the Central Bureau. Throughout the planning and demonstration campaigns we acted in this capacity primarily by coordinating the network and maintaining the documentation and communications on meetings and planning for the formative IGS.

Activities in 1994

The key activity of the Central Bureau in 1994 was putting together a strong team and building the foundation necessary to fulfill the responsibilities for the IGS. We have had a very good and enjoyable first year, with what I consider a lean, complementary team. We continue to work together and draw on expertise available locally from JPL, as well as from other locations to keep the Central Bureau responsive and flexible.

IGS Mail, IGSCB Mail, and Communications

When the IGS was formally approved by the IAG in August 1993, the Central Bureau prepared to begin formal operations starting January 1, 1994. The IGS Mail communication system was developed and implemented at the University of Bern by Werner Gurtner prior to the IGS Demonstration Campaign in May 1992. During the fall of 1993, Werner Gurtner accepted an invitation to work at JPL with the Central Bureau to prepare the transfer of IGS Mail to the Central Bureau. The IGS Mail was formally transferred in January 1994.

Just as IGS Mail and Reports were setup to maintain communication and connections between IGS Members, we felt a need to establish the IGS Central Bureau Mail to handle direct inquiries and business for the Central Bureau. This system works much like the IGS Mail with distribution to members of the Central Bureau (see Table 1). Nearly 700 messages directed to the Central Bureau were handled from March through December 1994.

In addition to the electronic communications, rarely a day goes by without the Central Bureau receiving standard mail, faxes, and telephone calls for information or assistance. There are many areas of the world interested in the IGS with no means to access the information electronically. We are sensitive to this and work to find alternative methods to transfer the information.

Table 1. Members of the Central Bureau in 1994, and time devoted to the Central Bureau activities.

Person	Title	% of Time
Steve DiNardo	Network Engineer	209'0
Werner Gurtner	Data Flow Chief	10%
Robert Liu	IGS Communications	10070
Ruth Neilan	Director	35%
Mike Urban	Systems Manager	10%
Priscilla Van Scoy	Administrator	35%
James Zumberge	Deputy Director	50%
Total		*2.6 Work Years*

Central Bureau Information System

During the transition of the IGS Mail to the Central Bureau, Werner Gurtner began developing the structure of the Central Bureau Information System (CBIS, see Section III, W. Gurtner, this volume). The system evolved a great deal over the last year and, by the end of 1994, had over 700 logins and 2000 file retrievals per week.

Meetings

The Central Bureau is responsible for organizing most IGS meetings. The first joint workshop with the International Earth Rotation Service was held in Paris during March 1994, jointly sponsored by the IGS and the IERS. Following this meeting the Second IGS Governing Board Meeting was held.

Workshop

The Central Bureau was responsible for organizing the December 1994 workshop, "IGS Workshop on the Densification of the ITRF through Regional GPS Networks" (See Section I, I. I. Mueller, this volume). Proceedings from this have been published by the Central Bureau and are available on request.

Publications

The IGS Directory was standardized and published in late 1994. This directory contains address information for nearly 1000 contacts. It is planned to be updated regularly and published annually. Those with access can locate the on-line version in the CBIS.

In August 1994, a news brief describing the IGS was sent to editors of relevant scientific and engineering publications. This brief was included in many publications through spring of 1995 as a means of publicizing information on the services available through the IGS.

The IGS also updates and distributes the IGS Resource Information Package on a quarterly basis. This contains information on the system, the station locations, how to access the CBIS, points of contact at the different centers, and so on.

The Central Bureau is also responsible for organizing, editing and publishing the IGS Annual Report, of which this is the first.

Copies of all IGS publications are available on request.

Future Activities

The Central Bureau will be involved in a number of activities in the next year including:

- collaboration with the Global Sea Level Observing System for the monitoring of tide gauge benchmarks using the GPS technique and the IGS network;
- assisting with the organization of the workshop on Special Topics and New Directions in Potsdam, Germany, May 1995;
- promoting the extension of the network into remote areas lacking continuous GPS coverage;
- investigating options for proposing the commercial data use policy for the IGS;
- preparation for the IUGG presentations and meetings;
- publication and distribution of an IGS Brochure.

Who is the IGS Central Bureau?

In closing, I thought that it would be appropriate to introduce the members of the Central Bureau in 1994.

The Network Engineer in 1994 was Steve DiNardo, who resigned from the Central Bureau and the GPS network tasks in early 1995. He has moved over to the exciting world of Synthetic Aperture Radar at JPL. Steve had been involved with GPS since the early 1980s. His experiences range from establishing the first continuous stations for JPL, through technical maintenance and support of many receivers and other institutions in the network. His work is certainly praised and respected, resulting in numerous stories about his ability to get a job done. If there was ever a critical installation with critical timing, Steve was the person people wanted. He will be remembered for his strong will and determination, and his unique ability to pull the most difficult task through successfully. The IGS will miss him, but we wish him the best of luck in his new endeavors. Keith Stark will be assuming the bulk of the network engineering tasks in 1995.

Werner Gurtner's time is funded by the University of Bern and it is difficult to express how vital his input has been to the success of the IGS. From designing the data flow, IGS Mail, his ideas on the CBIS, and his development and maintenance of RINEX, Werner has had an exceptional influence on the efficiency and automation of IGS systems.

Rob Liu did not join the Central Bureau until January 1994, but he is the person who spends 100% of his time managing the CBIS and the communications. He really keeps the communications hub operating.

Mike Urban works as the computer system manager for the UNIX workstations that support the IGSCB. It is because of his technical expertise that the IGS Mail system was transferred so efficiently. Mike and Rob were jointly responsible for developing and implementing the Web page of the CBIS.

Priscilla Van Scoy is our administrator and takes care of many details that the rest of us would no doubt overlook. She has been the key person in keeping our schedules, keeping us organized, and acting as our financial wizard. She is also responsible for updating and maintaining the IGS Directory.

Finally, (due to alphabetizing the family names) is Jim Zumberge, a keystone in the structure of the Central Bureau and the IGS. Jim acts as Deputy Director and oversees the IGS Communications tasks. He also acts as the liaison between the Analysis/Associate Analysis Centers and the Central Bureau. His sense of humor and sharp technical skills are crucial to the Central Bureau and contribute to a strong sense of teamwork.

We look forward to a busy and productive year in 1995.

The Central Bureau Information System

Werner Gurtner
Astronomical Institute University of Berne
Berne, Switzerland

Robert Liu
Jet Propulsion Laboratory
Pasadena, California

Introduction

The Central Bureau Information System was developed at the end of 1993, ready for the official start of the International GPS Service for Geodynamics (IGS) on January 1, 1994. During the same period the IGS Mail and IGS Report Services were transferred from the University of Berne to the Central Bureau.

The IGS Terms of Reference state that

> "The primary functions of the CB are to facilitate communications, coordinate IGS activities, establish and promote compliance to IGS network standards, monitor network operations and quality assurance of data, maintain documentation, . . ."

The Central Bureau designed the Information System to facilitate these tasks.

In addition, the contributors to IGS – tracking sites, the Operational Centers, the Data and Analysis Centers, as well IGS customers (researchers, geodesists, surveyors) – needed a source for up-to-date information about the availability of tracking data, IGS products, etc.

This Central Bureau Information System (CBIS) was to be easily accessible over the Internet (anonymous ftp) and the information mostly available in easy to handle ASCII data files. Alternate access methods were provided for as well, such as third-party e-mail servers and a World Wide Web home page.

Access

Currently the CBIS can be accessed as follows:

anonymous ftp

Internet address: `igscb.jpl.nasa.gov` (IP# 128.149.70.171)
directory: `/igscb`

The file /igscb/TREE.TXT (see Figure 1) outlines the directory structure of the Information System and gives an overview of the available files.

World Wide Web

CBIS Home Page: `http://igscb.jpl.nasa.gov/`

The home page gives a general introduction to the IGS and is directly linked

Figure 1. CBIS Directory Tree.

IGSCB.DIR			complete fi/e list
NEWS TXT			new features/changes
README TXT			CBIS general info
TREE TXT			directory structure info
center	README CEN		center info
	analysis	'center'.acn	Analysis Center descriptions
	data	'center'.dcn	Data Center descriptions
	oper	'center'.ocn	Operational Center descriptions
data	format	rinex2.txt	RINEX format specifications
		sp3 txt	SP3 orbit format specifications
	holding	'center'.syn	data center holdings
		'center'.s'yy'	data center holdings by year
		glob'mmyy'.syn	data availability by month
		glob'yyyy'.syn	data availability by year
	network	igs.net	IGS data network diagram
general	gps	constell.gps	NANU GPS constellation status
		euref.txt	EUREF Information System info
		nanu'yyyy'.mes	NANU messages by year
		nanu'yyyy'.sub	NANU subject index by year
		sources txt	catalog of GPS-related info sources
		status.zim	ZIMM current tracking status
	igs	g_board.igs	IGS Governing Board
		resource'nn'.ps	IGS Resource Information (Postscript)
		terms.igs	IGS Terms of Reference
	org	meetings.agu	AGU symposia/meetings
		meetings.iag	IAG symposia/meetings
mail	address	cddis.adr (.Z)	CDDIS SGP address catalog
		directory.txt	IGS Colleague Directory text
		dose.adr	DOSE Mail distribution list
		igsmail adr	IGS Mail distribution list
		igsreport.adr	IGS Report distribution list
		scign.adr	SCIGN Mail distribution list
	igsmail	IGSMESS INDEX	IGS Mail massaga index
		igsmess.'nnn'	IGS Mail messages
	igsreport	IGSREPORT INDEX	IGS Report index
		igsreport.'nnn'	IGS Reports
	regional	DOSE	DOSE Mail archive
		SCIGN	SCIGN Mail archive
product	'wwww'	igs'wwww'7.erp	IGS earth rotation parameters
		igs'wwww'[0-6].sp3	IGS combined daily orbits
		igs'wwww'7.sum	IGS weekly product summary
	holding	'center'.prd	analysis center product holdings
	iers	bulletinb.'nn'	IERS earth orientation
		eop90c04.'yy'	IERS earth rotation parameters
software	cbis	dos, unix, vms	CBIS browsing/ftp program
	compress	dos, vms	compression/decompression programs
	qc	aux, dos, unix, vms	quality check program for GPS data
station	coord	igsmap.ps	map of IGS tracking stations (PostScript)
		itrf'yy'.ssc	ITRF92 station coordinates
	general	BLNKFORM LOG	station log form (blank)
		antenna.gra	antenna diagrams
		rcvr_ant.tab	receiver/antenna table
	log	'site''mmyy'.log	station logs
	oldlog	'site''mmyy'.log	old station logs
	tie	localtie.chg	local tie changes/updates
		localtie.tab	local tie file
workshop.'mmyy'		various	IGS workshop information

to various directories on the CBIS. For more information the user can easily access the same files available through anonymous ftp.

E-Mail Servers

By sending an e-mail to the mail server bitftp@pucc.princeton.edu (or BITFTP@PUCC for BITNET users) containing the necessary ftp commands, it is possible to download files from a site without direct Internet access.

Example: Sending the following mail to the above-mentioned server will return an e-mail with the contents of the file TREE.TXT:

```
ftp igscb.jpl.nasa.gov
user anonymous
get /igscb/TREE.TXT
quit
```

Aone-line message with theword 'help' will return a detailed helpmessagefrom the e-mail server.

CBIS Contents

In the first year ofoperation the followingwereprovided:

Center Information

There are special information forms for IGS Data Centers (containing access information) and Analysis Centers (containing information about analysis procedures). A form for Operational Centers is currently under development.

Data Holdings

As each Data Center archives a subset of all the IGS tracking data, the CBIS maintains holding files for every Data Center showing for what days and sites data are actually available. Monthly and yearly summary files allow a quick overview.

General Information

Address files; distribution lists; GPS sources; GPS system information, daily compilation from the GPS Master Control Segment, "Notice Advisories to Navstar Users" (NANU); references to other organizations (AGU, IAG); data formats (RINEX); orbit file formats (SP3); Central Bureau resource sheets and network maps (PostScript); and data flow charts.

IGS Mail and IGS Reports

For reference use an archive of all IGS Mail and IGS Report messages is maintained on the CBIS. The Central Bureau also operates similar mail services for other related projects (DOSE, SCIGN). These messages can also be found in the same place.

Products

The CBIS provides in weekly subdirectories the combined IGS orbits and earth rotation parameter files. Product holding files (similar to the data holding files) are also maintained, showing where and what products are available. The CBIS also regularly downloads from the IERS the final IERS earth rotation parameter files and yearly ITRF solutions of tracking site positions and velocities.

Tracking Stations

For each permanent IGS tracking station is a corresponding station log form containing essential information about the station, such as receiver and antenna information, local ties, and contact persons. These files are maintained by either tracking station personnel or regional Operational Centers through standardized procedures. The logs also contain a complete history of the site from the start of the IGS test campaign (June 21, 1992) or since installation, through to the station's current operational status. There are also files detailing all of the GPS antenna types currently in use within the IGS network.

Software

A directory contains various DOS, UNIX, and VMS utilities for easy access to the CBIS, for data compression, and for performing quality checks of tracking data.

Access Statistics

The steady increase in CBIS activity is shown in Figures 2 and 3.

Figure 2. Logins to the CBIS by week since January, 1994.

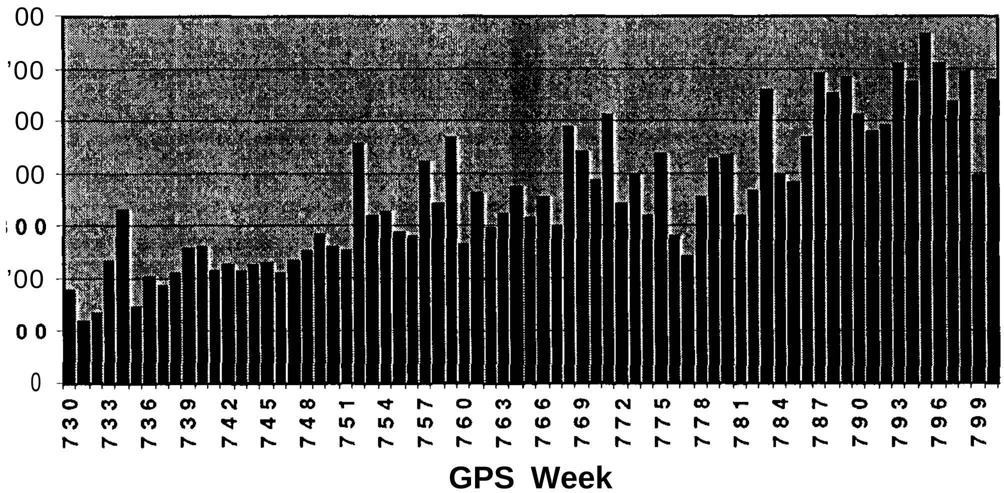
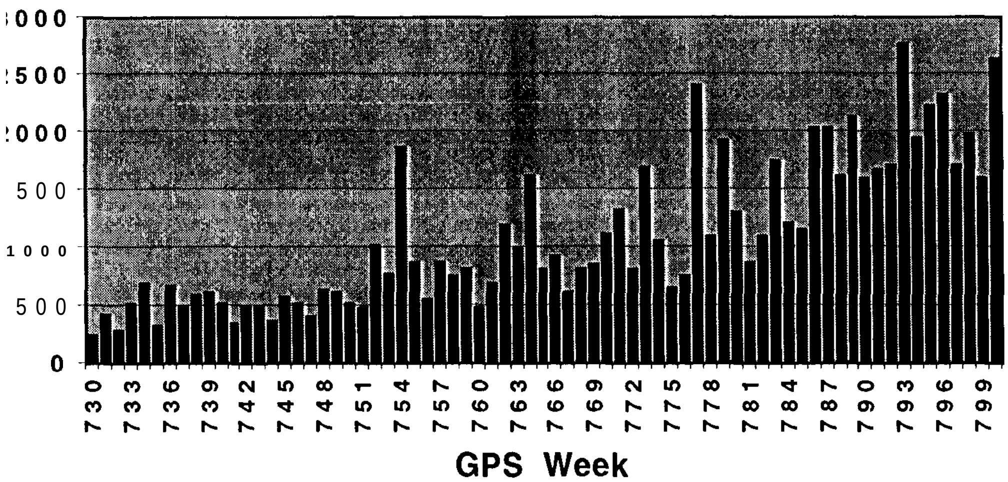


Figure 3. File retrievals from the CBIS by week since January, 1994.



IERS References, Contribution of the Central Bureau of IERS

Claude Boucher and Martine Feissel
Central Bureau of IERS
Paris, France

Following its Terms of Reference, IGS operates in close cooperation with the International Earth Rotation Service (IERS). The Central Bureau of the IERS is in charge of producing reference station coordinates/velocities on the basis of observations by space techniques and Earth Rotation Parameters. Conversely, IGS enhances the global accessibility and the quality of the ITRF, and it contributes to the determination of the Earth's rotation.

The International Terrestrial Reference Frame (ITRF)

Since the beginning of the IGS activities in 1992, the ITRF Section of the IERS Central Bureau (ITFS at Institut Geographique National) cooperates very closely with the different IGS participants (Central Bureau, Analysis Centers, Tracking Stations) for ITRF station coordinates/velocities, analyses of solutions provided by the different IGS analysis centers, as well as site information and local ties.

The ITFS Contribution to IGS activities

The main ITFS actions and contributions related to the IGS activities are the following:

- Providing the 1st version of ITRF/IGS station coordinates; SSC(IERS) 92 C 02 (epoch 1992.5), IGS mail # 33, July 1st, 1992. This set was computed by referring the ITRF91 station coordinates to epoch 1992.5 using its velocity field and adding the local ties between GPS and SLR/VLBI reference points.

- Providing the 2nd version of ITRF/IGS station coordinates; SSC(IERS) 92 C 03 (epoch 1992.5), IGS mail # 65, August 12, 1992.

- Providing the 3rd version of ITRF/IGS station coordinates; SSC(IERS) 92 C 04 (epoch 1992.5), IGS mail # 90, September 9, 1992.

- Providing the 4th version of ITRF/IGS station coordinates; SSC(IERS) 93 C 02 (epoch 1992.6). This version, together with an analysis of GPS solutions provided by the IGS analysis centers, was presented at the IGS Workshop in Berne, (Boucher and Altamimi, 1993). This set of station coordinates was computed in two steps. In the first step, a global combined GPS solution has been computed using 5 GPS solutions provided by 5 analysis centers: JPL, S10, CSR, CODE and EMR. In the second step, the global combined GPS solution has been combined with the ITRF91 at epoch 1992.6.

. Providing the 5th version of ITRF/IGS station coordinates; SSC(IERS) 93 C 03 (epoch 1993.06), IGS mail # 236, April 5, 1993. This set is extracted from the SSC(IERS) 93 C 02. It includes coordinates for 12 selected sites as decided at the IGS Workshop in Berne. It was mapped at 1993.06 epoch using the ITRF91 velocity field.

Table 1. ITRF92, SSC(IERS) 93 C 04 (epoch 1994.0). To be used** with **the IGS orbits in 1994

DOMES NUMBER	SITE NAME	FILE NAME	X / Sx (m)	Y / SY (m)	Z / Sz (m)	Vx / SVX (m/y)	VY / SVY (m/y)	Vz / SVZ (m/y)	
10302MOO3	TROMSO								
		TROM	2102940.408	721569.363	5958192.077	-0.017	0.013	0.005	
			0.006	0.006	0.006	.003	.003	.003	N
13407S012	MADRID								
		MADR	4849202.502	-360329.172	4114913.062	-0.007	0.020	0.015	
			0.006	0.005	0.006	.001	.001	.001	CN
13504MO03	KOOTWIJK								
		KOSG	3899225.303	396731.771	5015078.296	-0.014	0.017	0.007	
			0.007	0.006	0.006	.004	.003	.004	CN
14201M009	WETTZELL								
		WETT	4075578.644	931852.630	4801570.015	-0.017	0.016	0.009	
			0.005	0.005	0.006	.001	.001	.001	CN
30302MO02	HARTEBEESTHO								
		HART	5084625.437	2670366.570	-2768494.014	-0.003	0.019	0.015	
			0.011	0.010	0.008	.002	.002	.002	CN
401 O4MOO2	ALGONQUIN								
		ALGO	918129.578	-4346071.246	4561977.828	-0.015	-0.006	0.004	
			0.005	0.005	0.005	.001	.001	.001	CN
40127M003	YELLOWKNIFE								
		YELL	-1224452.415	-2689216.088	5633638.270	-0.022	-0.001	-0.005	
			0.006	0.006	0.006	.003	.003	.003	N
40405s031	GOLDSTONE_PEQ								
		GOLD	-2353614.103	-4641385.429	3676976.476	-0.014	0.004	-0.006	
			0.008	0.008	0.008	.001	.001	.001	CN
40408MOOI	FAIRBANKS								
		FAIR	-2281621.346	-1453595.783	5756961.940	-0.021	-0.004	-0.010	
			0.005	0.006	0.006	.001	.001	.001	CN
40424MO04	KOKEE_PARK								
		KOKB	-5543838.077	-2054587.442	2387809.612	-0.008	0.063	0.031	
			0.006	0.006	0.007	.001	.001	.001	CN
41705M003	SANTIAGO								
		SANT	1769693.238	-5044574.084	-3468321.125	0.001	-0.005	0.008	
			0.009	0.010	0.008	.003	.003	.003	N
501 O3M1O8	TIDBINBILLA								
		TIDB	-4460996.069	2682557.144	-3674443.875	-0.039	0.004	0.042	
			0.010	0.011	0.011	.002	.002	.002	CN
501 O7MOO4	YARRAGADEE								
		YAR1	-2389025.394	5043316.852	-3078530.861	-0.045	0.008	0.053	
			0.009	0.008	0.009	.002	.002	.002	CN

* N : NNR-NUVEL1 velocity
CN : ITRF92 velocity field (combined solution from SLR and VLBI estimates)

- Inclusion of six GPS/IGS solutions in the ITRF92 computation (Boucher *et* al., 1993).

- Providing ITRF92 coordinates/velocities for the 13 IGS fixed/constrained stations; SSC(IERS) 93 C 04; ITRF-P1 (epoch 1994.0), IGS mails # 421 and 430, December 22, 1993, and January 10, 1994. See Table 1.

Remark: The above 13 station coordinates refer to the GPS MONUMENTS with the exception of MADRID and GOLDSTONE.PEQ whose coordinates refer to the bottom of the antennas (ARP). The coordinates of TIDBINBILLA (named previously CANBERRA) were originally referred to the ARP. Here they are reduced to the GPS monument using the antenna height given in the file localtie.tab.

- ITRF-P2 combination at epoch 1993.0 of the six GPS/IGS solutions which was included in the ITRF92, in order to assess their quality and internal consistency. This analysis was presented at the IERS Workshop, March, 1994.

- Inclusion of five GPS/IGS solutions in the ITRF93 computation (Boucher *et al., 1994).*

- Providing ITRF93 coordinates/velocities for the 13 IGS fixed/constrained stations; SSC(IERS) 94 C 02; ITRF-P3 (epoch 1995.0), IGS mail # 819, December 26, 1994. As this set is the one currently used by the IGS Analysis Center, for the year 1995, it is reproduced herein Table 2.

Quality of the GPS/IGS station coordinate solutions

The quality of the GPS/IGS station coordinate solutions can be assessed with respect to the other IERS techniques such as VLBI and SLR (see IERS Technical Notes 15 and 18, Boucher *et al.*, 1993, 1994). After checking that the solutions of the different analysis centers are based on consistent references, the quality assessment can be performed by comparison and combination of the station coordinate sets. Several analysis have been performed in this way by the ITFS, through the ITRF computations containing some GPS/IGS station coordinate solutions as well as through specific GPS/IGS solution analyses (Boucher and Altamimi, 1993, Altamimi *et al., 1994).*

For the purpose of this Annual Report, we performed a specific analysis, called ITRF-P4, a weighted combination of GPS, SLR and VLBI Sets of Station Coordinates based on a seven- parameter transformation. The following corrections were introduced, as compared to the ITRF computation.

- Tidbinbilla local ties, see IGS mail # 819, and

- Correction of some antenna height errors in the CODE solution.

Taking into account these changes, the ITRF-P4 analysis provided the global residuals listed in Table 3.

Table 2. ITRF-P3: SSC(IERS) 94 C 02 (epoch 1995.0). To be used with the IGS orbits in 1995.

DOMES NUMBER	SITE NAME	FILE NAME	X 5X	Y SY	Z Sz	VX SVX	VY SVY	VZ SVZ
			.... m	....	....	.... m/y	....	....
10302MOO3	TROMSO							
		TROM	2102940.360	721569.398	5958192.092	-.0252	0.0162	0.0065
			0.004	0.004	0.004	.0043	.0033	.0090
13407S012	MADRID							
		MADR	4849202.459	-360329.148	4114913.089	-.0141	0.0222	0.0201
			0.003	0.003	0.002	.0006	.0004	.0006
13504M003	KOOTWIJK							
		KOSG	3899225.260	396731.803	5015078.324	-.0218	0.0212	0.0122
			0.005	0.005	0.003	.0017	.0016	*.0016*
14201M009	WETTZELL							
		WETT	4075578.593	931852.662	4801570.020	*-.0252*	0.0191	0.0123
			0.003	0.003	0.002	.0004	.0003	.0004
30302MO02	HARTEBEESTH							
		HART	5084625.431	2670366.543	-2768493.990	-.0054	0.0176	0.0216
			0.004	0,004	0.004	.0012	.0008	.0007
401 O4MOO2	ALGONQUIN							
		ALGO	918129.510	-4346071.228	4561977.846	-.0217	-.0021	0.0066
			0.003	0.003	0.003	.0004	.0005	.0005
40127M003	YELLOWKNIFE							
		YELL	-1224452.487	-2689216.070	5633638.283	-.0289	0.0006	-.0025
			0.003	0.003	0.004	.0036	.0050	.0087
40405s031	GOLDSTONE							
		GOLD	-2353614.169	-4641385.389	3676976.474	-.0191	0.0061	-.0047
			0.004	0.005	0.005	.0003	.0003	.0003
40408M001	FAIRBANKS							
		FAIR	-2281621.422	-1453595.760	5756961.945	-.0285	-.0019	-.0101
			0.003	0.003	0.003	.0003	.0004	.0004
40424MO04	KOKEE_PARK							
		KOKB	-5543838.126	-2054587.365	2387809.642	-.0129	0.0614	0.0292
			0.003	0.003	0.003	.0005	.0004	.0005
41705MO03	SANTIAGO							
		SANT	1769693.278	-5044574.137	-3468321.048	***0.0228***	-.0063	0.0256
			0.004	0.004	0.004	.0021	.0017	.0023
501 O3M1O8	TIDBINBILLA							
		TIDB	-4460996.070	2682557.105	-3674443.836	-.0354	-.0017	0.0412
			0.004	0.004	0.004	.0008	.0006	.0007
501 07MO04	YARRAGADEE							
		YAR1	-2389025.427	5043316.850	-3078530.871	-.0459	0.0090	0.0403
			0.005	0.005	0.004		.0013	.0010

Technique	Solution	N	WSP cm	WSU cm
	SSC(GIUB 94 R 01	7	0.6	0.8
VLBI	SSC(GSFC) 94R01	109	0.4	0.7
	SSC(NOAA) 94 R 01	106	0.4	0.9
	SSC(CODE) 94P 01	38	0.7	1.3
	SSC(EMR) 94P 02	16	0.7	1.8
GPS	SSC(ESOC) 94P 01	23	1.0	1.8
	SSC(GFZ) 94P 01	30	0.8	1.6
	SSC(JPL) 94 P 01	41	0.5	0.9
SLR	SSC(CSR) 94 L 01	83	1.9	2.4
SLR + GPS	SSC(DUT) 94 C 0 1	58	1.2	2.4

N : Number of stations common with other solutions
WSP : Weighted 2-D RMS post-fit residual
WSU : Weighted vertical RMS post-fit residual

Table 3. ITRF-P4: Global RMS residual coordinates at epoch 1993.0.

Quality of the GPS Earth Orientation Parameters

Polar Motion

Seven analysis centers derived daily solution of the coordinates of the pole (COD, EMR, ESOC, GFZ, JPL, NOAA, and S10). A series referred to a given Set of Station Coordinates (SSC) and computed in a consistent manner is considered homogeneous and labeled according to the usual IERS rules (see 1994 IERS Annual Report, p. V-3). The successive SSC used by the analysis centers were either those proposed by the IERS (see previous section) or those produced by the analysis centers and tied to an ITRF (91, 92, 93). The GPS polar motion series are therefore expected to match the IERS EOP series, after the appropriate internal corrections are applied (see IERS Annual Report, 1991: Table II-3, p. II-13; 1992: Table II-3, p. 11-17; 1993: Table II-3, p. 11-19). The level of agreements of the GPS polar motion with the IERS System is illustrated in Table 4, which gives for the ten quarters from Jul-Sept 1992 through Ott-Dec 1994 the weighted mean biases with respect to the IERS EOP series consistent with the SSC used in GPS analysis. Most quarterly biases are smaller than 0.5 mas (in absolute value), i.e. they are insignificant with respect to the level of internal accuracy of the IERS results over this period. However, some significant biases seem to exist between GPS polar motion series referred to the same SSC.

Table 4 also gives the weighted rms residual to the daily series IERS C 04 (see 1994 IERS Annual Report, p. 11-20). Over the period covered by Table 4, IERS C 04 is based largely on VLBI and SLR data. The decrease of the residuals with time truly illustrates the progressive convergence of GPS solutions towards the VLBI and SLR ones.

Analyses similar to those of Table 4 were provided during and at the end of the 1992 Campaign (Feissel *et al.*, ***1993).*** They are also provided monthly in the IERS Bulletin B, section 6.

Table 4. Agreement of the GPS pole coordinates with the IERS System (dX, dY) and standard deviation (sdev) from EOP(IERS) C 04 over the quarters Jul-Sep 1992 (Qt=1) through Ott-Dec 1994 (Qt=10).

Analysis Center: CODE — Unit: 0.001”

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
1	94 P 02	-0.67	0.07	0.68	-0.11	0.08	0.76	SSC(IERS) 92 C 04
2	94 P 02	-0.15	0.09	0.84	0.18	0.07	0.66	SSC(IERS) 92 C 04
3	94 P 02	0.30	0.08	0.74	0.44	0.09	0.87	SSC(IERS) 92 C 04
4	94P 02	0.38	0.05	0.43	1.08	0.04	0.42	SSC(IERS) 92 C 04
5	94 P 02	0.08	0.04	0.34	0.95	0.04	0.35	SSC(IERS) 92 C 04
6	94 P 02	-0.03	0.05	0.43	0.12	0.04	0.33	SSC(IERS) 92 C 04
5	94P 01	-0.35	0.04	0.30	-0.12	0.04	0.32	SSC(IERS) 93 C 03
6	94 P 01	-0.34	0.04	0.38	-0.44	0.03	0.25	SSC(IERS) 93 C 03
7	94 P 01	-0.19	0.04	0.38	-0.70	0.03	0.28	SSC(IERS) 93 C 03
8	94P 01	-0.24	0.03	0.30	-0.50	0.05	0.44	SSC(IERS) 93 C 03
9	94 P 01	-0.18	0.03	0.28	-0.31	0.03	0.25	SSC(IERS) 93 C 03
10	94 P 01	-0.13	0.03	0.29	-0.51	0.03	0.33	SSC(IERS) 93 C 03

Analysis Center: EMR — Unit: 0.001”

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
2	92 P 04	0.36	0.06	0.51	-0.22	0.07	0.53	SSC(IERS) 92 C 04
3	92 P 04	1.00	0.06	0.56	-0.32	0.05	0.46	SSC(IERS) 92 C 04
4	92 P 04	0.75	0.05	0.52	-0.22	0.05	0.43	SSC(IERS) 92 C 04
5	92 P 04	0.82	0.04	0.40	0.07	0.05	0.52	SSC(IERS) 92 C 04
6	92 P 04	0.67	0.05	0.52	-0.17	0.05	0.45	SSC(IERS) 92 C 04
7	94 P 01	0.03	0.05	0.48	-0.62	0.05	0.42	SSC(IERS) 93 C 03
8	94 P 01	-0.01	0.04	0.39	-0.73	0.05	0.51	SSC(IERS) 93 C 03
9	94P 01	0.09	0.04	0.34	-0.12	0.03	0.31	SSC(IERS) 93 C 03
10	94 P 01	0.03	0.03	0.33	-0.18	0.03	0.31	SSC(IERS) 93 C 03

Analysis Center: ESOC — Unit: 0.001”

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
1	92 P 02	1.04	0.14	1.33	0.18	0.16	1.51	SSC(IERS) 92 C 04
2	92 P 02	0.29	0.12	1.14	1.05	0.09	0.90	SSC(IERS) 92 C 04
2	92 P 02	0.29	0.12	1.14	1.05	0.09	0.90	SSC(IERS) 92 C 04
3	92 P 02	0.09	0.11	1.04	1.08	0.15	1.46	SSC(IERS) 92 C 04
4	92 P 02	-0.02	0.09	0.85	0.39	0.07	0.70	SSC(IERS) 92 C 04
5	92 P 02	0.22	0.05	0.45	0.03	0.06	0.62	SSC(IERS) 92 C 04
6	92 P 02	0.47	0.05	0.43	0.16	0.04	0.40	SSC(IERS) 92 C 04
7	94 P 01	-0.20	0.05	0.47	-0.25	0.04	0.35	SSC(IERS) 93 C 03
8	94’ P 01	-0.04	0.04	0.38	-0.20	0.05	0.46	SSC(IERS) 93 C 03
9	94 P 01	-0.12	0.04	0.43	0.18	0.04	0.38	SSC(IERS) 93 C 03
10	94P 01	-0.19	0.04	0.38	-0.04	0.04	0.42	SSC(IERS) 93 C 03

Table 4. (cont.)

Analysis Center: GFZ Unit: 0.001"

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
1	93 P 03	1.85	0.08	0.80	0.71	0.09	0.86	SSC(GFZ) 93P 03
2	93 P 03	2.17	0.14	0.76	-1.40	0,17	0.89	SSC(GFZ) 93P 03
3	94P 02	0.34	0.04	0.38	-0.49	0.04	0.34	SSC(GFZ) 94P 01
4	94 P 02	0.04	0.04	0.34	-0.71	0.03	0.29	SSC(GFZ) 94P 01
5	94 P 02	0.11	0.02	0.23	-0.44	0.03	0.27	SSC(GFZ) 94P 01
6	94 P 02	0.07	0.04	0.35	-0.64	0.03	0.24	SSC(GFZ) 94 P 01
4	94 P 03	0.08	0.06	0.32	-0.81	0,09	0.44	SSC(GFZ) 94 P 01
5	94 P 03	0.09	0.03	0.35	-0.48	0.03	0.39	SSC(GFZ) 94 P 01
6	94 P 03	0.05	0.03	0.41	-0.65	0.02	0.31	SSC(GFZ) 94 P 01
3	94 P 01	0.40	0.04	0.37	-0.05	0,04	0.33	SSC(IERS) 93 C 03
4	94P 01	0.12	0.04	0.34	-0.29	0.03	0.29	SSC(IERS) 93 C 03
5	94 P 01	0.22	0.02	0.23	-0.03	0.03	0.28	SSC(IERS) 93 C 03
6	94 P 01	0.21	0.04	0.34	-0.23	0.03	0.24	SSC(IERS) 93 C 03
7	94 P 01	0.26	0.04	0.38	-0.32	0.03	0.28	SSC(IERS) 93 C 03
8	94 P 01	0.35	0.04	0.35	-0.42	0.03	0.30	SSC(IERS) 93 C 03
9	94 P 01	0.30	0.03	0.29	-0.25	0.03	0.26	SSC(IERS) 93 C 03
10	94 P 01	0.22	0.03	0.28	-0.61	0.03	0.24	SSC(IERS) 93 C 03

Analysis Center: JPL Unit: 0.001"

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
1	92 P 02	-0.04	0.04	0.32	0.01	0.05	0.47	SSC(JPL) 92 P 02
2	92 P 02	-0.24	0.06	0.50	-0.08	0.05	0.44	SSC(JPL) 92P 02
3	92 P 02	-0.23	0.13	0.69	-0.09	0.07	0.37	SSC(JPL) 92 P 02
3	92 P 03	-0.17	0.06	0.57	-0.03	0.04	0.35	SSC(IERS) 92 C 04
4	92 P 03	0.17	0.06	0.62	-0.04	0.08	0.72	SSC(IERS) 92 C 04
5	92 P 03	0.01	0.04	0.37	0.13	0.04	0.36	SSC(IERS) 92 C 04
6	92 P 03	0.04	0.05	0.47	0.10	0.04	0.34	SSC(IERS) 92 C 04
7	94 P 01	-0.03	0.04	0.38	-0.42	0.04	0.38	SSC(IERS) 93 C 03
8	94 P 01	-0.19	0.04	0.35	-0.21	0.04	0.42	SSC(IERS) 93 C 03
9	94 P 01	-0.30	0,03	0.29	-0.22	0.03	0.30	SSC(IERS) 93 C 03
10	94 P 01	-0.33	0.03	0.28	-0.40	0.03	0.25	SSC(IERS) 93 C 03

Table 4. (cent,)

Analysis Center: NOAA Unit: 0.001"

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
3	94 P 02	1.33	0.10	0.88	1.02	0.09	0.78	
4	94 P 02	1.12	0.14	0.74	1.25	0.14	0.75	
4	94 P 03	1.26	0.11	0.87	-0.46	0.13	1.03	
5	94 P 03	0.54	0.11	1.04	-0.59	0.09	0.91	
6	94 P 03	-0.45	0.11	0.84	-0.07	0.10	0.76	
6	94 P 04	-0.28	0.07	0.40	-1.21	0.13	0.70	SSC(IERS) 93 C 03
7	94 P 01	-0.38	0.08	0.75	-0.67	0.09	0.87	SSC(IERS) 93 C 03
8	94 P 01	-0.23	0.08	0.76	-0.74	0.10	0.98	SSC(IERS) 93 C 03
9	94 P 01	0.35	0.06	0.56	-0.91	0.06	0.54	SSC(IERS) 93 C 03
10	94 P 01	0.80	0.05	0.45	-1.06	0.05	0.44	SSC(IERS) 93 C 03

Analysis Center: SIO Unit: 0.001"

Qt	series	dX	±	sdev	dY	±	sdev	Terr. reference
1	93 P 01	0.77	0.05	0.48	0.74	0.04	0.42	SSC(SIO) 93 P 01
2	93 P 01	1.19	0.06	0.47	1.05	0.08	0.63	SSC(SIO) 93 P 01
3	93P 01	0.94	0.05	0.45	-0.25	0.07	0.63	SSC(SIO) 93 P 01
4	93 P 01	1.27	0.05	0.43	-0.53	0.06	0.53	SSC(SIO) 93 P 01
5	93P 01	1.42	0.05	0.50	0.17	0.07	0.64	SSC(SIO) 93P 01
6	93P 01	1.41	0.05	0.44	-0.53	0.07	0.65	SSC(SIO) 93 P 01
7	94 P 01	0.46	0.05	0.45	0.41	0.04	0.41	SSC(IERS) 93 C 03
8	94P 01	0.52	0.08	0.73	-0.24	0.07	0.64	SSC(IERS) 93 C 03
9	94 P 01	0.40	0.04	0.37	-0.50	0.07	0.68	SSC(IERS) 93 C 03
10	94 P 01	0.76	0.04	0.37	-0.32	0.05	0.44	SSC(IERS) 93 C 03

The possibility of small systematic annual errors in the GPS polar motion series cannot be ruled out. Table 5 shows the sine and cosine components of the annual differences of the GPS series of polar motion over 1994 with a NOAA VLBI and a CSR SLR solution, described respectively in the IERS Technical Notes 17 and 19 (Chariot 1994, 1995). The uncertainty of the listed components is in general smaller than 0.08 mas.

Universal time and length of day

It is well known that due to imperfect modeling of the motion of the node of satellite orbits, the GPS analysis cannot derive a series of universal time (UT1) that is stable in the long term. Two centers (CODE, EMR) estimate daily a drifting UT after a unique initial tie to some reference. Using the filtering/ calibration technique described by Gambis *et al.* (1993), one can extract the high frequency content, i.e., for periods under 60 days, and estimate its statistical agreement with the IERS C 04 series, based mainly on VLBI, with a high frequency contribution of SLR. The results per quarter from July 1992 through December 1994 are shown in Table 6. The level of high frequency noise, about

Table 5. Annual differences of GPS polar motion with VLBI and SLR over 1994, modeled as a sin ($t-t_o$) + b cos (t-to), tin years, t_o = 1994.0,

Unit: 0.001"

	series	X sin	X Cos	Y sin	Y cos	Reference
CSR	94 L 01	0.14	0.08	0.00	0.24	NOAA 95 R 01
CODE	94 P 01	0.01	0.19	-0.34	0.02	NOAA 95 R 01
		-0.14	0.06	-0.34	-0.20	CSR 94 L 01
EMR	94 P 01	**-0.08**	**0.15**	**-0.56**	**0.14**	NOAA 95 R 01
		-0.23	0.01	-0.55	-0.11	CSR 94 L 01
ESOC	94 P 01	0.04	0.10	-0.38	0.03	NOAA 95 R 01
		-0.12	-0.01	-0.36	-0.21	CSR 94 L 01
G FZ	94 P 01	0.06	0.06	-0.10	0.10	NOAA 95 R 01
		-0.09	-0.07	-0.08	-0.17	CSR 94 L 01
JPL	94 P 01	0.12	0.16	-0.17	0.00	NOAA 95 R 01
		-0.01	0.05	-0.15	-0.26	CSR 94 L 01
NOAA	94 P 01	**-0.48**	0.01	0.19	0.01	NOAA 95 R 01
		-0.60	-0.02	0.24	-0.23	CSR 94 L 01
SIo	94 P 01	-0.17	0.15	0.12	0.56	NOAA 95 R 01
		-0.28	0.06	0.15	0.25	CSR 94 L 01

Table 6. High frequency differences of GPS universal time with IERS C 04 over the quarters Jul–Sep 1992 (QT=1) through Ott-Dec 1994 (QT=10). The standard deviations are for periods under 60 days. Accumulated lower frequency discrepancies can reach 4-5ms after one year.

Analysis centers: CODE, EMR. Unit: 0.001s

Qt	CODE	sdev	CODE	sdev	EMR	sdev
1	94 P 02	0.059				
2	94 P 02	0.052				
3	94 P 02	0.058				
4	94 P 02	0.048				
5	94 P 02	0.044	95 P 01	0.053		
6	94 P 02	0.049	95 P 01	0.039		
7			95 P 01	0.040	94 P 01	0.046
8			95 P 01	0.036	94 P 01	0.038
9			95 P 01	0.032	94 P 01	0.043
10			95 P 01	0.042	94 P 01	0.041

Table 7. Annual differences of GPS length of day with IERS over 1994 (same modeling as in Table 5).

Unit: 0.0001s

Series	a	b	Reference
ESOC 94 P 01	-0.15	0.05	IERS C 04
GFZ 94 P 01	-0.50	0.07	IERS C 04
JPL 94 P 01	-0.34	0.38	IERS C 04

40µs, suggests that GPS may play a role, alfter being calibrated by comparison with VLBI, in operational estimates of UT1.

Three other centers (ESOC, GFZ, JPL) provide results under the form of length of day, the time derivative of UT1, less sensitive to low frequency errors. These series can be searched for annual periodic differences with the IERS solution, as exemplified in Table 7. Considering the level of uncertainty of the estimation of the sine and cosine components (less than 0.008 ins), some significant annual systematic errors seem to be present.

References

Altamimi Z., C. Boucher, L. Duhem, 1994: Activity report of the ITRF Section of the IERS Central Bureau: ITRF92 and ITRF-P solutions, IERS Workshop, 21-22 Marsh 1994, Paris.

Boucher C, Z. Altamimi, 1993: Contribution of IGS 92 to the Terrestrial Reference Frame, IGS Workshop, 24-27 Marsh 1993, Berne, Switzerland.

Boucher, C. , Z. Atamimi, L. Duhem, 1993: ITRF92 and its associated velocity field, IERS Technical Note 15, Observatoire de Paris.

Boucher, C. , Z. Atamimi, L. Duhem, 1994: Results and Analysis of the ITRF93, IERS Technical Note 18, Observatoire de Paris.

Charlot, P. (cd.), 1994: Earth orientation, reference frames and atmospheric excitation functions submitted for the 1993 IERS Annual Report, IERS Technical Note 17, Observatoire de Paris.

Charlot, P. (cd.), 1995: Earth orientation, reference frames and atmospheric excitation functions submitted for the 1994 IERS Annual Report, IERS Technical Note 19, Observatoire de Paris.

Feissel, M. and Essaïfi, N. (eds), 1992:1991 IERS Annual Report, Observatoire de Paris.

Feissel, M. and Essaïfi, N. (eds), 1993:1992 IERS Annual Report, Observatoire de Paris.

Feissel, M. and Essaïfi, N. (eds), 1994:1993 IERS Annual Report, Observatoire de Paris.

Feissel, M., 1993: IGS'92, Comparisons of GPS, SLR and VLBI Earth orientation determinations. Final Report, Proc. 1993 IGS Workshop, Univ. Berne, p. 194.

Gambis, D., Essaïfi, N., Eisop, E., Feissel, M., 1993: Universal time derived from VLBI, SLR and GPS, Proc. 1993 IGS Workshop, Univ. Berne, p. 212.

The following persons have participated in the GPS terrestrial reference frame and Earth orientation analyses:

At IGN: C. Boucher, Z. Altamimi
At Paris Observatory: M. Feissel, E. Eisop, N. Essaïfi, D. Gambis.

Analysis Coordinator Report

Jan Kouba
Geodetic Survey Division, Geomatics Canada, Natural Resources Canada
Ottawa, Canada

Abstract

Coordination and cooperation amongst the IGS Analysis Centers (AC) are essential for reliable, precise and timely generation of IGS products. With significant assistance and cooperation of all AC's during 1994, IGS product formats, analysis and reporting have been standardized. In particular orbit and Earth Orientation Parameters (EOP) are now reported in the same formats by all AC'S. The individual AC orbit/station/EOP solutions and IGS orbit products are aligned to the current ITRF by constraining the same 13 fiducial stations at ITRF coordinates/velocities provided for this purpose by the Terrestrial Section of the International Earth Rotation Service (IERS). ITRF92 (of the date) was used during 1994 and ITRF93 is used in 1995. Every week, since Jan. 2, 1994, all the individual AC orbit/clock solutions have been evaluated and combined into official IGS orbit/clock solutions utilizing IERS EOP solutions (Bulletins A, B). The IGS weekly combinations/evaluations are summarized in IGS weekly summary reports and clearly demonstrate steady improvements in both precision and reliability for all AC's.

Introduction

In the interest of increasing precision, reliability and efficiency it is important that IGS encourage innovation, processing flexibility and redundancy, since typical global GPS data analyses are complex and demanding. However, some coordination, cooperation and standardization are required to minimize and explain differences, and to aid IGS users. Furthermore, solution evaluation and timely feedback to all AC'S are essential for increased precision and reliability. The IGS Analysis Coordinator, as stipulated in the IGS terms of references, performs all the above responsibilities. In addition to these functions, the Analysis Coordinator has to combine individual AC orbit/clock solutions into single IGS products. This is logical, as any combination requires product evaluations, feedback and coordination amongst all AC's, but it also imposes operational commitments which are clearly beyond a single person capability and thus requires an organizational support and effort similar to that of another AC. Since June, 1992 and during the 1993 IGS Pilot Project, Prof. C. Goad of Ohio State University coordinated AC'S. A common set of models and constants, largely consistent with the current IERS Analysis Standards (McCarthy, 1992), was adopted by all AC's. No combined orbits were produced during this period, but with the help of CODE AC, orbit comparisons were routinely done and distributed electronically within IGS (Goad, 1993). These simple orbit comparisons proved to be a very valuable feedback and were appreciated by all AC'S.

In October 1993, the author was asked by the IGS Governing Board (GB), and with the support of his organization, the Geodetic Survey Division (GSD), NRCan (formerly EMR), accepted the role of the IGS Analysis Coordinator. Until May 1994 François Lahaye, and since then Yves Mireault, both of GSD, have provided the necessary support and assistance and both have been largely responsible for timely and reliable production of IGS orbit/clock combinations. They have also developed automated procedures to generate the combinations and implemented many enhancements. The 1994 IGS orbit/clock combination and evaluation report, included in Appendix I, provides additional information on the methodology, the results and their performance during 1994.

1994 IGS Operational Analyses

The 1993 IGS Analysis Center workshop held in Ottawa, October 12-16, (Kouba (cd,), 1993), provided an important and unique opportunity for discussions amongst all the IGS AC's. The workshop participants representing all the IGS Data Centers (DC) and AC's agreed on further standardization of activities before the official start of IGS on January 1, 1994. It also identified and addressed two additional issues, namely the orbit/clock combination and a need for ITRF densification. The specific actions, schedules and the subsequent implementation dates as agreed to by all AC's and DC's at the workshop are listed in Table 1. Suitable methods for orbit evaluation and combination were discussed and recommended: for the IGS orbit combination it was the weighted average approach, first proposed by Springer and Beutler (1993) and further enhanced in Beutler *et* al. (1995). The dynamic long arc approach developed by Beutler *et al. (1994)* was adopted for orbit evaluation.

Table 1. Actions and recommends tions resulting from the 1993 AC Workshop.

Actions/Recommendations	Approximate date implemented
SP3 Orbit/clock Format (15min)	on or before Jan. 1, 1994
Two week submission deadline	Jan. 2, 1994 (GPS Week 0730)
13 station ITRF92 constraint	Jan. 2, 1994 (GPS Week 0730)
IGS Rapid/Final Orb. Combination	Jan. 2, 1994 (GPS Week 0730)
SP3 orbit accuracy codes	Feb., 1994 (GPS Week 0736)
Unconstr. solution capability	March, 1994 (all but one AC)
IGS EOP Format	Jul. 3, 1994 (GPS Week 0756)
Electronic AC questionnaire	Aug. 1, 1994 (all but two AC's)

The need for a new and more flexible orbit/clock format was recognized to allow for different sampling of clocks and orbits while accommodating orbit precision changes (e.g. during orbit repositioning), and possibly also station clocks, all in a simple and efficient manner. However, the internationally accepted SP3 format (Remondi, 1989) at 15 min intervals with header orbit accuracy codes was adopted for 1994. Perhaps the most lively discussions of the workshop dealt with solution submission deadlines, which should be as short as possible without compromising solution precision and reliability. As a compromise, a two week submission deadline was accepted. For orbit and EOP combination/evaluation, it is essential that all AC's use a consistent realization of the terrestrial reference frame (ITRF). Table 2 lists the ITRF92 coordinates/ velocities for the chosen 13 VLBI/SLR collocated stations used by all AC's. This ITRF92 coordinate set was provided by the IERS Terrestrial Section and adopted by all AC's for 1994 processing starting on January 2, 1994. The given ITRF92 coordinate set, including the antenna offsets for the 13 stations as cataloged by the IGS Central Bureau (CB) (file: LOCALTIE.TAB), represent the ITRF realization used for all IGS products/solution during 1994.

DOMES NUMBER	IGS NAME	x mm	Y mm	z mm	Vx mm/y	VY mm/y	VZ mm/y	*
10302MO03	TROM	2102940408	721569363	5958192077	-17	13	5	N
13407S01 2	MADR	4849202502	-360329172	4114913062	-7	20	15	CN
13504MO03	KOSG	3899225303	396731771	5015078296	-14	17	7	CN
14201 MO09	WETT	4075578644	931852630	4801570015	-17	16	9	CN
30302MO02	HART	5084625437	2670366570	-2768494014	-3	19	15	CN
401 04MO02	ALGO	918129578	-4346071246	4561977828	-15	-6	4	CN
40127M003	YELL	-1224452415	-2689216088	5633638270	-22	-1	-5	N
40405s031	GOLD	-2353614103	-4641385429	3676976476	-14	4	-6	CN
40408M001	FAIR	-2281621346	-1453595783	5756961940	-21	-4	-10	CN
40424MO04	KOKB	-5543838077	-2054587442	2387809612	-8	63	31	CN
41705MO03	SANT	1769693238	-5044574084	-3468321125	1	-5	8	N
501 03M108	TIDB	-4460996069	2682557144	-3674443875	-39	4	42	CN
501 O7MOO4	YAR1	-2389025394	5043316852	-3078530861	-45	8	53	CN

* N : NNR-NUVEL1 velocity
CN : ITRF92 velocity field (combined solution from SLR and VLBI)

Table 2.13 station ITRF92 coordinate/ velocity set used for IGS ITRF realization in 1994, (SSC(IERS)93C04, epoch 1994.0, IGSMAIL#430, sigmas: 5-11 mm for X, Y,Z and 1-4 mm/y for Vx, VY, VZ).

All AC's were required to fix or strongly constrain the above ITRF92 station coordinate and velocity set in their daily solutions. Some AC's chose to constrain more stations to improve their ITRF stability. The third initiative originating at the 1993 Ottawa workshop was the ITRF densification, an important and demanding issue. A combination of unconstrained solutions (addition of reduced normals) was identified as the most promising approach to this difficult and necessary task (Blewitt *et al.*, 1993). This required that all AC's develop the capability to provide their solutions with loose or no constraints. By March 94, most AC's were producing or ready to provide unconstrained complete solutions, including the corresponding reduced normal matrices. A new EOP format, initiated by Zumberge and Goad (1993), was required to satisfy specifics of IGS EOP determination (e.g. daily and sub-daily sampling and EOP rates) as well as to minimize EOP discontinuities in IGS orbit combination. The format discussion continued by e-mail and the new EOP format (Table 3) was adopted for all AC'S EOP solutions by July 3,1994.

It is interesting to note the differences amongst AC's in the daily EOP reports. Table 4 summarizes the EOP values and types for each AC. As one can see most AC's take a full advantage of all the new features of the IGS EOP format which may have significant impacts on the IGS orbit combinations (Appendix I).

Another useful initiative undertaken in 1994 was the analysis questionnaire which was completed and submitted to the IGS CB by most AC's by August 1994. The questionnaire revealed a wealth of detailed information, presented in a standard tabular form. It helped to understand and explain some small differences and it also provided new information for interested users, students, and the AC's themselves. Table 5, which is based on responses in the questionnaire and the December 1994 weekly AC submissions, highlights the

Table 3. IGS earth orientation parameter (EOP) format (adopted by July 3, 1994).

field	contents/HEADER	comment
Mandatory (i.e., all fields 1-10 must be coded, should follow the order below and must be separated by at least one blank, for more details see IGSMAIL # 662):		
1	MJD	modified Julian day, with 0.01 -day precision
2	Xpole	1 O'*-5 arcsec, 0.00001 -arcsec precision
3	Ypole	1O**-5 arcsec, 0.00001 -arcsec precision
4	UT1 -UTC, UT1 R-UTC	
	UT1 -TAI, UT1 R-TAI	10 "-6 see, 0.000001 -see precision (msec)
5	LOD, LODR	10'*-6 see, 0.001 -ms precision (µs)
6	Xsig	10 "-5 arcsec, 0.00001 -arcsec precision
7	Ysig	1 O'*-5 arcsec, 0.00001 -arcsec precision
8	UTsig	10"-6 see, 0.000001 -see precision (msec)
9	LODsig	10 "-6 see, 0.001 -ms " (µs)
10	Nr	number of receivers in the solution (integer)
11	Nf	number of receivers with "fixed" coordinates
12	Nt	number of satellites (transmitters) in the solution
optional (field 13->, only some may be coded, the order is also optional, sigma=O or omitted means fixed(apriori) value):		
13	Xrt	10"-5 arcsec/day 0.01 -mas/day precision
14	Yrt	10"-5 arcsec/day 0.01 -mas/day precision
15	Xrtsig	10"-5 arcsec/day 0.01 -mas/day "
16	Yrtsig	10"-5 arcsec/day 0.01 -mas/day "
17	XYCorr	X-Y Correlation 0.01 precision
18	XUTCor	X-UT1 Correlation 0.01 "
19	YUTCor	Y-UT1 Correlation 0.01 ".

Table 4. EOP reporting by IGS Analysis Centers (December 1994).

AC	X	Y	Xrt	Yrt	UT	LOD	Remarks
COD	EST	EST	EST	EST	EST	EST	EST - estimated (sigma > O)
EMR	EST	EST	APR	APR	EST	EST	APR - fixed/apriori (sigma=0,
ESA	EST	EST	O	0	APR	EST	or not given)
GFZ	EST	EST	O	0	APR	EST	O - parameter not given
JPL	EST	EST	EST	EST	EST	EST	
NGS	EST	EST	O	0	APR	O	
SIo	EST	EST	EST	EST	APR	EST	

most significant features of individual AC processing. Note that the station HART was down for most of December 1994, so that data from 12 out of the 13 ITRF selected stations were available and that some AC's exercised the option of constraining more stations. Specifically four AC's were constraining only the required minimum of 13 stations, while three AC's were constraining more stations than the required minimum of the 13 stations.

The number of used and fixed stations along with the computed orbit arc length are, in addition to data editing and validation, the most important factors affecting global solution precision. The differences between two orbits computed using either one or two radiation pressure (Rp) scale parameters (in addition to

AC	Stations used total	fixed	Orbit hours	Observation int.	type	#of press.	Rad. param.	Gravity model
COD	47	12	72	3min	DDF		2	GEMT3(8,8)
EMU	22	12	24	7.5	UDF		3	GEMT3(8,8)
ESA	23	12	48	6	DDF		2	GEMT3(8,8)
GFZ	38	18	32	6	UDF		2	JGM2(8,8)
JPL	32	12	30	5	UDF		2.5	JGM3(12,12)
NGS	33	23	31	0,5	DDF		2	GEMT3(8,8)
SIO	32	16	24	2	DDF		3	GEMT3(8,8)

Table 5. Selected characteristics of individual AC processing (December 1994; DDF-double difference, UDF-undifferenced; station HART was down for most of December 1994).

the Gy bias) are also significant, and cause about 10-cm orbit RMS differences (Lahaye *et al.*, 1993). The non integer value for JPL Rp scale number reflects a stochastic process involving two scales (Gx, Gz) but starting from the same *a priori* value. For information gravity models are also listed in Table 5. No significant differences in orbit precision, EOP and coordinate offsets can be seen in orbit combinations for GFZ (Appendix I) which uses JGM2 gravity model rather than GEMT3 used by most AC's. This was also independently confirmed by Klokocnik and Kostelecky (1995) who estimated maximum GPS orbit differences between GEMT2 and JGM2 were well below 1 cm based on Klokocnik and Kostelecky (1987).

1994 IGS Orbit/Clock Combination

In November 1993, to initiate an IGS orbit combination/evaluation, Dr. T. Springer of Delft Technical University provided his version of the weighted average software (Springer and Beutler, 1993) and an associated UNIX script. Subsequently, François Lahaye did the implementation on a GSD HP UNIX workstation, and a number of enhancements and improvements to allow automated, robust and flexible processing. He also added weighted clock averaging. At the same time a UNIX version of the long arc evaluation software developed by Beutler *et al.*, (1994) was provided by CODE. Dr. Elmar Brockmann visited GSD for one week and together with Yves Mireault of GSD installed the software. Subsequently Yves Mireault automated the script and made the necessary enhancements for the IGS combination/evaluation. Additional enhancements and improvements were tested and implemented during 1994. Table 6 lists the 1994 enhancements/changes in a chronological order.

Although many orbit combination/evaluation issues were settled during the Ottawa workshop, such as producing "Rapid" and "Final" orbits based on the IERS Bull. A and B, respectively, there were still many details to be considered for the IGS orbit/clock production. Most issues such as the IGS summary format were discussed and agreed on (by e-mail) by all AC's and some Data Centers (DC's). Others, such as the naming conventions for Rapid and Final IGS products, had to be adopted despite some opposition. This problem was caused by requirements to have a single IGS designation for orbit files which would always contain the best solution available and for archiving both the Rapid and Final IGS orbits. In the end a compromise was adopted and still is in effect, namely that IGS Rapid orbits are replaced with the IGS Final orbits and renamed with the designation IGR. The IGS label is hence always used for the best IGS orbits available.

Table 6. IGS Orbit/ clock combination enhancements changes implemented during 1993-1995.

Date	GPS Wk	Enhancements/changes implemented
Nov. 14/93	*724*	1st IGS orbit/clock combination
Jan. 02/94	730	ITRF92 adopted
Jan. 30	734	AC specific EOP used for the long arc evaluation
Feb. 13	736	absolute deviation orbit weights SP3 accuracy code, WRMS (weighted RMS) implemented
Mar. 27	742	ITRF-IERS(EOP) (1992 IERS A. R., Table II-3) corr. impemented (All IGS Final orbits corrected)
Mar. 27	742	an improved SV clock weighting based on non SA SVS
July 3	756	the new IGS EOP Format (Table 4) introduced
July 3	756	EOP rates used when given in orbit combination/ evaluation
July 24	759	reference clock resets in SV clock combination taken into account
Jan. 1/95	782	ITRF93 adopted

A number of problems/policy issues became only apparent after some weeks of operation. The general guidelines adopted were governed by several principles, such as fairness and impartiality to AC's, the IGS product reliability, accuracy and timeliness not being compromised, and that all the information submitted should be used, or at least considered in the IGS combined solution. This typically resulted in excluding AC orbit solutions for satellites with RMS of 1 m and larger, when confirmed by the long arc orbit evaluation, and satellite clock solutions with errors exceeding a few tens of ns. Similarly, any AC solution problems resulting in a few mas misalignment in orientation necessitates an orbit exclusion from the combination to prevent biasing the IGS solution. But all solutions are included in the statistics. Corrected solutions received after the completion of an IGS Rapid orbit/clock combination are only considered for the Final orbit/clock combinations for which all the latest AC solutions are downloaded again to ensure that the most recent solutions are used. The two combination/evaluation cycles, Rapid and Final increase reliability and facilitate comparative testing for new or experimental AC solutions.

As seen from the IGS combination statistics in Appendix I, during 1994 AC solutions have been steadily improving after an initial temporary increase in orbit RMS due to permanent AS implementation on January 31, 1994. By the end of December 1994, orbit RMS for most AC's were at or below the pre-AS levels of January, 1994 and in most cases approach 10 cm. The initial AS effect on the clock solutions was much more pronounced mainly due to hardware problems. However, GPS receiver hardware and software updates improved the clock solutions to approach again the sub-ns level for some AC'S. The sub-ns satellite and station receiver clock solutions are also reported daily by some AC's and show an unprecedented accuracy for global precise time transfers.

A steady improvement can also be seen in most cases for satellite coordinate translations, rotations, and scales. However, some notable unexplained small discontinuities, often only a few cm, are experienced at different times by most AC'S. Finding their cause may further increase precision and help to reduce the orbit RMS which is becoming increasingly more difficult.

The individual AC RY, RX rotations with respect to IGS orbits should, with the IERS(EOP)-ITRF corrections, correspond to IERS pole x, y combination differences, provided error-free orbits, the same weighting, and proper EOP and orbit correspondence are maintained. Table 7 lists statistics (means and sigmas of daily solutions) for the pole rotations based on the IGS Final orbits (Appendix I, Table 3) and the IERS EOP combinations during 1994 (IERS, 1995). Another way to view Table 7 statistics is that the mean differences and sigmas between AC EOP solutions and the IERS Bull. B were obtained in two ways, i.e. directly and indirectly via the IGS orbits. As expected the agreement for most AC's is remarkable. The differences for some AC's are likely due to a lack of correspondence (at certain times) between the AC orbits and EOP; these problems have already been noticed before for some AC's during 1993 (Beutler *et al.*, 1995).

AC	IGS Final Orbits				IERS (Bull. B)				Difference(IGS-IERS)			
	x	sigma	y	sigma	x	sigma	y	sigma	x	sigma	y	sigma
COD	-.17	.38	-.32	.37	-.18	.31	-.50	.36	.01		.18	
EMR	.08	.40	-.28	.47	.04	.39	-.41	.48	.04		.13	
ESA	-.19	.46	-.06	.43	-.14	.42	-.08	.44	-.05		.04	
GFZ	.39	.52	-.69	.45	.28	.30	-.40	.30	.11		-.29	
JPL	-.26	.36	-.24	.38	-.21	.35	-.31	.36	-.05		.07	
NGS	.23	.87	-.63	.68	.13	.80	-.84	.76	.10		.21	
SIO	.49	1.05	-.41	1.13	.53	.52	-.16	.65	-.04		-.25	
MEAN	,08	.11	-.38	.08	.06	.10	-.38	.09	.02	.02	.01	.08

Table 7. IGS Final Orbits and IERS (Bull. B.) pole x,y differences during 1994 (means and sigmas for daily solutions; units: mas).

1995 IGS Products and Possible Improvements

The ITRF92 coordinates (Table 2) still showed some inconsistencies of up to a few cm. The ITRF93 station coordinates and velocities have been greatly improved and slightly realigned to make them more consistent with the IERS EOP series. It was declared mandatory to adopt ITRF93 for all 1995 solutions. The ITRF93 improvements are clearly noticeable as the ITRF93 coordinate sigmas are about one half of the corresponding ITRF92 sigmas. No more additional IGS sites with reliable ITRF93 velocities could be identified, so that the same 13 stations were adopted for 1995 as well. The ITRF93 station coordinates and velocities adopted for 1995 are listed in Table 8. They were provided by the ITRF Section of IERS in December, 1994.

The ITRF93 realignment introduced small discontinuities in all the IGS series. The ITRF93-ITRF92 changes are insignificant for most applications. However, precise geodynamical applications require continuous and consistent solution series over many years. Fortunately, since IGS is still using the same 13 constraining sites, it is possible to determine the relationship between the 1994 and 1995 IGS products and the AC solutions more accurately than the nominal values given in the 1993 IERS Annual Report. Different ITRF92 - ITRF93 change estimates are listed in Table 9.

The first transformation set was obtained by a weighted transformation for the 13 ITRF92, ITRF93 station coordinates/velocities (Table 2, 8) and should be a good approximation of the expected change for all the AC'S. Since individual AC may be constraining more stations using different station distribution, data weighting, etc., the actual changes will vary slightly from AC to AC and from day to day. Some AC's estimated offsets for 1995 in their first AC summary report for 1995 (GPS Week 782). The transformation above is also quite consistent with the published transformation between ITRF92 and ITRF93 (Boucher *et al., 1994)* based on all ITRF stations and listed for completeness in the last three lines of

Table 8. 13 station ITRF93 coordinate velocity set used for IGS ITRF realization in 1995, (SSC(IERS)94C02, epoch 1995.0, IGSMAIL#819, sigmas: 2-5 mm for X, Y,Z and .3-9 mm/y for Vx, VY, Vz).

DOMES NUMBER	IGS NAME	X mm	Y mm	Z mm	VX mm/y	VY mm/y	Vz mm/y
10302MO03	TROM	2102940360	721569398	5958192092	-25.2	16,2	6.5
13407s01 2	MADR	4849202459	-360329148	4114913089	-14.1	22.2	20.1
13504MO03	KOSG	3899225260	396731803	5015078324	-21.8	21.2	12.2
14201 MO09	WETT	4075578593	931852662	4801570020	-25.2	19.1	12.3
30302MO02	HART	5084625431	2670366543	-2768493990	-5.4	17.6	21.6
40104MOO2	ALGO	918129510	-4346071228	4561977846	-21.7	-2.1	6.6
40127MO03	YELL	1224452487	-2689216070	5633638283	-28.9	0.6	-2.5
40405s031	GOLD	-2353614169	-4641385389	3676976474	-19.1	6.1	-4.7
0408MO01	FAIR	-2281621422	-1453595760	5756961945	-28.5	-1.9	-10.1
40424MO04	KOKB	-5543838126	-2054587365	2387809642	-12.9	61.4	29.2
41705MO03	SANT	1769693278	-5044574137	-3468321048	22.8	-6.3	25.6
50103M108	TIDB	-4460996070	2682557105	-3674443836	-35.4	-1.7	41.2
50107MO04	YAR1	-2389025427	5043316850	-3078530871	-45.9	9.0	40.3

Table 9. However, the first set oftransformation parameters should beonthe average closer to the actual AC product changes . The second set has been obtained for the IGS combination inthe same way. Only the R1, R2 orientation parameterswere derived from theIERS-ITRF92 misalignment(1992 IERS Annual Rep., p. II-17) which was applied to the IGScombinations in1994 and theIERS-ITRF93 misalignment(1993 IERS Annual Rep, p. II-19) which is used in 1995.

Subtractingmean R2, Reorientation corrections for1995 Final orbit

Table 9. Estimated discontinuities in IGS product series (orbits, EOP, station coordinates (SSC)) at 1995.00 (IGS(1994) IGS(1995)).

PRODUCTS	T1(cm)	T2(cm)	T3(cm)	D(ppb)	R1(mas) (y-pole)	R2(mas) (x-pole)	R3(mas)	Remarks (1)
IGS AC's(orb, EOP,SSC)	2.0	.8	.3	-.1	1.32	.82	.55	(2)
Sigma	.4	.5	.4	.6	.18	.16	.16	
Rates (./year)	.23	.04	-.08	.11	.13	.22	-.04	(2)
IGS Combined (orbits,EOP)	2.0	.8	.3	-.1	1.66	.68	.55	(3)
Sigma	.4	.5	.5	.6	0	0	.16	(3)
Rates (./year)	.23	.04	-.08	.11	.12	.15	-.04	(3)
ITRF92-ITRF93 (Boucher *et al.*, 1994)	2.2	.4	.1	-1.2	1.16	.53	.61	
Sigma	.2	.2	.2	.7	.09	.09	.08	
Rates (1 year)	.29	-.04	-.08	.00	.11	.19	-.05	

Remarks:

(1) The transformation parameters (T1-3,D,R1-3) are consistent with the 1993 IERS Annual Rep., (eqn. 3, p. II-52)

(2) Applicable only to daily constrained EOP/SSC/orbit AC solutions.

(3) The ITRF-IERS(EOP) misalignments, applied in IGS orbit combinations, were used to derive R1, R2, i.e. differencing the 1995.0 values computed from the Tables II-3 of the 1993 and 1992 IERS Annual Reports (p.II-19 and II-17, resp.); RI, R2 are exact hence sigmas are O.

combinations (Weeks 782-789) from the corresponding means of Table 7 (the last line) and adding the ITRF misalignment differences R2, R1 of Table 9 (line 4), yield the following average pole discontinuities:

pole x (1994-1995) = 0.64 ±0.07 mas,
pole y (1994-1995)= 1.48 ±0.09 mas.

This again is in a very good agreement with Table 9 (the first line), when respective sigmas are taken into account. Here, EOP/orbit consistency, the IERS Bulletin B continuity (at 1995.0) and consistency during 1994 and 1995 were assumed.

It should be pointed out that the ITRF93 velocities are slightly biased with regards to NNR NUVEL1A. However, the ITRF93 velocity field greatly reduces the apparent drift between IERS(EOP) and ITRF93 frames. The non NNR ITRF93 velocities cause only small orientation changes with comparable relative station precision. The rates for R1, R2, and R3 in Table 9 are consistent with the differences between NNR NUVEL11 and ITRF93 (Boucher *et al.*, 1994, p. 17) and can be used to maintain the past time evolution of the IGS products, or to transform the 1995 IGS products to the NNR reference frame.

IGS orbit/clock combination precision and reliability is achieved most efficiently by improved AC orbit/clock solutions. The next most significant impact on orbit/clock precision and reliability is expected from a pilot project (Blewitt *et* al., 1994) which is to evaluate and combine weekly station coordinate solutions from all AC's starting in April, 1995. This will improve station coordinate/velocity determination by combination of individual AC station coordinate solutions and reveal possible differences and/or problems. Although the solution improvements are more difficult to achieve below a 10 cm orbit RMS, some improvements could still be realized by using meteorological data for modeling of tropospheric delays and atmospheric pressure loading, and by antenna calibration at IGS stations. Radiation pressure model refinements could make it possible to process orbit arcs longer than 1-3 days with improved precision. Future improvements may also be realized by including GPS data from low-Earth-orbit satellites with GPS receivers in IGS global solutions.

It is also desirable to investigate alternative to the current IGS combination. For example, since all AC orbit/EOP solutions are now quite consistent, the weighted average combination including EOP can be accomplished directly in the ITRF, without the current EOP alignments prior to the IGS combination (see Appendix I for the IGS orbit/clock combination description). Improved weighting, robust estimation, and a clock combination which would preserve clock/orbit consistency should also be investigated. A need for external standards to evaluate GPS orbits/clocks at cm level was recently pointed out by Dr. M. M. Watkins of JPL. Precise point positioning determination of some strategically located stations utilizing AC and IGS orbit/clock solutions is required in near future to provide a ground truth for validation at the cm level.

Acknowledgments

The assistance and cooperation of Drs. Zuheir Altamimi and Claude Boucher of the IERS ITRF Section at IGN is gratefully acknowledged. Also the author would like to express appreciation to all AC colleagues who made this difficult task an enjoyable experience.

References

Beutler, G., J. Kouba, T. Springer, 1995, *Combining the orbits of the IGS Analysis* Centers, Bulletin Geodesique (in prep.); also in the Proceedings of the IGS Analysis Center Workshop, held in Ottawa, Canada, October 12-14, 1993, pp. 20-56,

Beutler, G., E. Brockmann, W. Gurtner, U. Hugentobler, L. Metvart, M. Rothacher, A. Verdun, 1994, *Extended Orbit Modelling techniques at the CODE Processing Center of the International GPS Service for Geodynamics (IGS):* Theory and initial results, Manuscript Geodetica, Vol. 19, No. 6, pp. 367-386.

Blewitt, G., Y. Bock, G. Gendt, 1993, *Regional Clusters and Distributed Processing,* Proceedings of the IGS Analysis Center Workshop, held in Ottawa, Canada, October 12-14, pp. 61-91.

Blewit, G., Y. Bock, J. Kouba, 1994, *Constructing the IGS Polyhedron by Distributed Processing,* Proceedings of the IGS workshop on the ITRF densification, held at JPL, Pasadena, Cal., Nov. 29-Dee 1.

Boucher, Z. Altamimi, L. Duhem, 1994, *Results and Analysis of the ITRF93*, IERS Technical Note 18, Observatoire de Paris, October.

Goad, C., 1993, *IGS Orbit Comparisons,* Proceeding of the 1993 IGS Workshop, held March 25-26, in Bern, Switz., (cd. by G. Beutler and E. Brockmann), pp. 218-225.

IERS REFERENCES, 1995, *Contribution of the Central Bureau of IERS*, *1994* IGS Annual Report, Chapter III (this volume).

Kouba, J. (edited by), Proceedings of the IGS Analysis Center Workshop, held in Ottawa, Canada, October 12-14.

Klokocnik, J. and J. Kostelecky, 1987, *Earth Gravity Field and High Satellite Orbits,* Bull. Astronom. Institute, Czechoslovakia, 38, pp. 334-344.

Klokocnik, J. and J. Kostelecky, 1995, *Short period effects of truncation and calibrated variances of GEMT2 and JGM2 on GPS orbits* (in Czech), an e-mail report to J. Kouba, dated Jan. 23/95 (private comm.).

Lahaye, F., C. Huot, J. Kouba, 1993, *Investigation of Solar Radiation Effects on GPS Precise Orbit Determination,* Proc. of the 44th Congress of the International Astronautical Federation, Graz, Austria, October, Paper reference #: IAF-93-A1. 7.

McCarthy, Dennis D. (cd.), 1992, *IERS Standards (1992),* IERS Technical Note 13, Observatoire de Paris, July.

Remondi, B. W., 1989, *Extending the National Geodetic Survey Standard GPS Orbit Formats, NOAA* Technical report NOS 133 NGS 46, November.

Springer, T. A. and G. Beutler, 1993, *Towards an Official IGS Orbit by Combining the Results of All IGS Processing* Centers, Proceeding of the 1993 IGS Workshop, held March 25-26, in Bern, Switz., (cd. by G. Beutler and E. Brockmann), pp. 242-250.

Zumberge, J. F. and C. Goad, 1993, *IGS processing Center standard report requirements and products formats,* Proceedings of the IGS Analysis Center Workshop, held in Ottawa, Canada, October, 12-14, pp. 6-16.

Appendix I
1994 IGS Orbit/Clock Combination and Evaluation

J. Kouba, Y. Mireault and F. Lahaye
Geodetic Survey Division, Geomatics Canada, Natural Resources Canada
(NRCan, formerly EMR)
Ottawa, Ontario, Canada

Abstract

Currently, seven orbit/clock solutions submitted to the International GPS Service for Geodynamics (IGS) are evaluated and combined weekly, usually within one day of the last submission. This IGS Rapid orbit/clock combination is based on the current IERS Rapid Service (Bulletin A) Earth Orientation Parameters (EOP). A second combination, the IGS Final orbit/clock combination, is generated as soon as the IERS final EOP values (Bulletin B) are available, typically within two months of the last observation. Both orbit/clock products are summarized and made available through the IGS electronic data/mail distribution. IGS Analysis Center solutions are consistent within 10-20 cm (coordinate RMS) as determined by independent comparison of daily orbits from a single Analysis Center to a week-long arc fit. For the long arc evaluations, the use of the Center-specific EOP solutions improves the results in most cases. Both satellite orbit and clock solutions are combined by means of a weighted average after proper alignments. The combinations of the submitted clock solutions show sub-ns consistency for the periods with no AS and l-ns consistency for periods with AS. The combination process produced orbit orientation misalignments which are indicative of the stability of respective EOP solution series and orbit/EOP consistency. For most Analysis Centers the mean X and Y rotation offsets with respect to the IERS EOP are - -0.4 mas and +0.1 mas respectively with an RMS less than 0.6 mas.

Introduction

Precise IGS orbits/clocks significantly simplify regional GPS data reduction by eliminating the need to process large data sets involving very long baselines which usually requires complex software. Furthermore, the IGS precise orbits ensure position results consistent with the International Terrestrial Reference Frame (ITRF).

Currently, seven IGS Analysis Centers contribute solutions to the IGS orbit/clock combination (see Table 1). Typically, orbits/clocks are combined within one or two days after the last submission or within 9 days after the last observation. The Ottawa workshop [Kouba, 19931 recommendations have been followed to produce and distribute orbit/clock combinations. The formats of the IGS product files are compatible with the submissions of most Analysis Centers, i.e. three types of files are produced weekly: seven daily orbit/clock files, one EOP file (based on Bulletin A or B) and one summary file. Table 2 summarizes step by step the combination procedure for both ephemerides and clocks based on the above recommendations. Note that the IGS orbit/clock combination and evaluation is performed on a weekly cycle.

The main purpose of this paper is to document in detail the current orbit/clock combination strategy and to summarize the 1994 results. In Section II, the long arc dynamic evaluation is described. In Sections III and IV, the orbit combination and the clock combination by weighted average are respectively addressed. Section V summarizes the implementation and enhancements to the software and finally, Section VI presents the IGS combination results for 1994.

Table 1. IGS Analysis Centers Contributing During 1994.

Center	Description
cod	Center for Orbit Determination in Europe (CODE) Bern, Switzerland
emr	Natural Resources Canada (NRCan) (Formerly Energy, Mines and Resources - EMR) Ottawa, Canada
esa	European Space Agency (ESA) European Space Operations Center (ESOC) Darmstadt, Germany
gfz	GeoForschungsZentrum (GFZ) Potsdam, Germany
jpl	Jet Propulsion Laboratory Pasadena, USA
ngs	National Oceanic and Atmospheric Administration (NOAA) Silver Springs, USA
sio	Scripps Institution of Oceanography La Jolla, USA

Table 2. Orbit and Clock Combination/ Evaluation Procedure.

Step	Description
1	Long Arc Ephemerides Evaluation for each Center: • seven daily satellite ephemerides are used as pseudo-observations in an orbit improvement program and the resulting residuals RMS examined.
2	Transformation to Common References: • the difference between each Center EOP solution and Bulletin A/B values are applied to the respective ephemerides; • prior to GPS week 742, clock offset and drift with respect to broadcast clock corrections were estimated and applied to a selected Center (reference Center), and all remaining Centers were aligned to the reference Center; • from GPS week 742, clock offset and drift with respect to broadcast clock corrections are estimated for each Center using non-SA satellites only and are applied to the respective Center.
3	Orbit/Clock Combination: • Center orbit weights are computed from the corresponding absolute deviations from the unweighed mean orbits; • prior to GPS week 742, Center clock weights were computed from the absolute deviations from the unweighed mean clocks of all satellites; • from GPS week 742, Center clock weights are computed from the absolute deviations from the broadcast clocks of non-SA satellites only; • satellite ephemerides and clock corrections are combined as weighted averages of all daily Center solutions.
4	Long Arc Ephemerides Evaluation for the IGS Combined Orbits: • daily IGS combined orbits are used as pseudo-observations in an orbit improvement program and the resulting residuals RMS examined.

Long arc orbit evaluation

The long arc evaluation was implemented to detect problems that could affect the daily weighted average combination and to assess the consistency of each Analysis Center solutions over a one week period. Ephemerides for each Center are analyzed individually and independently from the combination process (weighted average). The evaluation process comprises a few programs which have to be invoked for all seven Analysis Centers. These programs were developed at the Astronomical Institute of the University of Bern (AIUB) [Beutler *et al.*, 1994] and were implemented at NRCan to perform the orbit combination/evaluation on behalf of IGS.

To automate the process, script files written for a VAX-VMS computer by the University of Bern had to be converted for an HP-UX platform. The original script files were modified to include/exclude specific Centers, to choose between Center specific or Bulletin A/B EOP and to delete satellites for specific days/Centers.

Prior to orbit evaluation, the IERS Bulletin A/B or Center-specific EOP have to be converted into the same format and inconsistencies between Center-specific EOP files have to be taken into account. For example, some Centers provide UT1-UTC, others UT1R-UTC instead; some Centers used to give UT1-UTC at a time different than x and y pole values or did not provide UT1-UTC values at all. Starting with the GPS week 756 (July 3, 1994), the IGS and Center-specific EOP files were all submitted in the new IGS standard EOP format (see IGSMail #662). At the same time, pole rates (xrt, yrt) and LOD/LODR were introduced as part of the EOP files. Since GPS week 756, all long arc evaluation programs were modified in order to use these rates if provided by the Analysis Center.

In summary, daily precise ephemerides for a single Center are transformed into the J2000.0 inertial system using the Center EOP solutions. A seven-day a priori orbit arc is then generated for each satellite. Finally, using the daily J2000.0 ephemerides as pseudo-observations, the a priori weekly orbit arcs are improved by estimating six Keplerian elements and nine radiation pressure parameters per satellite. The above steps are repeated for each Analysis Center and the IGS solutions independently. For more detail see [Beutler *et* al., 1993 and Beutler *et al., 1994].* If problems like satellite maneuvers or momentum dumps arise, the seven day arc of the satellite in question can be divided in two independent arcs, estimating two sets of Keplerian elements and radiation pressure parameters.

Orbit combination by weighted average

The weighted average orbit combination software was jointly developed by T. Springer at the Technical University of Delft (TUD) and G. Beutler at the AIUB [Springer and Beutler, 19931.

Method Description

The orbit combination is performed using all Analysis Center submissions for a given day. Each Center's ephemeris is first rotated to establish a common orientation by applying the difference between its associated x- and y-pole coordinate solutions and the reference EOP. The most recent IERS Bulletin A pole coordinates are used as the reference for the Rapid orbit combination whereas the Final Combination uses the final IERS Bulletin B daily pole values.

These small rotations are necessary to account for possible systematic pole offsets between individual Analysis Center solution and to make the IGS combined orbits compatible with the IERS EOP. Note that both Bulletin A and Bulletin B pole values were corrected with the ITRF92 inconsistency parameters [1992 IERS Annual Report, Table II-3, page 11-17]. The rotated ephemerides for all Analysis Centers are weighted and combined to generate the IGS official orbits. The steps to produce the IGS orbits and the associated statistics are:

1. An unweighted mean orbit is first computed and a 7-parameter Helmert transformation is estimated between each rotated Center ephemeris $\left(P^{sat}_{cent}\right)$ and the mean ephemeris. These transformation parameters are computed using robust L1-norm estimates and are used to transform each Center ephemeris $\left(P'^{sat}_{cent}\right)$ Center weights $\left(W_{cent}\right)$ are derived from the mean absolute deviation of the mean ephemeris:

$$W_{cent} = \left(\frac{\left(3 \cdot \sum_{sat}^{Nsat_{cent}} Nepoch^{sat}_{cent}\right) - 7}{\sum_{sat}^{Nsat_{cent}} \sum_{i}^{Nepoch^{sat}_{cent}} \left| P'^{sat}_{cent} - \bar{P}^{sat} \right|_i} \right)^2 \qquad (1)$$

where

$Nsat_{cent}$ is the number of satellites per Center;

$Nepoch^{sat}_{cent}$ *is* the number of ephemeris positions per Center per satellite;

P'^{sat}_{cent} *is* the Analysis Center transformed satellite position $(X' \; Y' \; Z')^{sat}_{cent}$;

$\bar{P}^{sat}$ *is* the unweighted mean satellite position $(\bar{X} \; \bar{Y} \; \bar{Z})^{sat}$;

and the absolute deviation is

$$\left| P'^{sat}_{cent} - \bar{P}^{sat} \right| = \left| X'^{sat}_{cent} - \bar{X}^{sat} \right| + \left| Y'^{sat}_{cent} - \bar{Y}^{sat} \right| + \left| Z'^{sat}_{cent} - \bar{Z}^{sat} \right| \qquad (2)$$

2. A weighted average orbit $\left(\bar{P}^{sat}_{w}\right)$ is then computed using the Center weights as defined in (l):

$$\bar{P}^{sat}_{w} = \frac{\sum_{cent}^{Ncent^{sat}} W_{cent} \cdot P'^{sat}_{cent}}{\sum_{cent}^{Ncent^{sat}} W_{cent}} \qquad (3)$$

where $\left(Ncent^{sat}\right)$ is the number of Centers submitting a solution for that satellite.

3. Again, a set of 7-parameter Helmert transformation is estimated (L1-norm) between each Center and the weighted average orbit, but this time using satellite weights $\left(W^{sat}\right)$ which are computed as:

$$W^{sat} = \left(\frac{Ncent^{sat}}{\sum_{cent}^{Ncent^{sat}} \sum_{i}^{Nepoch_{cent}^{sat}} \frac{\left\| P'^{sat}_{cent} - \bar{P}^{sat} \right\|_i^2}{3 \cdot Nepoch_{cent}^{sat} - 7}} \right) \quad (4)$$

where

$$\left\| P'^{sat}_{cent} - \bar{P}^{sat} \right\| = \sqrt{\left(X'^{sat}_{cent} - \bar{X}^{sat}\right)^2 + \left(Y'^{sat}_{cent} - \bar{Y}^{sat}\right)^2 + \left(Z'^{sat}_{cent} - \bar{Z}^{sat}\right)^2} \quad (5)$$

4. Finally, the IGS combined orbits $\left(\bar{P}^{sat}_{comb}\right)$ are computed as the weighted average (similar to step 2), using the Center weights from (1) and the newly transformed Analysis Center ephemerides $\left(P''^{sat}_{cent}\right)$ using the last Helmert parameters estimated in step 3:

$$\bar{P}^{sat}_{comb} = \frac{\sum_{cent}^{Ncent^{sat}} W_{cent} P''^{sat}_{cent}}{\sum_{cent}^{Ncent^{sat}} W_{cent}} \quad (6)$$

5. The statistics produced in the weekly IGS report are computed as shown in equations 7 through 11.

a. The Center RMS $\left(RMS_{cent}\right)$ and weighted RMS ($WRMS_{cent}$) are found in each daily Table 2.*gpsweek.day* and in the last two lines of every Table 3.*gpsweek.day* of the IGS weekly report (in the 'Weighted Average" block) and are calculated as:

$$RMS_{cent} = \sqrt{\frac{1}{Nsat_{cent}} \sum_{sat}^{Nsat_{cent}} \left(RMS^{sat}_{cent}\right)^2} \quad (7)$$

$$WRMS_{cent} = \sqrt{\sum_{sat}^{Nsat_{cent}} W^{sat}_{cent} \cdot \left(RMS^{sat}_{cent}\right)^2} \quad (8)$$

where $\left(RMS_{cent}^{sat}\right)$ and $\left(W_{cent}^{sat}\right)$ are the satellite RMS fit and the satellite weight respectively for each Center. The former is found in every Table 3.*gpsweek.day* of the IGS report in the 'Weighted Average" block and (W_{cent}^{sat}) is computed from the accuracy codes provided by the Analysis Centers in their submitted SP3 files. They are computed as:

$$RMS_{cent}^{sat} = \sqrt{\sum_{i}^{Nepoch_{cent}^{sat}} \frac{\left\| P''^{sat}_{cent} - \overline{P}^{sat}_{comb} \right\|_i^2}{3 \cdot Nepoch_{cent}^{sat} - 7}} \tag{9}$$

$$W_{cent}^{sat} = \frac{\sigma_{cent}^{sat^{-2}}}{\sum_{sat}^{Nsat_{cent}} \sigma_{cent}^{sat^{-2}}} \tag{10}$$

where $\left(\sigma_{cent}^{sat}\right)$ is obtained from the SP3 accuracy codes.

Bad or marginal satellite solutions will show up in the Center orbit RMS but not in its weighted orbit RMS (WRMS) if appropriately acknowledged by the Center using the associated accuracy codes in the SP3 files. Failing to do so will generate a WRMS equal to or greater than the orbit RMS. This makes it possible for a Center to produce a complete solution including marginal satellites without disturbing their orbit statistics (WRMS). From the experience gained during 1994, it is recommended that Centers do not submit solutions for satellites with large anomalies (e.g. orbit RMS greater than several meters). Such solutions contribute little to the IGS orbit combination and often have to be excluded.

b. The accuracy values of the IGS combined ephemeris for each satellite $\left(\sigma^{sat}\right)$ are:

$$\sigma^{sat} = \sqrt{\frac{\sum_{cent}^{Ncent^{sat}} W_{cent} \cdot \left(RMS_{cent}^{sat}\right)^2}{\left(Ncent^{sat} - 1\right) \sum_{cent}^{Ncent^{sat}} W_{cent}}} \tag{11}$$

They can be found in every Table 1.*gpsweek.* b and in every Table 3.*gpsweek.day* of the IGS report under the "IGS" column in the 'Weighted Average" block. These accuracy values are used to compute the accuracy codes found in the headers of the SP3 orbit files containing the IGS combined ephemerides. If only one Analysis Center provides a solution for a given satellite, the corresponding accuracy code is set to O (unknown).

Examples of Table 1.*gpsweek*.a/b, Table 2.*gpsweek.day* and Table 3.*gpsweek.day* are given in Appendix II "IGS Combination Summary Report Description".

Clock combination by weighted average

Method Description

The satellite clock correction combination is performed in a fashion similar to the orbit combination. The individual Analysis Center clock corrections are first aligned to a common time reference by determining clock offsets and drifts between each Center and the time reference. Clock resets for a Center reference clock is handled properly by estimating additional clock offsets and drifts for Centers showing such behavior. Currently, GPS time as provided by broadcast clock corrections is used as the reference. Since under Selective Availability (SA) the broadcast clock corrections have an RMS of about 100 ns, direct alignment of each Analysis Center to broadcast clock corrections can cause the Center's clock corrections to be offset by as much as 10 ns. However, the best submitted clock solutions are consistent at the sub-ns level. Two strategies were used to overcome this problem:

a. A specified Analysis Center is chosen as the reference. Its clock corrections are aligned to GPS time through L1-norm estimation of clock offset and drift using broadcast clock corrections. The other Centers' clock corrections are then aligned to the transformed clock corrections of the reference Center, again by L1-norm estimation. The Center weights are computed from the absolute deviation of the transformed clock corrections with respect to the unweighed mean. In this manner, the best alignment possible is provided both between Analysis Centers (sub-ns) and with respect to the time reference (10 ns in the case of GPS time). This strategy was used from GPS weeks 730 to 741;

b. Each analysis Center's clock corrections are aligned to GPS time by L1-norm estimation of clock offset and drift using only non-SA satellite broadcast clock corrections (usually 3 satellites). Center clock weights are determined from the absolute deviation of this initial alignment with respect to the non-SA satellites. This way, the clock alignments to the GPS time are not affected by SA and more realistic weights are used in the clock combination, provided that the non-SA satellites are representative of each Center's clock solution quality. This strategy has been used since GPS week 742.

The transformed clock corrections are then combined as weighted averages over all submitted solutions. Unlike the orbit combination, no satellite specific weights are used in the estimations. The steps to produce the IGS satellite clock corrections and their statistics are:

1. First, a clock offset and drift between each Center's clock solutions and the broadcast clocks using non-SA satellites only is derived to align the Center clocks to GPS time. The Center clock solution after this first alignment will be referred to as $\left(\Delta t_{cent}^{sat}\right)$.

2. The Center clock weight (WCC,.,) *is* derived from:

$$W_{C_{cent}} = \frac{ABS_{cent}^{-2}}{\sum_{cent}^{Ncent} ABS_{cent}^{-2}} \qquad (12)$$

where

$$ABS_{cent} = \frac{\sum_{sat}^{Nsat_{cent}} \sum_{i}^{Nclk_{cent}^{sat}} \left| \Delta t_{brd}^{sat} - \Delta t_{cent}^{sat} \right|_i}{\left(\sum_{sat}^{Nsat_{cent}} Nclk_{cent}^{sat} \right) - 2} \tag{13}$$

Ncent is the number of Centers;

$Nclk_{cent}^{sat}$ **is the number of clock corrections for a given satellite and Center.**

3. A weighted average clock correction $\left(\overline{\Delta t}_w^{sat}\right)$ for each satellite and epoch is then computed using the Center clock weights:

$$\overline{\Delta t}_w^{sat} = \sum_{cent}^{Ncent^{sat}} W_{c_{cent}} \cdot \Delta t_{cent}^{sat} \tag{14}$$

4. A new set of alignment parameters (clock offset and drift) between the weighted clock average (14) and each Center is estimated (one set of parameters for all satellites). Every Center's clock solution is then realigned using these new parameters. It is referred to as $\left(\Delta t'^{sat}_{cent}\right)$.

5. Finally, the IGS combined clock corrections $\left(\overline{\Delta t}_{comb}^{sat}\right)$ are computed as the weighted average (similar to step 3), using the Center weights from (12) and the Center clock corrections generated in step 4:

$$\overline{\Delta t}_{comb}^{sat} = \sum_{cent}^{Ncent^{sat}} W_{c_{cent}} \Delta t'^{sat}_{cent} \tag{15}$$

6. The Center clock RMS $\left(RMS_{c_{cent}}\right)$ found in every Table 2.*gpsweek.day* of the IGS weekly report (last column) is:

$$RMS_{c_{cent}} = \sqrt{\frac{\sum_{sat}^{Nsat_{cent}} \sum_{i}^{Nclk_{cent}^{sat}} \left(\overline{\Delta t}_{comb}^{sat} - \Delta t'^{sat}_{cent} \right)_i^2}{\left(\sum_{sat}^{Nsat_{cent}} Nclk_{cent}^{sat} \right) - 2}} \tag{16}$$

Implementation and General Remarks

The ephemeris and clock combination should fulfill the following expectations:

- firstly, the IGS combined ephemeris/clock is to be the most reliable of all the submitted solutions;

- secondly, the reported statistics should reflect all information submitted by the individual Analysis Center even if they cannot be used for the orbit/clock combination. They provide useful feedback to the Analysis Centers.

Occasional difficulties may arise when some submitted solutions perturb the combination and thus should be excluded according to the first principle but kept according to the second. The L1-norm estimation scheme was therefore chosen on the basis of its robustness, i.e. its insensitivity to "outlier data", thereby satisfying both principles. During the initial phase of generating operational IGS combinations, it became clear that for certain severe cases (e.g. when a Center solution for one satellite in comparison with others shows RMS of several meters) the robust method may fail. This is due to insufficient redundancy provided by data from the seven individual Analysis Centers and, more importantly, due to the first stage unweighed averaging which is not a robust process, providing in some cases poor initial estimates. Similar problems arise with the clock combination since only four Centers provide clock solutions. Moreover, the assumption that non-SA satellites are always representative of the clock solution quality from each Center is sometimes questionable and limited by the satellite clock stability which is at 1-2 ns.

More research and experimentation is needed to avoid these problems. For this reason, the weight determination is based on absolute values since in extreme cases, it performed better than the sum of the square root weighting scheme. Inclusion/exclusion procedures have been adopted to allow the use of data only for statistics but not in the combination. This simple approach took care of the occasional problems encountered in the Rapid/Final combinations.

The following software enhancements were implemented before or during 1994:

- Possibility to process only parts of the week;
- Reference EOP selection option, i.e. Bulletin A or Bulletin B;
- Options to include/exclude satellites and/or Analysis Centers at different phases of processing;
- ITRF-IERS (EOP) corrections, which align the pole series with ITRF92 [1992 IERS Annual Report, Table II-3, page 11-171, used during 1994 for alignment to ITRF92;
- Use of the new IGS standard EOP format;
- Use of EOP rates (x_{rt}, y_{rt}) when provided by the Centers;
- Introduction of multiple reference clock resets in satellite clock combination.

1994 Results

In this section, results for the first year of IGS service, i.e. January 2 to December 31, 1994 (GPS weeks 730 to 781) are presented. Appendix H gives more detail on the meaning of the statistics included in the weekly IGS report.

Figures 1 to 7 display the weekly averages and standard deviations of the translations, rotations, and scale of the X, Y, Z satellite coordinates (for each

Analysis Center) after the daily Helmert transformations with respect to the IGS Final orbits (referred to the IERS Bulletin B). Table 3 shows each Center yearly means and standard deviations for the translations, the rotations, and the scale parameters of the daily Helmert transformations. The total number of days for which a solution was submitted by each Center is also shown. It should be mentioned that the X and Y rotation parameters are indicative of the stability of the Center x and y pole series provided that the Center orbit and EOP solutions are consistent. The scale may indicate possible differences in orbit modeling between Centers. Sudden jumps in the weekly parameter averages may indicate a change in the processing strategy and/or a change in the quality of the GPS data. For example, AS was permanently implemented as of January 31, 1994 (week 734, day 1) and it is clearly visible for some Centers,

Figure 8 shows the orbit coordinate RMS for the orbit combination and long arc evaluation. Three types of RMS are included in the orbit position RMS figures: the weighted combination RMS (WRMS), the combination RMS, and the long arc evaluation RMS. Figure 9 summarizes the clock combination RMS. Centers used in the clock combination are EMR, ESA, GFZ, and JPL. The other Centers are excluded because they either provide broadcast clocks (COD, NGS starting on GPS week 753), which are only used in clock alignment and clock weight determination, or clock corrections are not provided (S10, NGS prior to GPS week 753). For completeness, the clock information not used in the combination is still compared to the combined solution.

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
cod	μ	.01	.02	.01	-.32	-.17	.14	.0	364
	σ	.01	.01	.01	.37	.38	,33	.2	
emr	μ	.01	.00	-.01	-.28	.08	.04	-.2	364
	σ	.01	.01	.02	.47	.40	.27	.2	
esa	μ	.01	.00	.00	-.06	-.19	-.31	.1	364
	σ	.01	.01	,02	.43	.46	.52	.2	
gfz	μ	-.04	.01	.00	-.69	.39	-.43	-.3	364
	σ	.01	.01	.01	.45	.52	.25	.2	
jpl	μ	.00	.00	.01	-.24	-.26	.07	.0	364
	σ	.01	.03	.01	.38	.36	.48	.2	
ngs	μ	.03	-.01	-.03	-.63	.23	.60	.8	364
	σ	.03	.03	.04	.68	.87	.65	.7	
sio	μ	.01	-.03	.02	-.41	.49	.92	.4	363
	σ	.02	.02	.09	1.13	1.05	3.49	.5	

units: meters (m) (DX, DY, DZ);
milliarc-seconds(mas) (RX, RY, RZ);
parts-per-billion (ppb) (SCL);

μ is the mean;
σ is the standard deviation,

Table 3. Means and standard deviations of the daily Helmert Transformation parameters for 1994.

For some Centers, some RMS values were out of scale and not plotted completely (Figures 8 and 9). This was purposely done in order to make the figures easier to read (with similar scales). These outliers generally indicate a bad satellite or clock solution. In most cases, the bad satellite orbit or clock solutions were excluded from the combination but kept in the RMS computations. All exclusions are reported in the IGS weekly summary reports. High clock RMS for COD and NGS are generally due to broadcast clock resets for one or more satellites which are modeled by Centers' estimating clocks.

Effect of permanent AS implementation (GPS week 734) is clearly visible by looking at the clock RMS (Figure 9). The daily clock RMS before GPS week 734 despite of occasional high clock RMS for EMR, ESA, GFZ, and JPL shows that the RMS level increased from ns or sub-ns to about 10 ns after AS implementation. The COD and NGS clock RMS, which are based on broadcast clock corrections (Figure 9), show that SA was deactivated for most of GPS week 767 (days O-5). It was also deactivated on day 6 of GPS week 766 which is not apparent from Figure 9.

Examination of the figures shows that a considerable effort was made throughout the year by all Analysis Centers to improve the quality of orbit and clock solutions. Towards the end of the year, some clock RMS have again reached the 1 ns level and some orbit position RMS have been approaching the 10 cm level, despite AS.

Conclusion

Analysis Center orbit solutions have steadily improved and, towards the end of the year, most contributed orbit solutions show consistency approaching the 10 cm level (coordinate RMS) even under AS conditions. This is confirmed by independent long arc orbit evaluations. The IGS orbit combination attempts to use all submitted solutions, including days when satellites are being repositioned, Therefore, the IGS combined orbits should be the most complete and reliable of all the individual orbits submitted. Furthermore, the IGS orbits are expected to be more consistent in orientation and as precise as the best regional orbits. The satellite clock solution consistency was well below 1 ns during the month of January, 1994 when AS was not invoked. Since February 1994, when AS was invoked permanently, the clock solution consistency deteriorated to the 10 ns level mainly due to biased pseudorange observations from GPS receivers. However, hardware improvements and better solution strategies by all Analysis Centers resulted in the satellite clock solution consistency reaching again the 1 ns level. Further research is needed in such areas as orbit/clock weight determination, and robust outlier detection and elimination in the orbit/clock combination.

Acknowledgments

The weighted average orbit combination software, adopted for IGS orbit combination, was developed by Springer and Beutler (1993) and further improved and automated by T. Springer who also kindly provided us with the UNIX script. The long arc evaluation was developed at the Astronomical Institute of the University of Bern (AIUB) [Beutler *et al.*, 1993, Beutler *et al.*, 19941, automated and ported to HP UNIX with the assistance of E. Brockmann of AIUB.

References

Beutler, G., E. Brockmann, W. Gurtner, U. Hugentobler, L. Mervart, M. Rothacher and A. Verdun, 1994, *Extended Orbit modeling Techniques at CODE Processing Center of the International GPS Service for Geodynamics (IGS): Theory and Initial Results*, Manuscript Geodaetica, Vol. 19, No. 6, pp. 367-386.

Beutler, G., J. Kouba and T. A. Springer, 1993, *Combining the Orbits of the IGS Processing* Centers, Proceedings of the IGS Analysis Center Workshop, held in Ottawa, Canada, October 12-14, 1993, pp. 20-56.

International Earth Rotation Service (IERS), 1993, 1992 *ZERS Annual Report,* Observatoire de Paris, France.

Kouba, J., 1993 (Edited by), *Proceedings of the IGS Analysis Center Workshop* , held in Ottawa, Canada, October 12-14, 1993.

Springer, T. A. and G. Beutler, 1993, *Towards an Official IGS Orbit by Combining Results of all IGS Processing Analysis* Centers, Proceedings of the 1993 IGS workshop, held in Bern, Switzerland, March 25-26, 1993, pp. 242-249.

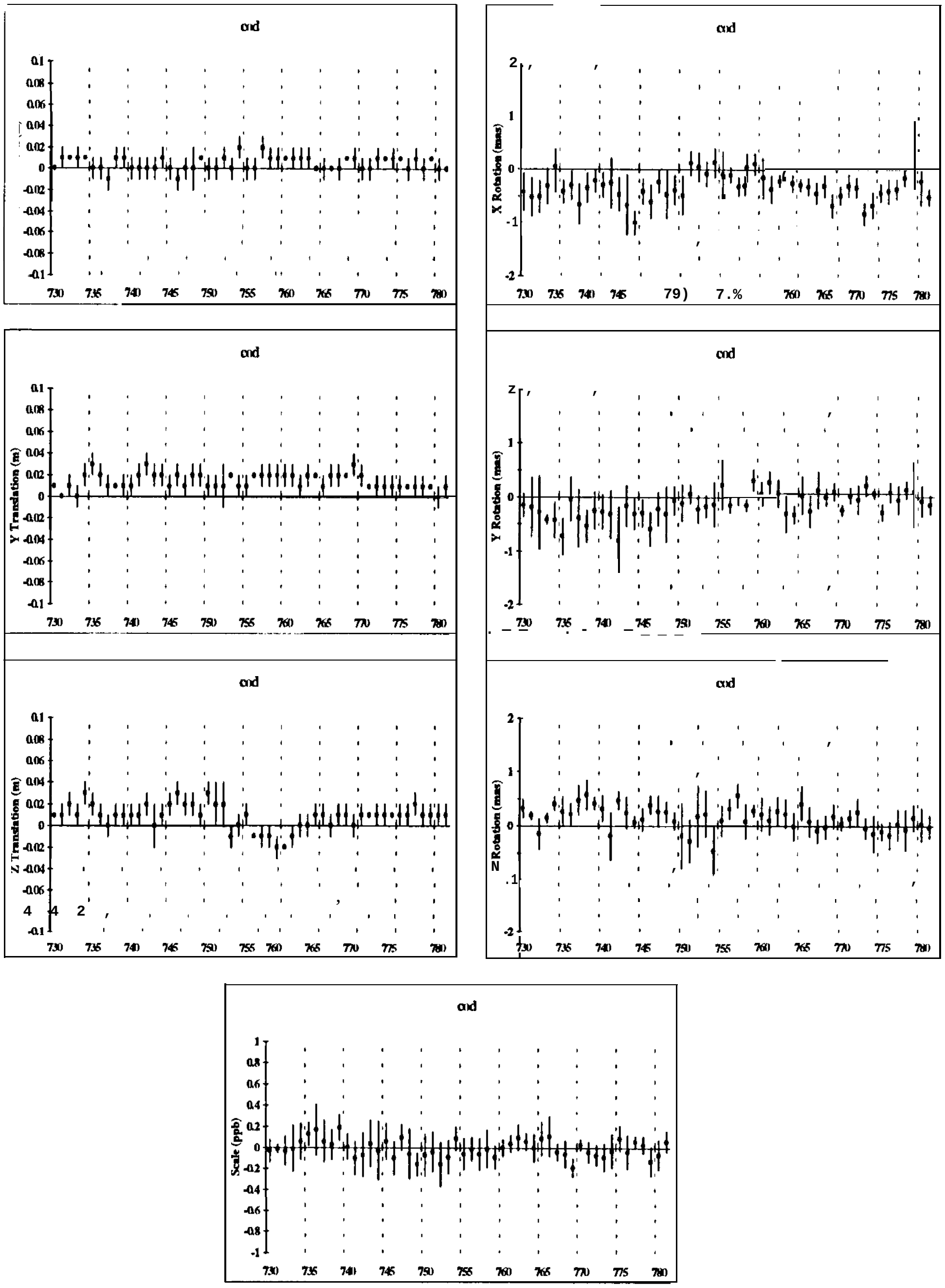


Figure 1. COD 1994: Weekly Mean 7-Parameter Helmert Transformations.

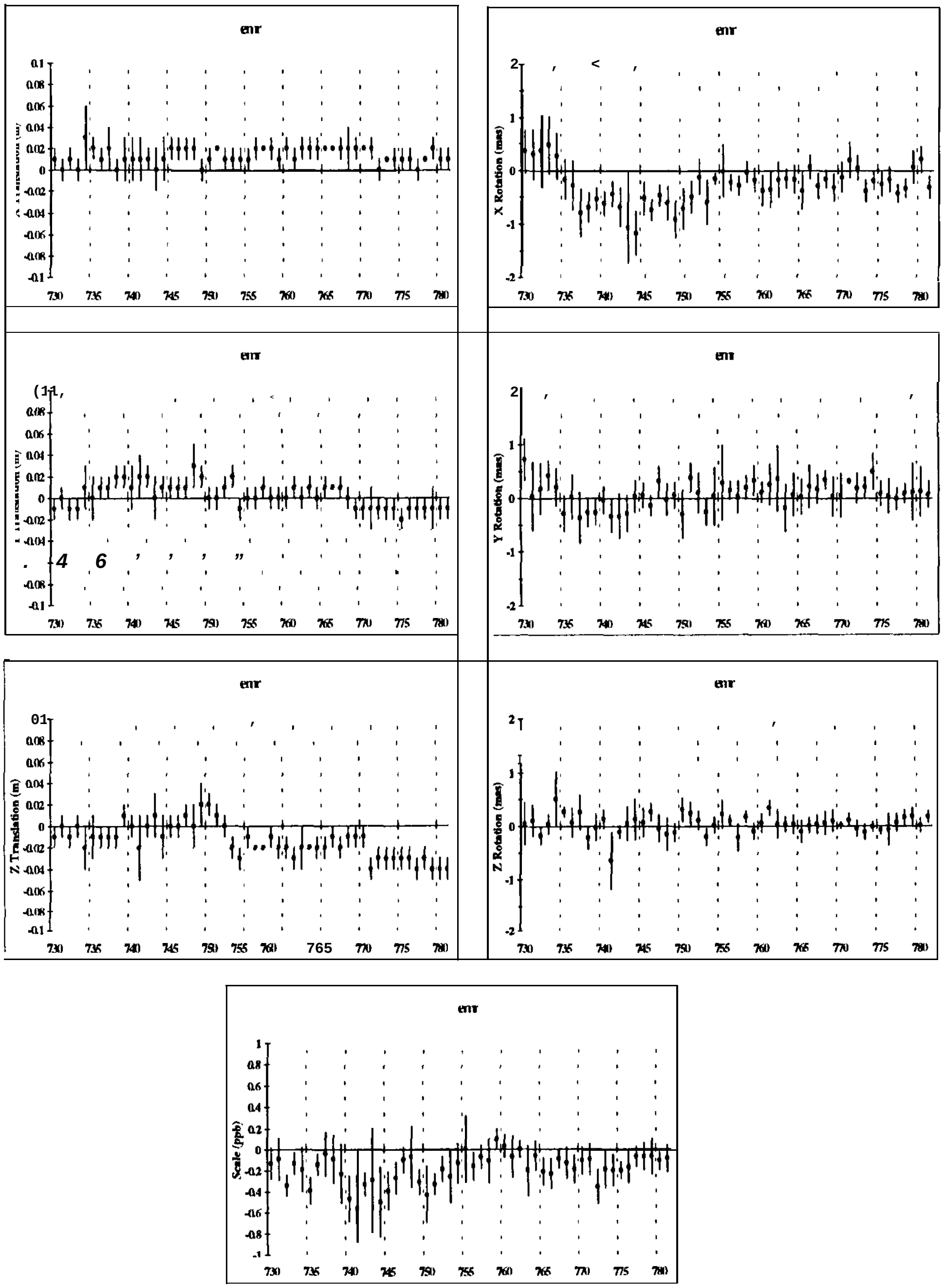
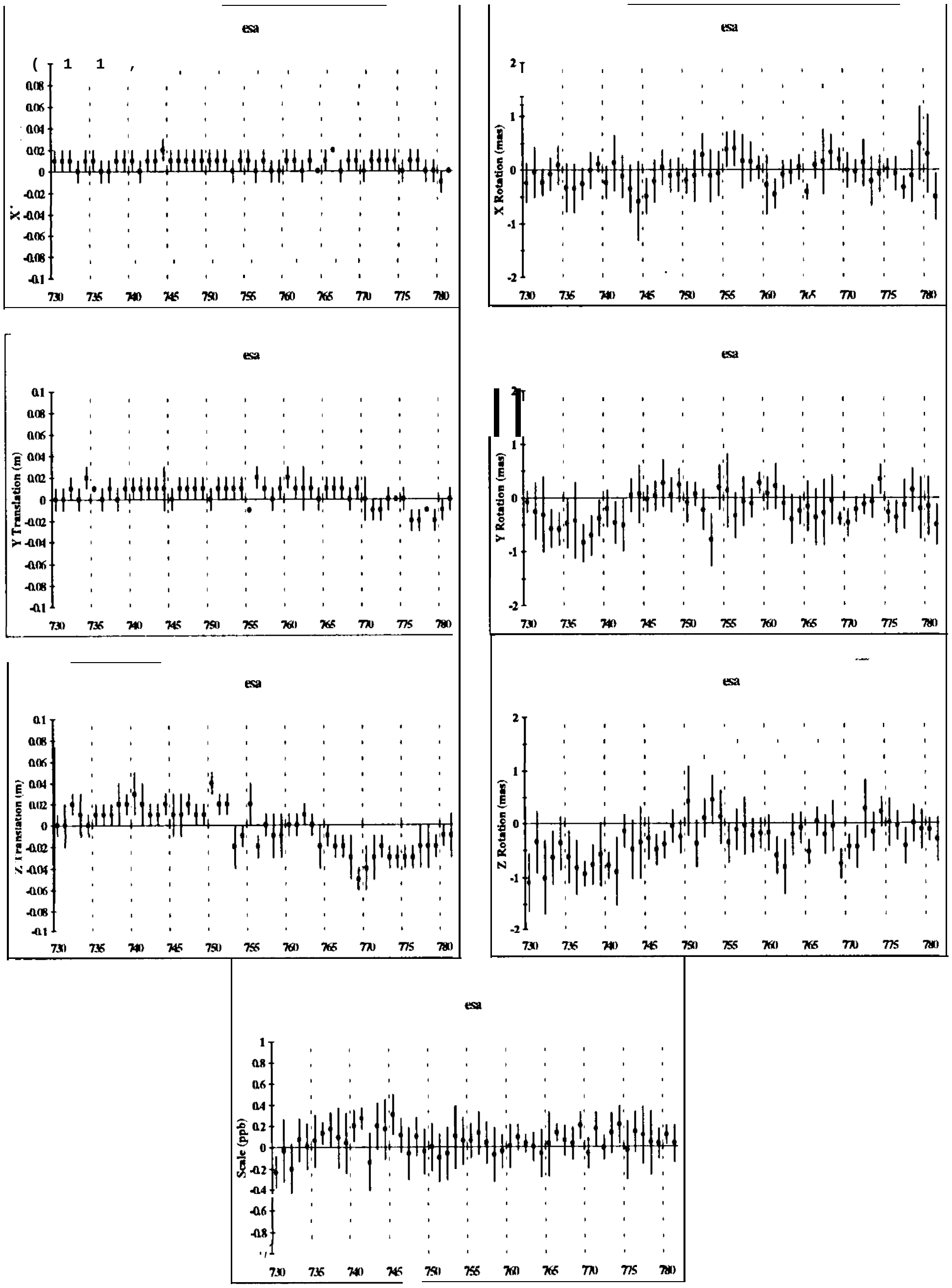


***Figure 2.** EMR 1994: Weekly Mean 7-Parameter Helmert Transformations.*

Figure 3. ESA 1994: Weekly Mean 7-Parameter Helmert Transformations.



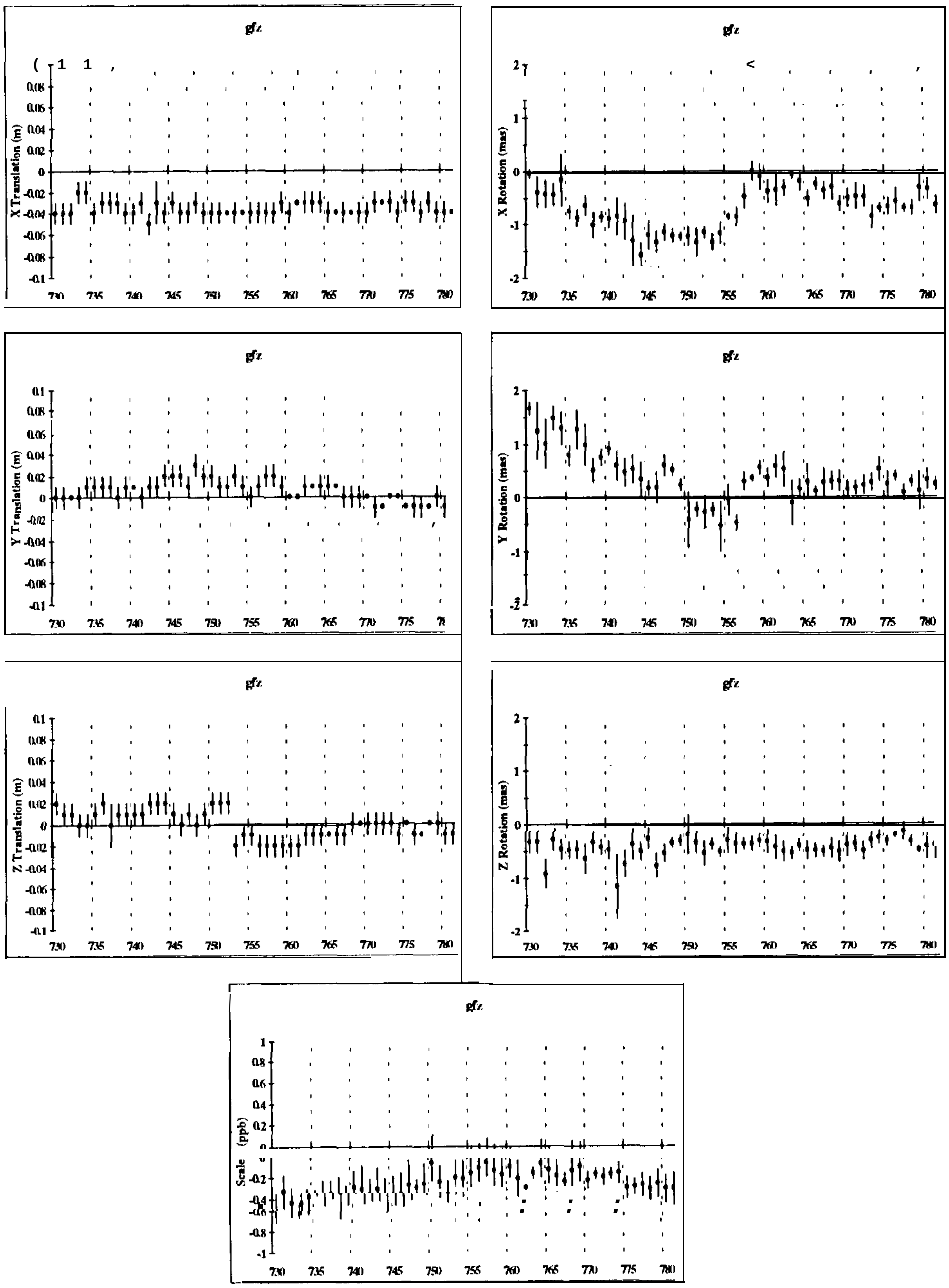
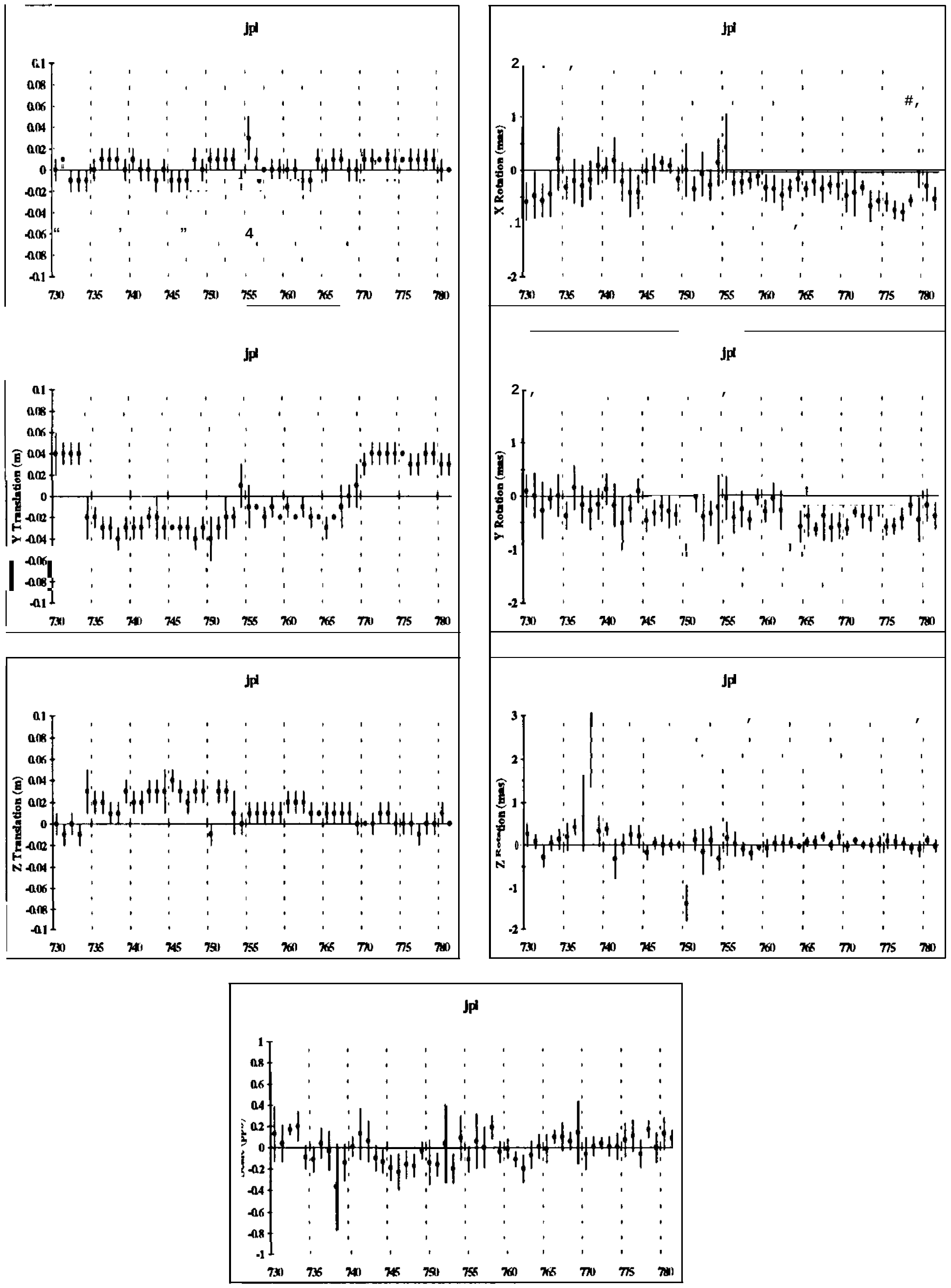


***Figure 4.** GFZ 1994: Weekly Mean 7-Parameter Helmert Transformations.*

Figure 5. JPL 1994: Weekly Mean 7-Parameter Helmert Transformations.



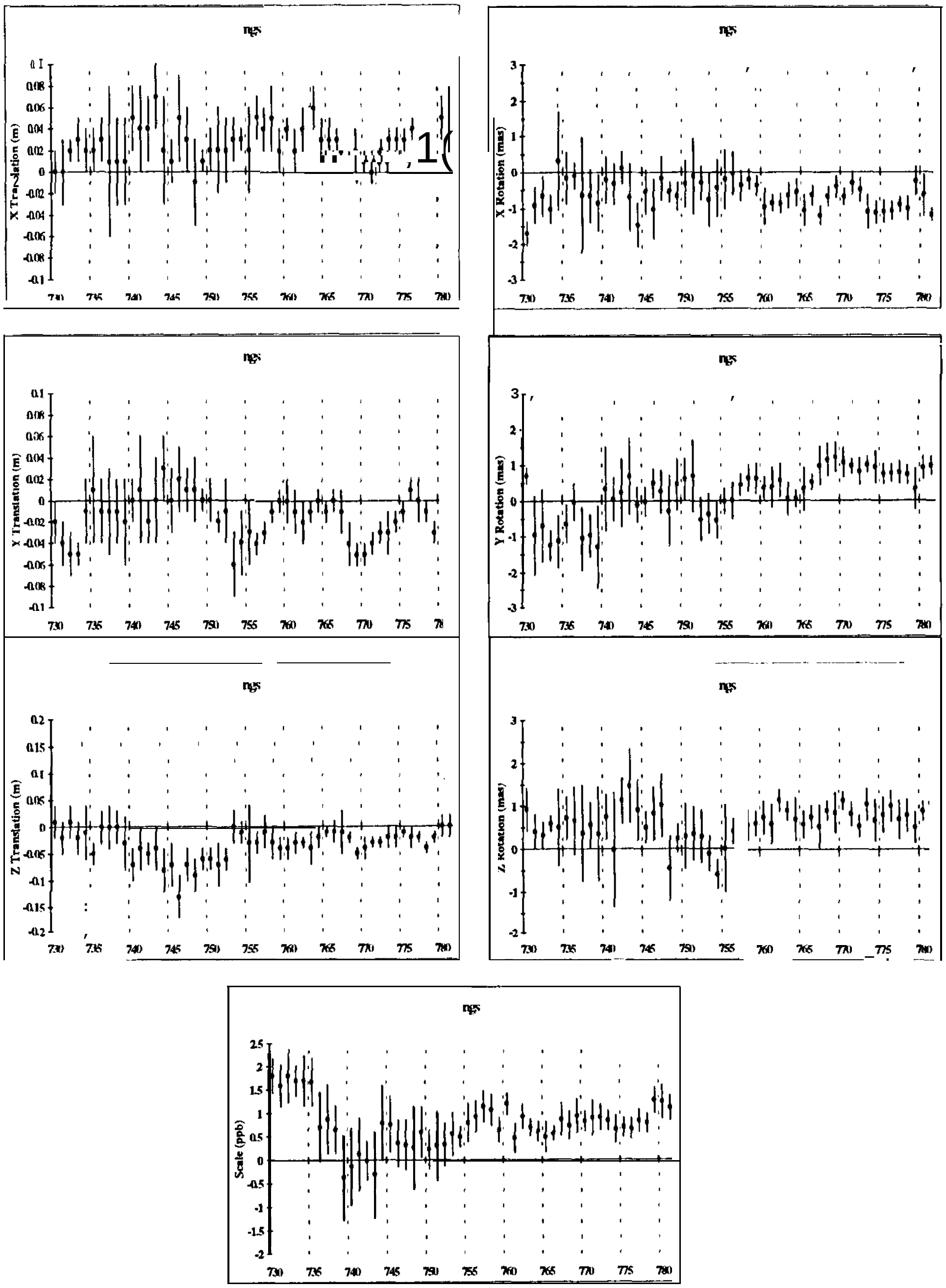
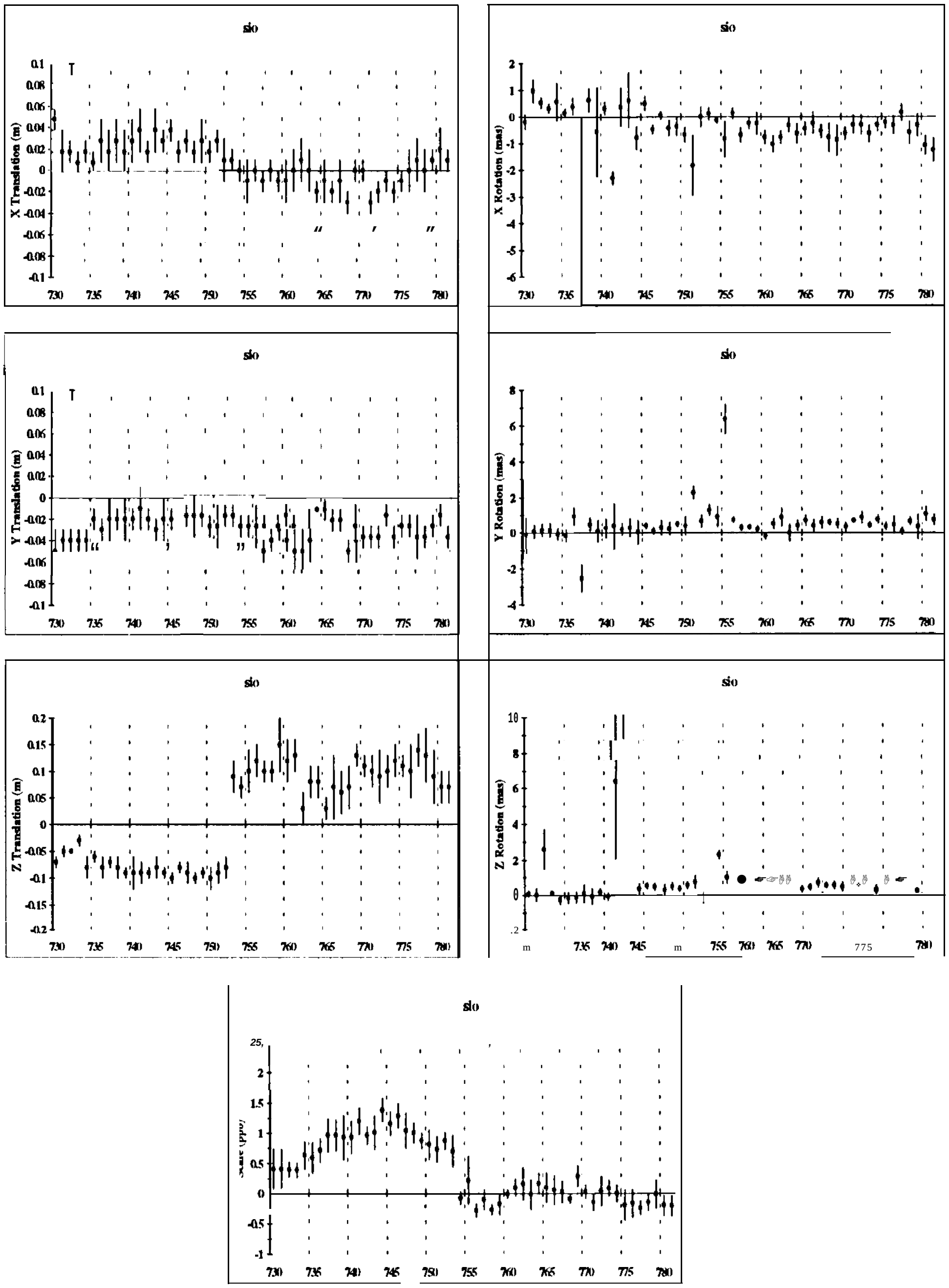


Figure 6. NGS 1994: Weekly Mean 7-Parameter Helmert Transformations..

Figure 7. SIO 1994: Weekly Mean 7-Parameter Helmert Transformations.



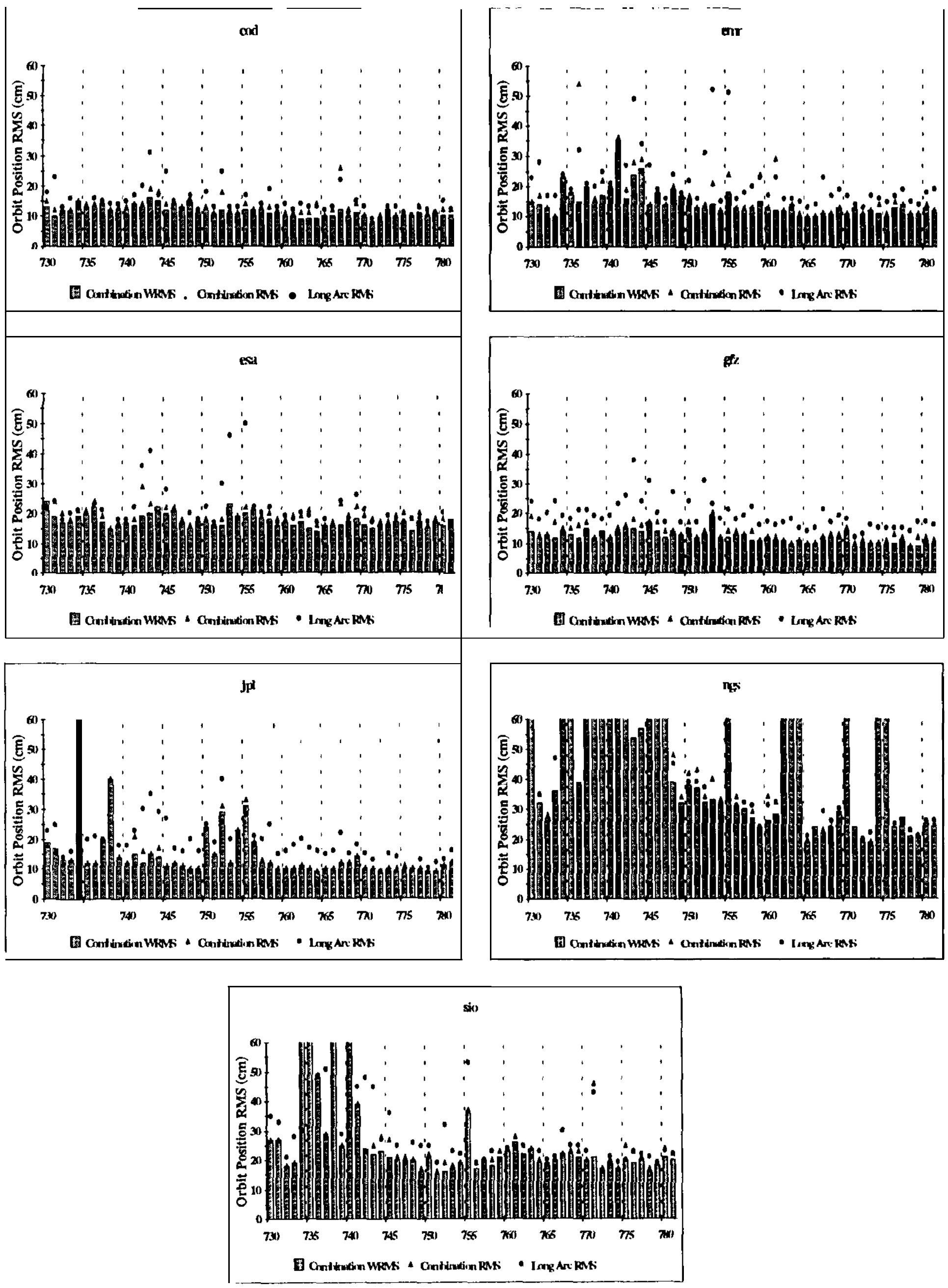
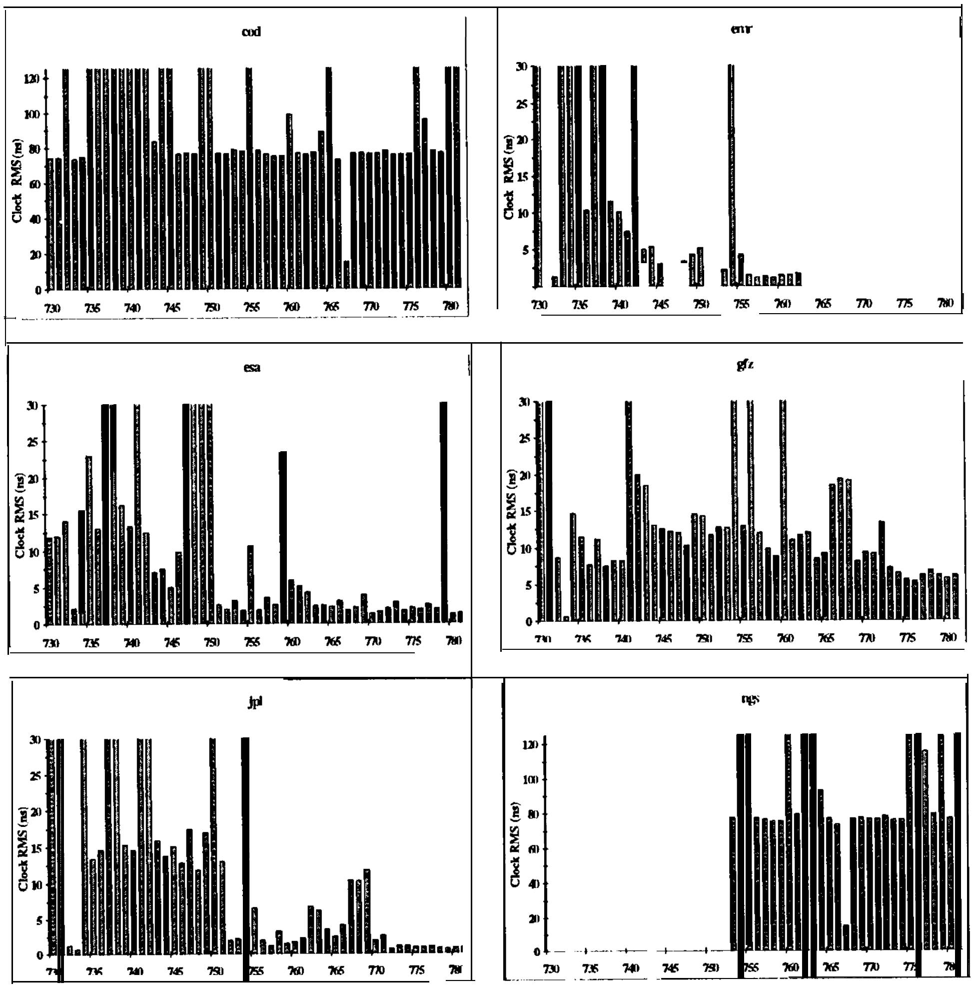


Figure 8. 1994 Weekly Mean Orbit Position RMS (all Analysis Centers.

Figure 9. 1994 Weekly Mean Clock RMS (all Analysis Centers except SIO).



Appendix II
IGS Combination Summary Report Description

Table 1.*gpsweek* of the IGS weekly report consists of two summary tables. Table 1.*gpsweek.* a contains the weekly mean and standard deviation of the transformation parameters (Helmert transformation, clock offset and clock drift) as well as the weekly mean position RMS, WRMS and clock RMS for each Analysis Center. The mean total number of stations used in each Center's submitted solution is given in the "STA" column. See the explanations on Table 2.*gpsweek.day* for more details on the transformation parameters and clock offsets and drifts given in Table 1.gpsweek .a. Note that the high clock RMS for COD and NGS was caused by resets in the broadcast clocks.

Table 1.0781 .a GPS week: 0781 MJD: 49711 .0-49717.0

CENT	STA	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	TOFT	TDRFT	RMS
cod	47	.00	.02	.01	-.51	-.15	-.02	.0	.12	.10	-52.1	70.4	7048,5
		.00	.01	.01	,15	.17	.21	.1			746.6	1359.9	
emr	22	.01	-.01	-.04	-.31	.09	.17	-.1	.12	.12	-70.4	-5.0	1.0
		.01	.01	.01	.21	.25	.11	.1			10.6	4.8	
esa	21	.00	.00	-.01	-.50	-.50	-.31	.0	.21	.18	-4.3	-2.6	1.4
		.00	.01	.02	.43	.37	.40	.2			18.3	8.0	
gfz	37	-.04	-.01	-.01	-.64	.24	-.40	-.3	.11	.11	-62.5	-7.1	6.2
		.01	.01	.01	.17	.13	.25	.1			12.0	4.0	
jpl	32	.00	.03	.00	-.50	-.39	-.02	.1	.12	.12	-66.0	-5.1	.9
		.00	.01	.00	.21	.25	.13	.1			10.6	5.2	
ngs	33	.05	-.02	.00	1.17	.98	1.05	1.1	.25	.24	171.5	-320.2	5155.9
		.03	.01	.01	.17	.26	.33	.2			448.5	843.9	
sio	33	.01	-.05	.07	-1.24	.73	.12	-.2	.22	.20	.0	.0	.0
		.01	.01	.03	.43	.31	.10	.2			.0	.0	

units: meters (m) (DX, DY, DZ, RMS, WRMS);
milliarc-seconds (mas) (RX, RY, RZ);
parts-per-billion (ppb) (SCL);
nanoseconds (ns) (TOFT, TDRFT, RMS).

Example of Table 1.gpsweek.a.

Table 1.*gpsweek* .b contains daily accuracy for each satellite of IGS combined orbits (Appendix I, equation 11). The same values can also be found in the IGS column of Table *3.gpsweek.day* in the 'Weighted Average" block. Satellites which were eclipsing at any time during the week have their PRN flagged with an "E". Occasional remarks are also added when satellites were repositioned or when no or little data were observed for a given satellite.

Example of Table 1.gps week.b.

Table 1.0781 .b GPS week: 0781 MJD: 49711 .0-49717.0

PRN	Day of GPS week 0	1	2	3	4	5	6	Remarks
1	4	4	6	6	6	6	6	
2E	5	6	6	6	7	6	7	
4E	6	5	5	5	5	5	5	
5E	5	5	4	5	5	4	5	
6	4	5	3	4	4	3	5	
7	6	6	5	5	5	6	6	
9	5	4	4	4	3	3	4	
12E	5	3	4	4	4	3	4	
14	3	5	6	4	4	3	4	
15E	8	6	5	6	6	6	7	
16	4	5	4	4	5	4	5	
17E	8	6	8	5	7	6	7	
18	5	4	5	3	4	4	4	
19	5	4	4	4	5	7	12	Lack of data on days 5 and 6.
20E	5	5	5	5	7	5	8	
21	4	5	5	6	5	4	5	
22E	5	6	7	7	7	6	7	
23	8	8	11	11	9	9	10	
24E	8	7	6	7	6	5	6	
25	5	5	4	5	6	6	6	
26	5	4	4	5	4	5	5	
27	4	4	3	4	4	4	5	
28	4	4	4	4	4	3	5	
29	3	4	3	3	3	3	3	
31	5	5	5	6	6	5	7	

units: centimeters (cm).

Table 2 of the report contains seven daily tables (labeled Table 2.*gpsweek.day*). Each table reports on the orbit and clock combination statistics for a particular day. Each Helmert transformation reported is actually the sum of the *a priori* transformation parameters (the rotation to common orientation, Appendix I, Section III) and of the transformation parameters that bring the Center ephemeris to the IGS combined ephemeris (Appendix I, Section III, step 3). Similarly, reconstructed satellite clock transformation parameters (offset and drift) are reported in these tables and are the sum of a *priori* alignment to GPS time (Appendix I, Section IV, step 1) and the final alignment parameters (Appendix I, Section IV, step 4). The first orbit RMS column is estimated with respect to the final Helmert transformation (Appendix I, equation 7). The WRMS column is a weighted version of the first RMS (Appendix I, equation 8).

The last RMS column is the RMS for clock residuals of the final clock transformation (Appendix I, equation 16). Since CODE and NGS provide only broadcast clock corrections in their daily submissions, the clock offsets and drifts for these Centers provide an indication of the IGS clock combination alignment to GPS time. The total number of stations used in each Centre's daily solution is given in the "STA" column.

Table 2.0781.0 GPS week: 0781 Day: O MJD: 49711.0

CENT	STA	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	TOFT	TORFT	RMS
cod	46	.00	.01	.02	-.58	-.03	-.12	.0	.13	.10	3.7	-2,1	76.7
emr	21	.01	.00	-.05	-.33	.02	.25	-.3	.14	.13	-54.7	-1.0	.6
esa	22	.01	.00	.00	-.63	-.69	-.54	.1	.21	.16	-6.5	7.9	1.6
gfz	37	-.03	.00	-.01	-.56	.21	-.31	-.3	.10	.08	-41.9	-11.5	6.5
jpl	32	-.01	.03	.00	-.44	-.45	.24	.1	.10	.10	-50.3	-1.5	.7
ngs	33	.06	-.03	.00	-1.03	.66	.91	1.4	.23	.21	4,0	-2.8	77.1
sio	33	.01	-.05	.07	-1.12	.82	.04	-.1	.20	.17	.0	.0	.0

units: meters(m) (DX, DY, DZ, RMS, WRMS);
milliarc-seconds (mas) (RX, RY, RZ);
parts-per-billion (ppb) (SCL);
nanoseconds (ns) (TOFT, TDRFT, RMS).

Example of Table 2.gpsweek.day.

Table 3 of the report contains 7 daily tables (labeled Table 3*.gpsweek.day*). Each is divided into two parts: one for the combination statistics ('Weighted Average" block) and one for the long arc evaluation statistics ("Orbit Dynamics" block). The former contains the Center daily orbit RMS for each satellite as computed in Appendix I, equation 9. For completeness, it also reports the standard deviations of the weighted average ephemerides (Appendix I, equation 11) which are used as accuracy codes for the IGS combined orbits (also given in Table 1*.gpsweek* b). The second part of the table contains the RMS of residuals per satellite and per day of the seven day arc fit of the individual Analysis Center ephemerides as well as that of the IGS combined orbits. Note that unlike the weighted average RMS, the long arc ("Orbit Dynamics") RMS are sensitive to orbit translation and EOP biases/errors. The last two lines of the table are the total RMS and WRMS (Appendix I, equations 7 and 8) also listed in Table 2*.gpsweek.day* and the total long arc evaluation RMS. Satellites which were eclipsing at any time during the week have their PRN flagged with an "E".

Example of Table 3.gpsweek.day.

Table 3.0781.0 GPS week: 0781 Day: O MJD: 49711.0

	Weighted Average								Orbit Dynamics (7 days)							
PRN	cod	emr	esa	gfz	jpl	ngs	sio	IGS	cod	emr	esa	gfz	jpl	ngs	sio	IGS
1	7	10	11	5	6	21	26	4	12	16	14	15	9	11	16	8
2E	19	12	14	10	10	18	21	5	9	14	13	15	6	21	15	8
4E	10	12	33	9	11	20	19	6	16	15	18	14	9	24	14	11
5E	8	12	15	8	7	19	26	5	8	15	19	17	7	19	18	11
6	9	8	27	5	6	15	20	4	11	14	14	12	7	16	17	10
7	15	22	28	10	12	19	19	6	10	17	12	12	9	15	13	7
9	8	17	16	4	9	24	17	5	9	20	12	12	6	16	13	10
12E	8	18	18	6	9	23	17	5	11	17	13	14	9	14	16	11
14	7	9	9	5	10	16	6	3	7	14	9	9	10	16	11	8
15E	9	14	23	11	18	52	13	8	10	23	32	20	14	54	24	18
16	8	7	16	7	7	18	18	4	6	11	11	10	7	16	9	6
17E	25	11	28	24	12	26	12	8	24	23	37	34	27	42	34	30
18	8	15	9	10	7	25	20	5	9	10	13	12	9	22	19	9
19	12	13	14	6	12	19	24	5	11	15	21	15	7	14	21	10
20E	5	10	26	8	7	24	21	5	8	18	20	14	7	26	13	10
21	12	7	10	9	4	18	13	4	8	13	15	10	7	12	12	7
22E	12	11	14	9	9	18	27	5	11	17	15	16	8	26	21	11
23	35	18	22	15	15	18	19	8	30	48	24	28	43	39	47	34
24E	6	23	52	10	13	30	14	8	13	27	18	18	11	26	20	13
25	10	21	13	6	8	25	21	5	9	12	13	12	6	26	24	9
26	10	5	9	5	10	24	28	5	9	11	15	11	9	19	17	8
27	15	6	14	7	8	19	19	4	11	10	12	13	5	19	12	7
28	6	11	7	10	8	16	16	4	11	12	17	14	7	13	13	9
29	7	12	7	7	5	18	10	3	8	12	10	10	9	20	10	8
31	9	10	16	11	8	16	27	5	6	13	16	13	8	19	22	7
RMS	13	13	21	10	10	23	20		12	18	17	15	12	23	19	13
WRMS	10	13	16	8	10	21	17									

units centimeters.

AUSLIG Regional GPS Data Center Summary for the IGS Annual Report 1994

Martin Hendy
Australian Surveying and Land-Information Group
Belconnen, Australia

Introduction

The Australian Surveying and Land Information Group (AUSLIG) began setting up a national fiducial GPS network in 1991. During 1992 this network was expanded to become a regional GPS network including four stations in Antarctica.

In July 1993 TurboRogue GPS receivers were purchased and sent to the three Antarctic stations Casey, Davis, and Mawson, and the sub-Antarctic station MacQuarie Island. All four stations were installed during the 1993–1994 Antarctic summer season. In 1994 these stations were contributed to the IGS network and the AUSLIG data center was begun.

Operations

The data center has continued to operate since then providing the IGS community with data from the sites: Casey, Davis, Mawson, and MacQuarie Island. Subsequently AUSLIG has placed a TurboRogue receiver at Hobart and now contributes these data to IGS also.

The AUSLIG data center runs on a Sun Sparc10 workstation and has approximately 1.3 Gb of disk space to support the data acquisition and supply to IGS. The data are available by anonymous ftp on Internet from ftp.auslig.gov.au. Data from some sites are also retrieved over the Internet and from other sites by using dial-up phone lines and tcp protocol. The data are received into the center on a continuous basis usually being retrieved in small files at fifteen minute intervals. This frequent retrieval of the data is necessary to support other GPS activities within AUSLIG. The goal for the data center is to provide data reliably within one day of collection.

The data center is staffed by two personnel in the geodesy group of AUSLIG. The geodesy group in AUSLIG operate and maintain this data center as a contribution to regional GPS activities and IGS global activities. Whilst some difficulties have been experienced during early 1995, enhancements currently underway are expected to reduce the likelihood of downtime to less than a few hours.

Problems

As with all ftp sites on Internet the center is always at risk from illegal attempts to access the system. AUSLIG suffered a hacker break-in in April 1995 which took the system down for a week whilst additional security measures were introduced. All AUSLIG Internet sites now have significantly improved security systems in place. However this is a problem which will be with us forever and will undoubtedly affect our operations at some time. New security measures still being introduced will mean that sometime in 1995 the current anonymous system will be replaced with a user/ password system for access by all IGS users and this will be advised with plenty of forewarning. These measures are intended to improve the reliability of the center operations to IGS.

Future Plans

Future plans for the data center are to acquire another UNIX workstation and significant hard disk capacity increase along with RAID 5 capability to support the ongoing commitment of AUSLIG Geodesy to IGS. The anonymous ftp system will also be upgraded to include spare disk capacity in the event of a failure. The goal is to have a system with a maximum downtime due to disk failures of less than six hours. All data held on line will also be held on a duplicate hard disk system so that quick restoration of the data will be possible. All data will be archived onto compact disks. The intention is to hold six to twelve months of data on line.

The installation of this improved system should be complete by end June 1995 and will allow AUSLIG to hold regional data from surrounding countries and to hold a full set of IGS products. It will also allow AUSLIG to supply data from more stations which are due to come on line to IGS during June/July 1995.

With this improved data archive system and continuing network expansion and collaboration with New Zealand and Asian countries, AUSLIG Geodesy intends to build and consolidate an ongoing commitment to the IGS and its goals as a regional data center. Data from New Zealand should be online from July 1995 onwards.

Contact Details

The contact for all inquiries regarding the center is:

Mr. Martin Hendy
P.O. Box 2
Belconnen ACT 2616
AUSTRALIA

PH: +616 2014350
FX: +61 6 2014366
Email: mhendy@nailhost. auslig.gov.au

Data Access

The data are available from this center via anonymous ftp from:

ftp.auslig.gov.au
cd gps/nnn where nnn is the day of year (1 . . . 366)

The data are held in UNIX compressed format as per IGS standards, and file naming also follows the IGS standards. Navigation files in rinex format are also provided and a single file with site identifier brdc is provided, which is a compilation of all navigation files from all regional sites.

CDDIS Global Data Center Report

Carey E. Nell
Computing Systems Office, NASA/Goddard Space Flight Center, Code 920.1,
Greenbelt, Maryland

Introduction

The CDDIS has supported the International GPS Service for Geodynamics (IGS) as a global data center since the IGS Test Campaign (Beutler, 1992) was conducted in June 1992. The IGS has now been an operational service for over a year; the CDDIS activities within the IGS during 1994 are summarized below.

Background

The Crustal Dynamics Data Information System (CDDIS) (Smith and Baltuck, 1993) has been operational since September 1982, serving the international space geodesy and geodynamics community. This data archive was initially conceived to support NASA's Crustal Dynamics Project (Nell, 1993); since the end of this successful program in 1991, the CDDIS has continued to support the science community through NASA's Space Geodesy Program (SGP). The main objectives of the CDDIS are to store all geodetic data products acquired by NASA programs in a central data bank, to maintain information about the archival of these data, and to disseminate these data and information in a timely manner to authorized investigators and cooperating institutions. Furthermore, science support groups analyzing these data submit their resulting data sets to the CDDIS on a regular basis. Thus, the CDDIS is a central facility providing users access to raw and analyzed data to facilitate scientific investigation. A portion of the CDDIS data holdings is stored on-line for remote access. Information about the system is also available via remote download or via the World Wide Web (WWW) (Berners-Lee and Cailliau, 1990) at the Uniform Resource Locator (URL) address *http://cddis.gsfc.nasa.gov/cddis.html*

In mid-1991, the CDDIS responded to the Call for Participation issued by the International Association of Geodesy (IAG) to support the new International GPS Service for Geodynamics (IGS). Support of the IGS as a data center was a logical outgrowth of the increasing involvement of the CDDIS in GPS data archiving in support of NASA programs. In the fall of 1991, the CDDIS was selected to serve as one of three global data centers for the IGS, providing archive and distribution services for the daily GPS observation data from the global network of cooperating sites and weekly products derived from these data. The Scripps Orbit and Permanent Array Center (SOPAC) at the Scripps Institution of Oceanography (S10) in La Jolla, California and the Institut Géographique National (IGN) in Paris, France were also designated as IGS global data centers.

System Description

The CDDIS archive of IGS data and products are accessible worldwide by way of a password-protected user account. New users can contact the CDDIS staff to obtain the required username and password, as well as general instructions on the host computer, directory structure, data availability, and pointers to the IGS Central Bureau Information System (CBIS) (Liu *et* al., 1995).

Computer Architecture

The CDDIS is operational on a dedicated Digital Equipment Corporation (DEC) VAX 4000 Model 200 running the VMS operating system. This facility currently has nearly nineteen Gbytes of on-line magnetic disk storage. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is accessible to users 24 hours per day, seven days per week. The CDDIS is available to users globally through electronic networks using TCP/IP (Transmission Control Protocol/Internet Protocol) and DECnet (VAX/VMS networking protocol), through dial-in service (300-, 1200-, 2400- and 9600-baud) and through the GTE SprintNet system. The diagram in Figure 1 presents the current system configuration and planned near-term system augmentations.

Currently, two magnetic disk drives, totaling 5.7 Gbytes in volume, are devoted to the storage of the daily GPS tracking data. A dual-drive, rewriteable optical disk system provides additional on-line disk storage for GPS data. This unit contains two 5.25-inch optical disk drives with a capacity of 325 Mbytes per platter. These disks also serve as the long-term archive medium for GPS data on the CDDIS. Approximately one week of GPS tracking data (with a network of seventy sites) can be stored on a single side of one of these platters. The older data continues to be stored on these optical disks and can easily be requested for mounting and downloading remotely by the user. Alternatively, if the request is relatively small, data are downloaded to magnetic disk, providing temporary on-line access.

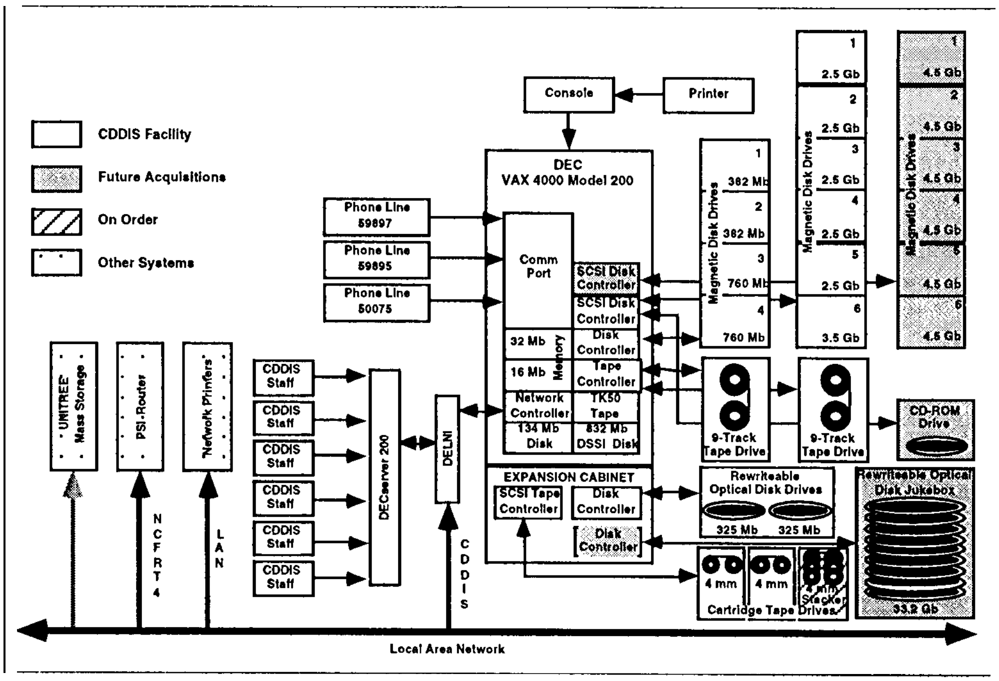


Figure 1. CDDIS Computer System Configuration.

System Access

As stated previously, the data archives on the CDDIS are accessible remotely through Internet, DECnet, and dial-up phone lines, Potential users of the CDDIS are asked to request user account name and password information since the GPS archives are not accessible through an open or "anonymous" account. Table 1 lists the remote access information for the CDDIS computer facility. The CDDIS permits both remote file transfer and direct connections through Internet (i.e., ftp or telnet) and DECnet (i.e., COPY over the network or SET HOST). Dial-up users can run KERMIT or XMODEM software on the CDDIS to upload GPS data and products to their remote hosts. General information about the CDDIS and the GPS data availability, as well as a link to the IGS CBIS, are accessible through the WWW.

Access Method	Host Name	Host Number	Comments
INTERnet	cddis.gsfc.nasa.gov	128.183.10.141	FTP and TELNET available
DECnet	CDDIS	15.217 (15577)	Remote copy and SET HOST available
Dial-up	CDDIS	301-286-9000	Autobaud 300,1200,2400
		301-286-4000	Autobaud to 9600

Table 1. CDDIS Computer Access Methods.

Directory Structure

The CDDIS has established separate disk areas for data, products, and supporting information (Figures 2 through 4). The CDDIS is operational on a VAX computer running the VMS operating system; users from the UNIX environment may find VMS directory structures and commands confusing. As on most systems, data accessible through the CDDIS are stored on disk volumes with directories. A complete file specification on the CDDIS VAX has the format:

DEVICE:[DIRECTORY.SUBDIRECTORY]FILENAME.EXTENSION;VERSION

where

DEVICE	is the physical device on which the file is stored
DIRECTORY	is the main directory containing the file
SUBDIRECTORY	is(are) the directory(s) under the main directory (mayor may not be required)
FILENAME	is the name of the file
EXTENSION	is the extension of the filename (_Z appended to the end denotes a compressed file)
VERSION	is the version number of the file, incremented if a new copy of the file is created

Some useful ftp commands used to navigate and retrieve files from the CDDIS VAX are listed in Table 2.

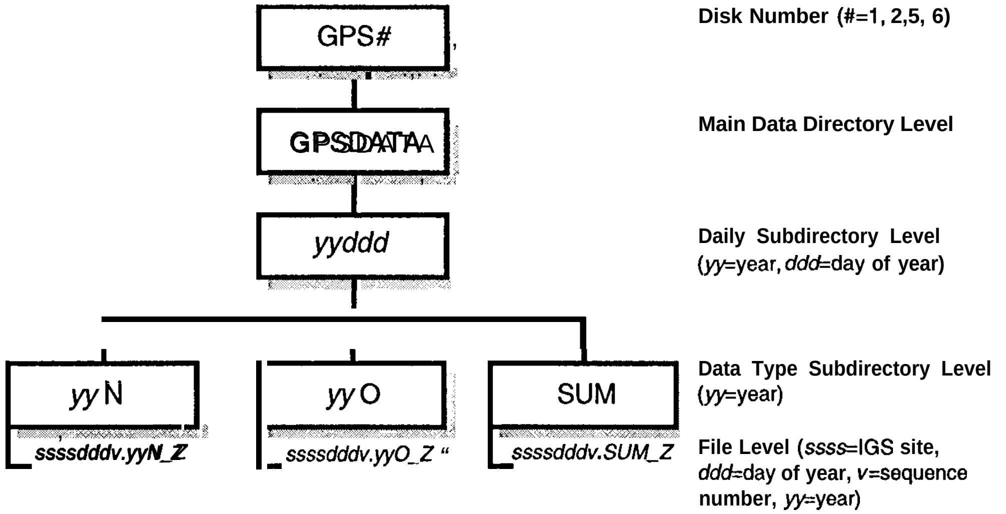


Figure 2. Directory Structure on CDDIS for GPS Data.

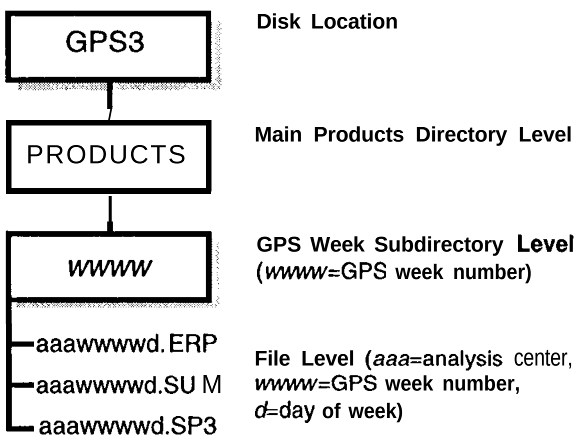


Figure 3. Directory Structure on CDDIS for GPS Products.

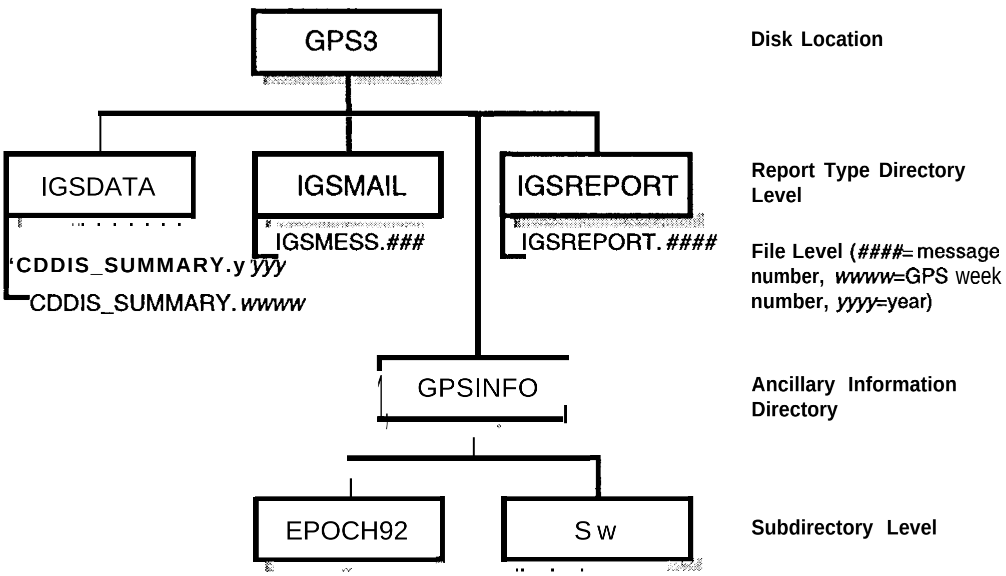


Figure 4. Directory Structure on CDDIS for Supporting GPS Information.

Table 2. Useful VAX FTP Commands.

Command	Definitions/Example	
CD	Change directory	
	Examples:	CD[.SUBDIRECTORY] (change directory to a subdirectory under the main directory)
		CD DISK: [DIRECTORY] (change directory to another disk and directory)
		CD DISK: [OOOOOO] (change directory to the root directory on disk device DISK; only valid for anonymous ftp access on CDDIS)
LS	List files in current directory	
DIR	List files in current directory with creation date and size, in VAX blocks, where one VAX block equals 512 bytes	
GET	Get a file	
	Example:	GET FILENAME. EXTENSION LOCALFILE (get file FILENAME, EXTENSION and store it in file LOCALFILE on the user's computer)
MGET	Multiple get	
	Example:	MGET FILENAME.* *.* (get all files starting with FILENAME and store them using the same naming convention on the user's home computer)

Archive Content

The CDDIS began archiving GPS tracking data in early 1992 in support of NASA programs. The user community for this archive has now expanded to include the IGS. As stated previously, the role of the CDDIS in the IGS is to serve as one of three global data centers. In this capacity, the CDDIS is responsible for archiving and providing access to both GPS data from the global IGS network as well as the products derived from the analysis of these data.

GPS Tracking Data

IGS users have access to the on-line and near-line archive of GPS data available through the three global archives. Operational and regional data centers (Gurtner and Neilan, 1995) were also selected by the IGS to provide the interface to the network of GPS receivers. For the CDDIS, the Australian Survey and Land Information Group (AUSLIG) in Belconnen, Australia, NOAA's Cooperative International GPS Network (CIGNET) Information Center (CIC) in Rockville, Maryland, the Natural Resources of Canada (NRCan) in Ottawa, Canada, the European Space Agency (ESA) in Darmstadt, Germany, the Geographical Survey Institute (GSI) in Tsukuba, Japan, and the Jet Propulsion Laboratory (JPL) in Pasadena, California make data available to the CDDIS from selected receivers on a daily basis. In addition, the CDDIS accesses the remaining two global data centers, S10 and IGN, to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by a regional data center. Table 3 lists the data sources and their respective sites that were transferred daily to the CDDIS in 1994; Table 4 presents detailed information on the sites whose data were archived in the CDDIS during 1994, with data availability information. These data are summarized and archived to public disk areas (Figure 2) in daily subdirectories; the summary and inventory information are also loaded into an on-line data base. Figure 5 illustrates the data flow, from station to public archive on the CDDIS. Typically, the archiving routines on the CDDIS are

Table 3. Sources of GPS Data on CDDIS.

Source	Sites								No. Sites
AUSLIG	CAS1	DAVI	HOB2[1]	MAC1					4
CIGNET	BRMU	FORT	HOB1[1]	RCM5	TAIW	TSKB[2]	WES2	WFRD	8/6
EMR	ALBH	ALGO	DRAO	STJO	YELL				5
ESA	KIRU	KOUR	MASP/'	PERT	VILL				5
GSI	TSKB								1
IGN	BRUS	GRAZ	HART	HERS	JOZE	KERG	KIT1	KOSG	
	MATE	METS	NYAL	ONSA	PAMA	TROM	WETT	ZIMM	16
JPL	AOA1	AREQ	BOGT	CARR	CASA	CIT1	EISL	FAIR	
	GOLD	GODE	HARV	JPLM	KOKB	LBCH	MADR	MDO1	
	MCMU	NLIB	OATT	PIE1	QUIN	SANT	TIDB	Uscl	
	USUD	WLSN	YAR1						27
SIO	MATH	MONP	PIN1	PVEP	SI03	VNDP			6
Totals:						70 sites from 8 data centers			

Notes: 1 The AUSLIG receiver HOB2 replaces the CIGNET receiver HOB1
2 In June 1994, GSI assumed responsibility for transmission of TSKB data

Table 4.1994 GPS Data Holdings of the CDDIS.

Site Name	N. Lat.	E. Long.	Mon. Name	Source†	Receiver Type	Start Date	End Date	No. Days
Albert Head, Canada	48°23	-123°29'	AL8H	E	Rogue SNR-8C	01-Jan-94	15-Feb-94	46
					Rogue SNR-8000	16-Feb-94	—	319
Algonquin, Canada	45°57'	-78"04'	ALGA	E	Rogue SNR-8000	23-Feb-94	24-Feb-94	2
			ALGO	E	Rogue SNR-8	01-Jan-94	15-Feb-94	46
					Rogue SNR-8000	17-Feb-94	—	317
Ankara, Turkey	39°53'	32" 45'	ANKA	c	MiniMac 2816AT	01-Jan-94	22-Apr-94	133
AOA, Westlake, CA	34°10	-118°50'	AOA1	J	Rogue SNR-8000	30-Aug-94	—	106
Arequipa, Peru	-16°28'	-71°38'	AREQ	J	Rogue SNR-8000	31-Jan-94	—	309
Bermuda	32"21'	-64°39	BRMU	C	Rogue SNR-8000	01-Jan-94	—	363
Bogota, Colombia	04°38'	-74°05'	BOGT	J	Rogue SNR-8000	07-Nov-94	—	17
Brussels, Belgium	50°18'	04°13'	8RUS		Rogue SNR-8000	10-Jun-94	—	204
Carr Hill, CA	35°53'	-120°26'	CARR	J	Rogue SNR-8000	28-May-94	—	210
Casey, Antarctica	-66°16'	110°32'	CASI	A	Rogue SNR-81OO	05-Jul-94	—	176
CIT, Pasadena, CA	34009'	-118°08'	CIT1	J	Rogue SNR-8000	07-Sep-94	—	116
Davis, Antarctica	-6B°34'	77"58'	OAV1	A	Rogue SNR-8100	05-Jul-95	—	149
Easter Island, Chile	-27009'	-109°23'	EISL	J	Rogue SNR-8000	23-Jan-94	—	238
Fairbanks, AK	64058'	-147"29	FAIR	J	Rogue SNR-8	01-Jan-94	—	362
Fort Davis, TX	30°38	-103°57'	FTOS	v	Rogue SNR-8000	21-Jan-94	31-Jan-94	11
Fortaleza, Brazil	-03°45'	-38035'	FORT	c	Rogue SNR-8000	01-Jan-94	—	361
Goldstone, CA	35°15'	-116"47'	GOLD	J	Rogue SNR-8	01-Jan-94	—	364
Graz, Austria	47°04'	15°30'	GRAZ	I	Rogue SNR-8	01-Jan-94	—	358
Green Bank, WV	38°26	-79°50	TO07	v	Rogue SNR-8000	09-Jan-94	10-Feb-94	32
Greenbelt, MO	39"01'	-76°50	GODE	J	Rogue SNR-8000	02-Jan-94	15-Dee-94	342
					Rogue SNR-81OO	16-Dec-94	—	16
Hartebeesthoek, S. Africa	-25°53	27°42'	HART	I	Rogue SNR-8	01-Jan-94	—	348
Harvest Platform, CA	34°28'	-120°41'	HARV	J	Rogue SNR-8000	01-Jan-94	—	365
Herstmonceux, Gr. Britain	50"52'	00°20	HERS	I	Rogue SNR-8A	01-Jan-94	—	358
Hobart, Australia	-42°48	147°26'	HOB1	c	Rogue SNR-8000	01-Jan-94	07-Aug-94	218
			HOB2	A	Rogue SNR-81OO	05-Jul-94	—	135
Jozefoslaw, Poland	51002'	21"30	JOZE	I	Trimble 4000SSE	01-Jan-94	—	359
Kerguelen Island	-49"21'	70°16	KERG	I	Rogue SNR-8C	16-Nov-94	—	46
Kiruna, Sweden	67°32'	20°09	KIRU	F	Rogue SNR-B1OO	01-Jan-94	—	362
Kitab, Uzbekistan	39"08	66°53'	KIT3	I	Rogue SNR-8000	02-Ott-94	—	88
Kokee Park, HI	22o OB'	-159040'	KOKB	J	Rogue SNR-8	01-Jan-94	—	346
Kootwijk, The Netherlands	52°11'	05°49	KOSG	I	Rogue SNR-8	01-Jan-94	—	264
					Rogue SNR-8000	24-Aug-94	22-Nov-94	91
Kourou, French Guiana	05°08'	-52°37'	KOUR	F	Rogue SNR-8C	01-Jan-94	—	365

Table 4. (cont.)

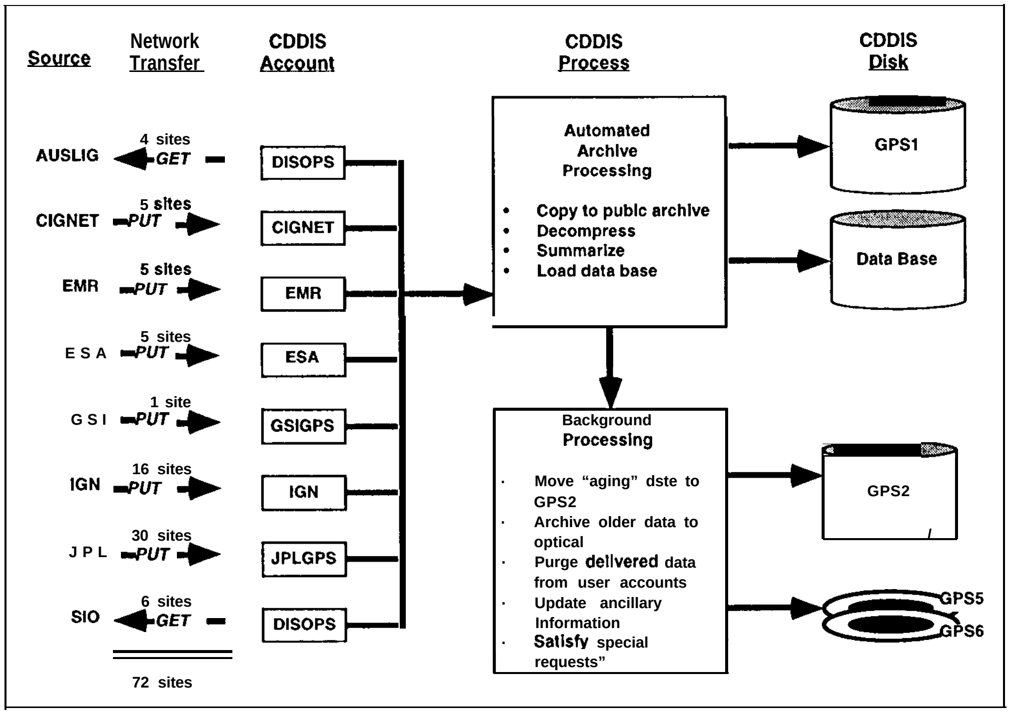
Lake Mathews, CA	33"52'	-117°27'	MATH	s	Trimble	4000SSE	01-Jan-94	—	342
Long Beach, CA	33028'	-118°09'	LBCH	J	Rogue	SNR-8000	26-Jul-94	—	158
Los Alamos, NM	35°47'	-106°15'	LOSA	v	Rogue	SNR-8000	08-Jan-94	01-Feb-94	11
Macquarie Isl., Australia	-54°30'	158"56	MAC1	A	Rogue	SNR-81OO	05-Jul-94	—	176
Madrid, Spain	40°26'	-04°15'	MADR	J	Rogue	SNR-8	01-Jan-94	—	361
Mammoth Lakes, CA	37°38'	-118°57'	CASA	J	Rogue	SNR-8000	01-Jan-94	—	315
Maspalomas, Canary Isl.	27°46	-15°38	MASP	F	Rogue	SNR-8C	01-Jan-94	11 -Sep-94	254
			MASI	F	Rogue	SNR-8100	04-Jun-94	—	211
Matera, Italy	40"39	16°42'	MATE	I	Rogue	SNR-8	01-Jan-94	—	364
McDonald, TX	30°41'	-104°01'	MDO1	J	Rogue	SNR-8000	01-Jan-94	—	364
McMurdo, Antarctica	-77°51'	166°40	MCMU	J	Rogue	SNR-8	14-Jan-94	02-Apr-94	59
					Rogue	SNR-8000	04-Apr-94	—	263
Metsahovi, Finland	60°13'	24°24'	METS	I	Rogue	SNR-8C	02-Jan-94	—	358
Monument Peak, CA	32"53'	-1 1&' 25'	MONP	s	Ashtech	Z-XII3	01 -Apr-94	—	199
Mount Wilson, CA	34013'	-118°04'	WLSN	J	Rogue	SNR-8000	15-Jul-94	—	168
North Liberty, 1A	41°46'	-91°34'	NLIB	J	Rogue	SNR-8000	01-Jan-94	—	339
Ny Alesund, Norway	78° 56'	11°52'	NYAL		Rogue	SNR-8	01-Jan-94	—	347
Oatt Mountain, CA	34°20	-118°36'	OATT	J	Rogue	SNR-8000	19-Jul-94	—	159
Onsala, Sweden	57"24'	11°56	ONSA		Rogue	SNR-8000	01-Jan-94	—	361
Pales Verdes, CA	33°45	-1 18" 24'	PVEP	s	Trimble	4000SSE	01-Jan-94	—	344
Pamate, French Polynesia	-17°34'	-149°34'	PAMA	I	Rogue	SNR-800	01-Jan-94	—	358
Pasadena, CA	34°12'	-118°10	JPLM	J	Rogue	SNR-8	01-Jan-94	13-Jun-94	164
					Rogue	SNR-8100	14-Jun-94	—	201
Penticton, Canada	49°19	-119°37'	DRAO	E	Rogue	SNR-8	01-Jan-94	09-Jan-94	9
					Rogue	SNR-8000	10-Jan-94	—	355
Perth, Australia	-31°58'	115"49'	PERT	F	Rogue	SNR-81OO	01-Jan-94	—	347
Pie Town, NM	34°18'	-108°07'	PIE1	J	Rogue	SNR-8000	01-Jan-94	—	363
Pinyon Flat, CA	33°37'	-116°27'	PIN1	s	Ashtech	Z-XII3	03-Jan-94	—	353
Quincy, CA	39°58'	-120°56'	QUIN	J	Rogue	SNR-8000	01-Jan-94	—	361
Richmond, FL	25°37'	-800 23'	RCM5	c	Rogue	SNR-8000	01-Jan-94	—	358
Saint John's, Canada	47036'	-52°41'	STJO	E	Rogue	SNR-8C	01-Jan-94	25-Feb-94	56
					Rogue	SNR-8000	26-Feb-94	—	304
Santiago, Chile	-33°09'	-70°40'	SANT	J	Rogue	SNR-8	01-Jan-94	—	341
Scripps, CA	32052'	-117°15'	SI03	s	Ashtech	Z-XII3	02-Jan-94	—	358
St. Croix, U.S. Virgin Isl.	17°45'	-64°35'	CRO1	J	Rogue	SNR-8000	14-Jan-94	14-Feb-94	31
Taiwan	25°01'	121°32'	TAIW	C	Rogue	SNR-800	01-Jan-94	—	353
					Rogue	SNR-8000	26-May-94	02-Jun-94	8
Tidbinbilla, Australia	-35°24'	148°59'	TIDB	J	Rogue	SNR-8	01-Jan-94	—	364
Tromso, Norway	69°40'	18°56	TROM	I	Rogue	SNR-8	01-Jan-94	—	359
Tsukuba, Japan	36006'	140°05'	TSKB	G	Rogue	SNR-8000	01-Jan-94	—	364
USC, Los Angeles, CA	34°01'	-118°18'	Uscl	J	Rogue	SNR-8000	1O-NOV-94	—	52
Usuda, Japan	36°08'	138°22'	USUD	J	Rogue	SNR-8000	01-Jan-94	—	364
Vandenberg, CA	34"34'	-120°30	VNDP	s	Rogue	SNR-8	01-Jan-94	13-May-94	127
					Ashtech	Z-XII3	14-May-94	—	216
Villafranca, Spain	**42°11'**	**-01°27'**	**VILL**	**F**	Rogue	SNR-81OO	25-Nov-94	—	36
Westford, MA	**42037'**	**-71°29'**	WES2	C	Rogue	SNR-8000	01-Jan-94	—	359
			WFRD	C	Rogue	SNR-8000	01-Jan-94	25-Aug-94	197
Wettzell, Germany	**49°09'**	12°53'	WETT	I	Rogue	SNR-BOO	01-Jan-94	—	356
Wuhan, China	30°35'	114°19'	WUHA	c	MiniMac	2816AT	01-Jan-94	20-Ott-94	277
Yaragadee, Australia	-29°03'	115"21'	YAR1	J	Rogue	SNR-8	01-Jan-94	—	364
Yellowknife, Canada	62029'	-114"29'	YELL	E	Rogue	SNR-8C	01-Jan-94	16-Mar-94	74
					Rogue	SNR-8000	17-Mar-94	—	289
Zimmerwald, Switzerland	46053'	07°28'	ZIMM	I	Trimble	4000SSE	01-Jan-94	—	364
Totals:	76 occupations at 72 sites						21,582 station days		

†Source definitions:

A AUSLIG	E: EMR	G: GSI	J: JPL	V VLBI (GSFC)
C: CIGNET	F: ESA	1: IGN	s: SIO	

Note: This table includes sites which were not continuously operated during 1994.

Figure 5. Flow of Data from IGS Site to the CDDIS.



executed several times a day for each source in order to coincide with their automated delivery processes. In general, the procedures for archiving the GPS tracking data are fully automated, requiring occasional monitoring only, for replacement data sets or re-execution because of system or network problems.

The CDDIS GPS tracking archive consists of observation and navigation files in compressed (UNIX compression) RINEX (Gurtner, 1994) format as well as summaries of the observation files used for data inventory and reporting purposes. Under the current sixty to seventy station network configuration, approximately 150 days worth of GPS data are available on-line to users at one time. During 1994, the CDDIS archived data on a daily basis from an average of sixty stations; toward the end of the year, this number increased to nearly seventy stations. Each site produces approximately 0.5 Mbytes of data per day; thus, one day's worth of GPS tracking data, including the CDDIS inventory information, totals nearly 35 Mbytes. For 1994, the CDDIS GPS data archive totaled nearly eleven Gbytes in volume; this represents data from nearly 21,600 observation days. Of the seventy or more sites archived each day at the CDDIS, not all are of "global" interest; some, such as those in Southern California, are regionally oriented. The CDDIS receives data from these sites as part of its NASA archiving responsibilities.

For each day, there is one observation and, typically, one ephemeris data file for each IGS site. The ephemeris data files for a given day are decompressed and then merged into a single file, which contains the orbit information for all GPS satellites for that day. This daily ephemeris data file, in compressed form and named BRDC*ddd*0.*yy*N_Z (where *ddd is* the day of year and *yy* is the year), is then copied to the archive disk in the ephemeris subdirectory for that day. Users can thus download this single file instead of all broadcast ephemeris files from the individual stations.

In general, the data delivered to and archived on the CDDIS during 1994 was available to the user community within 48 hours after the observation day. Figure 6 shows that nearly eighty percent of the data from all sites delivered to the CDDIS was available within one day of the end of the observation day; nearly ninety percent was available within two days. Figure 7 presents these statistics by data source. Figures 8 and 9 show these statistics for the 39 "global stations" (Liu, *et al.*, 1995) processed by three or more IGS Analysis Centers on a daily basis. As can be seen, the delivery statistics improve slightly for these sites. Figure 9 presents the availability information by site, with an overlay showing how many observation days were available during 1994; a few of the sites were not operational for a majority of 1994 and the statistics could reflect delays due to the initiation of the new data flow. These statistics were derived from the results of the daily archive report utilities (Gurtner and Neilan, 1995) developed by the IGS Central Bureau and executed several times each day on the CDDIS.

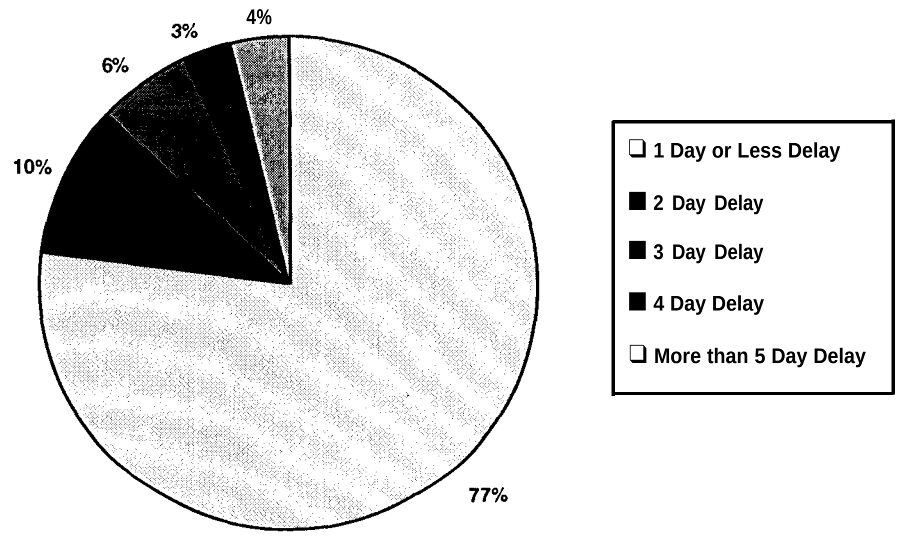


Figure 6. CDDIS GPS Data Availability Statistics.

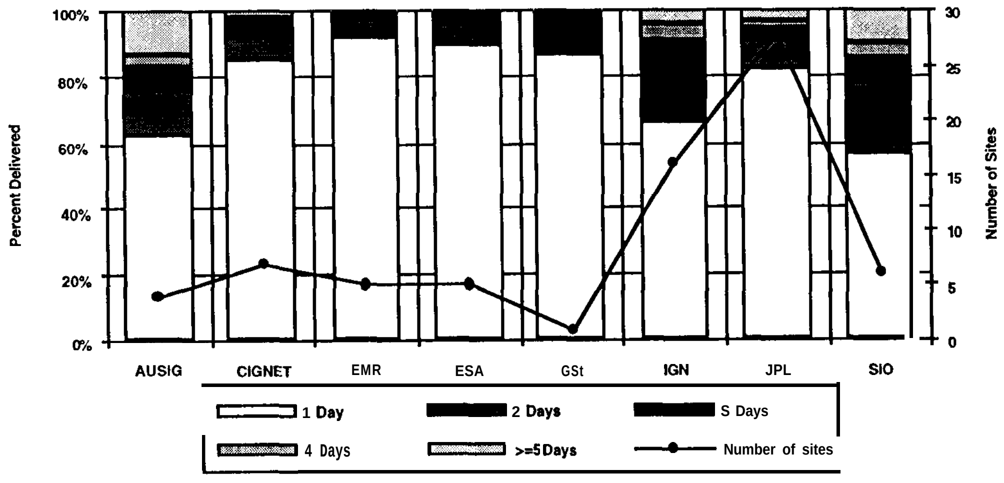


Figure 7. CDDIS GPS Data Availability Statistics (by Source).

Figure 8. CDDIS GPS Data Availability Statistics (Global Stations Only).

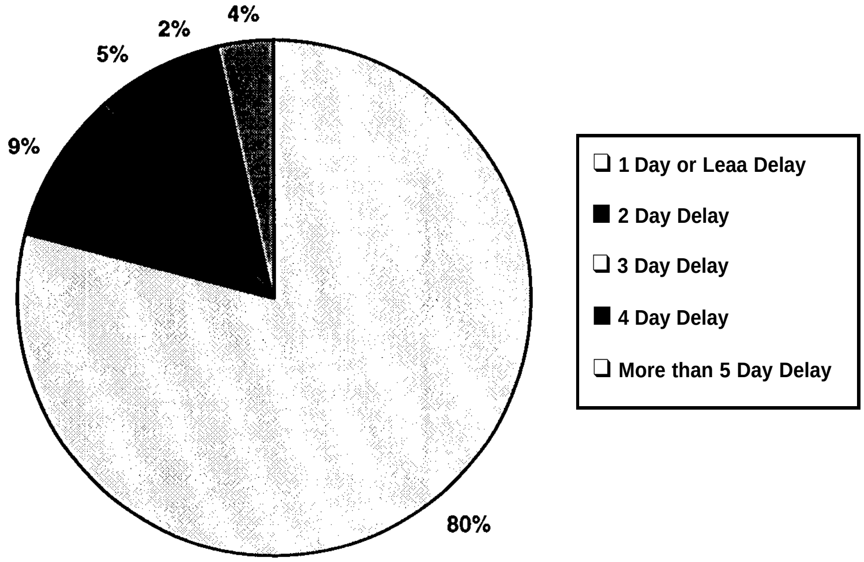
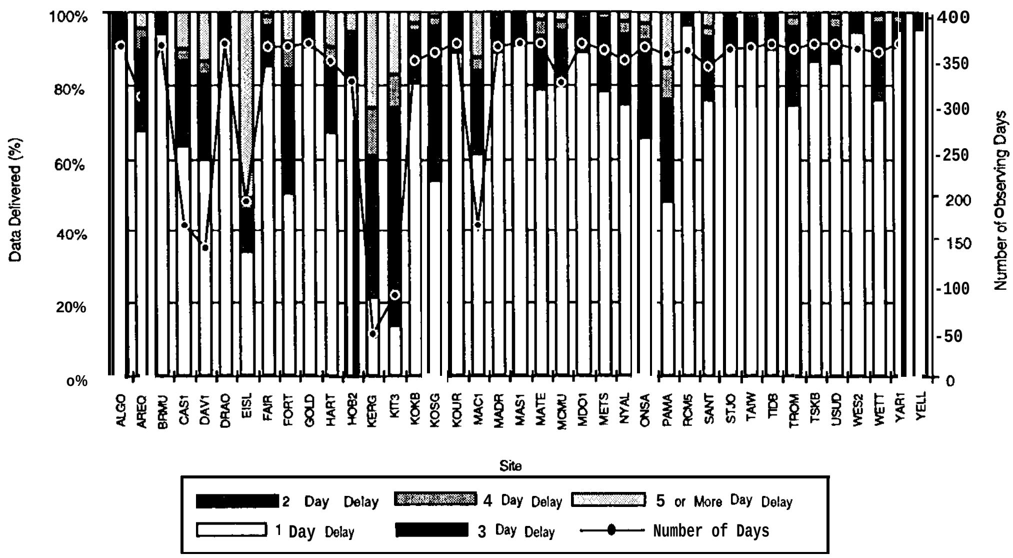


Figure 9. CDDIS GPS Data Availability Statistics by Site (Global Stations Only).



IGS Products

The seven IGS data analysis centers, the Center for Orbit Determination (CODE) at the Astronomical Institute of Berne (AIUB), Switzerland, ESA, the GeoforschungsZentrum in Potsdam, Germany, NRCan (formerly Energy, Mines, and Resources, EMR), JPL, the National Geodetic Survey (NGS) in Rockville, Maryland, and S10 retrieve the GPS tracking data daily from the global data centers to produce IGS data products. The CDDIS also archives these products, such as the daily and weekly precise satellite ephemerides, clock corrections, and the Earth rotation parameters. These files are sent to the CDDIS by the IGS analysis centers in the NGS SP3 format (Remondi, 1989), stored in their respective user accounts, and then copied to a central disk archive, generally in uncompressed ASCII format. The Analysis Coordinator for the IGS, located at NRCan, then accesses the CDDIS (or one of the other global analysis centers) on a regular basis to retrieve these products to derive the combined IGS orbits, clock corrections, and Earth rotation parameters as well as to generate reports on data quality and statistics on product comparisons (Beutler, *et* cd., 1993). Furthermore, users interested in obtaining precision orbits for use in general surveys and regional experiments can also download these data. The CDDIS currently provides on-line access to all IGS products generated since the start of the IGS Test Campaign in June 1992.

The derived products from the IGS Analysis Centers are typically delivered to the CDDIS within one to three weeks of the end of the observation week. Figures 10 and 11 present the product availability statistics (from analysis center to the CDDIS), in general and by source. The statistics were computed based upon the delivery date of the last file to arrive for the week. As can be seen, seventy percent of the derived products was available to the user community within seven days of the end of the observation week; nearly ninety percent was available within ten days. Figure 11 shows the average delay during 1994, in days and by source, of products delivered to the CDDIS. The time delay of the IGS rapid products is dependent upon the timeliness of the individual IGS analysis centers; on average, the combined orbit is generated within two to three days of receipt of data from all analysis centers.

Supporting Information

Ancillary information to aid in the use of GPS data and products is also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data archived at the CDDIS are generated on a routine basis. In addition, the CDDIS maintains an archive of and indices to IGS Mail and Report messages. These files are in directories on disk GPS3 as shown in Figure 4.

During 1994, the CDDIS staff completed a catalog (Nell, 1994) of the IGS Epoch '92 experiment. Epoch '92 was an intensive tracking period consisting of two weeks (July 25 through August 08, 1992) during the 1992 IGS Test Campaign; over 100 sites observed globally representing over thirty nations. The catalog, available in hardcopy or postscript form from the CDDIS, gives information on the sites occupied, maps, participating agencies, and data availability.

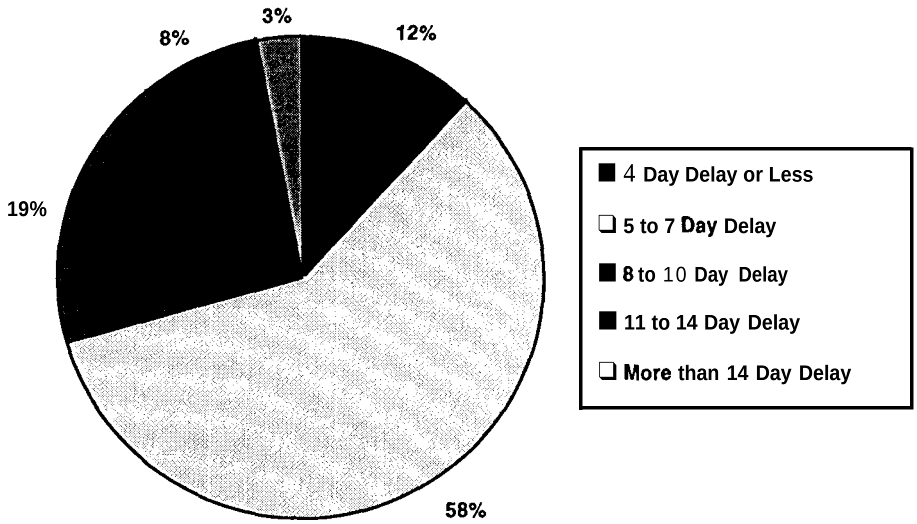
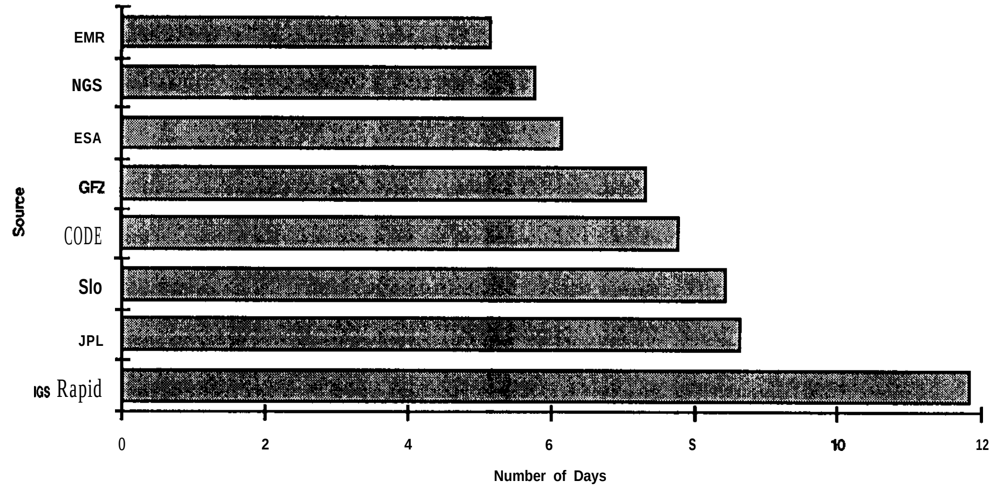


Figure 10. CDDIS GPS Product Availability Statistics.

Figure 11. Average Delay in GPS Product Delivery to the CDDIS (by Source).



System Usage

Figures 12 through 14 summarize the monthly usage of the CDDIS for retrieval of GPS data during 1994. These figures were produced daily by automated routines that peruse the log files created by each network access of the CDDIS. In total, nearly 640K files were transferred, amounting to approximately 160 Gbytes in volume. Averaging these figures, users transferred 53K files per month totaling 13 Gbytes in size, As can be seen, the monthly totals increased significantly during the latter months of 1994 and have continued on this trend during early 1995. The chart in Figure 14 details the total number of host accesses per month with the number of distinct (i.e., unique) hosts (i.e., users) per month shown as an overlay. Here, a host access is defined as an initiation of an ftp or remote DECnet copy session; this session may list directory contents only, or may transfer a single file, or many files. Figure 15 illustrates the profile of users accessing the CDDIS during 1994; these figures represent the number of distinct hosts in a particular country or organization. Nearly half of the users of GPS data available from the CDDIS come from U.S. government agencies, universities, or corporations.

The figures referenced above display statistics for routine access of the on-line CDDIS GPS data archives. However, a significant amount of staff time is expended on fielding inquiries about the IGS and the CDDIS data archives as well as identifying and making data available from the off-line archives. Table 5 summarizes the type and amount of special requests directed to the CDDIS staff during 1994. To satisfy requests for off-line data, the CDDIS staff must copy data from the optical disk archive to an on-line magnetic disk area, or for larger requests, mount the optical disks in a scheduled fashion, coordinating with the user as data are downloaded.

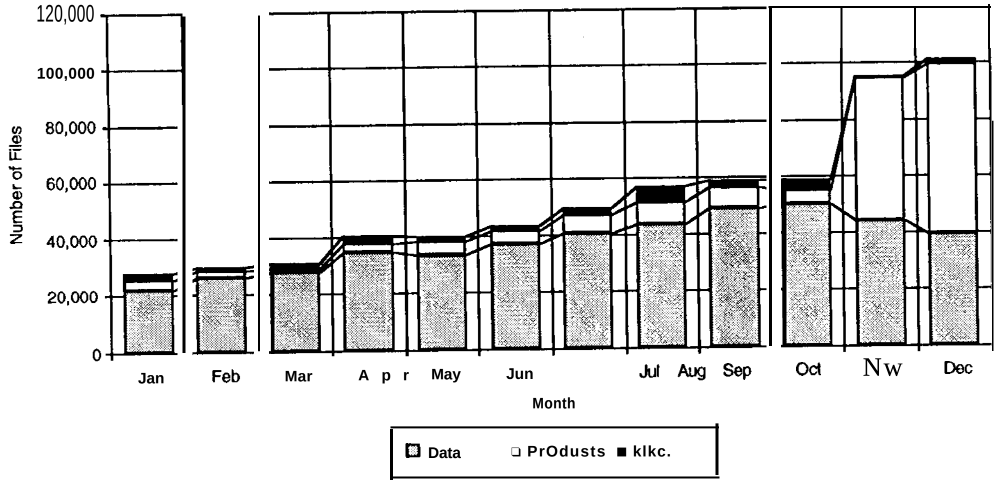


Figure 12. Number of Files Transferred During 1994 in Support of the IGS.

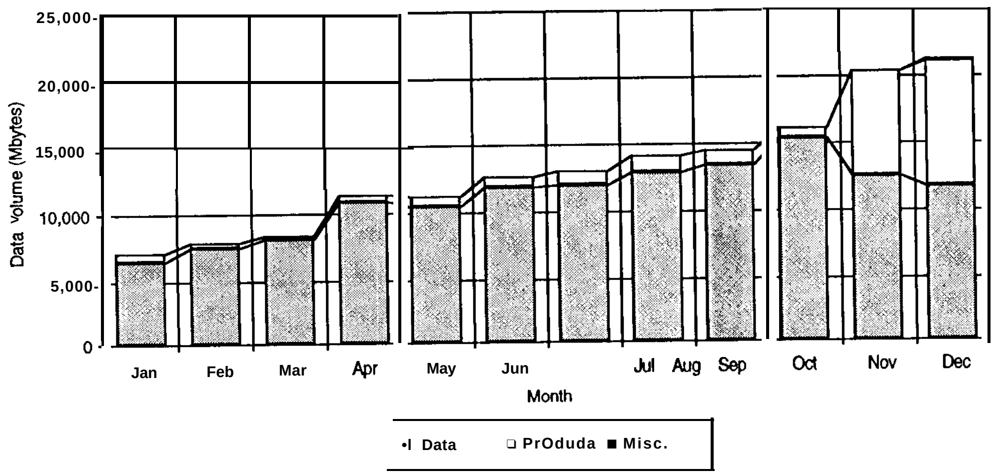


Figure 13. Volume of Data Transferred During 1994 in Support of the IGS.

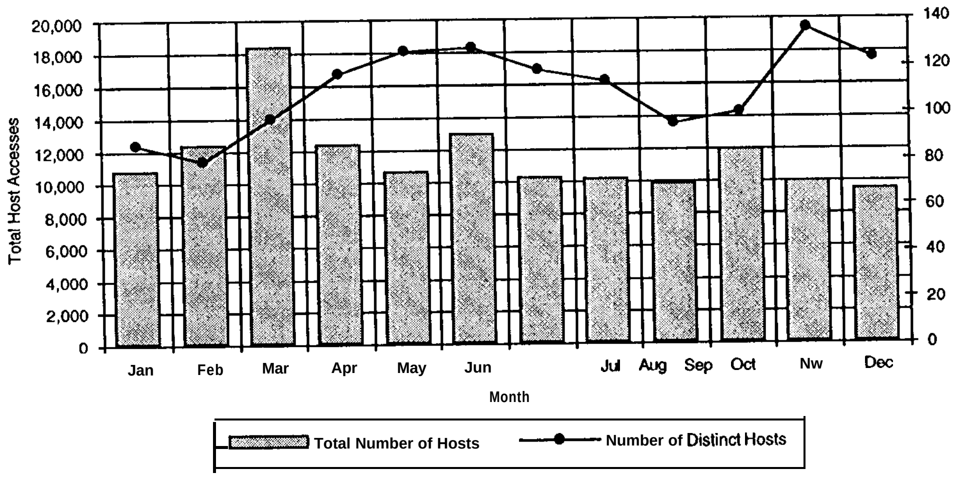


Figure 14. Number of Hosts Accessing the CDDIS in 1994 in Support of the IGS.

Figure 15. Distribution of IGS Users of the CDDIS.

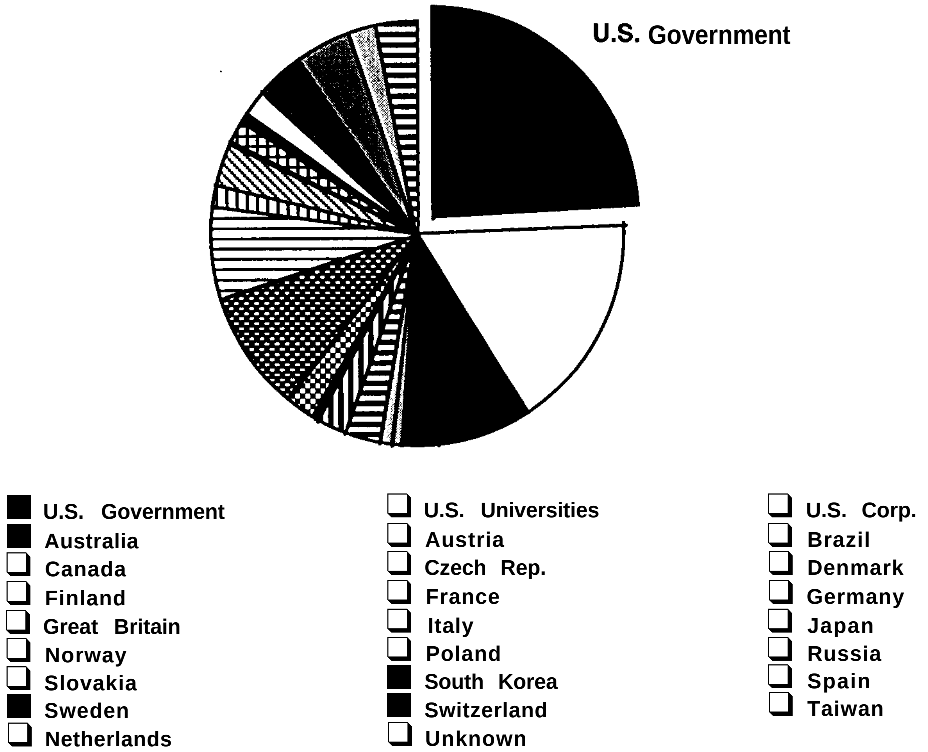


Table 5. Summary of Special Requests for GPS Data and Information in 1994.

Type of Request	Totals
General IGS/CDDIS information	-100 requests (phone, fax, e-mail)
Off-line GPS data	-55 requests (phone, fax, e-mail)
Amount of off-line data requested	-100,500 station days†
Volume of off-line data requested	-50 Gbytes

t-in this context, a station day is defined as one day's worth of GPS data (observation and navigation file in RINEX format)

Future Plans

Computer System Enhancements

There are several hardware acquisitions planned for the CDDIS during 1995 (see Figure 1). Additional magnetic disks will be procured to increase the time span of on-line GPS data and to enhance capabilities to satisfy special requests. An area of particular concern to the CDDIS staff is the ability to satisfy special requests for older, off-line GPS data. Currently, this is a time-consuming activity for the staff since all older data are stored on optical disks. Thus, procurement of additional hardware and research into using existing GSFC facilities, such as mass-storage devices, will be undertaken. The CDDIS could store the entire historical archive of GPS data (totaling over thirty Gbytes in size) on amass storage facility, remotely access the device, and transfer requested data to the CDDIS for temporary access by users. A combination of a CDDIS hardware augmentation and use of existing mass storage facilities could provide a viable solution to this problem.

A *4* mm tape "stacker" device will also be procured to aid in backup and security of the CDDIS data archives. This hardware can cycle through up to eight cartridges and will significantly improve the CDDIS configuration by providing an automated, unattended backup capability for the current disk storage as well as future augmentations.

Another area of interest is CD-ROM archiving and distribution. The CDDIS staff is reviewing the utility of procuring a CD-ROM pre-mastering facility that would also have the capability to write a limited number of CD-ROMs. Approximately two weeks worth of GPS tracking data would fit on a single CD. This CD-ROM technology could provide a convenient, affordable alternative to users who do not require near real-time access to the GPS tracking data. Furthermore, CD-ROMs could be used as an alternative archive medium that would be more platform independent than the rewriteable optical disks (formatted for VAX VMS computers) currently utilized by the CDDIS.

The CDDIS is also hoping to add an additional CPU to the current CDDIS computer configuration. This system would move the CDDIS facility into the next generation of DEC computer hardware and provide a batch processing capability, thus off loading the current processor for user-oriented and data base management activities. Required funding, however, has not been identified for this purchase.

Changes in the Data Archive

The IGS is currently studying ways to improve the integrity of data transmitted from the site to the data center level. To that end, a proposal is under review for use of a quality checking program developed by the University NAVSTAR Consortium (UNAVCO) that would analyze the daily observation file and generate a summary file containing various statistics on these data. Once the IGS adopts a revised procedure, the CDDIS would support this activity and provide on-line access to these summary files. This output would, in fact, reduce data processing at the CDDIS, since the file would replace the current CDDIS-generated summary file.

The IGS plans to invite Associate Analysis Centers to join the service to produce network solutions on a regional basis (Blewitt, *et* al., 1995). Furthermore, the existing IGS Analysis Centers will begin generating weekly station solutions of the global IGS network. The station position solutions and covariance matrices from both types of analysis centers will be available from the global analysis centers, including the CDDIS.

The CDDIS and GSFC'S Very Long Baseline Interferometry (VLBI) staff have been looking into providing meteorological data from global GPS stations collocated with VLBI antennas. Procedures have been initiated at the Greenbelt, Maryland, Fairbanks, Alaska, Kokee Park, Hawaii, and Westford, Massachusetts VLBI stations to record meteorological data during times when no VLBI observing or testing is being done. These data are extracted from VLBI logs and converted into RINEX format at the CDDIS. The meteorological data provided are dry temperature, relative humidity, and barometric pressure at thirty minute sampling intervals. The data are acquired and downloaded by the VLBI site personnel on a best effort basis with typically a one to three day delay. The test data sets are currently under review by the GPS community; once "operational", these data will be stored with the daily GPS observation and navigation data files. User feedback on these data are encouraged, such as what frequency of measurement, level of accuracy, and precision/resolution are required by GPS analysts for useful measurements. The GSFC staff hopes to make a general request to all global collocated GPS/VLBI sites for this type of data providing that the user community believes these meteorological data sets are useful.

Acknowledgments

The author would like to thank members of the CDDIS staff, Maurice Dube and Ruth Kennard (Hughes-STX). Their enthusiasm, dedication, and commitment to the efficient and timely operation of the CDDIS have made this system a successful contributor to the IGS.

References

Berners-Lee, T. J., and R. Cailliau. 'World Wide Web: Proposal for a Hypertext Project" available as: *http: I / info.tern.ch / hypertext /WWW/Proposal.html 1990.*

Beutler, G. "The 1992 IGS Test Campaign, Epoch '92, and the IGS Pilot Service: An Overview" in *Proceedings of the 1993 IGS Workshop.* Druckerei der Universitat Berne. 1993.

Beutler, G., J. Kouba, and T. Springer. "Combining the Orbits of the IGS Processing Centers" in *Proceedings of the IGS Analysis Center Workshop. 1993.*

Blewitt, G., Y. Bock, and J. Kouba. "Constructing the IGS Polyhedron by Distributed Processing" in *Proceedings of the IGS Workshop on the Densification of the ITRF through Regional GPS Networks. 1995* (in press).

Gurtner, W. "RINEX: The Receiver Independent Exchange Format" in *GPS World,* July 1994, v. 5, no. 7.

Gurtner, W. and R. Neilan. "Network Operations, Standards and Data Flow Issues" in *Proceedings of the IGS Workshop on the Densification of the ITRF through Regional GPS Networks. 1995* (in press).

Liu, R., et al. "Introducing the Central Bureau Information System of the International GPS Service for Geodynamics" in *International GPS Service for Geodynamics Resource Information.* January 1995.

Nell, C. E. "Data Archiving and Distribution for the Crustal Dynamics Project: The CDDIS" in *Contributions of Space Geodesy to Geodynamics: Technology.* AGU Geodynamics Series, Vol. 25. 1993.

Nell, C. E. *International GPS Service for Geodynamics (IGS): Catalog of Epoch '92 Events. 1994.*

Remondi, B. W. "Extending the National Geodetic Survey Standard Orbit Formats" in NOAA *Technical Report NOS 133 NGS 46. 1989.*

Smith, D. E. and M. Baltuck. "Introduction" in *Contributions of Space Geodesy to Geodynamics: Crustal Dynamics.* AGU Geodynamics Series, Vol. 23. 1993.

European Regional IGS Data Center

Heinz Habrich
Institute for Applied Geodesy
Frankfurt on Main, Germany

Introduction

The Institute for Applied Geodesy (IfAG) has established a Regional IGS Data Center (RDC) for Europe. Since the IGS Test Campaign, carried out in the period from June 21 to September 23, 1992, IfAG has been keeping all GPS tracking data from permanent GPS sites in Europe. The observation data are obtained from Operational Data Centers (ODC's), Local Data Centers (LDC's), or directly from the stations. The received data are uploaded to a Global Data Center (GDC) and the Center for Orbit Determination in Europe (CODE), and are also made available to other users and archived. The operation of the Regional Data Center has been continued after the IGS Test Campaign. The archive includes all European GPS tracking data from the IGS Pilot Phase, beginning with November 1, 1992, as well as all data collected since the establishment of the official IGS Service by the International Association of Geodesy (IAG) in January 1, 1994.

IfAG meets the requirements for an RDC as defined in the Terms of Reference (Beutler and Brockmann, 1993) and the IGS Position Paper 3 (Gurtner and Neilan, 1994). In addition to the operation of a RDC, IfAG also participates in the CODE, together with the Astronomical Institute of the University of Berne (AIUB), the Federal Institute of Topography (L+T), and the Institut Geographique National (IGN).

Data Handling

The RDC operates *on* an HP9000/750 workstation under the HP-UX operating system. The workstation is connected to the German WIN-Internet and allows anonymous ftp login. Table 1 shows the directory structure for the ftp user. A 1.2-GB hard disk is reserved for storing IGS-related data. The computer is accessible to users 24 hours per day, 7 days per week. A drive for rewriteable magneto-optical disks (650 Mbyte capacity) is installed for archiving the data. All data are backed upon DAT tape (1.3 GB).

Two subdirectories in the anonymous ftp directory serve to handle the daily GPS tracking data. One directory (named "indata") is used by LDC'S and ODC'S to transfer the data files to IfAG. This indata directory is continually checked for incoming files which are then copied to the second directory (named "outdata") where they are available for outside users. The files in the indata directory are subsequently deleted. In addition, a subset of the data is transferred to the GDC at IGN (Paris) and the IGS Analysis Center CODE (Berne).

The necessary procedures for this data handling consist of UNIX "shell scripts" being started through the "cron" clock daemon. Under normal conditions, the RDC operates automatically. In case of problems, the operator of the RDC can use an interactive menu system to quickly analyze the situation and solve the problems. It is important to note that there is no limit to the future number of stations the system can handle.

Table 1. Anonymous-ftp directory structure.

```
ftp-user —1— indata
              |
              1— outdata
              |
              1— ORBITS —I— wwww —1— CODwwwwx.xxx
              |                 1— IGSwwwwx.xxx
              1— IGSMAIL
              |
              1– IGSREPORT
              |
              1— COOR —1— ITRF92
                       1— ITRF93
```

GPS Tracking Data

GPS observation data from European permanent sites are downloaded to IfAG on a daily basis. The files are transferred in the compressed RINEX format. For each site, an observation and a navigation file is sent over the Internet line. Some sites send an additional summary file. Daily navigation files from all sites are concatenated into one file which includes all navigation messages for the European region. For this file, the station abbreviation "IfAG" is used (e.g. IfAG0290.95N.Z). A list of all stations is given in Table 2, and the location of the sites is shown in Figure 1.

The daily data amount to about 14 MB. The data are held online on disk for a period of 70 days, before being archived and removed from the hard disk. The volume of archived data for 1993 is approximately 3 GB, that for 1994 about 4 GB.

In general, the global IGS tracking data are passed through IfAG within one day and uploaded to the Global Data Centers. The necessary data handling actions are performed in 4-hour intervals. Figure 2 shows the delivery statistic for the last year and the beginning of the year 1995. Every file is checked for readability to verify success of transfer. The files being sent to IfAG come from different computer systems with different file naming conventions (e.g. compressed files have the extension".Z" under UNIX, "_z" under VMS). The files are uniformly renamed to the ".Z" extension and uppercase notation.

IGS-Products

The CODE Analysis Center sends the CODE precise orbits and Earth rotation parameters to IfAG. These orbits are also archived and made available to the anonymous ftp user (Table 1). Additionally, the IGS orbits are downloaded from the Crustal Dynamics Data Information System (CDDIS). First, the IGS rapid orbits are downloaded, and as soon as the IGS final orbits are available, these will replace the rapid orbits at IfAG. CODE and IGS orbits are kept online, starting with GPS week 729. IGS Mail and IGS Report messages are also copied to disk. Index files give a summary for both message types. Users will also find ITRF coordinates with velocities and transformation parameters on the disk.

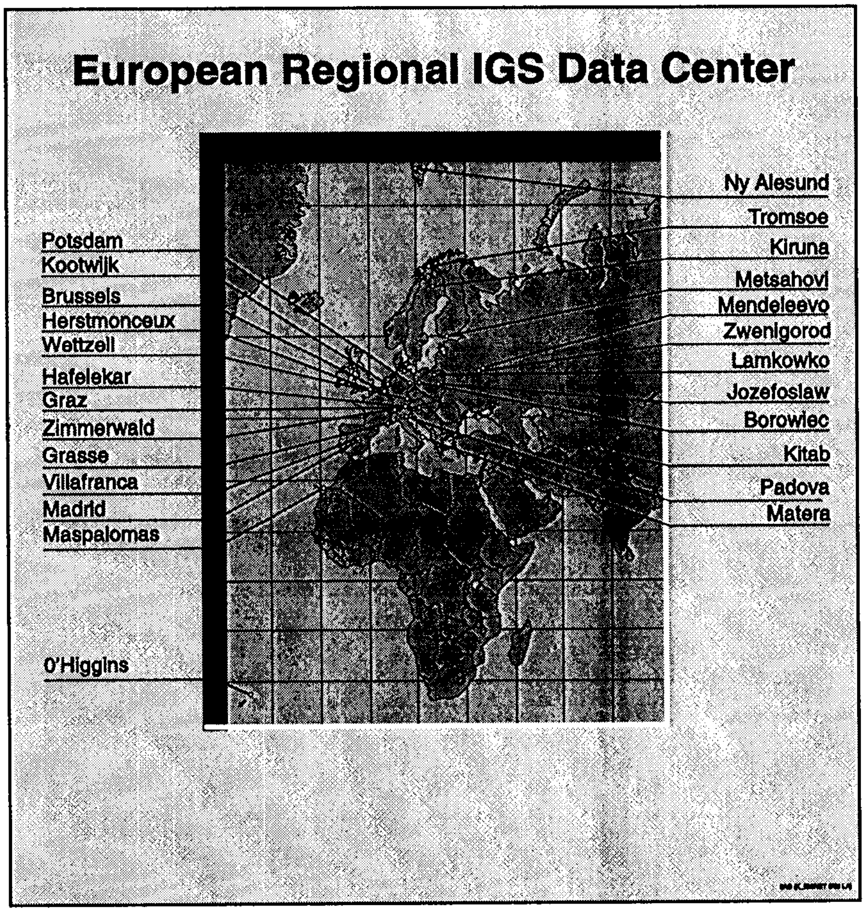


Figure 1. GPS Tracking Network.

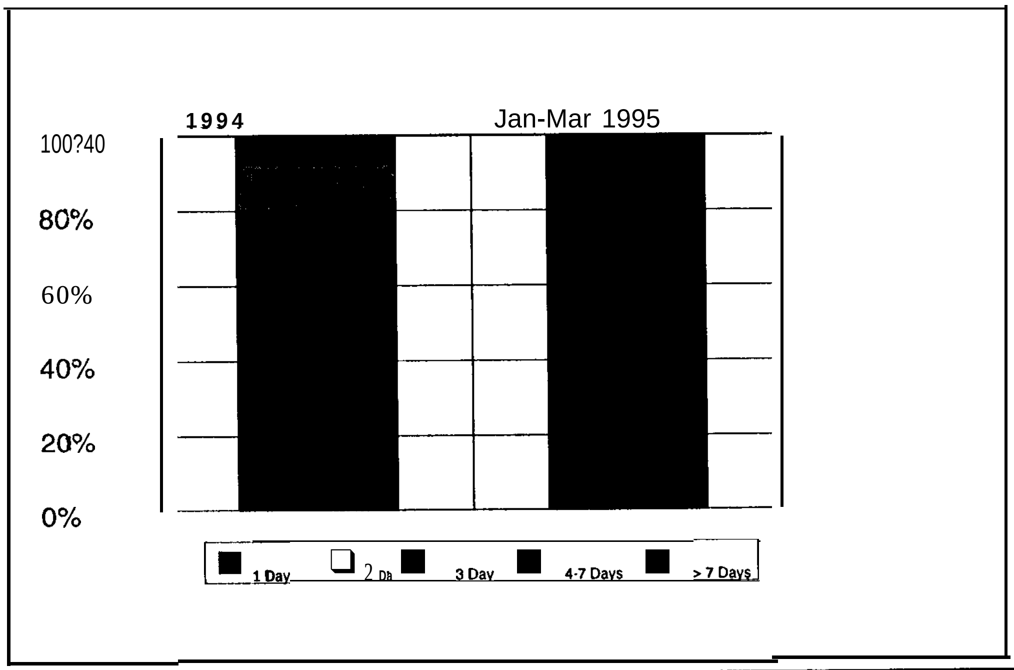


Figure 2. Data Delivery Statistic.

Table 2. Station list for the European Regional IGS Data Center.

Sitename	Country	Abbr.	Lat. N	Long.E	Receiver Type	Source •	Transmission **
Borowiec	Poland	BOR1	5217	1704	Rogue SNR-8000	Graz Observatory	2:23+24 h
Brussels	Belgium	BRUS	5047	421	Rogue SNR-8000	Royal Observ. Bel.	0:47
Grasse	France	GRAS	4345	655	Rogue SNR-81OO	IGN	14:00
Graz	Austria	GRAZ	4704	1529	Rogue SNR-8C	Graz Observatory	2:05
Hafelekar	Austria	HFLK	4718	1123	Rogue SNR-8C	Graz Observatory	2:09
Herstmonceux	England	HERS	5052	0020	Rogue SNR-8C	Greenwich Observ.	1:20
Jozefoslaw	Poland	JOZE	5206	2102	Trimble 4000SSE	Graz Observatory	14:10
Kiruna	Sweden	KIRU	6751	2058	Rogue SNR-81OO	ESA/ESOC	1:04
Kitab	Uzbekistan	KIT3	3908	6653	Rogue SNR-8000	GFZ	5:04
Kootwijk	Netherlands	KOSG	5210	0548	Rogue SNR-8000	Delft Uni. of Tech.	2:20
Lamkowko	Poland	LAMA	5353	2040	Rogue SNR-8000	Graz Observatory	14:15
Madrid	Spain	MADR	4025	-0414	Rogue SNR-8	IGN	12:30
Maspalomas	Spain	MAS1	2745	-1537	Rogue SNR-81OO	ESA/ESOC	1:18
Mendeleevo	Russia	MDVO	5602	3713	Trimble 4000SSE	Delft Uni. of Tech.	0:40+24 h
Matera	Italy	MATE	4038	1642	Rogue SNR-8	Telespazio S.p.A.	1:30
Metsahovi	Finland	METS	6013	2423	Rogue SNR-8C	Statens Kartverk	3:29
Ny Alesund	Norway	NYAL	7855	1151	Rogue SNR-8	Statens Kartverk	3:31
O Higgins	Antarctica	OHIG	-6319	-5754	Rogue SNR-8000	I FAG, Wettzell	1:15
Onsala	Sweden	ONSA	5723	1155	Rogue SNR-8000	Statens Kartverk	3:33
Pad ova	Italy	UPAD	4524	1152	Trimble 4000SSE	Telespazio S.p.A.	2:04
Potsdam	Germany	POTS	5223	1304	Rogue SNR-8000	GFZ	1:04
Tromsoe	Norway	TROM	6939	1856	Rogue SNR-8	Statens Kartverk	3:35
Villafranca	Spain	VILL	4026	-0357	Rogue SNR-8000	ESA/ESOC	1:10
Wettzell	Germany	WETT	4908	1252	Rogue SNR-800	IfAG, Wettzell	0:55
Wettzell	Germany	WTZR	4908	1252	Rogue SNR-8000	I FAG, Wettzell	1:20
Zimmerwald	Switzerland	ZIMM	4652	0727	Trimble 4000SSE	Federal Office Top.	2:30
Zwenigorod	Russia	ZWEN	5541	3645	Rogue SNR 800	GFZ	+ 72h

* Center or station sending data to IFAG

•* Data transmission to I FAG in UTC, end of observation 0:00 UTC, derived form period Feb - Mar 1995

Access to Data

Users can access the GPS tracking data and the IGS products using the anonymous ftp account. See Table 3 for login information. Older data (not available online) can be restored from the magneto-optical archive disk on request.

Table 3. Internet access.

European IGS Data Center
Institut fuer Angewandte Geodaesie
Richard Strauss Allee 11
60598 Frankfurt Main
Germany

Internet login: ftp 141 .74.240.26(igs.ifag.de)
user: anonymous
passwd: < your E-Mail address >

Contact: Heinz Habrich (habrich@igs.ifag.de)

GPS Information and Observation System (GIBS)

Contact: FAX +49 3415634415
E-Mail gibs@ leipzig.ifag.de

Users with no Internet connection can get CODE and IGS orbits through the GPS Information and Observation System (GIBS). GIBS was established at IfAG to support civil GPS users in the Federal Republic of Germany, but has been made available to users worldwide.

Conclusion

The European IGS Data Center has two functions. Firstly, IfAG contributes to the flow of global IGS site data from the receivers to the Global Data Centers. Secondly, IfAG stores all GPS tracking data from permanent sites in the European Region. We experienced an increasing number of permanent sites in Europe over the last years. Making all these data available at *one* Data Center is a useful contribution to all GPS-related projects.

References

Beutler, G. and E. Brockmann: Proceedings of the 1993 IGS Workshop, March 25–26, 1993, Druckerei der Universität Berne, 1993

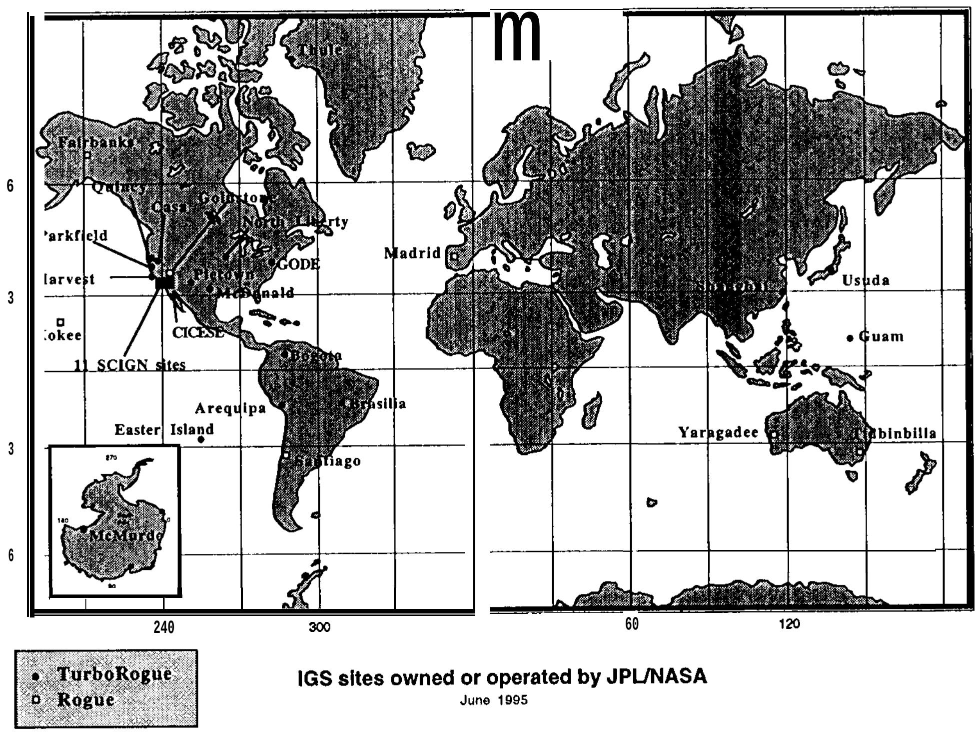
Gurtner, W. and R. Neilan: Network Operations, Standards and Data Flow Issues, Proceedings of the 1994 IGS Workshop: Densification of the ITRF through Regional GPS Networks, Position Paper 3, November 30–December 1, 1994, Jet Propulsion Laboratory, Pasadena, CA, 1995.

JPL's Regional IGS Data Center

G. Franklin, B. Iijima, P. Kroger, U. Lindqwister, T. Lockhart, A. Mikolajcik, M. Smith, and K. Stark
Jet Propulsion Laboratory
Pasadena, California

Introduction

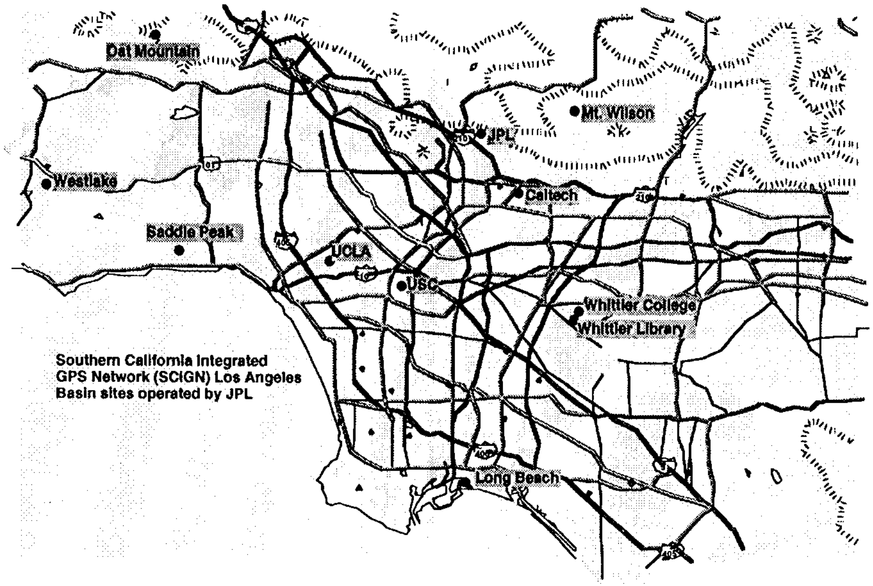
JPL/NASA has been installing and operating permanent GPS stations for more than 5 years, starting with the deployment of the 6-station TOPEW POSEIDON ground tracking network. This permanent Network was installed during the early 1990s in support of the Topex oceanographic mission in collaboration among JPL/NASA, CNES, CEE, and ISAS. Since then JPL/NASA has installed an additional 15 stations globally in support of the IGS and the GPS Global tracking Network, and than 15 other stations for various regional and local Networks (for example, the SCIGN array in Southern California) and projects (for example, the permanent DOSE site at Mammoth Lakes). The maps in Figures 1 and 2 show the global and local distributions of JPLINASA-operated or -supported GPS sites. We are currently operating 37 permanent GPS stations for global, regional, and local Networks and projects. Current plans call for implementing another 20-25 sites in the next 2-3 years.



IGS sites owned or operated by JPL/NASA
June 1995

Figure 1.

Figure 2.



Data Handling

JPL/NASA participated in the IGS test campaign in Jun-Sep, 1992, and have been supplying the IGS community with data ever since. We are currently obtaining raw and formatted GPS data (CONAN binary and DMD formats) directly from GPS receivers and also raw and formatted data from several Network partners. The formatted GPS data are currently made available on-line for 120 days and archived both on-site and off-site on CD-ROM discs after 40 days. The archiving of data is performed once per week, when 3 CD-ROM disc copies are made of the GPS data (one stored off-site). The formatted data are stored in the RINEX format and compressed using the standard UNIX data compression utility. Raw CONAN binary and DMD format (from the three Deep Space Network stations at Goldstone, CA; Madrid, Spain; and Tidbinbilla, Australia) data are stored for 30 days on-line and also archived off-line on CD-ROM discs. The on-line storage capacity currently encompasses 4 GBytes.

JPL/NASA uploads data via regular telephone lines, Internet, and NASCOM (direct NASA communications lines from the three DSN stations) in 24-hour file segments. All routine data uploading and handling operations at the JPL/NASA data center have been automated. The data transfers start immediately after UTC midnight, and under ideal conditions all the data are obtained within 12 hours. In practice, more than 95% of the data is collected automatically every day, with the remaining data uploaded the next day by the automated upload system or manually. All global stations that are part of the IGS Network forward data to the CDDIS Global Data Center at the Goddard Space Flight Center every day.

The data are uploaded automatically via telephone lines or direct serial connections using Microphone Pro scripts running on Macintosh computers. The networked Macintoshes at JPL use Telebit T2500 Trailblazer modems to dial up stations with standard telephone connections. Three parallel lines are currently in use to dial more than 30 stations. The data files are usually uploaded in CONAN binary format to reduce data transmission time and save costs. Remote Macintoshes, which are connected to the Internet, use direct serial connections to the TurboRogue receiver to upload data from 8 stations. The resulting files are stored on the Macintoshes until a workstation at JPL completes a successful FTP transfer from the Macintoshes to the local workstation, after which the file is removed from the Macintosh. The data collection and handling computer at JPL is a DEC 3000/500 Alpha workstation which transfers the files from the Macintoshes and then decompresses, inventories, validates, formats, and distributes the data. The process requires about a minute of CPU time on the DEC workstation per station per day.

Data Access

The data may be accessed via anonymous FTP from bodhi.jpl.nasa.gov (128.149.70.66) under /pub/rinex. The data are listed by day-of-year, and the file naming convention is the GIPSY convention (DDMMMYYNAME_r0.rnx_z). The '_z' indicates the UNIX compression of the file. Tables 1 and 2 below summarizes the access paths:

Table 1. Data Access Information.

Short Name:	JPL
Institution:	Jet Propulsion Laboratory
Function within IGS:	Special Data Center
Mail Address:	4800 Oak Grove Drive Pasadena, CA 91109, USA
Contact:	Keith F. Stark
Telephone:	(818) 3545922
Fax:	(81 8) 3934965
E-Mail:	stark@logos.jpl.nasa.gov (internet)
Telnet Access:	None
FTP Access:	bodhi.jpl.nasa.gov (128.149.70.66) anonymous
Computer Operating System:	HP 9000/715 HP-UX, VAX/VMS
Amount of data on line:	120 days
Access to off-lint? data:	Special arrangements

Table 2. Directory Structure.

Directory	Subdirectory	Description
directory specifications are for our guest computer BODHI.		
pub		top level
	/rinex	rinex area indexed by day of year
	/raw	raw data area indexed by day of year
	/docs	supporting documentation and IGS MAIL
	/software	supporting software
	/topex	Topex orbit data

References

Additional information about the GPS Global Tracking Network and the SCIGN Network maybe obtained via the World Wide Web at the following addresses:

1. JPL's Global GPS Time Series Data:
   http://sideshow.jpl .nasa.gov/mbh/series .html

2. JPL's contribution to the Southern California Dense Array:
   http://milhouse.jpl .nasa.gov/

GL/NOAA Operational Data Center

Miranda Chin
National Oceanic and Atmospheric Administration
Silver Spring, Maryland, USA

The Organization

The GL/NOAA Operational Data Center (GODC) was established by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) for establishing and monitoring permanent GPS tracking stations. GODC currently monitors 9 stations located at Westford, MA, Bermuda, Richmond, FL, Fortaleza, Brazil, Table Mountain, CO, Sterling, VA, Annapolis, MD, Solomon Island, MD, and Wallops Island, VA (Figure 1). However, only data from Westford, Bermuda, Richmond, Fortaleza, and along with data sent by Taiwan and Wuhan are forwarded to IGS. The stations around the Chesapeake Bay area have been established for the purpose of environmental study. Similarly, the Table Mountain station provides data to the National Geodetic Survey (NGS) Continuous Operating Reference System (CORS) for geodetic control.

The Functions

Real-Time Operation Monitoring

A GL/NOAA GPS tracking system consists of a GPS receiver, an antenna, a PC with sufficient hard disk space, an Uninterrupted Power Supply (UPS), a high speed modem, a network connection, and communication software packages. Some stations are equipped with a hydrogen maser frequency standard and meteorological instruments. Diagram 1 shows a tracking system layout.

This tracking system provides a remote operation monitoring capability from GODC using PCs and modems. The common monitoring features used are:

- Examining receiver tracking status
- Modifying data download procedure
- Changing tracking configuration
- Performing troubleshooting
- Rebooting the on-site PC

Data Communication and Preprocessing

First, the daily GPS observations and meteorological measurements are downloaded from the receiver to the on-site PC at 10 minutes past midnight UTC via a direct connected RS232 cable. After that, the Hewlett Packard (HP) 755 computer at GODC gets the data from 6 stations via Internet and a 486/PC gets Sterling and Annapolis data via a high speed modem. In addition, Fortaleza data are sent by Instituto National De Pesquisas Espaciais (INPE) from Sao Paulo, Brazil and Taiwan data are sent by Institute of Earth Sciences from Taipei. Figure 2 shows the data communication network and Diagram 2 shows data flow.

Figure 1. GL/ NOAA GPS Permanent Tracking Network.

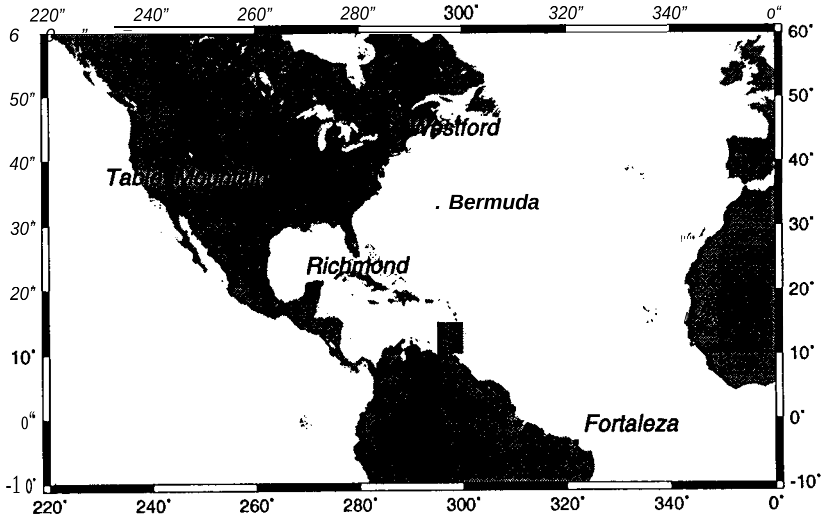


Diagram 1. GU NOAA GPS Tracking System Layout.

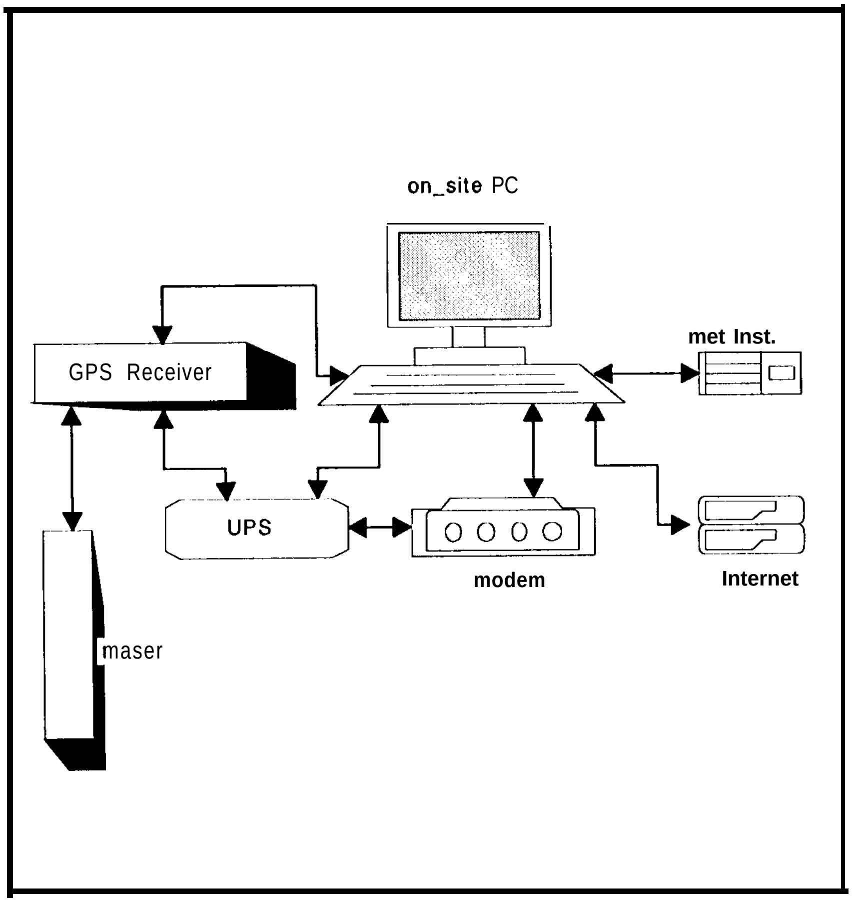


Figure 2. GL/ NOAA GPS Data Communication Network.

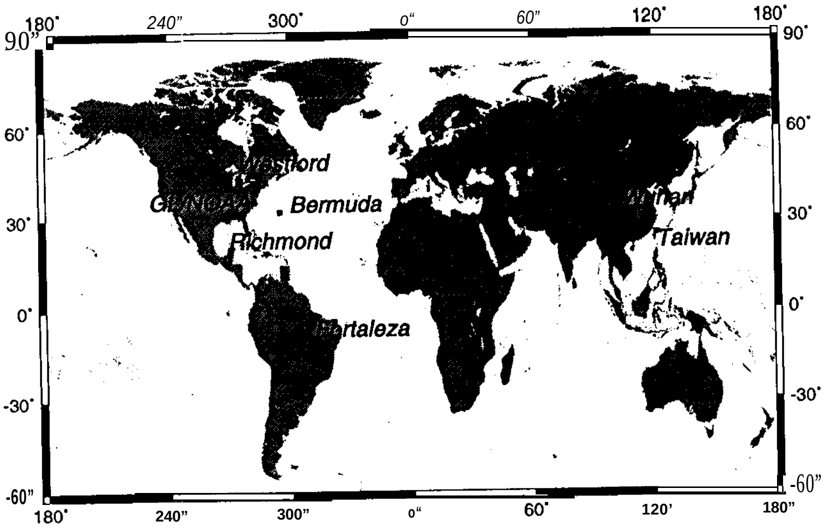
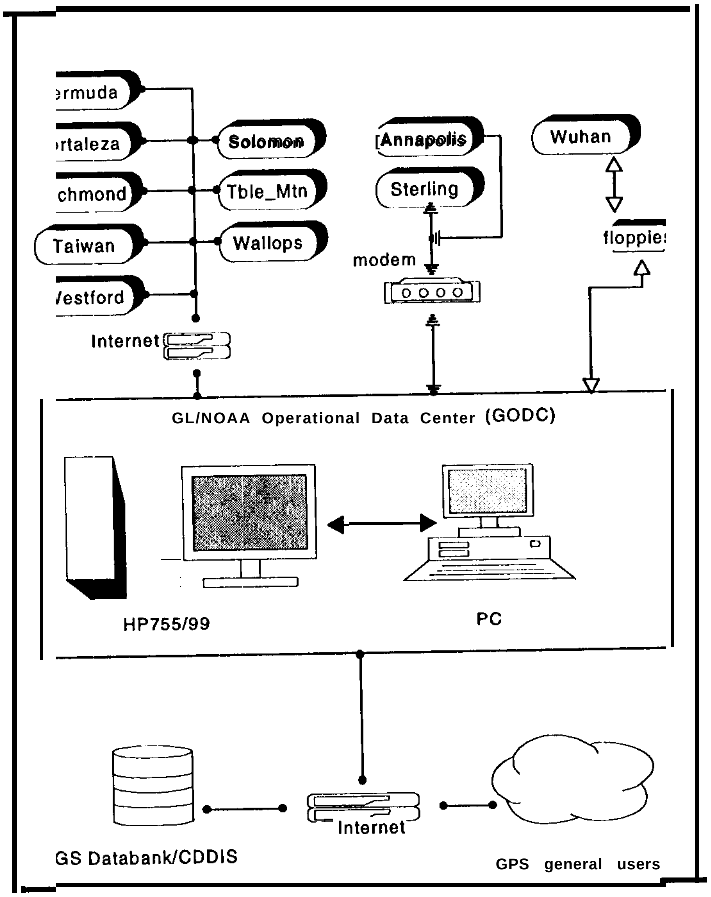


Diagram 2. Data Acquisition, processing and Distribution.



After all data have been collected at GODC, the HP 755 starts the following tasks:

. Decompression
• Format Conversion - RINEX
. Quality Control - QC
• Distribution

Finally, RINEX and raw format data are posted on the HP 755 for general users; from Bermuda, Fortaleza, Richmond, Taiwan, and Westford only the RINEX data are sent to CDDIS.

The entire data downloading, preprocessing, and distribution procedure has been automated so that it requires minimal human intervention.

Additionally, the weekly GPS data from Wuhan are sent by the Wuhan Technical University of Surveying and Mapping to GODC for processing and uploading to CDDIS.

/formation Distribution

GODC keeps the most current 200 days' data on-line. To access these data via Internet:

Network address: gracie.grdl.noaa.gov or 140.90.160.199
Login id/password: anonymouslanonymous
Directories:
dist/cignet/dxxxa_yy : GPS observations in RINEX format
dist/cignet/dxxxb_yy : GPS observations in raw binary format
dist/cignet/Ngsorbits : NGS precise ephemeris
dist/cignet/Globals : Daily broadcast ephemeris
(where: xxx - day of the year; yy - last 2 digits of year)

GODC also keeps older data off-line. Users need to send an e-mail or phone in for requesting the data:

email: linda@gracie.grdl. noaa.gov
Tel: 301-713-2852 Fax: 301-713-4475
Mailing Address: GL/NOAA Operational Data Center
NOAA N/OES13
SSMC IV, Sta. 8202
1305 East-West Highway
Silver Spring, MD 20910

Operation Capacity

Data on-line/off-line storage

GODC uses a HP 755/99 workstation for data acquisition, processing, distribution, and archiving. The workstation has 128MB of RAM and a total of 20.9GB on-line disk storage; in addition, GODC keeps off-line data on optical cartridges and DAT tapes.

Normally, GODC makes one copy for each of the raw binary data and ASCII data; however, starting GPS week 563, an additional copy of ASCII data are also kept on DAT tapes.

Communication Facility

GODC provides both Internet and modem access for data communication. The Internet bandwidth used is 1.44GB; the modem speed is 19,200 baud rate.

Future Plans

In addition to establishing new GPS permanent stations for geodesy and environmental studies, GODC is planning to improve the on-line data access technology and database management.

NRCan Operational Centre Report

Robert Duval
Geodetic Survey Division, Geomatics Canada, Natural Resources Canada
Ottawa, Ontario, Canada

The Geodetic Survey Division (GSD) of Geomatics Canada, in partnership with Geological Survey of Canada, is operating the Canadian Active Control System (CACS) to provide improved GPS positioning capability for the Canadian surveying and geophysical community as well as for other spatial referencing needs. The system consists of unattended tracking stations, referred to as Active Control Points (ACP's), which continuously record GPS measurements for all satellites in view. Each ACP is equipped with TurboRogue SNR 8000 GPS receiver and an atomic frequency standard. Meteorological observations are also collected at selected ACP sites.

The Geological Survey of Canada is responsible for the operation of four sites, part of the Western Canada Deformation Array (WCDA), which are located at Penticton, Victoria, Williams Lake and Holberg in the province of British Columbia. Geodetic Survey operates ACP'S located in Algonquin Park and Ottawa, province of Ontario; Yellowknife, North West Territories; St. John's, province of Newfoundland; Schefferville, province of Quebec; and Churchill, province of Manitoba. Data from five core sites, Algonquin (ALGO), Victoria (ALBH), Penticton (DRAO), St. John's (STJO) and Yellowknife (YELL), are contributed on a daily basis to the International GPS Service for Geodynamics (IGS).

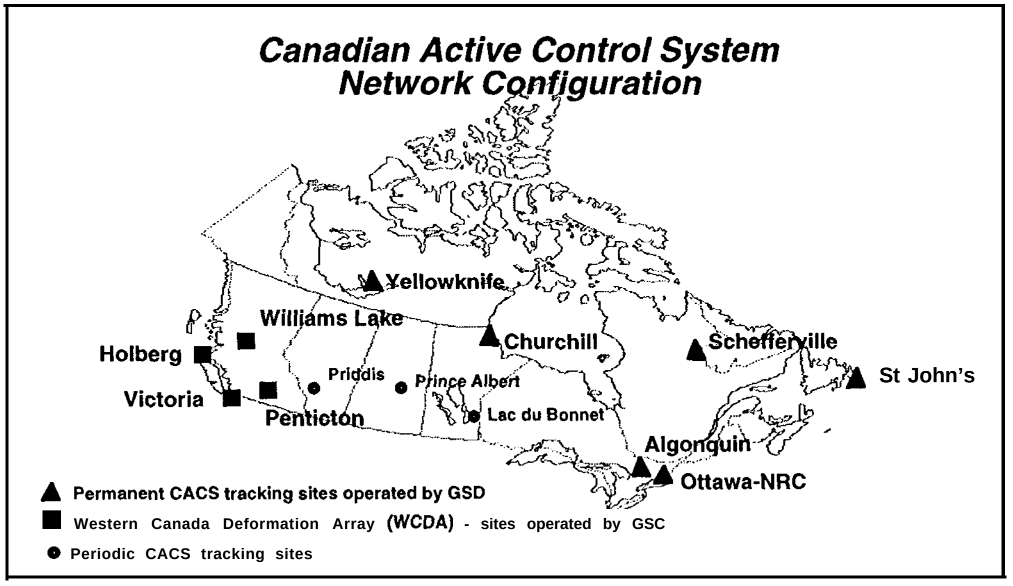
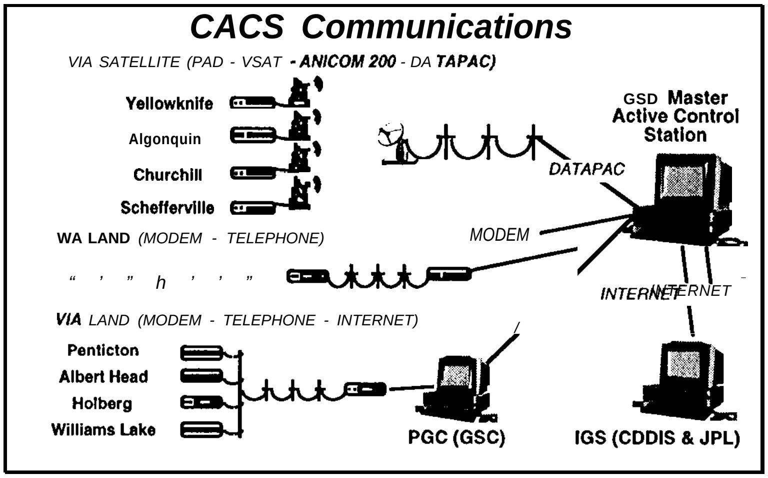


Figure 1.

Data Retrievals

Data from the sites operated by GSD are retrieved every four hours using an automated computer data acquisition facility in Ottawa. Communication to the sites is done either via high-speed modem through conventional phone lines or relayed via satellite link to a public packet switching network (DATAPAC). Data from the WCDA sites are downloaded once a day to GSC computer in Victoria, B. C., via high speed modems using conventional phone lines and later retrieved by GSD over Internet using the File Transfer Protocol, All data from the Canadian stations are retrieved in the Conan binary format. Data from additional 24 sites of the IGS network are used daily for the generation of NRCan orbits. The IGS data are retrieved in RINEX format either from CDDIS or JPL database.

Figure 2.



Data Validation

All GPS data retrieved by GSD are verified before further processing. Two separate programs developed at GSD are used to evaluate and report on the GPS data quality (Heroux and Caissy, 1993). The first one, GPS Ionosphere and Multipath Program (GIMP) uses combinations of dual-frequency code and carrier phase measurements to assess the level of ionospheric activity and multipath conditions at each site. It detects and estimates cycle slips in the carrier phase measurements from ionospheric delay and widelane combinations. A daily summary of station tracking performance is provided by GIMP which includes a table by satellite PRN number indicating start and end time, number of data points, number of gaps and cycle slips, ionospheric activity and multipath indicators. A 24-hour summary of the observed satellite arcs is generated in a graphical form.

The second program Single Point And Range Corrections (SPARC) is a single point positioning program that uses dual frequency code observations and broadcast ephemerides to evaluate range residuals, receiver position and clock offset and drift with respect to GPS time. *A priori* knowledge of the receiver location and stable frequency reference allow to assess the performance of the GPS system and the effects of Selective Availability and Anti-Spoofing.

These programs, provide warning the operator if certain quality thresholds have not been met.

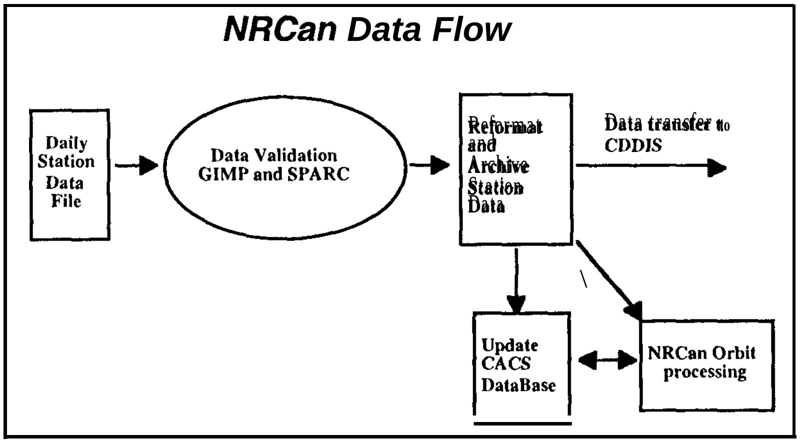


Figure 3.

Data Dissemination

Following the validation, data from the Canadian sites are converted to RINEX format. Data files are normally made available for public dissemination five hours following the observation day. At the same time, files for the five core stations are transmitted to IGS archives at CDDIS. Data sets that were flagged during the validation process are investigated and made available as appropriate. IGS analysis centres can access directly NRCan GPS archives via a password protected FTP service. Public dissemination of the NRCan data and products is provided through an interactive bulletin board service accessible via modem or Internet. None of the global IGS station data retrieved by GSD are made available for further distribution. Our policy is to direct requests for these data sets to the agencies which operate the stations. Raw GPS data disposition and availability of data for year 1994 are summarized in the following two tables:

Table 1. Data disposition.

Origin	Format	Period On-line	Transferred to CDDIS	Available on Public Archives	Archived Permanently
CACS core stations	Conan Binary	30 days	No	Yes	Yes
(ALBH, ALGO, DRAO, STJO, YELL)	RINEX	180 days	Yes	Yes	No
CACS regional stations	Conan Binary	30 days	No	Yes	Yes
	RINEX	180 days	No	Yes	No
Global IGS stations	RINEX	30 days	N/A	No	Yes

Table 2. Availability of the CACS observational data in 1994.

STATION	Data made available within: 1 day	2 days	3 days	4 days	5 days	6 days	No data available
ALBH	353	8	3	1	0	0	0
ALGO	**343**	**12**	**6**	1	1	1	**1**
DRAO	**353**	**7**	**3**	1	**0**	**0**	1
STJO	343	10	6	1	0	1	4
YELL	360	4	0	0	0	0	1

Archiving and back up of raw GPS data and results

All raw GPS data retrieved by GSD are archived daily in their original format on optical disk. Incremental backup of the optical and system disks (all new or modified files) is performed daily on DAT tapes. Full backup is performed every two week. Once full, the optical disks are kept permanently along with two copies of their content on DAT tapes.

Following the computation of the precise ephemerides by NRCan Analysis Centre, the precise satellite clock corrections are computed at 30-second intervals for all satellites visible from Canada. The NRCan precise ephemerides and satellite clock corrections are archived and made available to users.

Reference

P. Heroux, and M. Caissy (1993). Canada's Active Control System Data Acquisition and Validation, Geomatica Vol. 47, No. 3 & 4, Autumn 1993, pp. 233–243

ANNEX 1

Validation Software GIMP

The GPS Ionosphere and Multipath Program (GIMP) has been developed for the CACS to evaluate and report the ionospheric and code multipath conditions prevailing at a site where dual frequency carrier phase and code observations are collected. It also detects and estimates cycle slips in the carrier phase from the ionospheric delay and widelane combinations of the carrier and code measurements. This program uses single station observations, is fast to execute and gives a quick look at station tracking performance.

The ionospheric delay variations observed from the dual-frequency carrier phases of each satellite tracked are combined to obtain an average daily ionospheric gradient. This value is normalized to mm/see to accommodate various sampling rates. This combination of dual-frequency carrier phases is also used to monitor cycle slips on L1 or L2 which are characterized by jumps of a multiple of 5.4 cm in the time series.

As long as the carrier phases are cycle slip free, the code/carrier widelane ambiguity remains constant for a given satellite. Therefore, it is possible to look at observed widelane ambiguity variations over the sampling interval or with respect to a mean value computed at an arbitrary reference time. By setting the reference time to the arc start time, an arc multipath variation estimate is obtained by differencing the multipath observed at each epoch with the updated mean arc value. The interval variations show mainly the high frequency component of multipath whereas the arc value will indicate the longer term, lower frequency component. The widelane is also a valuable time series for detection of station level cycle slips which are characterized by jumps of a multiple of 86 cm in the time series.

The program output gives the data file name and station with the observation date and data rate. The receiver tracking performance is reported by arc and satellite PRN number. The arc statistics include the start and end epoch, the number of data points per arc, the number of gaps and cycle slips detected. The ionospheric gradient is represented by RMS in cm over the sampling interval and in mm/sec. The RMS for the interval and arc multipath are given in meter in the last two columns. The last line of the table combines information from all observed arcs.

A 24 hour tracking table provides a visual representation of observed satellite arcs in ascending PRN order. Any asterisk (*) represents 20 minutes of P-code data while the (x) indicates cross-correlation tracking. The hat sign (A) shows the occurrence of cycle slips. When data in the Con an binary format is processed a channel tracking table identifying the PRN number tracked on each channel is also provided.

Table 3. Sample of GIMP output.

GPS Ionosphere and Multipath Program (GIMP-17/09/1993)

File : screen/ algo.std — Data Rate: 30 sec.
Station: ALGO — Date : 28/ 3/1995

SAT PRN #	START TIME (hh:mm:ss)	END TIME (hh:mm:ss)	#OBS.	#GAP	#C. S.	IONOSPHERIC VARIATIONS (cm.)	(mm./s,)	MULTI PATH INTVL (m.)	ARC (m.)
1	8:20:30.	14:53:30.	790	0	3	1.36	.45	.48	.41
2	0: 0: 0.	1: 2: 0.	126	0	0	1.34	.45	.72	.59
2	18:56: 0.	23:59: 0.	607	0	0	5.14	1.71	.56	.51
4	0: 0: 0.	4:36:30.	556	0	2	14.25	4.75	.69	.56
4	22:14: 0.	23:59: 0.	211	0	0	1.83	.61	1.25	1.01
5	0: 0: 0.	4:14: 0.	509	0	0	1.28	.43	.48	.40
5	9:39:30.	13:10: 0.	423	0	1	5.39	1.80	.97	.73
5	23:55: 0.	23:59: 0.	9	0	0	3.39	1.13	6.68	5.01
"	"	"	"	"	"	"	"	"	"
"	"	.	"	.	"	"	"	.	.
"	"	"	"	"	"	"	.	"	"
28	7: 2: 0.	9:22: 0.	269	2	1	.75	.25	.22	.21
28	15:17:30.	20:18: 0.	602	0	0	1.54	.51	.20	.20
29	1: 6:30.	3: 3:30.	180	6	4	*****	70.89	7.12	16.54
29	13:45: 0.	18:55: 0.	621	0	0	3.01	1.00	3.89	8.91
31	16:24:30.	21:57: 0.	667	0	1	11.26	3.75	.72	.65
	0: 0: 0.	23:59:30.	19948	18	37	21.32	7.11	1.43	2.80

SATELLITE TRACKING TABLE

```
 1                                 xxxxxxxxxxxxxxxxxxxx
 2  -                                                            xxxxxxxxxxxxxxxx
 4  xxxxxxxxxxxxxx                                                         xxxxxx
 5  xxxxxxxxxxxxx                xxxxxxxxxxxx                                   x
 6         xxxxxxxxxxxxxxxx                   —       x
 7  xxxxxxxx^                                                        xxxxxxxxxxxx
 9  xxxx              xxxxxxxxxxxxxxxx                                      xxxxx
12  ●*****             ***,********                                    ●*******
14  xxxxx                           xxxxxxxxxxxxxx                        xxxxxxx
15                            x — x x x                   X x x X x - ' x
16      xxxxxxxxxxxxxxxxxxx
17              xxxxxxxxxxxxxxxxxx
18     xxxxxxxxx                              xxxxxxxxxxxxxxx
19                                               X x X x — —    ^
20     xxxxxxxxx               xxxxxxxxxxxxx
21                     xxxxxxxxxxxxxxxxxx
22                                      xxxxxxxxxxxxxxxxxx
23               xxxxxxxxxxxxxxxxxxx
24  xxxxxxxxxxxxxxxxxxx                                                        xx
25                             xxxxxxxxxxxxxxxxxxxx
26             xxxxxxxxxxxxxxxxxx                                    xx
27                xxxxxxx                            xxxxxxxxxxxxxxxx
28                  *A******                  ***************  ●
29     —                                xxxxxxxxxxxxxxxx
31                                             — —  x  X  x  x
    888999899877865666767998788898799888877867776777876677877776778788789
    ---+----+-----+-----+----+----+-----+-----+-----+-----+-----+-----+-----+-
    0    2     4     6    8    10   12   14   16  18  20       22        24
```

CHANNEL TRACKING TABLE

```
 1  0000000000000  2222222222222222222222222  2222222222222220000000000000000
    5555555555555  7777778111111111111111111  9999999999999992222222222222222

 2  0000000022  222222222222222222  2222222222222  1111111111111110000000000000
    7777777799  666666666666666666  0000000000000  8888888888888887777777777777

 3  2222222222222222222  0000000000000000111111111111122  2222222222222222  22
    4444444444444444444  9999999999999999444444444444455  7777777777777777  44

 4  ooo2222222222  11111111111  llllll2222222222222222222        111111111111110
    2229    0000000077777777777777777555555555555555555        555555555555555

 5   lllll22ooooooooooooooo222222oooooooooooooooooooolllllllllllllllloooooo
    22222996666666666666666888888555555555555556666666699999999999999999444444

 6  00000000000000    2222222222222222222  222222222222222222     2211111111
    44444444444444    3333333333333333333  222222222222222222     6622222222

 7  11112111111111111111111111  0000000000000000000022222222222222222    1111111
    44449666666666666666666666  1111111111111111111188888888888888888    4444444

 8  0000111111111        1111111111111111111        33333333333333333 00000
    9999888888888        2222222222255555555        11111111111111111 99999

----- + ---- +----- + ----- +-----+ ----- + --- --+----- + ----- +-----+ ----- + ----- +----- +-
      0    2     4     6     8     10    12    14    16    18    20    22    24
```

ANNEX 2

Validation Software SPARC

SPARC is a single-point positioning program that uses pseudo-ranges to all observed satellites to generate a GPS navigation solution at each epoch providing the receiver's three dimensional position and clock offset with respect to GPS time. Comparing the epoch single-point positioning results to the tracking stations known position is useful to monitor the quality of the broadcast ephemeris and clocks and evaluate the level of Selective Availability (SA). The station GPS receiver clock performance can also be assessed.

Table 4. Sample SPARC output.

```
              Single Point and Range Corrections (SPARC- v. 2.2-1994-09-21)
---------------------------------------------------------------------------
File    : screen /algo. std                        Data Rate:     30 sec.
Station:         ALGO                              Date      : 28/ 3/1995

                     SINGLE-POINT POSITIONING MODE
                   NO DIFFERENTIAL CORRECTIONS APPLIED
---------------------------------------------------------------------------
SATELLITE          ARC                          RESIDUALS      C/A - P CODE
  PRN#   START TIME   END TIME        NB      AVG      RMs      AVG     RMs
         (hr:mm:ss)  (hh:mm:ss)               (m)      (m)      (m)     (m)

    1     8:20 :30.0 14 :51:30.0      783    -9.29    17.36      .00     ,00

    2     0: 0:  .0    1: 2:  .0      120      .48    10.85      .00     .00
    2    18:56:  .0  23:59:  .0       601      .01    13.25      .00     .00

    4     0: 0:  .0    4:36:  .0      552    -2.99    17.10      .00     .00
    4    22:15:  .0  23:59:  .0       204    -3.13    11.64      .00     .00

    5     0: 0:  .0   4: 13:30.0      509    -2.70    17.31      .00     .00
    5     9 :39:30.0  13: 7:  .0      416     6.81    15.74      .00     .00
    5    23:55:  .0  23:59:  .0         9    -9.21     7.73      .00     .00

    "         "          "              "      "        "        "       "
    "         "          "              "      "        "        "       "
    "         "          "              "      "        "        "       "
   28     7: 2:  .0    9:22:  .0      267     2.91    12.43      .00     .00
   28    15: 17:30.0 20:18:  .0       599     1.90    11.62      .00     .00

   29     1: 6:30.0   3: 3 :30.0      147    -3.10    16.89      .00     .00
   29    13:45:  .0 18:54 :30.0       621      .76    14.94      .00     .00

   31    16:25:  .0 21 :56:30.0       652    -1.07    13.75      .00     .00

---------------------------------------------------------------------------
                                    19647      .00    14.48
---------------------------------------------------------------------------


---------------------------------------------------------------------------
                  POSITIONING RESULTS FROM 2877 ESTIMATES
        X (m)      Y (m)       Z (m)     LAT (dms/m)   LONG (dins/m)   HEIGHT (m)

*IN I  918129.58  -4346071.25  4561977.83   45 57 20.880   -78  4  16.916  200.906
• AVG  918129.42  -4346068.77  4561974.08   45 57 20.853   -78  4  16.899  196.501
*RMS      19.71        37.58       42.79        27.34            18.39      50.46
*DIF       -.16         2.48       -3.75         -.84              .35      -4.40
---------------------------------------------------------------------------
              RECEIVER CLOCK PARAMETERS FROM  2874 ESTIMATES
          TIME       OFFSET         S  D  OFFSET     DRIFT          S.D. DRIFT

ALGO     172800.0     -264.9 m        +/-  1.2      -10.2 m/day       +/-  2.1
       0:  0:  .0     -883.8 nsec     +/-  4.1      -34.0 nsec/day    +/-  7.1
---------------------------------------------------------------------------
```

ANNEX 3

Index of the NRCan GPS Archives

NOTE: The IGS analysis centres are provided with access to NRCan GPS archives via a password protected FTP service. Public distribution of the NRCan data and products for general uses is provided through an interactive bulletin board service accessible via modem or Internet.

Table 5. Index of NRCan GPS archives.

GSD/NRCan **GPS Archives**
(accessible via a password protected FTP service)

```
pub/ gps/products/   emrWWWWD. sp3          GPS ephemerides in SP3 format
       |        |                           generated by NRCan for GPS week
       |        |                           'WWWW' and day 'D' (0= Sunday)
       |        |
       |        /    emrWWWW7 erp           Earth Rotation Parameter file
       |        |                           generated by NRCan
       |                                    for GPS week 'WWWW'
       |        |
       |        /    emrWWWW7.sum           Ephemerides Analysis summary file
       |                                    for GPS week 'WWWW'
       |
       /rinex /day_DDD/   ssssDDD0 YYo.z    Compressed RINEX obs files
       |                                    for station 'ssss' ,
       |             |                      day 'DDD', year 'YY'
       |
       |             /    ssssDDD0 YYn. Z   Compressed RINEX nav files
       |             |                      for station 'ssss' ,
       |                                    day 'DDD', year 'YY'
       |             |
       |             /    SSSSDDD0  YYm     Meteorological obs files
       |                                    for station 'ssss' ,
       |                                    day 'DDD', year 'YY'
       |
       /rogue / day_DDD/  ssssDDDB . YYc    Raw obs files in Rogue
       |                                    Conan binary format for
       |                                    station 'ssss' , day 'DDD' ,
       |                                    block 'B' (1-6), year 'YY'
       |
       /sat_clocks/YYmmm/ YYmmmDD. elk. Z   Post-processed Precise Satellite
       |                                    clocks at 30 sec computed
       |                                    for year 'YY' , month 'mmm'
       |                                    day ' DD' for Canadian coverage
       |
       /glob_clocks/YYmmm/ YYmmmDDg. elk. Z Post-processed Precise Satellite
       |                                    clocks at 30 sec computed
       |                                    for year 'YY' , month 'mmm'
       |                                    day 'DD' for global coverage
       |
       /software/                           Miscellaneous programs for file
       |                                    manipulation
       |
       /station/  ssss. log                 General information on Canadian
       |       |                            active control station 'ssss'
       |
       |       / CACS_coord. 1st            Coordinate list for Canadian
       |                                    Active Control Stations
       |
       /tracks/   SSSSDDD1 .YYt             Data validation summary from
              |                             software GIMP, includes ionos-
              |                             pheric activity and multipath
              |                             levels and tracking table for
              |                             station ' ssss' (includes global
              |                             sites used by NRCan) , day 'DDD' ,
              |                             year ' YY'
              |
              / ssssDDD1 . YYv              Data validation summary based on
                                            point positioning software
                                            DCRAP for station ' ssss' (includes
                                            global sites used by NRCan) ,
                                            day 'DDD', year 'YY'
```

Annual Report 1994 of the CODE Processing Center of the IGS

M. Rothacher, R. Weber, E. Brockmann, G. Beutler, L. Mervart
Astronomical Institute, University of Berne
Berne, Switzerland

U. Wild, A. Wiget
Federal Office of Topography
Wabern, Switzerland

C, **Boucher,** S. **Botton**
Institut Géographique National
Paris, France

H. Seeger
Institut für Angewandte Geodäsie
Frankfurt, Germany

Introduction and Overview

This contribution to the IGS Annual Report for 1994 actually covers the time period from mid-1992 till the end of 1994.

CODE (the Center for Orbit Determination in Europe) is a joint venture of the following institutions:

- the Swiss Federal Office of Topography (L+T),
- the French Institut Geographique National (IGN),
- the German Institute for Applied Geodesy (IfAG), and
- the Astronomical Institute of the University of Berne (AIUB).

The processing center is located at the AIUB. The computations are performed on a cluster of VAX/ALPHA computers, one being reserved for IGS processing only. (The other ALPHAs and VAXes are also used for other projects of the institute or even by other institutes of the University of Berne.) The Bernese GPS Software is used for processing. Table 1 documents that the daily workload at CODE has been steadily growing since June 1992.

The IGS Network(s) Analyzed by CODE

When the CODE Processing Center of the IGS started its official operations for the IGS on June 21, 1992, it was the declared goal to provide the best possible

Solution Characteristic	Number used by CODE in processing			
	June 1992	Jan. 1993	Jan. 1994	Jan. 1995
Number of Satellites	19	21	26	25
Number of Stations	25	28	38	49
Number of Observations	50,000	60,000	180,000	250,000
Total Number of Param.	2,000	2,300	6,200	9,000
Ambiguity Parameters	1,500	1,800	*5,500*	*8,000*

Table 1. Workload of the daily "three-day" CODE solutions.

GPS orbits *over Europe* to the European GPS community. In addition it was the intention to produce and make available so-called ***free-network solutions*** for all permanent *European IGS tracking sites* (available in time to be included into the CODE series). Earth orientation parameters and global coordinates initially were considered in second priority only. This was why three types of solutions were produced by CODE during the 1992 IGS Test Campaign (June 21–September 21, 1993):

(a) A Global Solution with initially 22 stations (including 4 European stations) with the goal to produce (global) orbits and earth orientation parameters using the GPS data from tracking sites with known coordinates from VLBI and SLR (wherever possible).
(b) A pure European Orbit Solution using the data of 12 European tracking sites. The coordinates of the tracking sites were kept fixed on the SLR and VLBI values wherever possible. No pole parameters were estimated; the values were taken over from the IERS.
(c) A European Free Network Solution using the same material as in analysis (b). In addition to the orbit parameters the coordinates for all stations were estimated (loose *a priori* constraints were applied to avoid singularities).

This processing scheme was modified with the start of the *IGS Pilot Service* (1 November 1992). The European solutions (b) and (c) were discontinued, but all European stations of steps (b) and (c) not already implemented in solution (a) were incorporated as *free* stations (coordinates estimated) into the analysis (a). Thus, our global orbit series, from that time onwards, had the emphasis on Europe. The global orbits were based on 28 stations by the end of 1992 (Table 1). The CODE Annual Report for 1992 (Beutler *et al., 1993)* describes the CODE contribution to the ITRF section of the IERS for 1992. This contribution was based on the free network solution (c) for the time interval of the 1992 IGS Test Campaign and on the *free* European IGS subnet of our global analysis based on observations from November 1, 1992–March 31, 1993.

Table 2 gives an overview of the stations used by the CODE processing center today including the approximate date when the stations were first included into the CODE solution series. In addition one may extract from Table 2 the stations which were and are kept fixed in the CODE routine solutions. The number of stations has been growing considerably since 1992, but even today the emphasis is on Europe in the CODE analysis.

The CODE general processing scheme was again modified on April 1, 1993, when *all* stations were formally introduced as unknown parameters into the daily processing; instead of actually fixing stations (coordinates not showing up in the list of unknown parameters) we started to closely constrain them (sub-millimeter level). This procedure allowed it to base the daily solutions on a well defined set of ITRF station coordinates (virtually fixed), but to remove these constraints afterwards for annual or even multi-annual solutions: so-called *free network solutions* based on a superposition of hundreds of daily normal equation systems could now be generated for the entire IGS network considered by CODE. Results of this kind are described in the CODE annual report for 1993 (Rothacher *et al.*, 1994). Let us include in Figure 1 the CODE velocity estimates based on 23 months of daily solutions (April 1993–February 1995). The velocity estimates stem from a *free network solution* with no constraints on any site coordinates and with the velocity of Wettzell kept to the ITRF93 value. The C04 pole series was used and no ERPs were estimated.

Europe -17 stations			North America -13 stations		
GRAZ	Graz	Jun 92	ALGO*	Algonquin	Jun 92
MADR*	Madrid	Jun 92	GOLD*	Goldstone	Jun 92
METS	Metsahovi	Jul 92	DRAO	Penticton	Jun 92
TROM*	Tromsoe	Jun 92	YELL*	Yellowknife	Jun 92
HERS	Herstmonceux	Jun 92	KOKB*	Kokee Park	Jul 92
NYAL	Ny-Alesund	Jun 92	FAIR*	Fairbanks	Jul 92
WETT*	Wettzell	Jun 92	STJO	St. John's	Jul 92
MAS1	Mas Palomas	Jun 92	RCM5	Richmond	Ott 92
KOSG*	Kootwijk	Jun 92	QUIN	Quincy	Nov 92
MATE	Matera	Jun 92	PIET	Pietown	Jan 93
ONSA	Onsala	Jun 92	WES2	Westford	Mar 93
ZIMM	Zimmerwald	Mar 93	BRMU	Bermuda	Ott 93
JOSE	Jozefoslaw	Aug 93	MDO1	McDonald	Nov 93
BRUS	Brussels	Nov 93	South America -6 stations		
BORI	Borowiec	Jun 94	KOUR	Kourou	Nov 92
POTS	Potsdam	Nov 94	SANT*	Santiago	Nov 92
LAMA	Lamkowko	Dec 94	FORT	Fortaleza	Ott 93
Australia and Antarctica			AREQ	Arequipa	Mar 94
9 stations			EISL	Easter Island	Aug 94
TIDB*	Tidbinbilla	Jun 92	BOGT	Bogota	Nov 94
YAR1*	Yaragadee	Jun 92	Asia -5 stations		
MCMU	McMurdo	Jun 92	TAIW	Taiwan	Jun 92
PAMA	Pamatai	Jul 92	USUD	Usuda	Jun 92
HOB2	Hobart	Mar 93	TSUK	Tsukuba	Mar 94
DAV1	Davis	Aug 94	KIT3	Kitab	Ott 94
CAS1	Casey	Nov 94	SHAO	Shanghai	Jan 95
KERG	Kerguelen Islands	Nov 94	Africa -1 station		
GUAM	Guam	Jan 95	HART*	Hartebeesthoek	Jun 93

*Fixed or closely constrained in daily processing

Table 2. IGS sites used in CODE processing. Date of first appearance listed.

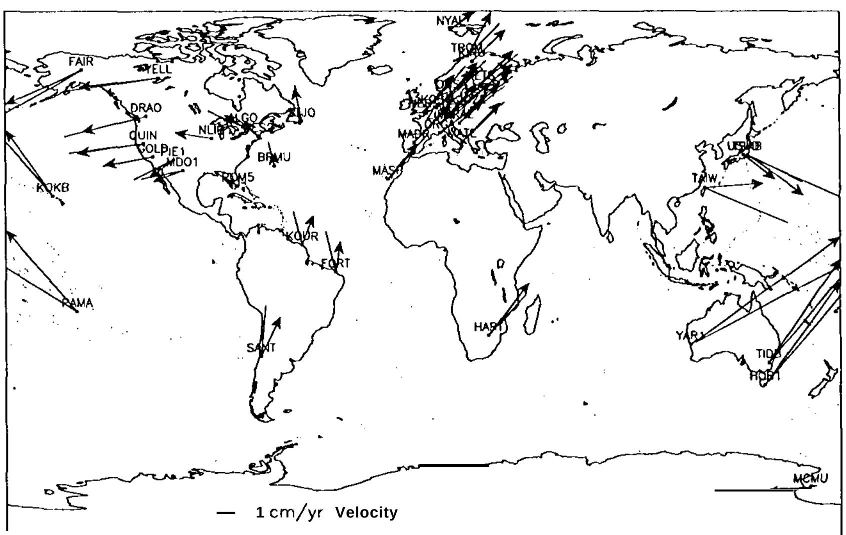


Figure 1. Station velocities estimated by CODE based on the solutions April 1993-February 1995 (arrows: CODE estimates, lines: ITRF values).

Research Work in the Environment of the CODE *Processing Center*

A processing center of the IGS only can be kept alive if the algorithms, the models, and the solution strategies are continuously improved and optimized. Although CODE is a joint venture of four institutions one has to take into account that its resources are comparatively small. The research thus had to be focused on specific areas. The name “CODE” implies that the orbits of GPS satellites are of primary interest. Other research areas were generated by the need to further analyze or improve the daily results of the CODE processing center. Let us briefly summarize the key issues.

Operational Aspects

In the preparation phase (1991–mid-1992) the emphasis had to be put on the automation of the data flow and the daily processing, on the improvement of the preprocessing procedures, and on the implementation of the IERS Standards (McCarthy, 1992) into our software. This early phase of developments is documented in Gurtner *et al.* (1992) and Fankhauser (1993).

During the 1992 IGS Test Campaign, the CODE Analysis Center, probably like each of the other IGS Analysis Centers, was mainly preoccupied keeping the pace of routine processing, that is, to process one day of observations within one calendar day. Towards the end of 1992 the procedures became more and more smooth, which made it possible to develop and implement significant model improvements. This research work was coordinated by M. Rothacher and G. Beutler.

Ambiguity Resolution

Ambiguity resolution strategies for regional and global applications were developed by L. Mervart. The key idea was to use to the extent possible the CODE products (which so far are all based on ambiguity-free solutions) and to resolve the ambiguities in the baseline mode. Mervart *et al.* (1994) could demonstrate that it is possible to safely resolve the ambiguity parameters up to baseline lengths of about 300 km even without making use of precise GPS code measurements. With the refinement of the strategies, with the improvement of the CODE orbits, and eventually with the development of the IGS orbits, ambiguity resolution became possible on baselines considerably longer than 1000 km. Results are given in L. Mervart’s Ph.D. thesis, where one also finds a discussion of the impact of ambiguity resolution on the estimated orbits and earth rotation parameters (Mervart, 1995).

Stacking of Normal Equation Systems

Not only daily solutions, but also annual solutions, e.g., for the IERS (International Earth Rotation Service) were produced by the CODE Processing Center (See Beutler *et al.*, 1993 and Rothacher *et al.*, 1994). For such *big* solutions it was necessary to develop *stacking procedures* for the normal equations turned out in the daily routine. The research in this area is performed by E. Brockmann. His input material consists of the normal equation systems stored during the daily processing. These *daily* normal equation systems are combined by the program ADDNEQ to give a wide variety of results. It is, for example, possible to produce free-network solutions (where, as opposed to the daily routine, no stations are kept fixed), where station velocities maybe solved for in addition to the station coordinates. Moreover it is possible to produce *new* series of earth rotation parameters, as soon as a change of the ITRF (e.g., for the transition from ITRF92 to ITRF93 on January 1, 1995) takes place. The early stages of the ADDNEQ program are documented in Brockmann *et al.* (1993); results obtained in 1993 maybe found in Rothacher *et al.* (1994).

The technique of combining normal equation systems was considerably extended and generalized in 1994. Since mid-1994 it is possible to produce *long arcs* (three-day arcs for the routine processing, in particular) based on one-day arcs using the program ADDNEQ. This led to a considerable reduction of the daily processing times. Since January 1995 the official CODE solutions delivered to the IGS are based on this technique. The theory underlying these developments is documented in Beutler *et al.* (1995). More information may be found below in the following section.

Earth Rotation Parameter Models

Our parameter estimation program GPSEST allows the estimation of x and y (the position of the pole *on* the surface of the earth), UT1-UTC, and the nutation in obliquity and longitude as polynomials of a user-defined degree. The individual polynomials refer to user-defined contiguous time intervals. Because *a priori* weights may be put on individual parameters it is possible to solve only for the first and higher derivatives of UT1-UTC and the nutation terms. Because of the necessity to solve for the orbital elements (right ascension of the ascending node and inclination in particular) in addition to the earth orientation and rotation parameters it is not possible to solve for offsets in UT1-UTC and in the nutation terms. More information maybe found in section "Models for the Earth Orientation Parameters" of this report.

Orbit Modeling

The radiation pressure models recommended by the IERS Standards were critically reviewed in Beutler *et al.* (1994): long arc analyses (arc lengths up to two weeks) revealed that the ROCK4, ROCK42 models (Fliegel *et al.*, 1992) are one of the important accuracy limiting factors and that alternative models lead to much better results. In the same article, pseudo-stochastic pulses (instantaneous velocity changes at given epochs in predetermined directions) were discussed. Pseudo-stochastic pulses are routinely set up for the eclipsing satellites in the CODE solutions. The orbit model presented in Beutler *et al.* *(1994)* is the model which is today used by the IGS Analysis Center Coordinator for the weekly quality control (long arc analysis) of the orbits delivered by all IGS processing centers (Beutler, Kouba, and Springer, 1995). The technique actually used today by the IGS Analysis Center Coordinator to combine the orbits of the IGS processing centers were developed by the Bernese GPS/IGS team, too (Springer and Beutler, 1993; Beutler, Kouba, and Springer, 1995). Orbits will be considered in more detail in section "Orbit Model Investigations" of this report.

Tropospheric Refraction

The atmosphere is an important accuracy-limiting factor for regional and global applications of the GPS. Whereas ionospheric refraction maybe eliminated almost perfectly by forming the so-called ionosphere-free linear combination of the original carriers, the troposphere has to be *modeled* in the processing in order to obtain high accuracy results. This modeling maybe performed in different ways (deterministic or stochastic). At CODE a deterministic scheme is used, where (at present) 12 tropospheric zenith delay parameters are set up per day and station. For the three-day solutions this number is (at present) reduced to four parameters per station and day in the program ADDNEQ. Up to 12 parameters (per day and station) maybe used for special studies. There are strong correlations between tropospheric refraction and GPS height estimates. This is why in our results (as in all GPS results) the height is not quite as well determined as the horizontal station coordinates. Improvements of the mapping function still seem possible in our case, however. We consider introducing an elevation-dependent weighting and a cut-off elevation angle of 15 instead of 20 degrees in future. More information may be found in section Atmosphere Models.

The Ionosphere

By forming the so-called geometry-free linear combination, i.e. the difference in meters of the L1 and L2 (phase or code) observations, it is possible to study the ionosphere in some detail. The observations of the IGS network were used to generate regional ionosphere models (and maps) by U. Wild in his Ph.D. thesis (Wild, 1994). Moreover Wild studied short period variations (in space and time), so-called stochastic variations, of the ionosphere. Obviously the IGS network might be used for ionosphere studies, too. Hopefully this development will take place soon.

The stochastic behaviour of the ionosphere was of vital interest to Schaer (1994). The concepts in this contribution but also from Mervart (1995) might lead to new global ionosphere models.

Receivers and Antennas

The antennas of the GPS receivers proved to be of importance to achieve millimeter accuracies in GPS surveying. Helix and crossed-dipole antennas disappeared: today, almost uniquely, microstrip antennas are in use. But even then the differences between different antenna types are substantial and need to be addressed. The problem becomes of vital importance if different antenna types (microstrip antennas from different manufacturers) have to be combined in the same survey. This problem was addressed several times by the AIUB. The antenna test in the Thun GPS test area of the Federal Institute of Topography in Fall 1994 was the latest in a series of experiments (Gurtner *et al.*, 1994).

Description of the Daily Routine at CODE

The processing scheme was modified several times during the time period of this report. At present we proceed as follows: typically three days after the observations were taken the processing of the data of a given day is started automatically in the early morning, provided that enough data are available at CODE for the day. When the operator arrives in the morning he may already check the first results and take corrective actions if necessary.

In a first processing step the data are translated from RINEX to the internal (binary) Bernese format. In this step inconsistencies (wrong file names, wrong station names, “new” antenna heights) are sorted out. This step unfortunately still needs user interaction because obviously at many sites the generation of the daily RINEX files is not done in automatic (*hands off*) mode. Preprocessing (code processing, single-difference formation, phase-cleaning) is done with the best orbit information available at that time; today this is usually a one-day extrapolation of our previous three-day solution (see below).

At this stage we are ready to produce a first one-day solution based on the observations of exactly one day. The primary result consists of an improved orbit for the current day. The phase preprocessing is repeated with this improved orbit; this time all cycle-slips should be safely detected, and, if possible, corrected. If this is not possible, new ambiguities are set up. The principal difference between AS and non-AS processing resides in the number of ambiguities which have to be set up in this step.

With this improved data set a new one-day solution is generated, this time including the estimation of earth rotation parameters. If the solution is acceptable the three-day solution (Figure 2) is produced. The three-day solution was produced *from scratch* prior to January 1, 1995, afterwards it was produced by combining the normal equation systems of the three one-day solutions corresponding to the three-day solution (see next section).

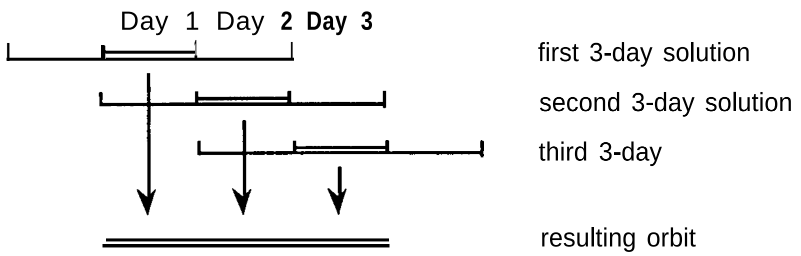


Figure 2. Processing in overlapping three-day intervals at CODE.

Development of Solution Strategies

Only one series of results are made available by CODE to external users. Internally more solution series are generated:

[G1-Series] Since June 1992 the complete information for the final one-day-solutions is stored. Precise ephemerides files, earth rotation parameters (x, y, UT1-UTC, nutation terms), and station coordinates are available for later comparison. We will present more information in sections "Models for the Earth Orientation Parameters" and "Orbit Model Investigations." G1 orbit files and earth orientation files are available upon request. No troposphere files are stored for this solution.

[G3-Series] This was the official series of CODE results prior to GPS week 751. Pseudo-stochastic parameters in along-track and radial directions are setup twice per day for the eclipsing satellites. Prior to April 1995 the pulses were set up at 00:00 h and 12:00 h UT, afterwards at the epochs of shadow exit. The earth orientation and rotation parameters x,y, and UT1-UTC (actually the increments relative to the rapid pole series) are modeled as first order polynomials for each of the three days. Continuity of the parameters is imposed at the day boundaries. The zero-order term of the UT1-UTC polynomial is constrained on the *a priori* value for the first day. The estimated troposphere parameters are available for this series since January 1, 1994.

[H3-Series] The only difference between the G3 and the H3 solutions consists of the model for the earth orientation parameters. x, y, and UT1-UTC are modeled as first degree polynomials over the entire three-day interval. The H3 solution is our official product since GPS week 751. The estimated troposphere parameters are available for this series.

[Q1-, Q3-Series] These solution series are generated since October 1994. They are solutions based on about 33% of fixed ambiguities (80% for baselines below 2000 km) using the methods developed by Mervart(1995). Apart from that the solutions correspond to solutions G1 and H3, respectively.

[C3-Series] This series is produced since January 1, 1994. It includes the first time derivatives for $\Delta\psi$ and $\Delta\varepsilon$ in addition to the other earth orientation parameters. All other characteristics are identical with the H3-series.

The Program ADDNEQ

This program was developed to combine the normal equation systems of our routine solutions. ADDNEQ required modifications in our daily routine. In order to be able to produce so-called free network coordinate solutions it was necessary to formally introduce all stations into the daily routine but to constrain them to their *a priori* ITRF values. Since April 1, 1993 all solutions are produced in this mode.

The program ADDNEQ (Rothacher *et al.*, 1994) was considerably generalized in 1994. Today it is the central tool of the CODE processing center of the IGS:

- ADDNEQ may now be used to form n-day arcs, $n \geq 2$, from one-day arcs (Beutler *et al.*, 1995). This new development saves many hours of CPU in the daily routine.
- More troposphere parameters (12 per station and day) are setup in the one-day solutions. ADDNEQ allows it to produce solutions based on 2-, 4-, 6-, and 12-hour troposphere intervals (per station and day).
- ADDNEQ may handle first time derivatives of $\Delta\varepsilon$ and $\Delta\psi$ of nutation parameters, and may be extracted from ADDNEQ. Time series are (internally) available from January 1, 1994.
- The capabilities to change the reference frame (e.g., from ITRF92 to ITRF93) are fully implemented and active. As soon as a new reference frame becomes available new solutions (coordinates, orbits, etc.) may be extracted easily from ADDNEQ back to day 91 of year 1993.

Atmosphere Models

Two methods are used today in global applications of the GPS to take into account tropospheric refraction:

(a) Estimation of site- and time-specific tropospheric zenith delay parameters, where *a priori* constraints may be introduced for each parameter and for differences between subsequent parameters (pertaining to the same station).

(b) The tropospheric zenith correction is assumed to be a stochastic process in time with a power spectral density (PSD) supplied by the user. In this case the conventional least squares approach has to be replaced by a Kalman filter technique.

In the production version of the Bernese GPS Software method (a) is implemented, Method (b) was available in a test version (Rothacher, 1992) but it was never used for IGS processing.

At present we use the following strategy: 12 troposphere parameters are set up per station and day in the one-day solutions. When the routine three-day solutions are set up using the daily normal equation systems the number of troposphere parameters is reduced from 12 to 4 parameters per station and day. This makes the official solutions after the change of the processing strategy on January 1, 1995 compatible with the earlier solutions but it allows us to produce at any time series of solutions using more troposphere parameters. At present no constraints (neither absolute nor relative) are imposed.

Figure 3 shows the troposphere parameters of weeks 781-783 for Wettzell using 4 and 12 troposphere parameters per day for each site of the network used

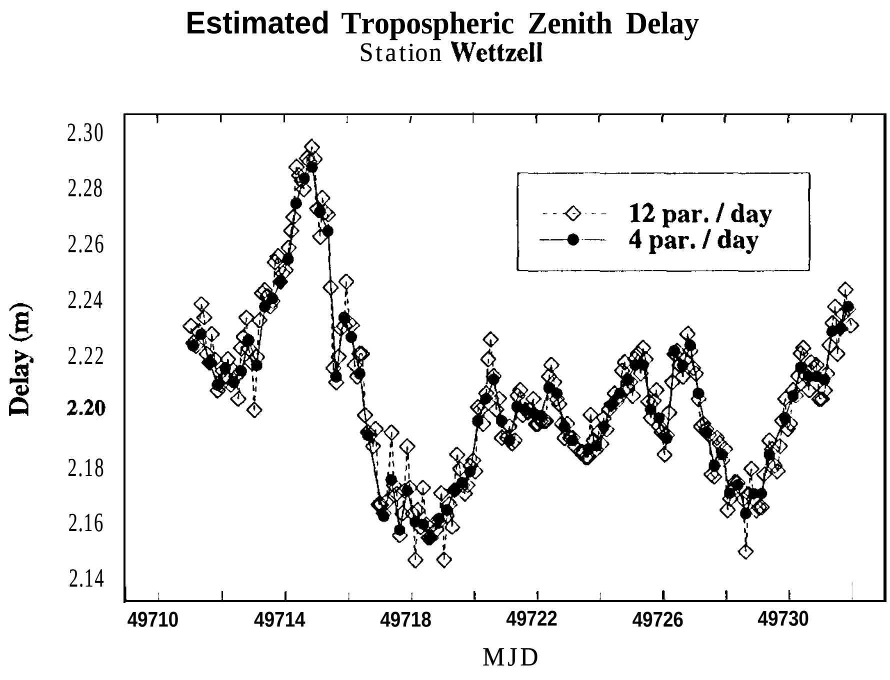


Figure 3. 4 vs. 12 troposphere parameters per day for Wettzell, weeks 781-783.

in our routine solution. One can see that essentially the curve with four parameters per day is a smoothed version of the curve with 12 daily estimates.

Figure 4 shows that our troposphere estimates are highly correlated with tropospheric refraction: The estimated troposphere parameters for Wettzell for the year 1994 (four values per day) are compared with the tropospheric refraction corrections which were computed using the Saastamoinen model with surface meteorological data (temperature, pressure, humidity) from Wettzell as input. The annual mean of the difference *estimate-sensor* is about 1 cm, the

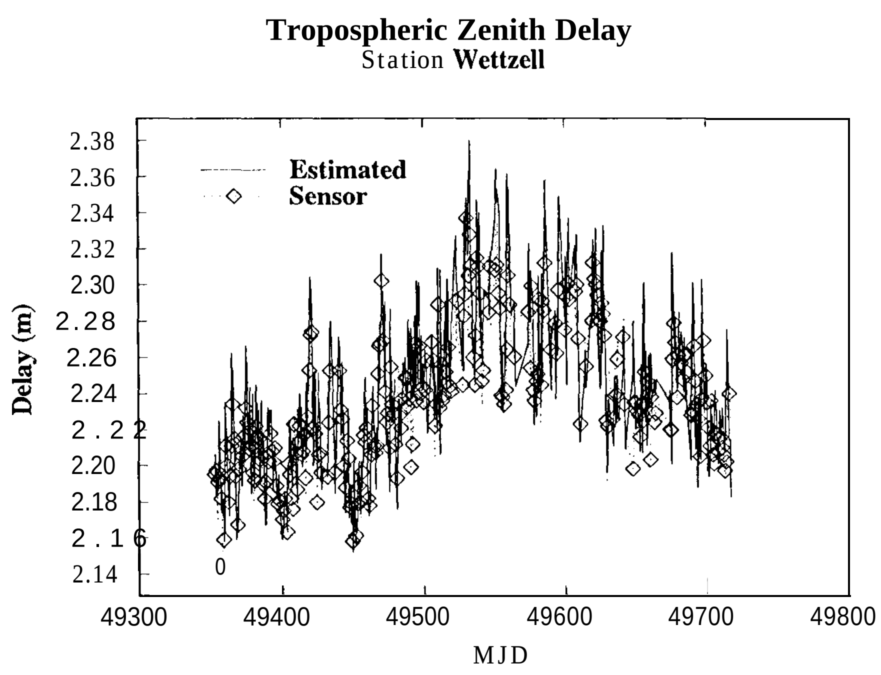


Figure 4. Tropospheric refraction from surface meteorological data and from GPS estimates for Wettzell in 7994.

corresponding rms about 2 cm. This is about the order of magnitude with which tropospheric refraction might be predicted using surface meteorological data.

Estimates of the type shown in Figure 4 exist since 1 January 1994 for the entire IGS network processed at CODE.

Models for the Earth Orientation Parameters

The parameter estimation program GPSEST and program ADDNEQ allow one to split up the interval covered by observations (usually one or three days) into $n \geq 1$ subintervals. Within each of the subintervals the pole parameters x, y, UT1-UTC, and the nutation terms in obliquity and longitude are modeled as polynomials of a user-defined degree $q \geq 0$. Continuity of the polynomials at the interval boundaries may be enforced. All parameters are estimated relative to an *a priori* model. In our routine solutions we utilize the ERP series produced by the Rapid Service Subbureau of the IERS for the parameters x, y, and UT1-UTC and the IAU 1980 model for nutation.

Prior to June 14, 1993 (GPS week 701) the polynomial degree was q=O, afterwards q= 1 where we required the pole coordinates to be continuous at the day boundaries. So, before June 14, 1993 we modeled each component of the pole by three parameters in every three-day solution, afterwards by four, formally six parameters (3x (1 offset+ 1 drift per day) *minus 2* continuity conditions). Until GPS week 751 we divided the three days covered by our *official* solutions into three one-day bins, afterwards we switched to one three-day bin (where internally we still produce the solution corresponding to three bins; it is the G3- as opposed to the the H3-solution). After GPS week 751 the formal number of parameters per pole parameter was therefore reduced to two (one offset and one drift parameter for the entire three-day interval).

The main reason for the model change of June 14, 1993 was to make our estimates compatible with the *a priori* models for the pole (which are continuous). Therefore, after June 14, 1993, it was possible to iteratively improve the pole coordinates in the final processing step (three-day solution). The reason for the change of GPS week 751 was to reduce the number of empirical pole parameters in our estimates.

Because it is not possible to solve for UT1-UTC (correlations with the nodes of the satellites) but only for its time derivatives with the GPS we have to constrain the zero degree polynomial term pertaining to the first bin of our empirical ERP model to the value of the *a priori* model. Thus, the actual number of parameters for our UT1-UTC estimates was two prior to June 14, 1993, three between June 14, 1993 and May 28, 1994, and one afterwards. By integrating these estimated time derivatives it is formally possible to reconstruct UT1-UTC relative to an initial value taken, for example, from VLBI.

Nutation parameters are formally solved for since January 1, 1994 only. All nutation parameters are heavily constrained in our routine solutions in such a way that no model differences exist in the solutions made available to external users. In the C3-solutions produced with ADDNEQ we solve for exactly one drift parameter over the three-day interval for the nutation in obliquity and longitude (we remove the weights put on the nutation drift parameters). As mentioned above, the C3-solutions correspond to the H3-solutions (to our official solutions) in all other respects (with the exception of the model for nutation).

Let us conclude this section with a few results. Figures 5,6, and 7 show for the year 1994 the correlations between the x- and y- coordinates of the ephemeris pole (on the surface of the earth), the x-coordinate and the UT1-UTC-drift and

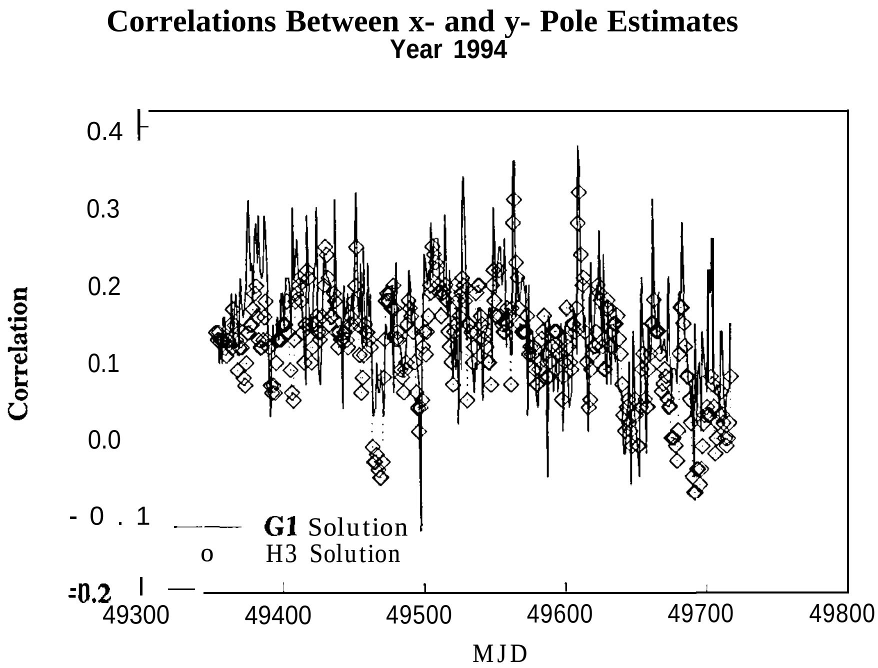


Figure 5. Correlations between x- and y- estimates of polar wobble for 1994.

the y-coordinate and UT1-UTC drift, respectively. The solid line corresponds to the values extracted from the one-day solution (G1), the dotted line to the three-day solutions (H3).

First we clearly see in Figure 5 a positive correlation of about 0.15 to 0.20 between the x- and the y-coordinates. We attribute this to the unsymmetrical distribution of the tracking stations. This positive correlation is somewhat smaller in the three-day solutions.

Figures 6 and 7 reveal a much better behavior (significantly smaller correlations) of the three-day than the one-day solutions. In practice the estimates corresponding to our one-day solutions (G1) are somewhat noisier than our three-day solutions (H3). Instead of an rms error of 0.45 mas for x and y for the G1 solutions when compared to the C04 pole values we have one of only 0.3 mas for the H3 solutions. Figure 8 reveals that the arc length is of vital importance for our UT1-UTC drift estimates. The solutions corresponding to the three-day solutions are clearly superior. Still unresolved is the almost-constant drift of about 4 msec/year. In practice this drift does not really matter. It maybe taken out of our results very easily. If this is done our series maybe used for the interpolation of UT1-UTC values established by VLBI and for extrapolation over certain time-spans.

Figures 9 and 10 show a power spectrum of the nutation drift rates in longitude and in obliquity for a time interval of 14 months (January 1994 to February1995).Althoughthe time interval for such an analysis is still small (We are looking for signals of fractions of mas per day) it is very encouraging to see that the periods to be expected according to the nutation theory actually show up in these figures. We believe that the GPS has the potential to contribute to the establishment of the celestial reference frame in the frequency domain corresponding to periods between one and 40 days. Only an analysis of several years of data makes sense. We expect that with one more year of data rather reliable estimates for about 10 terms may be extracted. First computations are encouraging.

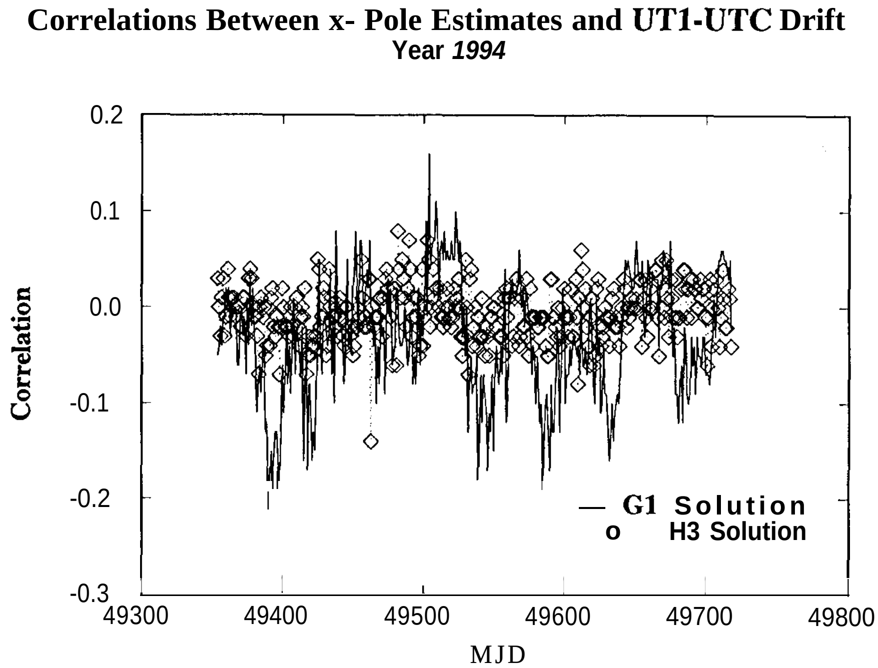


Figure 6. Correlations between x-estimate of polar wobble and UT1-UTC drift for 1994.

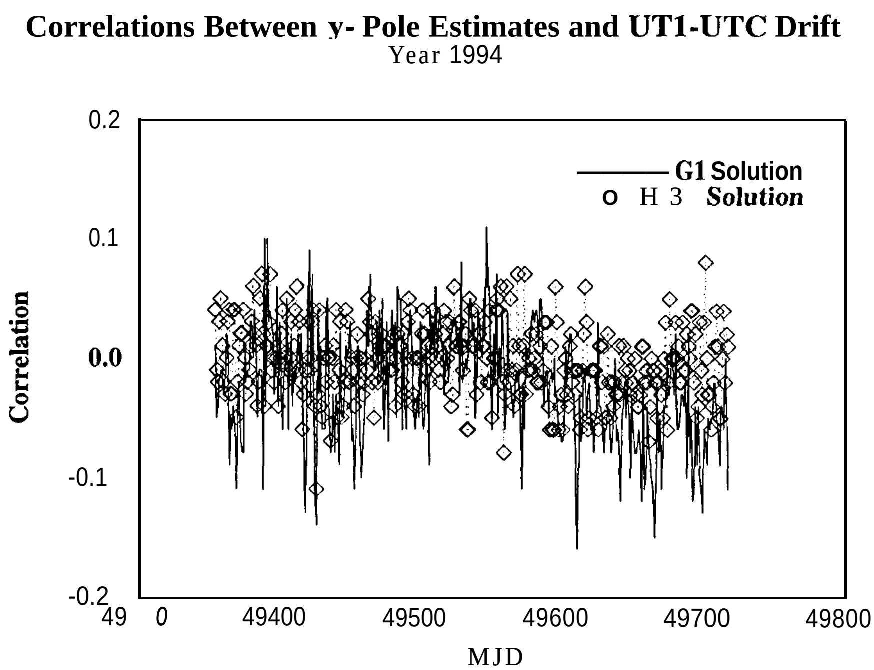


Figure 7. Correlations bet ween y-estimate of polar wobble and UT1-UTC drift for 1994.

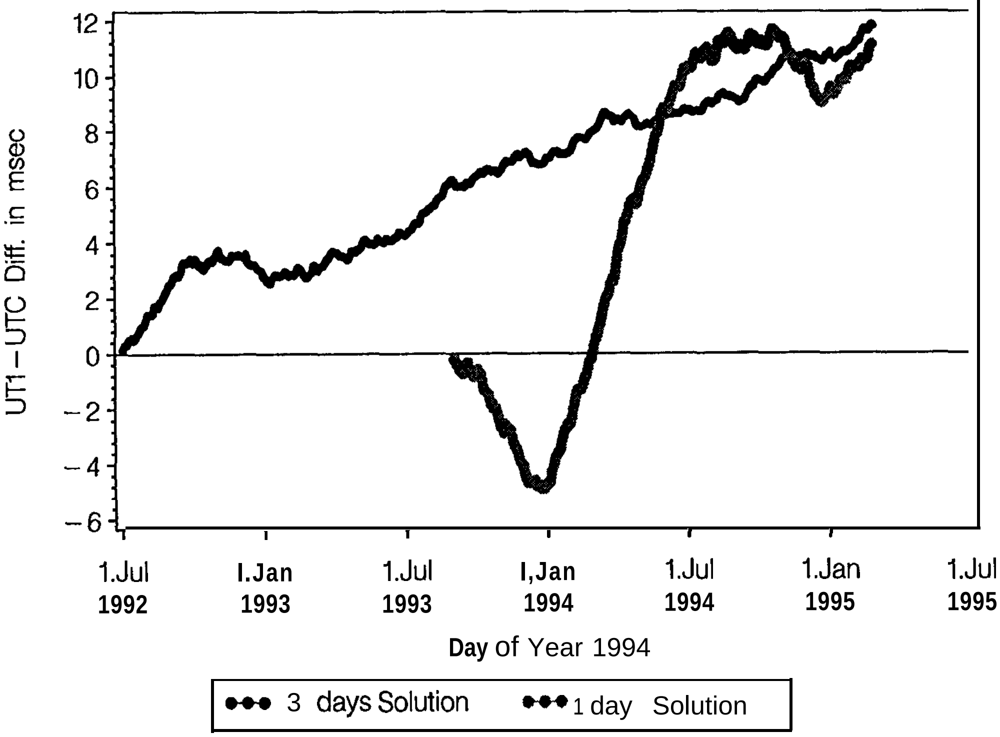


Figure 8. UT1-UTC estimates from one- vs. three-day solutions relative to VLBI estimates (from C04).

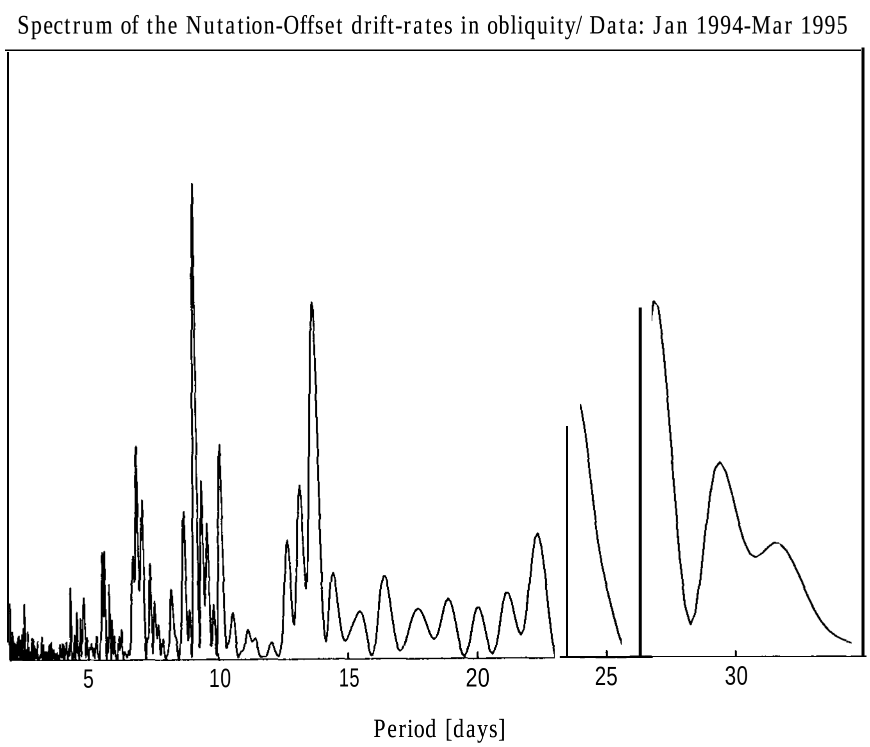
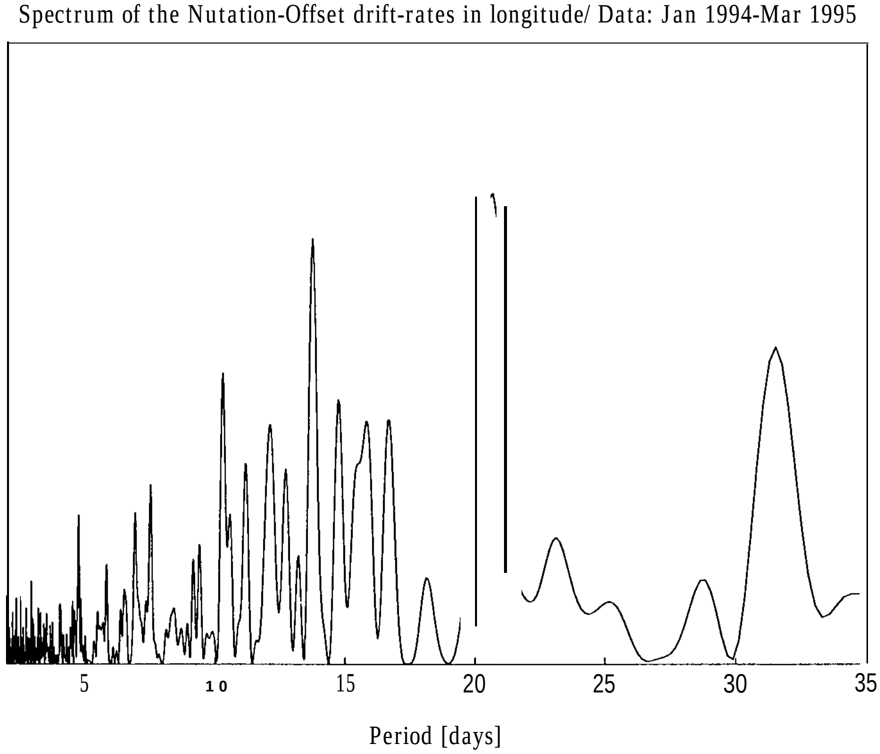


Figure 9. Frequency analysis of the drifts in $\Delta\varepsilon$ as estimated by the CODE ***processing center.***

Figure 10, Frequency analysis of the drifts in $\Delta\psi$ as estimated by the CODE processing center.



Orbit Model Investigations

The main characteristics of the orbit model used for our routine processing are summarized in Table 3.

In our parameter estimation program GPSEST we may solve for a number of pseudo-stochastic velocity changes (pulses) at predetermined times (Beutler *et al.*, **1994)** for a user-specified list of satellites. The user may set up any number of stochastic epochs; up to three pulses per epoch (in radial (R), along-track (S), out-of-plane (W) directions) may be estimated. We make use of this option for the eclipsing satellites since late 1992. Until April 1995 we introduced along-track and radial velocity changes at O h and at 12 h UT for these satellites; afterwards pulses in R- and S- directions were and are setup at the shadow exit times. In addition pseudo-stochastic pulses may be set up at O h UT and at 12 h UT for problem satellites (e.g., for PRN 23). The pseudo-stochastic pulses are constrained by (user-defined) *a priori* weights. At present these *a priori* constraints are 10^{-6} m/s^2 for the pulses in R direction and 10^{-5} m/s^2 for those in S direction. These pseudo-stochastic pulses considerably improved our orbit modeling capabilities for eclipsing satellites.

Modeling problems may be encountered for eclipsing and non-eclipsing satellites during certain time periods (hours to two days). Such problems may be associated with phenomena like the momentum dump. If the introduction of pseudo-stochastic pulses does not remove the problem in a satisfactory way (if the rms of the phase observable is still too high) we may also set up new arcs for these problem satellites at one or all of the day boundaries. Prior to the use of ADDNEQ for the production of the three-day arcs it was also possible to make use of the windowing technique by excluding observations of the first and the third day for such satellites.

Table 3. Basic orbit characteristics for CODE orbits.

Characteristic	Comment
Geopotential	Gem-T3 + terms C_{21}, S_{21} according to IERS Standards
GM	398600.4415 km3s-2
ae	6378137 m
Sun	GMs = 132712500000 km3s-2
Moon	GMm = 4902.7890 km^3s^{-2}
Ephemeris	JPL DE200 or Newcomb approximation
Direct radiation	ROCK4 and ROCK42 models for Block I and II satellites, respectively (S1 O and S20 models used)
	Satellite masses
	PRN 02 878.2 kg PRN 16–19 883.2 kg
	PRN 12 519.8 kg 20 887.4 kg
	PRN 14 887.4 kg 21 883.9 kg
	PRN 15 885.9 kg 23 972.9 kg
	all other satellites 975.0 kg
Orbit parameters	Oscillating Keplerian elements (a, e, i, r.a. of asc. node Ω, perigee ω, argument of latitude u_0 at initial time). Direct radiation pressure p_0 pointing from sun to satellite, y-bias p_2 pointing into space-body fixed y-axis. For eclipsing and (other) problem satellites: Estimation of pseudo-stochastic velocity changes (see explanation in text)
Earth shadow	Cylindrical shadow (radius = $(a_e + a_p)/2$) a_e, a_p equatorial pole radius of earth
Earth tides	Solid earth tides. Love number k_2 = 0.285. Ocean tides not implemented
Relativity	Optional, at present not included
Orbit generation	Numerical integration using a collocation method (Beutler, 1990). Integration step size = 1 h, order of integration = 10

Attitude control poses a problem for GPS satellites during the eclipse phases (Bar-Sever, 1994). At present this problem is dealt with at CODE in a very simple way: data of the eclipse satellites are automatically eliminated during and shortly after the eclipse phases. This completely removes the geometrical effect (due to the unmodeled motion of the satellites' antenna phase centers); the dynamical effect is absorbed by the pseudo-stochastic pulses at shadow exit times. It is planned to solve for the geometrical effect in future, although we do not expect a dramatic improvement of our orbit quality for eclipsing satellites by this measure.

At CODE we regularly analyse the orbital elements (we form mean elements to better see the evolution of the satellite system), the estimated radiation pressure parameters, and the estimated stochastic parameters. Let us comment on a few results of such an analysis performed with the CODE material stemming from June 1992–end of 1994. Table 4 gives an overview of this time period from the point of view of the CODE processing center.

In Table 4 we included the epochs of the maneuvers(day only), the associated changes in the (mean) semimajor axes, and the mean drift rates of the mean semimajor axis in meters/day. We see that these drift rates reach values up to 7 m/d. We also see that the satellites in one and the same orbital plane show significantly different drift rates. These drifts are caused by the resonance terms of the geopotential. The terms with (n=3, m=2) give rise to the largest resonance perturbations. As a matter of fact it is not the orbital plane, but the geographical longitude of the ascending node which determines these drift rates (Hugentobler

Table 4. Satellite events since mid-1992, including the maneuvers as they were detected at CODE processing center, the change in the semimajor axis a associated with the maneuvers, and the mean rate of change of a over the time period mid-1992–end of 1994. Column Flag (F): "n": New satellite included into the CODE processing, "+": Old satellite excluded from the CODE processing.

PRN	Plane	Processed since	Processed until	F	# Man	Epochs	da	da/dt
09	A	1993 7 25	1994 12 31	n	1	1994 4 20	2113 m	-3.1 m/d
19	A	1992 7 26	1994 12 31		2	1993 1 16	1318 m	-1.8 m/d
						1994 12 15	1467 m	
27	A	1992 9 30	1994 12 31	n	1	1994 3 3	1701 m	-2.7 m/d
25	A	1992 7 26	1994 12 31		2	1993 3 25	-2334 m	6.0 m/d
						1994 3 17	-2121 m	
02	B	1992 7 27	1994 12 31		1	1993 8 30	-572 m	0.4 m/d
05	B	1993 9 28	1994 12 31	n	1	1994 9 2	2980 m	-7.5 m/d
20	B	1992 7 26	1994 12 31		2	1993 4 13	2402 m	-5.1 m/d
						1994 8 16	2755 m	
22	B	1993 4 7	1994 12 31	n	2	1993 5 27	526 m	6.5 m/d
						1994 2 09	-3025 m	
06	C	1994 3 27	1994 12 31	n	2	1994 4 11	53462 m	-5.4 m/d
						1994 4 16	31744 m	
07	C	1993 6 18	1994 12 31	n	2	1993 12 16	594 m	4.2 m/d
						1994 11 10	-2386 m	
28	C	1992 7 26	1994 12 31		1	1992 12 16	788 m	-0.7 m/d
31	c	1993 4 29	1994 12 31	n	1	1993 11 1	-2020 m	4.3 m/d
04	D	1993 11 21	1994 12 31	n	1	1994 3 28	-2695 m	7.0 m/d
15	D	1992 7 26	1994 12 31		1	1993 8 2	1730 m	-2.5 m/d
17	D	1992 7 26	1994 12 31		1	1994 1 20	720 m	-0.6 m/d
24	D	1992 7 26	1994 12 31		2	1993 9 27	-2539 m	5.3 m/d
						1994 11 29	-2334 m	
14	E	1992 7 26	1994 12 31		2	1993 3 5	2579 m	-6.9 m/d
						1994 4 27	2938 m	
16	E	1992 7 26	1994 12 31		2	1992 12 4	-2660 m	6.7 m/d
						1994 2 2	-3044 m	
23	E	1992 7 26	1994 12 31		1	1993 9 20	-1678 m	2.6 m/d
21	E	1992 7 26	1994 12 31		0			0.4 m/d
01	F	1992 12 7	1994 12 31	n	1	1994 10 13	-2257 m	4.0 m/d
18	F	1992 7 26	1994 12 31		2	1993 3 17	2569 m	-5.8 m/d
						1994 5 6	2425 m	
26	F	1992 7 26	1994 12 31		1	1993 8 12	-2381 m	4.2 m/d
29	F	1993 1 4	1994 12 31	n	4	1993 5 20	1914 m	-4.4 m/d
						1993 9 7	-1161 m	
						1993 11 4	1528 m	
						1994 10 28	2006 m	
Block I Satellites:								
03	-	1992 7 26	1994 04 07	+	o			0.2 m/d
11	-	1992 7 26	1993 5 4	+	0			-0.1 m/d
12	-	1992 7 26	1994 12 31		0			-2.9 m/d
13	-	1992 7 26	1993 12 31	+	o			1.5 m/d

and Beutler, 1993). This fact is documented by Figure 11 showing the drifts in the semimajor axis (as extracted from Table 4) as a function of twice the geographic longitudes of the ascending node (as observed on day 300 of year 1994).

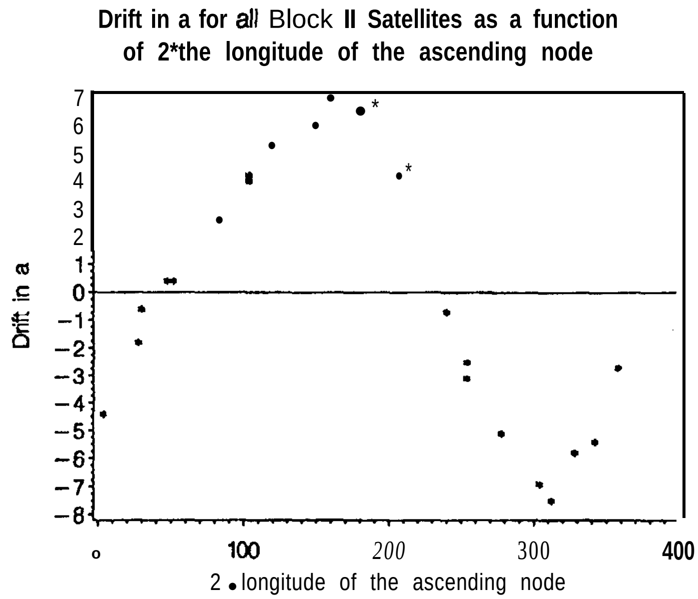


*Figure 11. Drift in **semimajor** axis a as a function of twice the geographic longitude of the ascending node.*

We also analyzed the radiation pressure parameters as estimated by CODE since mid-1992. Before giving some examples it is worthwhile to remind ourselves that the main term of the ROCK4/42 models is a perturbation along the line sun-satellite. This main term is of the order of 10-7 m/s^2. The differences between the ROCK4/42 T-, S- models, and a model taking into account an acceleration acting uniquely along the line sun-satellite (let us call it the Z-model, Z like Zero *a priori* model) are of the order of a few 10^{-9} m/s^2 only. These differences are thus only of second order as compared to the total direct solar radiation pressure.

How significant are the differences between different radiation pressure models? At CODE we addressed this question several times during the previous three years by using the three mentioned models as a *priori* models in processing. With arc lengths up to 3 days we were never able to demonstrate the superiority of one of the three models. In order to be compatible with all the other processing center we decided in 1992 to use the ROCK4/42 T-models—although there are good arguments which favor the Z-model (it would be much better suited as a basis for a new model based on estimated terms only). From that time onwards we thought to use the T-model. Unfortunately we became aware of the fact recently that, through some strange misunderstandings, we actually and unintentionally used the S-model during the last almost three years!

Again, how significant are the differences between different radiation pressure models? One answer to the question is contained in Table 5 which shows the parameters and the rms per satellite coordinate of similarity transformations between precise orbit files generated using the ROCK4/42 T-, S-, and the Z-model. The three files were generated by interpreting the same set of orbital positions of three consecutive precise CODE ephemerides files as pseudo-observations in an orbit-determination program. The middle day was then extracted to generate the three resulting files compared in Table 5 (which corresponds to the procedure we follow in our routine processing).

Table 5. Parameters and rms errors of similarity transformations between orbit files generated using the ROCK4/42 S, T-, and the Z-model (constant acceleration over one revolution).

TO	DX	DY	DZ	RX	RY	RZ	SCALE	RMS	TRAFO
49612.0	0.000	0.000	-0.001	0.0	0.0	0.0	0.000	0.022	S → T
49612.0	-0.001	0.000	0.003	0.0	0.0	0.0	0.000	0.022	S → T
49612.0	-0.001	-0.001	0.004	0.0	0.0	0.0	0.000	0.037	S → T

It seems safe to conclude from Table 5 that the differences between the three different *a priori* radiation pressure models are not significant. An inspection of the residuals of individual satellites reveals that therms is around 1 cm or below for all but the eclipsing satellites, which may have rms errors of up to 3 or 4 cm. After a few more tests we will switch to the ROCK4/42 T-model for our routine solutions to remove this regrettable, but not very important inconsistency.

Figure 12 shows the reconstructed direct radiation pressure values corresponding to the Z-model for PRN 19, where the shadow periods were excluded. For this reconstruction we added the average of the components in the direction sun-satellite stemming from the ROCK4/42 S-model and corresponding to the "true" geometry to our actual p_0 estimates. The sinusoidal shape is due to the changing distance between sun and earth (ellipticity of the earth orbit around the sun). This term may of course easily be taken out.

Figure 13 shows that the dominant characteristic after removing the annual

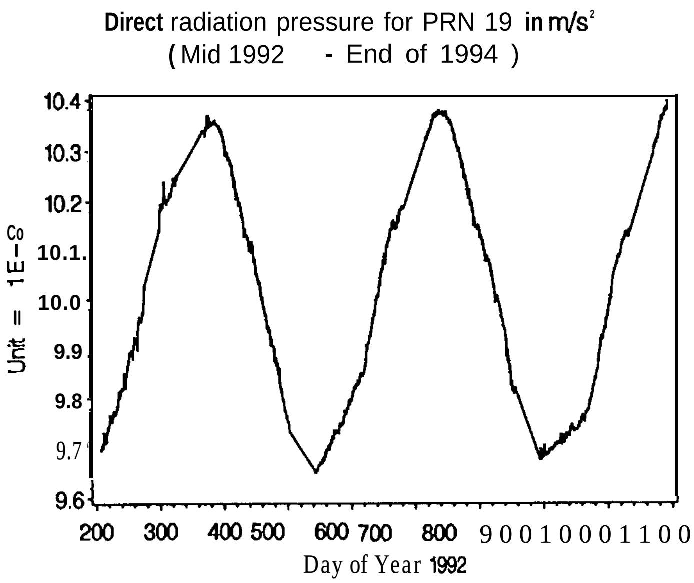


Figure 12. Direct radiation pressure for PRN 19 (June 1992-December 1994).

variation is roughly semiannual. The residuals are correlated with the angle 2γ, where γ is the angle between the normal to the orbital plane and the direction from the earth to the sun. The dotted line shows the residuals after taking out in addition to the annual the semiannual term (best fitting trigonometric series " truncated after the terms of order 2 in the argument 2γ). The noise of the estimates is below 10^{-10} m/s^2.

Figure 14 finally gives the mean values for the (reconstructed) direct solar radiation pressure parameters (referring to the Z-model) for all satellites. We clearly see the common characteristic of Block I, Block II, and Block IIa satellites. We also see the abnormal behaviour of PRN 23.

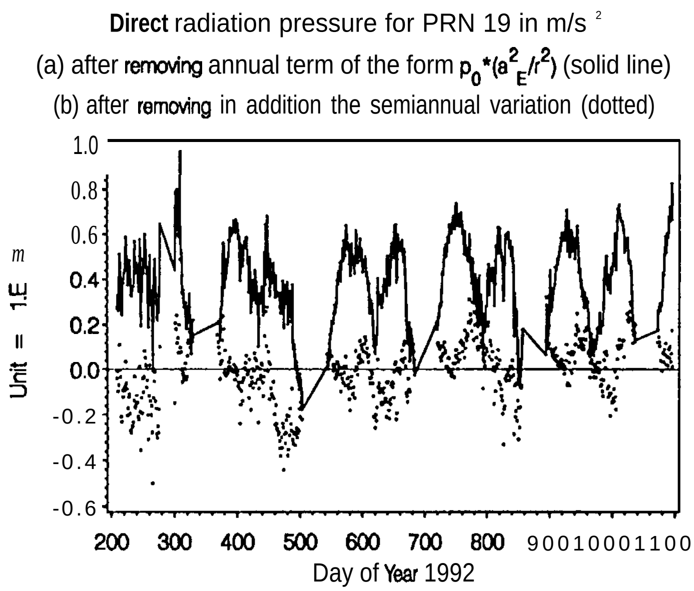


Figure 13. Direct radiation pressure after removing the annual term (solid line) and the semiannual term (dots),

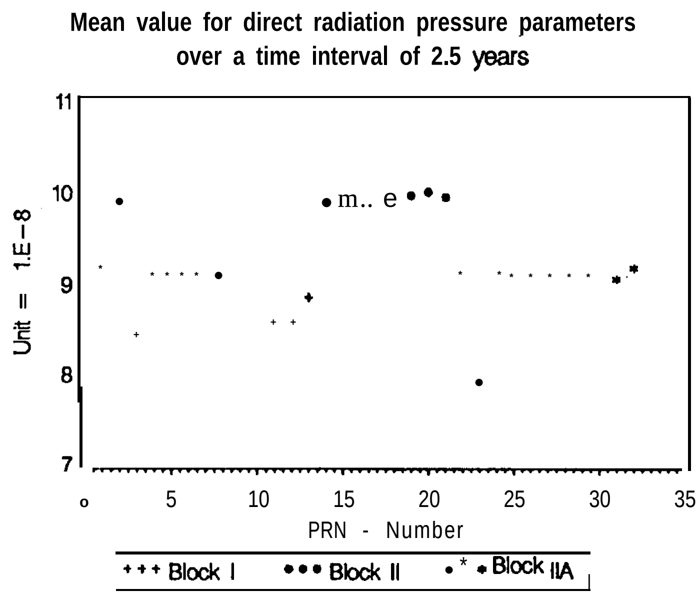


Figure 14. Mean values for direct radiation pressure parameters over a time interval of 2.5 years.

Table 6 summarizes the mean radiation pressure parameters corresponding to the ROCK4/42 T-model. This reconstruction was done by taking out the mean value of the S-models over one revolution and by adding the mean value corresponding to the T-models.

Table 6 contains in condensed form one of our a *priori* radiation pressure model files. There are two more of these files available, one for the ROCK4/42 S-model and one for the Z-model (based on a pure direct radiation pressure along the line sun-satellite). The actual radiation pressure has to be computed by adding to the ROCK4/42 T-model values (based on the masses in the above table) the term in column "DPO" in Table 6; the resulting (vectorial) sum has to be scaled by the current value of r^2_0/r^2, where r_0 is the mean distance sun–satellite (astronomical unit), and r is the actual distance sun–satellite. For the sake of completeness we also include in Table 6 the mean values of the y-biases as computed over the time period mentioned.

Table 6. A priori radiation pressure model referring to the ROCK4/42 T-models. Established on an analysis based on the alai/y estimates of p. and p_2 by the CODE processing center.

Satellite Specific Data — 08-Mar-95

Radiation Pressure Model: T9501O1 (Rock Model T, Fliegel et al., 1992)

IPRN	Block No.	Mass (Kg)	DPO (1.E-8)	P2 (1.E-8)	Rock Mode (T=1,S=2)
1	3	975.0	+0.2132	-0.5640	1
2	2	878.2	-0.0169	-0.3178	1
3	1	521.8	-0.1788	-0.2655	1
4	3	975.0	+0.1072	-0.7666	1
5	3	975.0	+0.1145	-0.4401	1
6	1	453,8	0.0000	0.0000*)	1
6	3	975.0	+0.1410	-0.8875	1
7	3	975.0	+0.0807	-0.8180	1
8	1	440.9	0.0000	0.0000*)	1
9	1	462.6	0.0000	0,0000*)	1
9	3	975.0	+0.0835	-0.6081	1
11	1	522.2	-0.0385	-0.3159	1
12	1	519.8	-0.0475	-0.1326	1
13	1	520.4	+0.2326	+0.0332	1
14	2	887.4	+0.0859	-0.7411	1
15	2	885.9	+0.0450	-0.5184	1
16	2	883.2	-0.0033	-0.5385	1
17	2	883.2	+0.0009	-0.4713	1
18	2	883.2	+0.0321	-0.6809	1
19	2	883.2	+0.0924	-0.4080	1
20	2	887.4	+0.1929	-0.2303	1
21	2	883.9	+0.0601	-0.1410	1
22	3	975.0	+0.1479	-0.4627	1
23	3	972.9	-1.0906	-0.8189	1
24	3	975.0	+0.2121	-0.8389	1
25	3	975.0	+0.1196	-0.5758	1
26	3	975.0	+0.0943	-0.6713	1
27	3	975.0	+0.0709	-0.6201	1
28	3	975.0	+0.1557	-0.5162	1
29	3	975.0	+0.1210	-0.7231	1
31	3	975.0	+0.0959	-0.3349	1

Block number: Block 1=1, Block II=2, Block IIA=3

*) No information available for these block I satellites (out of operation prior to the start of the IGS).

It is instructive to inspect the daily estimates of the y-bias parameter p_2. We include the estimates for PRN 19 in Figure 15. Again we exclude the estimates during the shadow periods (there are severe correlations between the y-bias and the pseudo-stochastic pulses in S-direction). We clearly see a periodic pattern with the angle 2γ, where y is the angle between the normal to the orbital plane and the direction earth-sun. We also see that the pattern changed considerably around June 1994. The reason for this change might be correlated with the change of the attitude control. This behaviour also shows that the mean values in Table 6 have to be interpreted rather carefully.

Attempts were made at CODE to improve the force model for GPS satellites. One result is the program ORBIMP, which allows to solve for empirical force terms as they were suggested by Colombo (1989), for the parameters of a new radiation pressure model, for albedo parameters, and for the resonance terms of the geopotential. ORBIMP uses the satellite positions of the precise ephemerides files (SP3-Format) as pseudo-observations. Beutler *et al.* (1994) suggested to decompose radiation pressure into three orthogonal components, namely an acceleration in the direction sun-satellite, an acceleration along the space-body

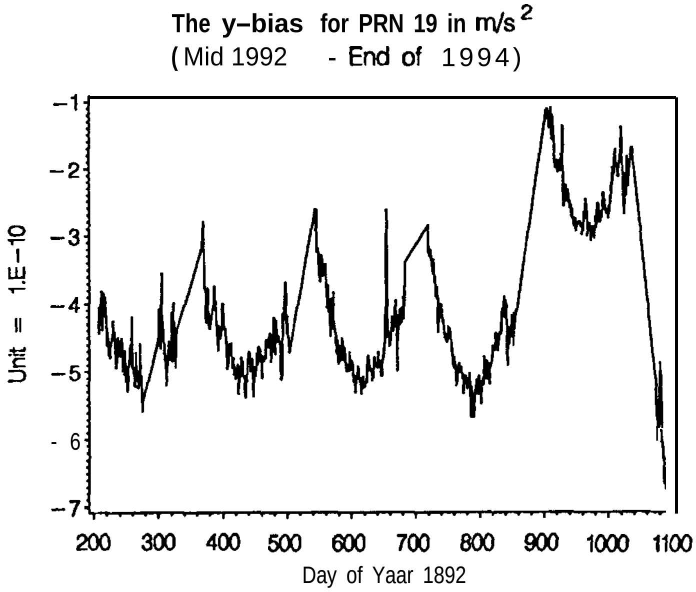


Figure 15. The y-bias estimates for PRN 19 over a time interval of 2.5 years.

fixed y-axis, and the third acceleration normal to the first two accelerations. Each component is then modeled by a trigonometric series using the argument of latitude u_0 as an independent argument. If these series are truncated after the terms of first order, 9 radiation pressure parameters have to be solved for, The fit of 7- to 14-day arcs to satellite positions of precise ephemerides files as produced by the IGS analysis centers is of the order of 10–20 cm, which is very close to the actual accuracy of these orbits. More information maybe found in Beutler *et al.* **(1994).**

ORBIMP is used by the IGS Analysis Center Coordinator for the so-called long-arc analyses. The same program is also used at CODE to check the quality of the daily orbit files before they are sent to the IGS data centers. Let us include in Figure 16 the rms per satellite coordinate for all satellites for GPS week 789 using the G1- (=one day) and the H3- (=the official) solution. PRN 23, showing (as usual) an abnormal behaviour, was excluded from Figure 16. We can see that the 3-day solution H3 is slightly superior to the G1 solution.

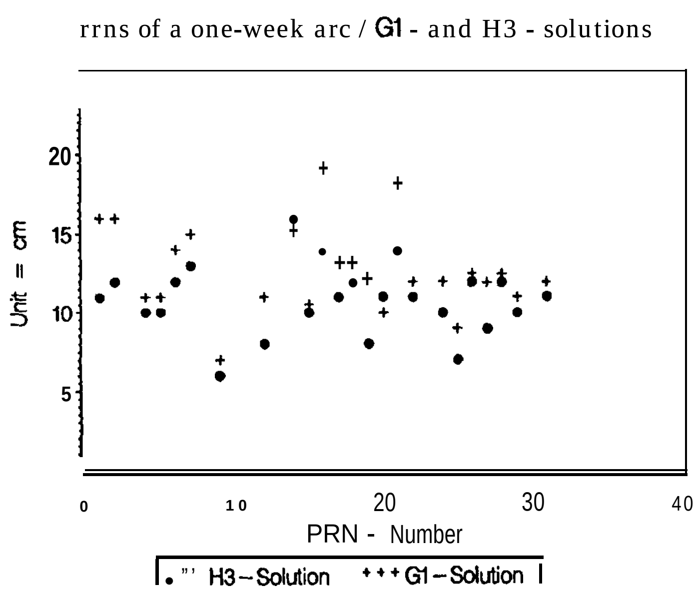


Figure 16. Rms of a one-week arc through the G1 - and the H3- solutions.

References

Bar-Sever, Y. E. "New GPS Attitude Model." IGS Mail No. 591, IGS Central Bureau Information System, 1994.

Beutler, G., M. Rothacher, W. Gurtner, T. Springer, E. Brockmann, S. Fankhauser, S. Botton, L. Mervart, U. Wild, A. Wiget. "Annual Report of the CODE Processing Center of IGS for 1992," *IERS Technical Note 14*, pp. P3–P13, Central Bureau of IERS, Observatoire de Paris, P. Charlot, 1993.

Beutler, G., J. Kouba, T. Springer. "Combining the Orbits of the IGS Analysis Centers.", accepted for publication by *Bulletin Geodesique,* October 1994, 1995.

Beutler, G., E. Brockmann, U. Hugentobler, L. Mervart, M. Rothacher, R. Weber. "Combining n Consecutive One-Day-Arcs into one n-Days-Arc." Submitted for publication to *Manuscript Geodaetica*, October 1994, 1995.

Brockmann, E., G. Beutler, W. Gurtner, M. Rothacher, T. Springer, L. Mervart. "Solutions Using European GPS Observations Produced at the Center for Orbit Determination in Europe (CODE) During the IGS Campaign." *Proceedings of the 1993 IGS Workshop* , Druckerei der Universitat Bern, 1993.

Fliegel, H. F., T. E. Gallini, E. R. Swift. "Global Positioning System Radiation Force Model for Geodetic Applications." *Journal of Geophysical Research,* Vol. *97,* No. B1, pp. *559–568, 1992.*

Fankhauser, S. "Die Bestimmung von Erdrotationparametern mit Hilfe von GPS-Beobachtungen." Diplomarbeit, Mitteilung Nr. 29 der Satellitenbeobachtungsstation Zimmerwald, 1993.

Gurtner, W., E. Brockmann, S. Fankhauser, M. Rothacher, T. Springer, S. Botton, L. Mervart, A. Wiget, U. Wild. "Automated Data Flow and Processing at the Center for Orbit Determination in Europe (CODE) during the 1992 Epoch Campaign." *Proceedings of the 1993 IGS Workshop* , Druckerei der Universitat Bern, 1992.

Gurtner, W., G. Beutler, L. Mervart, M. Rothacher. "Azimuth- and Elevation Dependent Phase Corrections for Geodetic GPS Antennas." *EOS Transactions* Vol. 75, No. 44, 1 November, 1994 Fall Meeting, 1994.

Hugentobler, U., G. Beutler. "Resonance Phenomena in the Global Positioning System." *Dynamics and Astrometry of Natural and Artificial Celestial Bodies,* Poznan, Poland, 1993.

McCarthy, D. D. "IERS Standards (1992)." *IERS Technical Note 13,* Observatoire de Paris, July 1992.

Mervart, L., G. Beutler, M. Rothacher, U. Wild. "Ambiguity Resolution Strategies using the Results of the International GPS Geodynamics Service (IGS)." *Bulletin Geodesique (1994),* Vol. 68, pp. 29–38, 1994.

Mervart, L. "Ambiguity Resolution Techniques in Geodetic and Geodynamic Applications of the Global Positioning System." Ph.D. Thesis, Druckerei der Universitat Bern, 1995.

Rothacher, M. "Orbits of Satellite Systems in Space Geodesy." Geodätisch-geophysikalische Arbeiten in der Schweiz. Schweizerische Geodatische Commission (SGK), Vol. 46, 1992.

Rothacher, M. G. Beutler, E. Brockmann, S. Fankhauser, W. Gurtner, T. Springer, S. Botton, L. Mervart, A. Wiget, U. Wild. "Results of the Center for Orbit Determination in Europe (CODE) During the 1992 IGS Campaign." IAG-Symposium, Potsdam, 1992, Vol. 112, pp. 24-27, 1993.

Rothacher, M., G. Beutler, W. Gurtner, S. Botton, C. Boucher. (1993). "Results for the IGS Data Processing at the 'Center for Orbit Determination in Europe' (CODE)." Proceedings *of the 1993 IGS Workshop,* Druckerei der Universitat Bern, pp. 133–144.

Rothacher, M., G. Beutler, E. Brockmann, W. Gurtner, L. Mervart, R. Weber, U. Wild, A. Wiget, H. Seeger, C. Boucher. "Annual Report of the CODE Processing Center of the IGS for the Year 1993." *IERS Technical Note 17, 1994.*

Rothacher, M., G. Beutler, E. Brockmann, W. Gurtner, L. Mervart, R. Weber, U. Wild, A. Wiget, H. Seeger, C. Boucher. "Annual Report of the CODE Processing Center of the IGS for the Year 1994." *IERS Technical Note,* in press.

Schaer, St. "Stochastische Ionosphaerenmodellierung beim Rapid Static Positioning mit GPS." Diplomarbeit, Astronomisches Institut, Universität Bern, Druckerei der Universität Bern, November 1994.

Springer, T.A., G. Beutler. "Towards an Official IGS Orbit by Combining the Results of All IGS Processing Center." *Proceedings of the 1993 IGS Workshop,* Druckerei der Universitat Bern, 1993

Wild, U. "Ionosphere and Geodetic Satellite Systems: Permanent GPS Tracking Data for Modelling and Monitoring." Geodätisch-geophysikalische Arbeiten in der Schweiz, Bd. 48, 1994.

The ESA/ESOC IGS Analysis Centre

T. J. Martin Mur, J. M. Dow, C. Garcia Martinez, and J. Feltens
ESA/European Space Operations Centre
Darmstadt, Germany

Introduction

ESOC is the satellite control center of the European Space Agency (ESA). It is responsible for the operations of the ESA satellites, its ground stations, and its communications network. In order to operate the satellites that are under control of ESA, ESOC has to be able to precisely determine their orbits, the position of the possible tracking stations, and other geodetic parameters. A state of the art software package has been developed over a number of years at ESOC and before the IGS campaign started it was already well proven through extensive processing of data from many satellites, including satellite laser ranging (SLR) from Lageos and Starlette. Although not able to handle GPS data types (pseudo-range and phase) at that time, a multi-satellite solution capability was already implemented. After submitting the proposal for ESOC participation as an IGS Analysis Centre a major effort was undertaken to develop GPS capabilities in our software. Important aspects of the use of the ESOC orbit and geodetic parameter estimation software are that this software is independent from other packages in use for GPS analysis, and the possibility of consistent processing of other geodetic satellite data with a single package (SLR, Doris, GPS, altimetry, PRARE, . ..).

ESOC is preparing for the use of GPS or other GNSS in operational and precise orbit determination. Some European spacecraft have already been equipped with GPS receivers and it is foreseen that some ESA spacecraft will also use GPS. An additional application of GPS of interest for ESOC is the use of GPS receivers located in our ground stations to obtain ionospheric corrections for single-frequency ranging.

We have been participating as an IGS Analysis Centre from the beginning of the IGS. Our first solutions for orbital and polar motion parameters were transmitted to the CDDIS on 24 July 1992, about one month after the start of the Epoch 92 campaign. By early August the delay with respect to real time was reduced to about 10 days. Along with several other centers, ESOC continued to process IGS data after the decision of the IGS Campaign Committee in October 1992 to continue the IGS activity in the form of an “IGS Pilot Service” and then in January 1994 as the IGS Operational Service. These series have guaranteed continuity of the IGS activities after the success of the first campaign.

ESOC IGS Analysis

ESOC is using the observation of most of the Rogue and TurboRogue receivers in the IGS network. Those that are always used are the 13 fixed stations and our own stations. Additional receivers up to a total of about forty are added to improve the global distribution of observations. We use phase double differences as our basic observable, because they are especially well-suited for batch estimation. With double differences the satellite and clock biases for every epoch do not need to be estimated with the same accuracy as that of the measurement, so the total number of parameters to be estimated is greatly reduced. Precise clock biases areproduced in post-processing, after the orbits have been determined.

Preprocessing

Preprocessing is done with the program GPSOBS. GPSOBS reads RINEX observation files and obtains independent ionospheric-free double-difference phase combinations. An elevation cut-off angle of 20 degrees is used. Cycle slip detection is performed using two-integer, almost-ionospheric-free combinations, the 4L1 - 3L2 and the 5L1 - 4L2. Satellite center of mass and phase wind-up corrections are performed at this step. For the satellite center-of-mass correction the following values are used:

- Block I: 0.210, 0.000, 0.854m in satellite x, y, z.
- Block II/IIA: 0.279, 0.000, 1.026m in satellite x, y, z.

GPSOBS also estimates the station clock biases to correct the time tags of the measurements. Double-difference phase measurements are output every six minutes. Observations of eclipsing satellites are excluded during eclipse and 30 minutes after it. We are not modeling the biased-satellite yaw model because it does not fully predict the attitude of the satellite.

Orbit and Geodetic Parameter Estimation

Orbit and geodetic parameter estimation is performed using the program BAHN. BAHN is a batch least-squares estimator for dynamic orbit determination. We use a 48-hour arc in order to obtain the precise orbit and erps for each day, with 12 hours before and after the central day.

Measurement Models

- Velocity of light: 299792.458 km/s
- Troposphere: Willmann model.
- Ionosphere: first-order term removed by using the so-called ionospheric-free combination.
- Plate motions: ITRF values used when available, if not Nuvel-NNR.
- Tidal displacements: Wahr model used for solid earth tidal displacement. Pole tide and ocean and atmospheric loading are not modeled.
- Ground antenna phase center calibration: not used. Only Rogue and TurboRogue receivers with Dorne-Margolin choke-ring antennas used.

Dynamic Models

- Geopotential: GEM-T3 up to degree and order 8 with the GM (398 600.4415 km^3/s^2), C21 and S21 from the IERS standards.
- Third-body forces: Sun, Moon and four planets regarded as point masses. Ephemeris form JPL DE200, GM of Sun 132712440000.0 km^3/s^2, GM of Moon 4902.7991 km^3/s^2.
- Solar radiation pressure: ROCK4 and ROCK42 approximations denoted as TIO and T20 used for Block I and Block 11 satellites. One scale factor and one Y-bias estimated per arc.
- Tidal forces: Wahr model for solid earth tides, Schwiderski for ocean tides.

Reference Frames

- Inertial: Geocentric, mean equator and equinox of 2000 Jan. 1 at 12:00 (J2000.0).
- Terrestrial: ITRF reference frame realized through a set of 13 station coordinates and site velocities.
- Interconnection: Precession, IAU 1976 Precession Theory; Nutation, IAU 1980 Nutation Theory; Celestial pole offsets from IERS Bulletin B; relation between UT1 and GMST, Aoki 1982; Pole and LODR estimated as constants for 24-hour intervals; Tidal variations in UT1, Yoder model.

Numerical Integration

Adams-Bashforth/Adams-Moulton predictor-corrector of order 8 started with a Runge-Kutta/Shanks of order 8. Integration step of 6 minutes.

Estimated Parameters

- Station coordinates: 13 stations fixed to the agreed ITRF positions. Remaining station positions estimated.
- Orbital parameters: Initial position and velocity, solar radiation pressure-scale factor and y-bias estimated as constant through the 48-hour orbital arc.
- Double-difference phases ambiguities estimated as real values.
- Earth rotation parameters: x and y pole and LODR estimated as constants for 24-hour intervals. LODR is the excess of the length of the day regularized as described in the IERS standards.
- Receiver clock biases and drifts estimated as constant parameters between clock resets.
- Maneuvers estimated as instantaneous velocity changes.
- Tropospheric zenith delay and shape parameter estimated linear in 6-hour intervals.

Precise Clock Bias Estimation

The Rogue and TurboRogue receivers used for our IGS Analysis can track the P code when Anti-Spoofing (AS) is not activated. When AS is activated they track the CA code and the cross-correlation between the codes in L1 and L2. With these two measurements a code in L1 is directly obtained (CA code) and a code in L2 can be reconstituted by adding the cross-correlation delay to the CA code. We have observed that these receivers have a bias between the P and the CA code. This bias can be clearly observed when the receiver is tracking simultaneously P and CA code (e.g., for a satellite that is not performing AS). The value of the bias depends on the particular receiver and its software and can be as big as 60 meters. In order to calculate the clock biases the values of the CA pseudo-range biases have to be estimated. This has to be done every day because of unannounced receiver changes.

We are using the daily average of double difference pseudo-range residuals as the basic observable to estimate the CA biases. For most of the receivers these biases do not depend on the PRN number, but for others we have to calculate a bias for every satellite.

The precise clock bias values are estimated from pseudo-ranges and carrier phase by using the CA pseudo-range biases and the parameters estimated in BAHN to correct the measurements.

The clock bias estimation is separated into a clock drift estimation using carrier phase and a clock bias estimation that uses the estimated clock drifts and pseudo-ranges. Satellite clock bias values are constrained to the Navigation Message values to produce values aligned with the GPS system time. The evolutions of the drift of receivers connected to hydrogen masers is also constrained to stabilize the drift and clock estimates.

Precise values are obtained every 60 seconds and can be used to interpolate the satellite clock value at any time.

Post-Processing and Quality Control

The orbits obtained with BAHN are combined with the precise clocks and output every 15 minutes in a file with the sp3 format. The erps are output to a file with the IERS format.

Quality control is performed by checking the following:

- Post-fit double-difference phase measurement residuals per station and satellite.
- Orbit overlaps between consecutive days.
- Pseudo-range residuals after calculating the clock biases.
- Agreement of the estimated clocks with the values contained in the Navigation Message.

Multi-Arc Parameter Estimation

BAHN can output the observation equations to a file. These equations can be accumulated for a number of arcs in order to obtain a multi-arc solution using the MULTIARC package. Our typical sequence for this is:

- An unconstrained run of BAHN to produce observation equations for all the parameters of interest, including positions and velocities for all the stations.
- Generation of normal equations from the observation equations.
- Elimination of those parameters that are not of interest in a multi-arc solution. The parameters that are eliminated are the ambiguities, the tropospheric parameters, the clock parameters and the satellite state vectors.
- Accumulation of the normal equations in a free-network solution for station coordinates, site velocities and erps.
- Check of the free-network solution by obtaining constrained solutions.

Recently we have developed the capability to generate station coordinate solutions in the Sinex format, that will be used for IERS and IGS submissions.

Products

Our routine products are the following:

- Daily orbits and clocks in the sp3 file: esawwwwd.sp3, wwww being the gps week and d the day of the week (O-6). These are values at 15 minute intervals and include the accuracy codes.
- weekly eop (pole, LODR) solutions in IERS format: esawwww7.erp.
- weekly summaries: esawwww7.sum.

We are also producing and archiving satellite clock bias files at 60 minute intervals. For these we are using our own internal format. They are available on request.

We have provided the IERS with several solutions, including more recently the following:

- EOP (ESOC) 94 P 01: an eop solution, including the integration of the LODR values to obtain a continuous UT1 series.
- SSC (ESOC) 95 P 01: a free network station coordinate and velocity solution based in 274 days of observations in 1994. It is referred to the IERS terrestrial reference frame by fixing the EOP at their Bulletin B values and by loose constraints on the positions and velocities to the ITRF92 values.

Outlook

We are planning to produce weekly free-network station coordinate solutions in the Sinex format. Other developments of interest for the IGS that we are planning to implement this year are the generation of ionospheric TEC models, the use of ocean loading to calculate station position displacements and the study of new models for satellite radiation forces.

References

J. M. Dow, T. J. Martin Mur, and M. M. Romay Merino, ESA's Precise Orbit Determination Facility, ESA Bulletin no. 78, May 1994, pp. 40–50.

H. Fliegel, T. Gallini, and E. Swift, Global Positioning System radiation force model for geodetic applications, J. Geophys. Res. 97(B1), pp. 559–568, January 1992.

D. D. McCarthy (cd.), IERS Standards (1992), IERS Technical Note 13, Observatoire de Paris, July 1992.

J. T. Wu, S.C. Wu, G.A. Hajj, W.I. Bertiger, and S.M. Lichten, Effects of antenna orientation on GPS carrier phase, Manuscript Geodaetica (1993) 18, pp. 91–98.

IGS Analysis Center at GFZ Potsdam

G. Gendt, G. Dick, C. Reigber
GeoForschungsZentrum Potsdam
Potsdam, Germany

Abstract

The GeoForschungsZentrum Potsdam (GFZ) operates as Analysis Center in the International GPS Service for Geodynamics (IGS). For automated data analysis the software package EPOS.P.V2 was developed at GFZ which has been in use permanently since 1993. The main features of the analysis software and the technology of automated data processing for IGS as well as achieved results are presented in this article.

Introduction

The GPS technology has become one of the most important geodetic techniques for regional and global studies of the Earth's kinematics. To support high-precision geodetic and geophysical research activities using GPS the concept of the "International GPS Service for Geodynamics (IGS)" was developed. The official IGS, founded under the auspices of the International Association of Geodesy, started its routine operation on January 1, 1994.

One of the *seven* IGS Analysis Centers was implemented at the GeoForschungsZentrum (GFZ) Potsdam. It has participated in the IGS from the very beginning. For this purpose the automated GPS Analysis Software package EPOS.P.V2 was developed, being operational since 1993. It was used for the first time in the IGS Pilot Service and since January 1, 1994 in the IGS routine analysis. The software was improved steadily to meet the increasing requirements of the IGS routine processing (new estimation parameters, growing number of stations, etc.).

The activities of the IGS Analysis Center at GFZ and some of the main features of the developed software package, the data processing and the results are described in the following sections.

Software and Processing Technique

The EPOS.P.V2 software package is dedicated to the processing of undifferenced phase observations from the GPS configuration.

Basic Equations and Main Software Features

Using undifferenced phase measurements to GPS satellites the basic observation equations for simultaneous analysis of any number of stations and satellites after ignoring atmospheric, relativistic and noise effects can be written in a simplified form as follows (Landau, 1988):

$$s_i^j(t) = L_i^j(t) + A_i^j + cT_i(t) - c\,t^j(t) \qquad (1)$$

where: s - distance between station i and satellite j
L - distance from measured beat-phase (single frequency or any linear combination)
T - station clock error
τ - satellite clock error
A - unknown time-independent ambiguity
t - epoch of measurement
c - velocity of light

All receivers measure at the same epoch t. The clock errors T_i are supposed to be small enough to be neglected in their influence on the satellite clock error t^j; e.g., $(d\,t^j / dt)\,T_i$ are negligible and all stations will have the same satellite clock. For sampling rates of typically 2 to 6 minutes the clocks have to be treated as white noise processes. Therefore for each epoch one clock parameter must be solved for each station and each satellite. Due to a linear dependency between all clock parameters one clock must be chosen as reference and has to be fixed; e.g., $T_1=0$, and all clock parameters have to be determined relative to this reference clock. (It is reasonable but not necessary to fix the same reference at all epochs.) As reference, a stable station or satellite clock should be selected. Having masers for a lot of IGS stations, one of these could be chosen as reference.

After setting $T_1=0$ there is still a linear dependence between the satellite clocks t^j and the ambiguities A_1^j, as it can easily be seen from (1). It can be solved by using the reference station/reference satellite concept (Goad, 1985), where all ambiguities connected with a reference station or satellite have to be set to zero; e.g., $A_1^j = A_i^1 = 0$. It can be shown that the remaining ambiguities are equivalent to those of double differencing. Such an algorithm will be much more complicated for the real data because each cycle slip requires a new ambiguity.

In the GFZ software another concept is used which handles the rank defect in a simpler way. In our implementation only one reference clock is fixed and all ambiguities are solved for. There are two possibilities to handle the remaining rank defect: (i) to align the ambiguities to the P-code distances, to use these values as *a priori* values and to constrain them in the adjustment according to the accuracy of the P-code; (ii) to adjust phases and P-codes simultaneously. Here the clocks t^j and the ambiguities A_i^j can be separated with the accuracy of P-code.

The normal equations system consequently has numerical instabilities being of two different kinds: fictitious instability due to unfavorable units, and real instability arising from the clock-ambiguity problem or from free-network adjustment. To solve this problem we use a normalization of the normal equation matrix for the first kind of instability and a regularization after Tichonov (Kunert, 1976) for the real instability. Regularization after Tichonov is applied as follows by the addition of regularization coefficients a_{ii} to the main diagonal of normal equations:

$$(N + a)\,dx = b \qquad (2)$$

with $v^T P^{-1} v + dx^T a\, dx \longrightarrow$ minimum,
a is a main diagonal matrix,

where regularization coefficients a_{ii} have to be as small as possible to have no significant influence on the minimization function VT $P^{-1}v$ —> min (UT P^{-1} u >> $dx^T a\ dx$).

The described observation equations are taken as a basis for the main algorithms of the EPOS.P.V2 software package. Compared to the double-difference principle, the processing of undifferenced phase and/or P-code observations has the following advantages: (i) possibility to estimate clock behavior of stations and satellites relative to reference clock; (ii) identical time parameters for P-code and phase observations; (iii) estimation of post-fit residuals for each satellite-station pair; (iv) simple algorithm for data selection; (v) no special treatment of correlations. The amount of data which enters into the analysis is bigger than for double-difference analysis, especially if rather isolated stations are used. This was of some advantage in the beginning of IGS when the network was sparse in some regions. After getting a more densified IGS core network this, of course, is less important. In the following, the main components of the data flow and all steps of the automated data processing for IGS will be described.

Communication and Data Holding

Every night an automatic procedure compares the content of our data holding with those of Data Centers:

Crustal Dynamics Data Information System (CDDIS),
Institut fuer Angewandte Geodaesie (IfAG) and
Institut Geografique National (IGN).

To minimize the transatlantic data transfer IfAG and IGN are the preferred data acquisition centers. New or updated files are then copied from the according data center. The files are accepted only if they pass an integrity check, including numerous simple tests (correct formal data structure, plausible ionospheric effects, etc.).

Preprocessing and Cleaning

Raw RINEX data of each day are processed station by station. As a result RINEX files with sampled original data (normally 6-rein intervals) and a LOG-file for each station are produced. With the sole exception of the sampling rate, the GPS measurements remain in their original form during the processing. In the LOG-files cycle-slips (identified and corrected if possible), outliers, and short data intervals (smaller than one hour between two ambiguities) are marked.

Cleaning the data with a station by station technique has some limitations, especially for Anti-Spoofing (AS) data. Therefore a double-difference cleaning procedure is used in parts of the network data where double differences can be formed. In order to get clean undifferenced data all possible double differences are formed to identify an erroneous station-satellite pair in case of a jump. It proved to be useful to execute such double-difference cleaning with a much higher sampling rate (e.g., 60 see) to get rid of strong ionospheric disturbances under AS conditions. This first cleaning step identifies cycle slips up to 10 cm even under AS.

Post-fit data cleaning is necessary in the regular analysis in order to identify the small remaining jumps as well as jumps in those parts of the data where double differencing cannot be performed. Looking at series of residuals for station-satellite pairs one can easily recognize jumps in the residuals. Because of the correlations between the clocks such jumps can be seen in all station-satellite residuals at the same epoch and the problem is to identify the erroneous station-satellite pair.

Analysis

The analysis is an iterative process where the following programs from *Merge* to *Clean* are used to determine the solution. The first iterations perform data cleaning. After obtaining clean data some additional iterations are necessary to get the final convergence for the parameters to be adjusted (satellite state vectors, ERP, and clocks).

Merge. The RINEX data are merged to a RINEX-like file including all selected stations and satellites, taking into account the LOG-files, the elevation height and the simultaneity of the data (for one epoch at least two satellites for each station and two stations for each satellite).

Orbit: first part. The satellite motion equations and variational equations are integrated and stored in a data base. Usually the initial state is predicted from the previous day, but can also be taken from broadcast messages. For the integration of the satellite motion an implicit single-step method integrating directly second order differential equations (Everhart, 1974) is used which automatically controls the step size. The variational equations are integrated by a multi-step method of Stoermer-Cowell (Stiefel and Scheifele, 1971), which integrates the large number of equations in a more effective way.

Orbit: second part. The orbits and partial derivatives from the variational equations are interpolated to epochs of the actual GPS data. The residuals and partial derivatives are computed and observation equations are formed and stored in a file (input for the Solve part). First tests of data quality are done and first clock determinations using P-code measurements are performed.

All dynamic and geometric models in this program are based on the IERS Standards (McCarthy, 1992). The main model parameters are given in Table 1.

Solve. In this part the parameters selected by the user are estimated by a HELMERT blocking method, i.e. each parameter can be eliminated for an arbitrarily chosen time interval and then estimated by backward substitution. At the beginning, normal equations of selected linear combination (i.e. ionospheric free L3) are built from the observation equations. The effective construction of normal equations for P-code measurement is made by eliminating the ambiguity parameter in the already-built normal equations for phase measurements. Normal equations are accumulated for one measurement epoch. At the end of each epoch the time parameters are eliminated, and the reduced normal equations are accumulated to the end of the first selected time interval. Ambiguities are eliminated at the end of each session. Finally a normal equation matrix with global parameters (e.g., station coordinates, GM, etc.) remains, which is stored in a data base for further processing (input for *Combination* program). This matrix is stored without any constraints; it can be used in different variants later in the *Combination* part. After inversion of the stored matrix all eliminated parameters are estimated by backward substitution. The estimated parameter corrections as well as post-fit residuals are stored in files for use in the next iteration.

Clean. Data cleaning is performed in two different ways. If large cycle-slips still exist, the stored post-fit residuals from the Solve part enter again into the

Table 1. Main parameters of EPOS.P. V2.

Reference frame	
CIS:	mean equator and equinox of J2000.0
Precession:	IAU 1976
Nutation:	IAU 1980
Tectonic plate model:	NNR NUVEL-1 or individual ITRF velocities
Solid earth tides:	Wahr model, h2=0.609, l=0.0852, permanent tide included
Ocean loading site displacement:	coefficients from Scherneck (Scherneck, 1991)
Dynamic model	
Gravity field:	JGM2
GM:	398600.4418 km3/s2
Velocity of light:	299792.458 km/s
Earth tides:	Wahr model
Ocean tides:	Schwiderski model
Corrections to rotational deformations:	C(2,0), C(2,1), S(2,1)
Indirect perturbation of oblateness of the Earth:	applied
Third body effects:	Sun, Moon, Jupiter, Venus
Solar radiation:	ROCK4 and ROCK42, including thermal reradiation (TIO, T20 formulation of Fliegel et al., 1992)
Relativistic equation of motion:	no
Tidal variations in UT1:	zonal tides with periods <35 days
Measurement model	
Tropospheric model:	Saastamoinen
Relativistic clock corrections:	applied

double-difference cleaning program already used in the preprocessing. Otherwise undifferenced single station-satellite cleaning for detection of small outliers and cycle-slips is done. During the iterations for data cleaning the orbit integration is not repeated in every step, unless the remaining jumps in the residuals are very small. The new information from each cleaning step is stored in the LOG-files for the next iteration which starts with the *Merge* part.

Combination. During the last iteration the normal equation matrix with the global parameters (e.g., station coordinates) is stored in the Solve part. These normal equations can be accumulated over longer time intervals in different variants. Selection of various constraints, fiducials, etc. is possible. This way normal equations are combined for longer time intervals (semiannually, yearly solutions) to derive the global station coordinate solutions with fixed or adjusted site velocities.

This software is also used for control of solution quality by computing daily or weekly repeatability of station coordinates. This way the consistency of marker information is checked.

Operational IGS Data Processing at GFZ

Beginning with the 1992 IGS Campaign the observations of the global IGS network (recently about 80 stations) permanently flow into the Data Centers: CDDIS, IGN, IfAG, and S10 (Scripps Institution of Oceanography). From these centers the data files are copied via ftp to the GFZ data archives from which the analysis is started on a daily basis. The generated products for GPS week 'wwww' and day of week 'n' (n=0,1,2,...,6) are

GFZwwwwn.SP3	daily files with GPS ephemeris/clock information at 15 min intervals in SP3 format, including accuracy codes computed from the orbit overlaps
GFZwwww7.ERP	weekly ERP (pole coordinates, length of day - LODR)
GFZwwww7.SUM	weekly processing summary.

Being an official IGS Analysis Center, GFZ generates its products weekly and transmits them to the data centers at IGN and CDDIS with a delay of only a few days after data acquisition. The delivered orbit files are included in the combination of all submitted individual orbit solutions, so they contribute to the official IGS precise orbit product. All GFZ products as well as IGS precise orbits are available via ftp from the GFZ anonymous account as well as from the CDDIS and IGN data centers. The ERP products are also submitted to the International Earth Rotation Service (IERS) and to the U.S. Naval Observatory (USNO).

Solve-for Parameters

The adjustment part of EPOS.P.V2 chooses an arbitrary time interval for parameter estimation. Usually the following time intervals for parameter estimation are used in our routine analysis:

Satellite state:	32-h interval
Reflectance coefficient and y-bias:	32-h interval
ERP (pole and LOD):	24-h interval
Tropospheric zenith path delay:	4-h interval
Ambiguities	
Epoch time parameters	

The arc length of 32 h was chosen so that at least two satellite revolutions could be observed at any site. Each arc starts at midnight. Only the ERP solutions from 24-h intervals are used (Figure 1). In order to control the accuracy of adjusted orbits the rms values of differences between two adjacent arcs are calculated for an overlapping interval of 6 h.

Sites and Satellites Analyzed

At the end of 1994 about 45 sites were analyzed at GFZ AC. The distribution of the sites is given in Figure 6. Information about the initial coordinates (ITRF, GFZ) and velocities (ITRF, NUVEL, GFZ) for each site is given in Table 2. Here also the fiducial sites (fixed to the initial values) as well as the number of days with observations in 1993 and 1994 are given. All usable satellites were analyzed. Satellite information is given in Table 3.

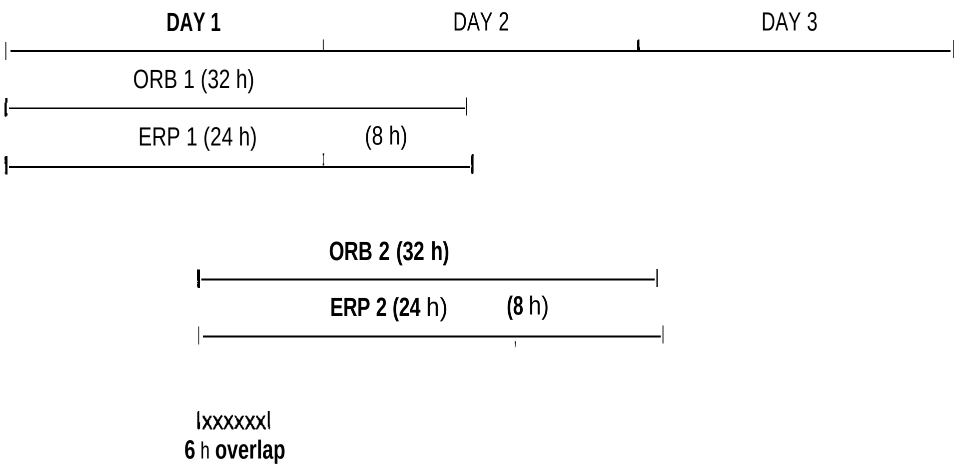


Figure 1. Scheme for parameter estimation.

Data and Computer Resources

For the daily analysis undifferenced ionospheric free phases with a sampling rate of 60 sec (preprocessing with double-difference cleaning) and 6 min (analysis itself) are used. The routine analysis of such amounts of data demands rather large processing times and computer resources. One iteration takes 20 min on a CONVEX machine, so that one data segment of 32 h with Anti-Spoofing data of 45 sites is usually ready after 2.5 to 3 h. The computer memory is maximally used for the *Solve* part which requires 60-MB main memory and 1OO-MB disc space. Permanent data files are in the order of 20 MB for one day.

Results and Comparisons

This section presents various results and comparisons, achieved in the first two years of GFZ participation in the IGS. These results give a first impression about the possibilities of the GPS software package and the obtained accuracies.

Determination of global reference frame

From the globally distributed station network and a data span of 2 years it is possible to determine the global reference frame with very high accuracy. The consistency of the coordinate solution can be seen from daily and weekly repeatabilities. They serve also for the quality check of data as well as for the control of marker information (e.g., eccentricities of antenna positions for different epochs).

A fiducial-free global set of coordinates for 40 IGS stations has been determined. In Figure 2 the weekly repeatability for selected European stations relative to the fixed station Wettzell is given for longitude, latitude and height. The accuracies depend on the distance to Wettzell and are of&2 to ±4 mm for the horizontal component and of ±5 to ±11 mm in the height. For the whole wide-scale European network with 5000-km extension the weekly repeatability gives ±5.2 mm in the height,andabout±2mm in the horizontal components (Figure 3).

Such level of accuracy is reachable for all regions with a sufficiently dense site distribution, i.e. for Europe, North America, and Australia. For isolated stations the accuracies are worse: the variations are three to five times larger.

Table 2. Site Information.

Site	Fixed	up to 94/365 Coordinates	up to 94/365 Velocities	from 95/ Coordinates	from 95/ Velocities	days in 1993	days in 1994
ALGO	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
AREQ		GFZ	NUVEL	GFZ	ITRF93		329
BOGT		GFZ	NUVEL	GFZ	NUVEL		55
BRMU		GFZ	NUVEL	ITRF93	ITRF93		56
CAS1		GFZ	NUVEL	GFZ	NUVEL		56
DAV1		GFZ	NUVEL	GFZ	NUVEL		166
DRAO		ITRF92	ITRF92	ITRF93	ITRF93	272	365
EISL		GFZ	ITRF92	GFZ	ITRF93		157
FAIR	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
FORT		GFZ	NUVEL	GFZ	ITRF93	153	365
GOLD	F	ITRF92	ITRF92	ITRF93	ITRF93		365
GUAM		GFZ	NUVEL	GFZ	NUVEL		
HART	F	ITRF92	ITRF92	ITRF93	ITRF93	365	348
HOB1		GFZ	ITRF92	ITRF93	ITRF93	365	218
HOB2		GFZ	ITRF92	GFZ	ITRF93		154
JPLM		ITRF92	ITRF92	ITRF93	ITRF93	365	365
KERG		GFZ	NUVEL	GFZ	NUVEL		42
KIT3		GFZ	NUVEL	GFZ	NUVEL		126
KOKB	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
KOSG	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
KOUR		ITRF92	ITRF92	ITRF93	ITRF93	272	365
MAC1		GFZ	NUVEL	GFZ	NUVEL		55
MADR	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
MASP	F	ITRF92	ITRF92	GFZ	ITRF93	365	253
MASI		ITRF92	ITRF92	GFZ	ITRF93		211
MATE	F	GFZ	ITRF92	ITRF93	ITRF93	365	365
MCMU		ITRF92	NUVEL	ITRF93	ITRF93	335	352
MCM4		ITRF92	NUVEL	ITRF93	ITRF93		
MDO1		GFZ	NUVEL	GFZ	ITRF93		56
METS		ITRF92	NUVEL	ITRF93	ITRF93	270	365
NLIB		GFZ	NUVEL	ITRF93	ITRF93		56
OHIG		GFZ	NUVEL	GFZ	NUVEL	365	365
ONSA		ITRF92	ITRF92	ITRF93	ITRF93	272	365
PAMA		ITRF92	NUVEL	ITRF93	ITRF93	365	340
POTS		GFZ	NUVEL	GFZ	GFZ		164
RCM2		GFZ	NUVEL	GFZ	ITRF93	229	
RCM4	F	GFZ	NUVEL	GFZ	ITRF93	33	
RCM5	F	GFZ	NUVEL	GFZ	ITRF93	27	365
SANT	F	ITRF92	ITRF92	ITRF93	ITRF93	365	365
STJO		ITRF92	NUVEL	ITRF93	ITRF93	365	365
TAIW	F	ITRF92	NUVEL	GFZ	ITRF93	365	365
TIDB	F	GFZ	ITRF92	ITRF93	ITRF93	365	365
TROM	F	ITRF92	NUVEL	ITRF93	ITRF93	365	365
TSKB		GFZ	NUVEL	GFZ	ITRF93		56
USUD		GFZ	NUVEL	GFZ	ITRF93	365	365
WES2		GFZ	NUVEL	ITRF93	ITRF93	272	365
WETT	F	ITRF92	NUVEL	ITRF93	ITRF93	365	365
YAR1	F	ITRF92	NUVEL	ITRF93	ITRF93	365	365
YELL		ITRF92	NUVEL	ITRF93	ITRF93	365	365

Table 3. Satellite information.

Center-of-mass corrections: IERS Standards
Block 1: x=O.21O m, z=0.854 m
Block 2: x=O.279 m, z= I .023 m

GPS space vehicle masses: from Fliegel *et al.* (1 992) and Feltens (1 991)
972.90 kg for PRN 14567922-32
878.15 kg for PRN 2
521.81 kg for PRN 3
440.89 kg for PRN 8
522.16 kg for PRN 11
519.82 kg for PRN 12
520.42 kg **for** PRN 13
887.36 kg for PRN 14
885.90 kg for PRN 15
883.23 kg for PRN 16171819
887.36 kg for PRN 20
883.90 kg for PRN 21

Weekly variations of the geocenter in x and y are of the order of ±2 to ±4 cm and in z of ±12 cm. The scale has an accuracy of $\pm 1\times10^{-9}$.

Another way to estimate the accuracy of the determined reference frame is by 7-parameter similarity (HELMERT) transformations between two annual solutions and between our global solution and ITRF93 (label SSC(IERS)94C01) (Table 4). The two annual solutions of 1993 and 1994 coincide within ±2 to ±4 mm in the north, ±2 to ±5 mm in the east and ±5 mm in the height component dependent of which velocities have been used—ITRF or GFZ ones (Gendt *et al.*, 1995). A comparison with ITRF gives ±4 mm in the horizontal and ±9 mm in the height component.

Baseline Rates and Site Velocities

Due to the high accuracy of the GPS technique it is possible to determine global tectonic motions from time intervals of only a few years.

In the routine IGS analysis the daily, fiducial-free, and unconstrained normal equations for station coordinates are stored into a data base for further analysis. Investigations over long time intervals demands an effective technology for combining of solutions. To reduce the computing times and the amount of files, computation and archiving of weekly normal equations have been performed. By combining daily normal equations into weekly ones, the combination software produces homogeneous sets of equations based on the same *given* initial values for station coordinates, eccentricity values, and tectonic model. This way it is easy (i) to introduce new initial coordinates, (ii) to use the most recent eccentricities values for the solution, (iii) to change the tectonic model for the coordinate determination. The errors of chosen *a priori* site velocities are negligible for such short time intervals (one week or even one month, if, in future, data over many years have to be analyzed), The combined normal equations can be extended by parameters for site velocities.

The tectonic motions have been determined in two variants:

1. Baseline rates from weekly coordinate solutions. The advantage of this method is the control of data quality and eccentricities as well as a good evaluation of solution stability and accuracy. Episodic motions remain visible.

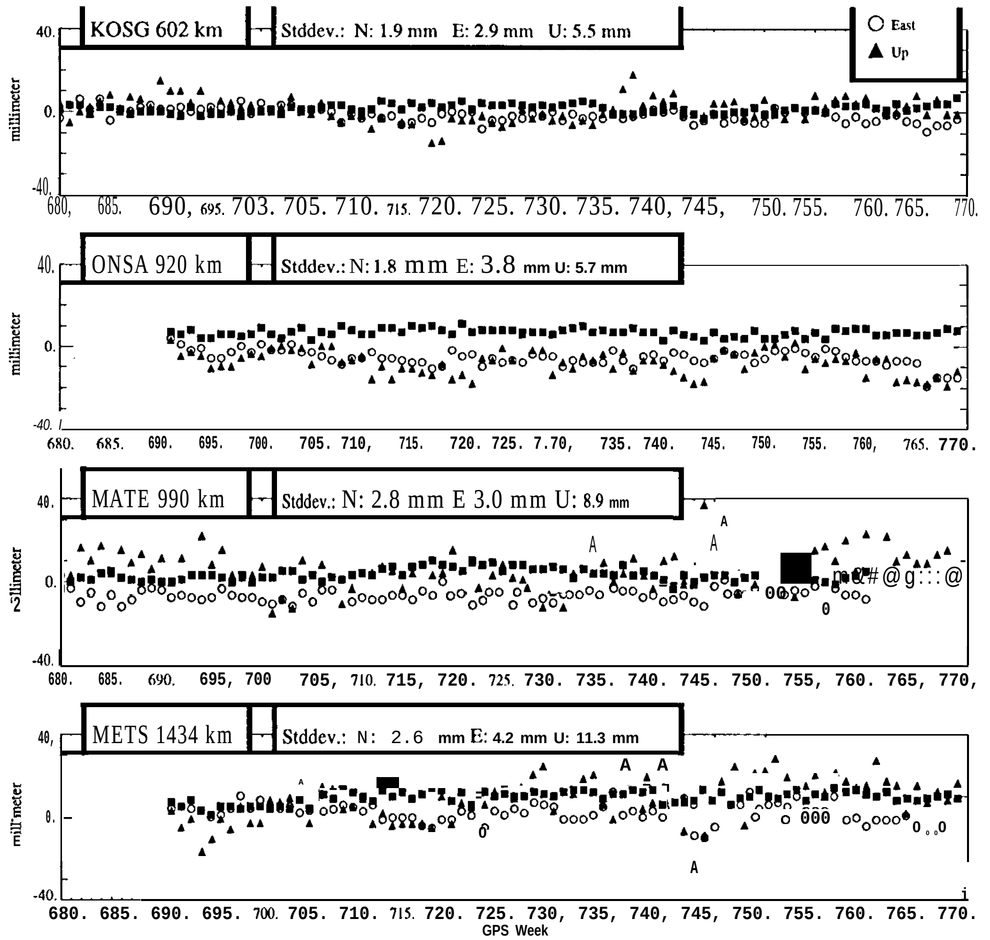


Figure** 2. **Weekly repeatability of station coordinates. Variations of north, east, and height components relative to the fixed site Wettzell (distance to Wettzell is given).

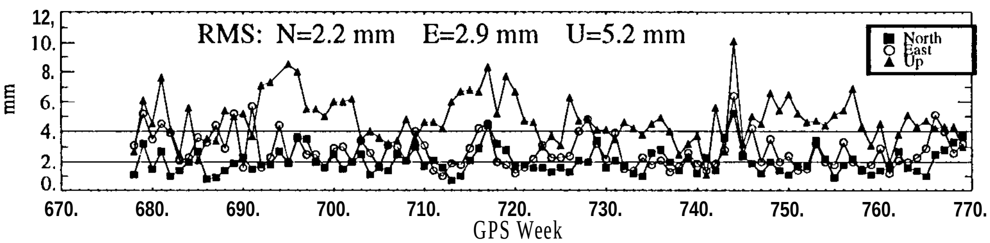


Figure** 3. **Stability in the European network (residuals of Helmert transformations between solutions of adjacent weeks).

Table 4. Helmert transformations of global coordinate solutions using ITRF or GFZ velocities.

(Unit: mm)

Variant	No. of sites	ITRF velocities N	ITRF velocities E	ITRF velocities H	GFZ velocities N	GFZ velocities E	GFZ velocities H
GFZ93–GFZ94	24	4.2	5.4	4.6	2.3	2.8	5.0
alto., only Europe & N. America	16	2.7	2.3	3.3	0.9	0.9	3.7
alto., only Europe	8	1.4	1.2	2.3	0.6	0.5	2.5
GFz93/94-ITRF93	24	4.2	4.0	9.1			

2. Simultaneous adjustment of station coordinates and their velocities from the whole data set. This method gives optimum weighting of the data. Correlations between coordinates and velocities are automatically taken into account. Episodic motions cannot be seen. In this variant the accuracies are too optimistic and have to be scaled according to the first variant.

Some of the baseline rates derived from the first variant together with determined slopes are shown in Figure 4. The slope values from the ITRF are given for comparison. For baselines of about 1000 km (WETB-MATE) the scattering is ±3 mm, for longer baselines the scattering increases by 1.5 to 2 mm

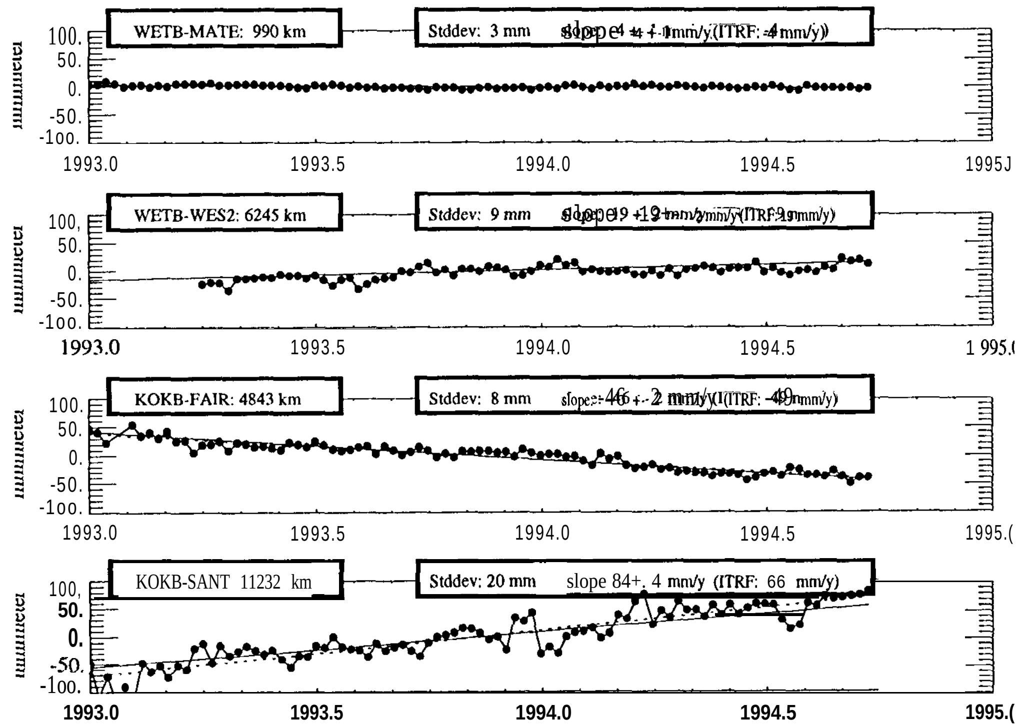


Figure 4. Baseline rates from weekly coordinate solutions (----: ITRF value for comparison).

per each 1000 km. The plate tectonic motion can be seen clearly. Figure 5 gives the baseline rates from KOKB and WETB to their neighboring sites. The accuracies of the shorter baselines in Europe are ±1 mm/yr. In regions where we have a good site distribution (Europe, North America) even for longer baselines accuracies of ±2 mm/yr can be obtained. In these cases the agreement with the velocities from NUVEL or ITRF are in the range of a few mm/yr. For isolated stations, especially in the Southern hemisphere, the accuracy is about ±5 mm/yr. Even here we have a close agreement to other models.

Figure 6 shows the velocities as resulting from the global simultaneous adjustment of coordinates and velocities. Here again, the agreement with NUVEL and ITRF velocities for Europe and North America is obvious. In the Australian region a small net rotation can be observed, which probably originates from a relatively weak connection to the global network.

In the Southern hemisphere recently a lot of new sites became available. So we can expect to have an accuracy of ±2 to ±3 mm/yr in a global scale within the next few years.

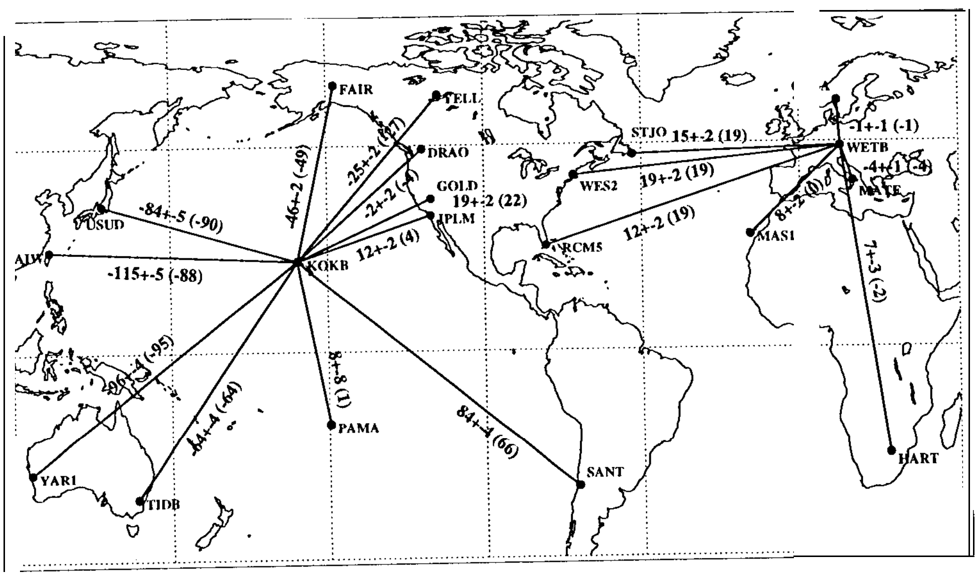


Figure 5. Baseline rates of KOKB and WETB to neighboring sites (ITRF values are given in parentheses).

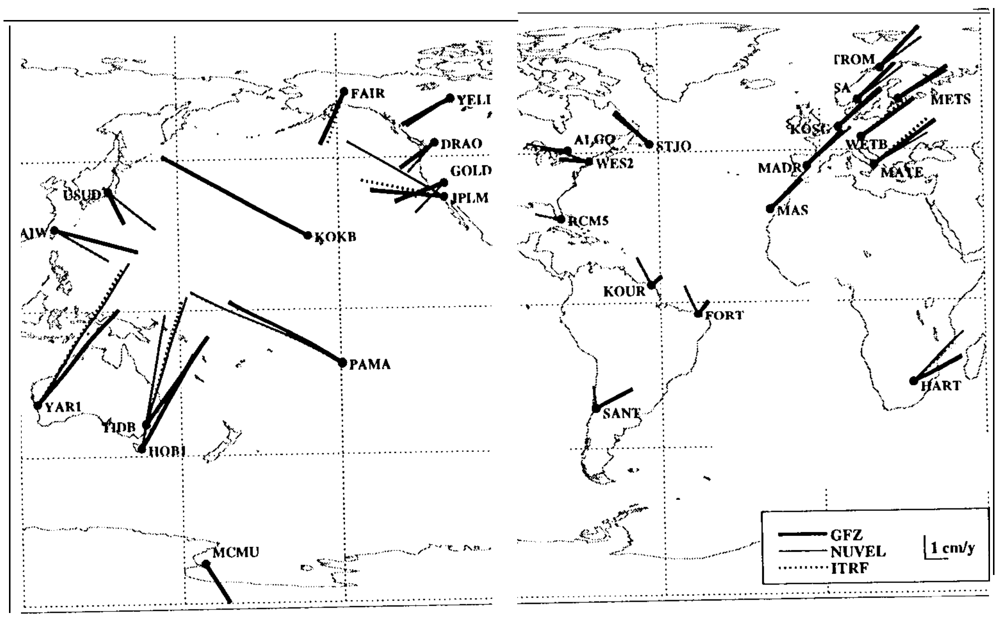


Figure 6. Site velocities from 2 years of IGS data (NUVEL-1 and ITRF values are given for comparison).

Our results show that data of only two years yield accuracies comparable to hose from analysis of SLR and VLBI data over 5 to 10 years. This demonstrates he advantage and great potential of the GPS technique for global applications. 3ecause we will have a densification of the network in the near future which is nlikely for the SLR and VLBI techniques, the importance of the GPS technique becomes very obvious.

Determination of Earth Rotation Parameters

The adjustment part of our software package gives the possibility to choose an arbitrary time interval for parameter estimation. Besides the estimation of diurnal ERP (pole and LOD) in the routine IGS analysis, ERPs with semidiurnal resolution were calculated and analyzed. To assess the stability and accuracy of our ERP results, comparisons with solutions of other IGS analysis centers and with results from other techniques were performed.

To estimate the accuracy of the ERP series for each single IGS Analysis center the smoothed mean of all these solutions was taken. The differences of all solutions to the mean curve for 1993 and 1994 are shown in Figure 7. It is clear that the scattering of the solutions has significantly improved from the beginning of 1993 to the end of 1994. The most recent accuracy is about ±0.3 mas. Such an improved accuracy is due to better site distribution, a more precise reference system, and good data cleaning. The most results of daily estimations of length of day (LODR) from 32-h arcs have an accuracy of ±0.06 ms compared to Bulletin B (Figure 8).

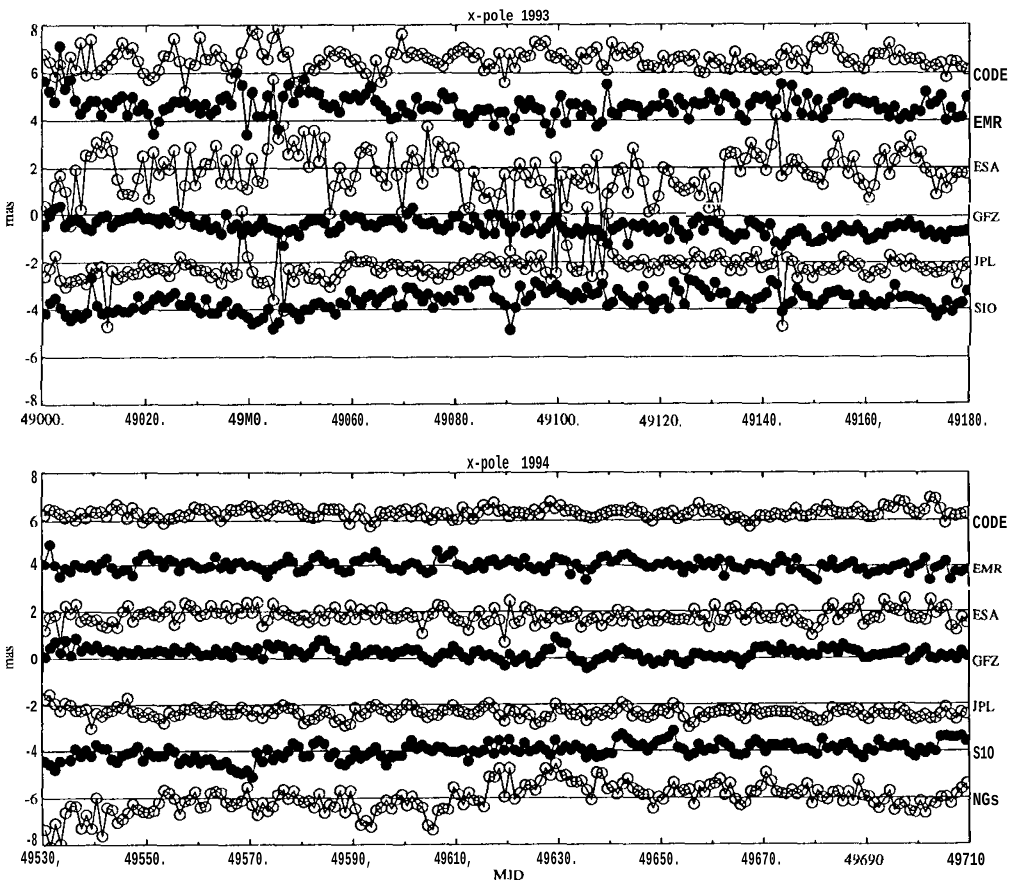


Figure 7. Daily polar motion results of IGS Analysis Centers (x-component). Differences to smoothed mean of all solutions. Improvement of accuracy of solutions from the beginning of 1993 to the end of 1994.

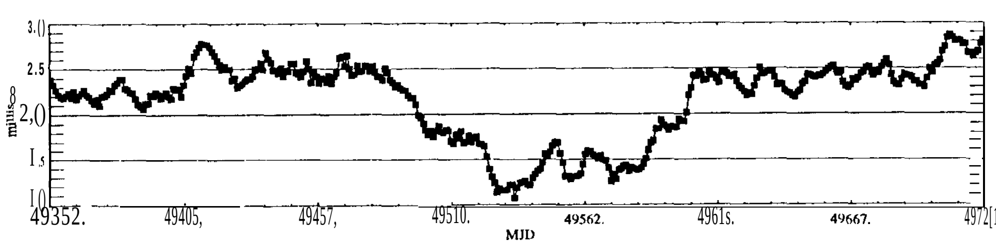


Figure 8. Daily LODR values for the year 1994 compared with IERS Bulletin B solution.

To evaluate the accuracy of GPS derived polar motion a comparison with results from other techniques have been performed. For this purpose one ERP series from VLBI determined by National Oceanic and Atmospheric Administration (NOAA, USA) and three series from SLR computed by GFZ and by the Center for Space Research/University of Texas (CSR) were chosen (Figure 9). The high short periodic stability of GPS results can clearly be seen (Figure 9 a,b). There is an excellent agreement to the SLR result with three days resolution. Highly resolved SLR curves have a considerably higher scattering caused by the unhomogeneous data distribution in smaller data intervals. GPS is today the only technique which can deliver routinely a high quality series of polar motion with daily resolution.

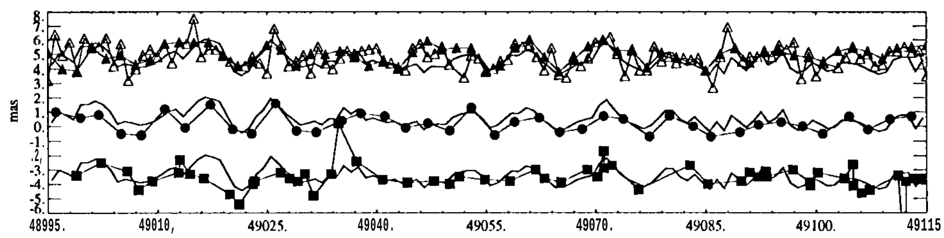


Figure 9. Daily polar motion from GPS (_-ERP (GFZ)94P01) compared with results from other techniques (x-pole, differences to IERS Bulletin B, arbitary origin): (▲,△) - SLR, ERP (GFZ)94L03/04, resolution of 2 and 1 days; (■) - VLBI, EOP(NOAA)93R07, 24-h-Sessions; (o) - SLR, EOP (CSR)94L01, resolution of 3 days.

To demonstrate the accuracy of GPS in the subdaily ERP determination, polar motion with 12-h resolution was computed (Gendt *et al.*, 1994). Compared to the daily resolution, there is a difference of ±0.25 and ±0.27 mas for X and Y-poles, respectively. In the computation of subdaily ERP's, of course, all constant disturbances of the inertial system, such as orbital errors and nutation errors, are absorbed by diurnal periods in the ERP's. This can clearly be seen from the alternating differences to the daily series in some intervals (Figure 10). Nevertheless, this example demonstrates the high accuracy of highly resolved ERP from GPS.

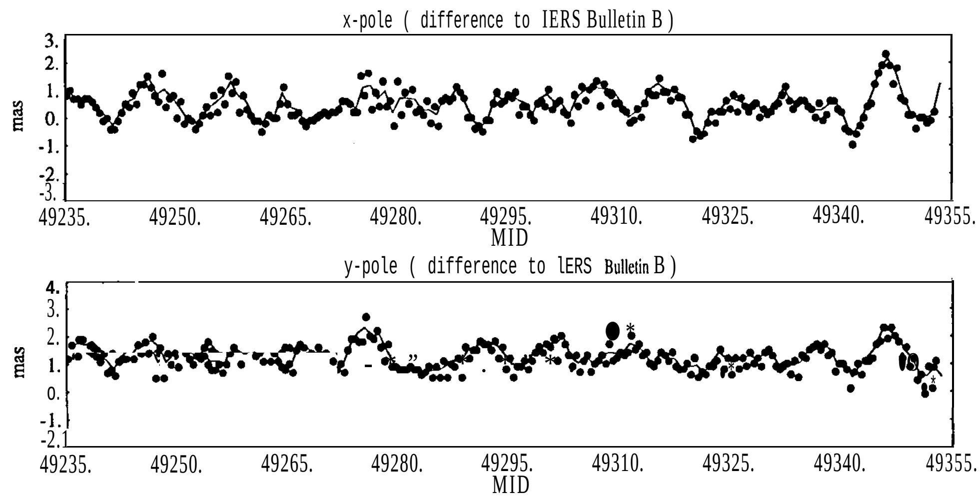


Figure 10. Highly-resolved GPS polar motion (differences to IERS). Semidiurnal results ERP(GFZ)94P02 compared with diurnal polar motion ERP(GFZ)94P01.

The GFZ orbits are computed on a daily basis using 32-h arcs. Simultaneously with the orbital state vector the reflectance coefficient and the Y-bias are adjusted for. Even for such a small interval as two revolutions the reflectance coefficient is very stable. The same holds for the Y-bias for non-eclipsing orbits. The quality of the orbits can be assessed by orbit overlapping and by comparisons with the results of other analysis centers as well as with the official IGS orbits (mean of all centers). Such a comparison for 1994 is shown in Figure 11. It can be stated that the GFZ orbits with an accuracy of better than 15 cm are among the best IGS orbits.

Satellite clocks are adjusted for each epoch and represent a part of the orbit products. The stability of clock determination was of ±0.6 ns for non-AS days. Since the AS was permanently switched on January 31, 1994 the accuracy of clock estimation was decreased.

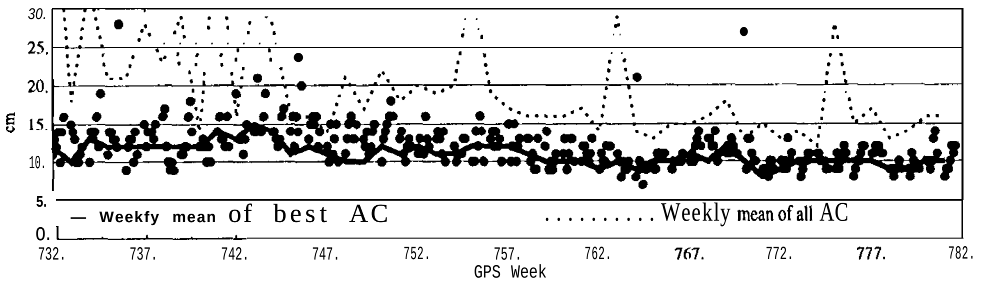


Figure 11. Differences of GFZ orbits to the official IGS orbits (daily mean of all satellites). For comparison weekly means of the differences of the best Analysis Centers (AC's) and of all AC's are *shown.*

Conclusions

The results presented here from a relatively short data span of 2 years show the considerable contribution of GPS to many areas of geodetic and geodynamic research. For the determination of pole coordinates GPS currently yields the highest precision and highest resolution among all techniques. For the future a combination of GPS and VLBI seems to be the best choice where VLBI would provide the link to inertial reference frames (e.g., UT1) that are inaccessible for satellite techniques.

Also GPS will play a major role for realizing and maintaining the global reference frame and its changes in time. The densification of the IGS Network will provide accuracies of ±2 to ±3 mm/yr for all regions of the Earth within the next 2 to 3 years. Global control networks maybe installed by SLR and VLBI to investigate possible systematic effects of the GPS technique and to obtain a high precision in defining the geocenter (SLR).

References

Everhart, E. (1974). An efficient integrator of very high order and accuracy with appendix listing of RADAU. Tech. Report, Denver Res. Inst., Denver, Colorado.

Feltens, J. (1991). Nicht-gravitative Storeinfluesse bei der Modellierung von GPS-Erdumlaufbahnen, Theses, Publication of the Deutsche Geodaetische Kommision C 371, Muenchen.

Fliegel, H. F., T. E. Gallini and E. R. Swift (1992). Global Positioning System Radiation Force Model for Geodetic Applications, *J. Geophys. Res.* **79**, Bl, 559-568.

Gendt, G., G. Dick, W. Mai, Ch. Reigber, Th. Nischan (1994). Earth Rotation Parameters and Station Coordinates from GPS Data. *IERS Technical Note* No.17, Paris, P37–P41.

Gendt, G., G. Dick, Ch. Reigber, W. Sommerfeld, Th. Nischan (1995). Earth Rotation Parameters, Station Coordinates and Velocities from GPS Data. *IERS Technical Note,* Paris, in press.

Goad, C. (1985). Precise Relative Position Determination Using Global Positioning System Carrier Phase Measurements in a Nondifference Mode. In: *Proceedings of the First International Symposium on Precise Positioning with the Global Positioning System,* Rockville, MD, April 15–19,1985, Vol. I, 347–356.

Kunert, F. (1976). Pseudoinverse Matrizen und die Methode der Regularisierung. BSB G. G. Teubner Verlagsgesellschaft, Leipzig.

Landau, H. (1988). Zur Nutzung des Global Positioning Systems in Geodaesie und Geodynamik: Modellierung, Softwareentwicklung und Analyse. Schriftenreihe der Universitaet der Bundeswehr Muenchen, Heft 36, Neubiberg.

McCarthy, D. (Ed.) (1992). IERS Standards. *IERS Technical Note No. 13,* Paris.

Scherneck, H. G. (1991). A Parametrized Solid Earth Tide Model and Ocean Tide Loading Effects for Global Geodetic Baseline Measurements, *Geophys. J. Znt., 106, 677–694.*

Stiefel, E. L. and G. Scheifele (1971). *Linear and regular celestial mechanics.* Springer Verlag, Berlin, Heidelberg, New York.

Jet Propulsion Laboratory IGS Analysis Center 1994 Annual Report

J. F. Zumberge, M. B. Heflin, D. C. Jefferson, M. M. Watkins, F. H. Webb
Jet Propulsion Laboratory
Pasadena, CA

Background

Members of the Tracking Systems and Applications Section in the Telecommunications and Engineering Division of Caltech's Jet Propulsion Laboratory (JPL), are funded by the National Aeronautics and Space Administration (NASA) to participate as an Analysis Center (AC) for the International GPS Service for Geodynamics (IGS).

The Section is comprised of several Groups, of which four are concerned primarily with GPS technology, data, and analysis. These are (i) the GPS Networks and Operations (GNO) Group, supervised by U. J. Lindqwister; (ii) the Earth Orbiter Systems (EOS) Group, supervised by S. M. Lichten; (iii) the GPS Systems Group, supervised by L. Young; and (iv) the Space Geodesy and Geodynamics Systems (SGGS) Group, supervised by M. M. Watkins.

While members from all of these Groups contribute at least indirectly to JPL's IGS AC efforts, members from the SGGS Group (Heflin, Watkins, Webb, Zumberge) and the EOS Group (Jefferson) are most directly involved. The SGGS Group has been involved in the analysis of data from a globally-distributed network of GPS receivers beginning with the first Global International GPS experiment in 1991 (Heflin *et al.*, 1992).

Evolution in 1994

Beginning June 21, 1992, JPL began to analyze data from the global network on a daily basis. For details on the evolution of strategy in 1992 and 1993 see, respectively, Zumberge *et al.* (1993a) and Zumberge *et al.* (1994). Additional general information on the JPL IGS Analysis Center maybe found in Zumberge (1993b).

Pre-AS Strategy

At the beginning of 1994, anti-spoofing (AS), the encryption of P-code, was not yet implemented full time. Our analysis strategy at that point consisted of using the ionosphere-free combination of both pseudorange and carrier phase, with data noise values of 1 cm and 1 m, respectively. Data below 15 degrees elevation were excluded. The phase data were decimated to 7.5 minutes, and the pseudorange data were carrier-smoothed over the same interval.

Data corresponding to each GPS day were analyzed in 30-hour batches centered on GPS noon. Estimated parameters were satellite state vectors and solar radiation pressure (srp), receiver coordinates, zenith wet troposphere delay at each receiver site, station and satellite clock offsets, carrier phase ambiguities, and Earth orientation. Satellite x- and y- srp parameters were allowed to vary stochastically by 10%, and the y bias by 10^{-13} km/s^2. Zenith wet troposphere delay was modeled as a random walk with 1 cm^2/hr variance derivative.

The Williams solid Earth tide model was used; it differs from the IERS standards by an insignificant amount. Pole tide and the Love number variation at K1 frequency were modeled according to IERS Technical Note 13 (McCarthy, 1992). Ocean loading was modeled according to Scherneck (1991). The Earth's gravity field was described by the JGM2 12x12 multipole expansion using terms up through degree and order 12 (Nerem *et* al., 1994). The value of GM used was 398600.4415 km^3/s^2 (Ries *et al.*, 1992).

Nominal values of the parameters for each GPS satellite [3 each for position and velocity, and two for solar radiation pressure (srp)] were from the broadcast ephemeris. Weak a *priori* constraints of 1 km and 10 mm/s for position and velocity, respectively, were imposed. The T10-T20 solar radiation pressure model was used for srp (Fliegel, 1992).

As an example, the analysis of January 21 included data from 43 stations and 25 satellites. There were nearly 60,000 phase and pseudorange measurements each, from which 1556 parameters were determined. (Parameters allowed to vary stochastically are counted only once. These include station and satellite clocks, station zenith wet troposphere delay, and satellite srp.) The rms post-fit residuals for the phase measurements were typically a few mm. Those measurements with more than 5 cm post-fit residual for phase, or 5 m for pseudorange, were considered outliers and excluded.

Anti Spoofing

With the onset of full-time AS on January 31, our strategy was altered in three major ways, In retrospect two of these changes were in fact an overreaction to the difficulties associated with AS, and were imposed largely because the effect of the third in mitigating those difficulties was not yet fully realized.

The reactive changes were (1) elimination of pseudorange altogether in the parameter-estimation phase of analysis (pseudorange was still used for pre-fit data editing) and (2) an increase of the minimum elevation angle from 15 degrees to 20 degrees. Both of these steps were taken to reduce the amount of high-noise data, the major effect of which is the introduction of undetected phase breaks.

Clearly the more beneficial change was to improve the detection of phase breaks. To this end, we began to insert phase bias parameters for any station-satellite pair at any time for which the temporal discontinuity in post-fit residual exceeded 10 cm. That is, consider a given station-satellite pair with measurements x_i and post-fit model values z_i. Denote by t_i the time Of measurement i. In the event that

$$|x_{i+1} - z_{i+1} - x_i + z_i| > 10 \text{ cm} ,$$

a new phase bias parameter is introduced for that station-satellite pair at time t_{i+1}. This was the third change.

Although computationally expensive, requiring as it does an extra parameter estimation step, it was the single most effective change in dealing with noisy AS data. (More recently, by requiring temporal continuity in L1–L2, we have improved our pre-fit data editing so that, even with AS, the number of undetected phase breaks prior to parameter estimation has been significantly reduced, although not entirely eliminated.)

The stochastic treatment of satellite srp parameters was also eliminated, in the belief that the data were too noisy to reliably estimate these parameters.

Following these initial changes, there were a number of modifications to the strategy throughout the year (Table 1). The most noteworthy of these were:

- reintroduction of pseudorange data from TurboRogue receivers
- implementation of a yaw model and estimating yaw-rate parameters for eclipsing GPS satellites (Bar-Sever *et al.*, 1995)
- routine analysis of essentially *all* IGS stations, by first determining satellite parameters (orbits and clocks) with a 3 l-station global network, then fixing those parameters and analyzing all other stations, one at a time (Zumberge *et al.*, 1995)
- improved detection of potential problem stations by analysis of baseline loops (Figure 1)
- return to 15-degree elevation angle cutoff
- return to moderate (l%) stochastic variation in satellite srp

The current strategy is summarized on the Central Bureau information System, available on the World Wide Web (WWW) at location `http://igscb.jpl.nasa.gov/`; choose "Analysis Centers" and fetch the file `jpl.acn`.

Table 1. **Strategy** ***Evolution, 1994.***

Action	date
nominal non-AS strategy	Jan 1
initial AS strategy: no pseudorange, 20-degree elevation angle cutoff, post-fit data editing	Jan 31
include pseudorange from 8 TurboRogues (10-m data noise)	May 22
include P-code from all TurboRogues (l O-m data noise)	Jun 16
incorporate loop baseline preprocessing	Aug 29
eliminate phase breaks at day boundaries	Sep 9
analyze global network, then other sites with fixed transmitter parameters	Sep 20
implement GPS yaw-attitude model	Sep 20
reduce data interval from 7.5 to 5 minutes	Sep 20
Change to JGM3 12x12 gravity field (Watkins e: al. , 1994)	Ott 9
Use 1% srp stochastic variation on x and y, 1 e-14 km/s^2 on y bias.	Ott 9
reduce data noise on pseudorange to 1 m (don't use pseudorange from CASA, MCMU, RCM5)	Ott 9
edit rinex files with broadcast orbits and clocks	Ott 1 3
lower elevation angle cutoff to 15 degrees (but not Ott 18)	Ott 1 7
Use extended UTPM model (Herring, 1994)	Dec 10

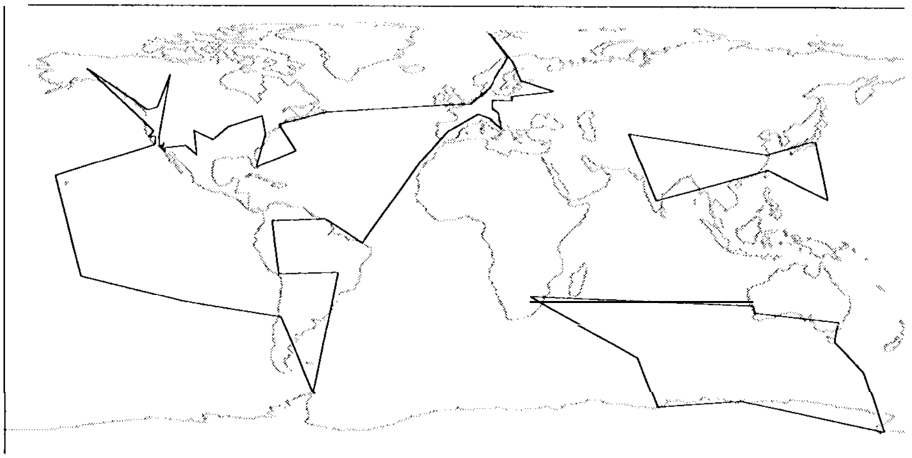


Figure 1. Each IGS site is included in one of three polygons. Using broadcast orbits, each baseline corresponding to an edge of the polygon is analyzed. If the results for a pair of connected baselines are anomalous, the site corresponding to the common vertex is excluded.

Fiducial Errors

To define the reference frame of our orbit product, coordinates and velocities of sites listed in Table 2 were fixed at their ITRF-92 values (Boucher *et al.*, 1993; see also IGS mail messages 421 and 430). Also indicated in Table 2 are errors and periods affected in our assumed monument coordinates and/or antenna heights.

Access to Products

Nine files are distributed weekly to two public areas. The files for a given GPS week are indicated in Table 3, and include a summary file, a file containing estimated Earth orientation parameters, and one file for each day of the week

Table 2. Fiducial Errors, 1994.

Site			error (cm)	dates affected (1994)
ALGO	Algonquin Park	Canada	-8.2	Feb 16
FAIR	Fairbanks	US		
GOLD	Goldstone	us		
HART	Harteebesthoek	South Africa	-3.2	Jan 01 - Dec 31
KOKE	Kokee Park	us		
KOSG	Kootwij k	Netherlands		
MADR	Madrid	Spain	7.0	Apr 20 – Dec 31
SANT	Santiago	Chile		
TIDB	Tidbinbilla	Australia	16.9	Apr 23 – Dec 31
TROM	Tromso	Norway		
WETT	Wetzzell	Germany	-7.0	Jan 01 - Apr 09
YAR 1	Yaragadee	Australia		
YELL	Yellowknife	Canada		

Table 3. IGS Products.

filename	contents
jpl⟨wwww⟩7. sum	narrative summary
jpl⟨wwww⟩7 . erp	Earth rotation parameters for GPS week wwww
jpl⟨wwww⟩⟨d⟩.sp3	GPS ephemerides for GPS week wwww, day d, sp3 format

Following these initial changes, there were a number of modifications to the strategy throughout the year (Table 1). The most noteworthy of these were:

- reintroduction of pseudorange data from TurboRogue receivers
- implementation of a yaw model and estimating yaw-rate parameters for eclipsing GPS satellites (Bar-Sever *et al.*, 1995)
- routine analysis of essentially *all* IGS stations, by first determining satellite parameters (orbits and clocks) with a 3 l-station global network, then fixing those parameters and analyzing all other stations, one at a time (Zumberge *et* al., 1995)
- improved detection of potential problem stations by analysis of baseline loops (Figure 1)
- return to 15-degree elevation angle cutoff
- return to moderate (1%) stochastic variation in satellite srp

The current strategy is summarized on the Central Bureau information System, available on the World Wide Web (WWW) at location http://igscb.jpl.nasa.gov/; choose "Analysis Centers" and fetch the file jpl.acn.

***Table 1.* Strategy Evolution, 1994.**

Action	date
nominal non-AS strategy	Jan 1
initial AS strategy: no pseudorange, 20-degree elevation angle cutoff, post-fit data editing	Jan 31
include pseudorange from 8 TurboRogues (10-m data noise)	May 22
include P-code from all TurboRogues (l 0-m data noise)	Jun 16
incorporate *loop* baseline preprocessing	Aug 29
eliminate phase breaks at day boundaries	Sep 9
analyze global network, then other sites with fixed transmit ter parameters	Sep 20
implement GPS yaw-attitude model	Sep 20
reduce data interval from 7.5 to 5 minutes	Sep 20
Change to JGM3 12x12 gravity field (Watkins *et* al., 1994)	Ott 9
Use 1% srp stochastic variation on x and y, 1.e-14 km/s^2 on y bias.	Ott 9
reduce data noise on pseudorange to 1 m (don't use pseudorange from CASA, MCMU, RCM5)	Ott 9
edit rinex files with broadcast orbits and clocks	Oct 13
lower elevation angle cutoff to 15 degrees (but not Ott 18)	Ott 1 7
Use extended UTPM model (Herring, 1994)	Dec 10

with estimated satellite positions. All of these are available from each of the IGS Global Data Centers (located at Goddard Space Flight Center, Scripps Institution of Oceanography, and Institut Géographique National).

The files are available from JPL using anonymous ftp to

    sideshow. jpl.nasa.gov

in directory

    pub/jpligsac/⟨wwww⟩

where ⟨wwww⟩ is the 4-digit GPS week. For example, for GPS week 780, the files to be found in pub/ jpligsac/0780 are

    jpl07800.sp3.Z
    jpl07801.sp3.Z
    jpl07802.sp3.Z
    jpl07803.sp3.Z
    jpl07804.sp3.Z
    jpl07805.sp3.Z
    jpl07806.sp3.Z
    jpl07807.erp.Z
    jpl07807.sum.Z

Note that the day numbers in the sp3 files range from O for Sunday through 6 for Saturday. (For weeks 717—Ott 3, 1993 through Ott 9, 1993—and earlier, there is often a single sp3 file for the entire week, in which case the day digit is 7.) The definition of the sp3 ephemerides format can be found in the IGS Central Bureau Information System (igscb.jpl .nasa. gov), under igscb/data/ f ormat.

In addition to the official IGS products, a one-line "engineering" record for each day and site analyzed in the current calendar year is kept in the file

    pub/jpligsac/ytd.eng

Engineering data from earlier years can be found in ⟨yyyy⟩. eng, where ⟨yyyy⟩ is the four-digit calendar year. An excerpt from ytd. eng is given in Table 4.

Additionally, files specific to the GIPSY software (Lichten, 1990; Meehan *et al.*, 1992; Blewitt, 1993; Webb and Zumberge, 1993) are available in

```
date
|          site ('.' means point-positioned)
|          |    number of time tags for which clock solution is valid
|          |    |    rms deviat n from straight line of clock solution (ns)
|          |    |    |         ift of clock solution (parts per trillion)
|          |    |    |         |          clock solution at noon (usec)
|          |    |    |         |          |         # of pseudorange mess
|          |    |    |         |          |         |     rms ( cm)
|          |    |    |         |          |         |     |   # of phase mess.
|          |    |    |         |          |         |     |   |     rms (mm)
|          |    |    |         |          |         |     |   |     |   orig
|          |    |    |         |          |         |     1   1     1   1    tot
|          |    |    |         |          |         |     |   |     | <-breaks->
```

1995-01-01	ALBH	360	3.88	0.986	2.52	1933	54	1932	4	43	51
1995-01-01	BOR1.	360	1.97	0.399	-1.25	1993	41	1973	11	35	35
1995-01-01	FAIR	360	0.0654	-0.0423	-0.16	0	.	2047	7	60	71
1995-01-01	GPS10	360	1.01	-25.4	-233	2256	59	4113	9	66	100
1995-01-01	GPS13	338	79.5	-2.37	-134	3025	56	4682	10	111	232
1995-04-15	WLSN.	287	91.6	0.421	1.3	1658	66	1648	9	53	55

Table 4. Sample records of engineering data.

pub/ gipsy_products, where yearly directories exist. Within each yearly directory are two subdirectories, orbits and clocks. For example, for April 1, 1995, the files

```
pub/gipsy_products/1995 /clocks /1995 -04- 01CLOCK.Z
pub/gipsy_products/1995/clocks/1995-04-01badCLOCK.Z
pub/gipsy_products/1995/orbits/1995-04-01.att.Z
pub/gipsy_products/1995 /orbits /1995-04-01.eci.Z
pub/gipsy_products/1995/orbits/1995-04-01tpeo.nml.Z
```

contain information on, respectively, precise GPS clock solutions, times and satellites for which precise clock solutions are unavailable, informationon the attitudes ofeclipsing GPS spacecraft, precise satellite ephemeridesin an Earth-centered inertial reference frame, and Earth orientation information. More information can beobtainedfrom gipsy@cobra.jpl . nasa. gov.

Finally, WWW pages located at

http: //sideshow. jpl .nasa. gov/mbh/series html

provide graphical time series of station coordinates.

Results

Results for station coordinates and Earth orientation, independent of errors in fiducial coordinates, are described by Heflin *et al.* (1995) from which Figure 2 is an example.

The performance of the operational Earth orientation series with respect to the IERS Bulletin B Final values is summarized in Table 5. A plot of excess

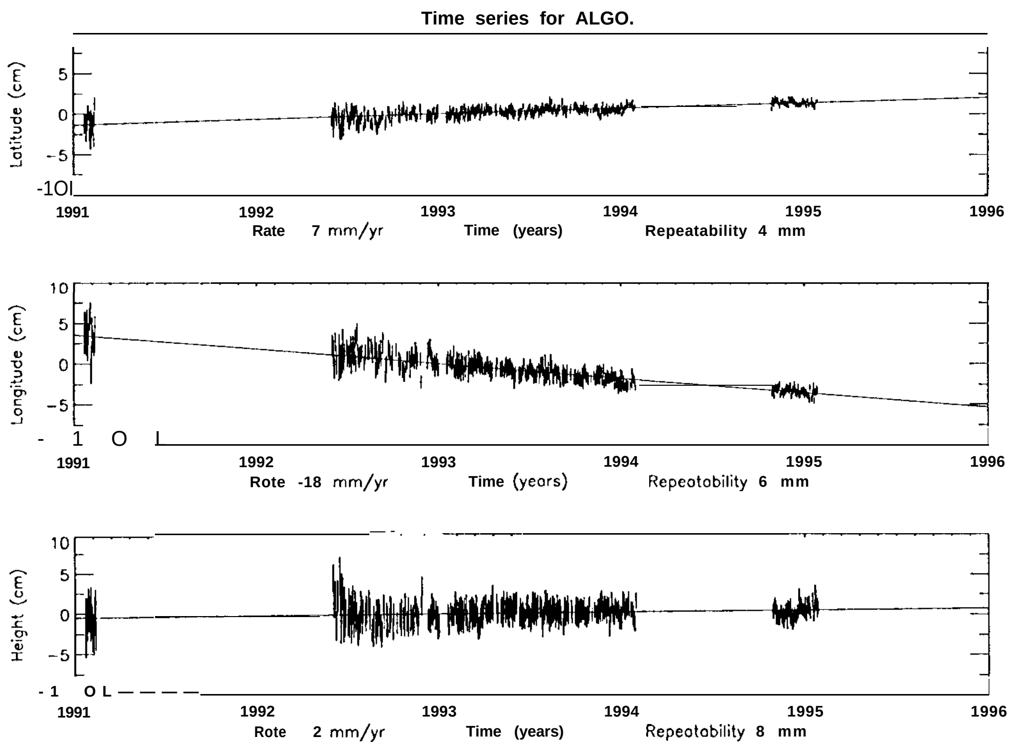


Figure 2. An example of a time series from the JPL IGS Analysis Center. Plots like this can be accessed on the World Wide Web at location *http: // sideshow.jpl.nasa.gov/ mbh/seri es. h tml.*

quantity	bias	sigma
X (mas)	0.21	0.46
Y (mas)	1.37	0.44
LODR (usec)	-61	87
(after Ott 9:	-3	40)

Table 5. Operational Earth orientation series.

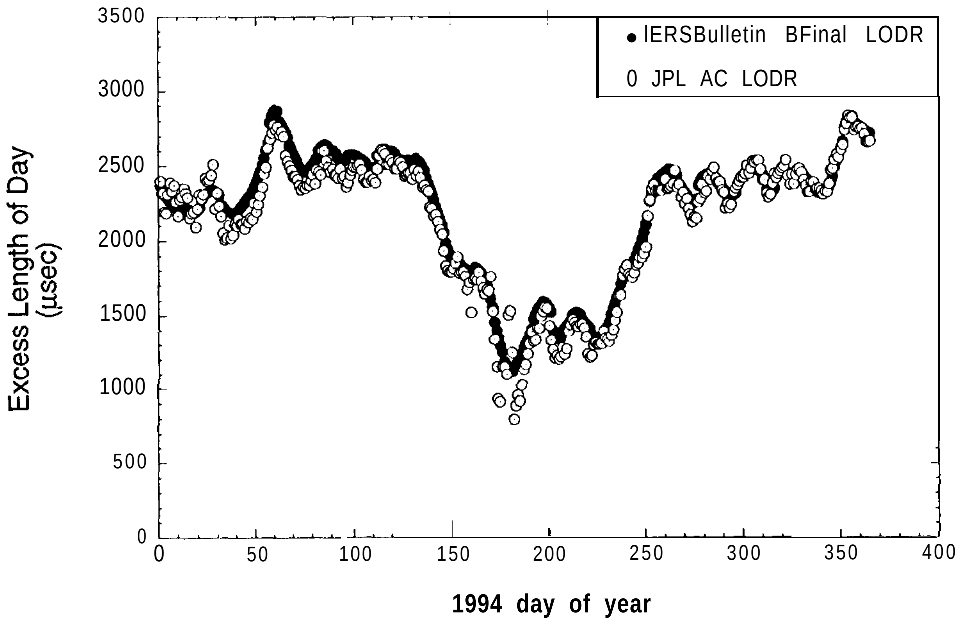


Figure 3. Operational length-of-day series during 1994, compared with IERS Bulletin B Final values.

length of day versus 1994 day number is given in Figure 3.

Our single most important measure of orbit quality is the extent to which estimated values of a satellite's position near midnight agree with similar estimates based on data from adjacent days. For a given satellite and day we define

$$Q^2 \equiv \sum_t \{ |x(t) - x_-(t)|^2 \} + \sum_t \{ |x(t) - x_+(t)|^2 \},$$

where $x(t), x_-(t), x_+(t)$ are the vector estimates of the satellite's position at time t using data from the current, previous, and subsequent days, respectively. In the first sum t ranges over the first three hours of the current day, while in the second sum it ranges over the last three hours of the day.

Shown in Figure 4 is a plot of the daily median value of Q, over all satellites. The daily variability of Q was typically 28 cm before October 9, and was reduced to 14 cm afterwards. The reduction in Q, both in its daily median and variability, is associated with the events in Table 1.

Finally, shown in Figure 5 is the distribution in the delay between data acquisition and product delivery. Our nominal goal is to deliver a week's worth of products on Friday (or earlier) following the Saturday that marked the close of the previous GPS week.

Figure 4. Orbit repeatability during 1994.

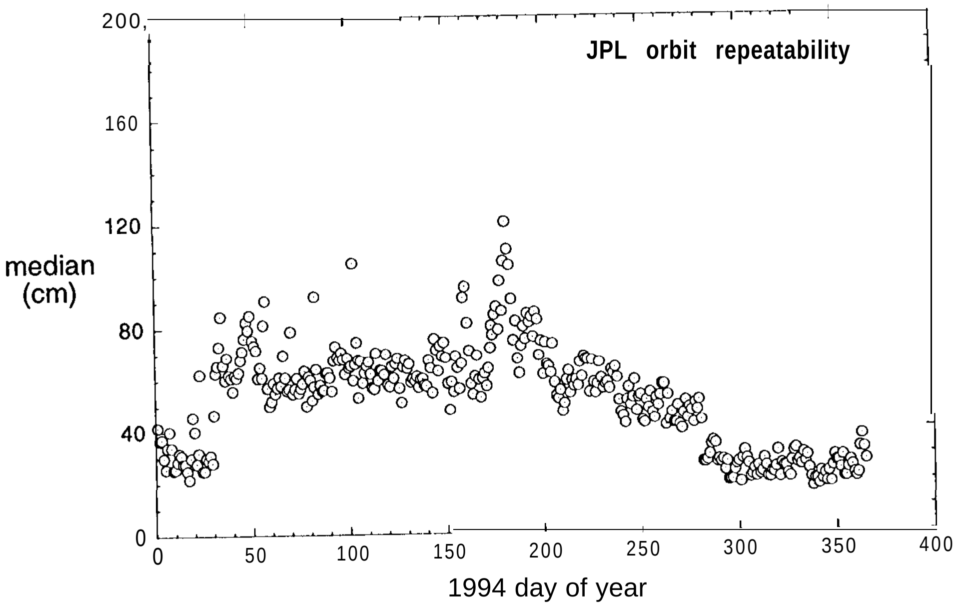
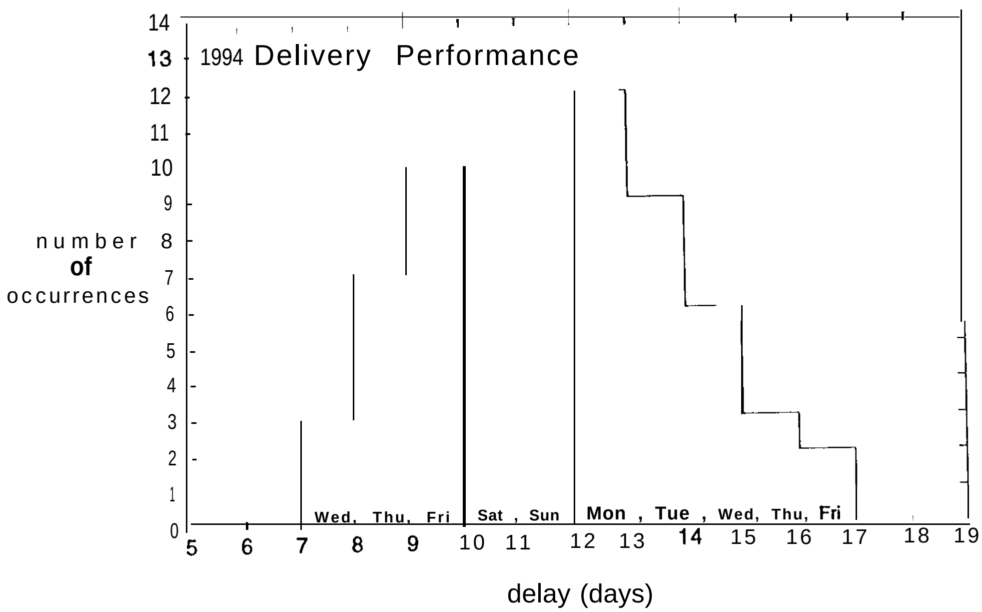


Figure 5. Delivery performance during 1994.



New for 1995

Site Selection *and Precise Point Positioning*

Because of the continuing expansion of the global IGS network during 1994, we have recently implemented a site-selection algorithm as follows:

- include Yellowknife and Algonquin (the two TurboRogue receivers that are IGS fiducials)

- from the set of remaining TurboRogue receivers, include successively the next 15 most isolated (those that are furthest away from the current set of included sites)

- include the remaining 11 IGS fiducials

- include the next 3 most isolated sites, without regard to receiver type

- choose an additional 3 sites at random

This algorithm provides a total of 34 sites, of which 31 have been chosen to be well distributed globally. Of the 31, a subset of 15 are well-distributed TurboRogues, allowing good determination of satellite clocks. (As new receivers are added in isolated regions, we will increase the number of sites in the global analysis.)

The remaining sites are analyzed with satellite parameters fixed at their just-determined values from the global solution.

The precise-point-positioning strategy has allowed us to analyze data from essentially all IGS sites, with horizontal repeatabilities at the few-mm level, and vertical repeatabilities at the cm level. We believe that this strategy is the key to analyzing dense networks of hundreds of receivers.

To avoid the consequences of errors in fiducial coordinates, we have recently (April 2, 1995) begun to compute free-network orbits and clocks, and use these in every day's precise point positioning. Thus, coordinates of these sites will be in the same reference frame as those used in that day's free-network global solution. The inclusion of 3 sites at random in the global solution means that all sites will occasionally participate in the global solution, allowing a comparison with precise point positioning results.

The WWW page at

http: //sideshow.jpl.nasa.gov/mbh/point.html

provides the time series of free-network point position results.

Automation

Beginning in April 1995, an automated process developed by Ron Muellerschoen of the EOS Group provides rapid precise orbits and clocks, within about a day of the end of data collection. These orbits are accurate to a few tens of cm, and, very valuable in their timeliness.

A second automated process periodically looks for new data files from IGS sites. If satellite parameters from the rapid orbit service are available for the corresponding day, such data are analyzed with precise point positioning. Both engineering data and site coordinates are saved. This process runs asynchronously with the rapid orbit service.

These automated processes will be used to develop before-the-fact quality control procedures for the normal AC operation.

Densification of the Terrestrial Reference Frame

As one of the seven AC's in the IGS, JPL will start submitting weekly coordinate solutions to the Global Data Centers sometime in calendar 1995. Additionally, we will expand our analyses to include comparison of such coordinate solutions among all AC's, as described by Blewitt (1995).

Acknowledgments

Geoffrey Blewitt served as Supervisor of the SGGS Group until January 1994. Our success in participating as an IGS Analysis Center owes much to Geoff.

The authors appreciate the efforts of the GNO Group in ensuring that data from the global network are made available for analysis in a timely fashion.

Our AC benefits from cooperation and collaboration with members of the EOS Group, in particular Yoaz Bar-Sever, Winy Bertiger, and Ron Muellerschoen.

It is a pleasure to be involved with the international community of IGS participants. We particularly acknowledge fruitful exchanges with Yehuda Bock, John Dow, Gerd Gendt, Jan Kouba, Gerry Mader, and Markus Rothacher.

The work described in this report was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Bar-Sever, Y., J. Anselmi, W. Bertiger and E. Davis, "Fixing the GPS Bad Attitude: Modeling GPS Satellite Yaw During Eclipse Seasons" in *Proceedings of the ION National Technical Meeting,* Anaheim, CA, January 1995.

Blewitt, G., "Advances in Global Positioning System Technology for Geodynamics Investigations: 1978-1992," *Contributions of Space Geodesy to Geodynamics: Technology,* eds. D. E. Smith and D. L. Turcotte, American Geophysical Union Geodynamics Series v. 25, p. 195–213, 1993.

Blewitt, G., Y. Bock, and J. Kouba, "Constructing the IGS Polyhedron by Distributed Processing" in *Proceedings of the IGS Workshop on Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks* , May, 1995, J. F. Zumberge and R. Liu, eds.

Boucher, C., Z. Altamimi, and L. Duhem, *IERS Technical Note 15,* "ITRF and its associated velocity field," October, 1993.

Fliegel, H. F., T. E. Gallini, and E. R. Swift, Global Positioning System Radiation Force Models for Geodetic Applications, *J. Geophys. Res.,* 97(B1), 1992.

Heflin, Michael, Winy Bertiger, Geoff Blewitt, Adam Freedman, Ken Hurst, Steve Lichten, Ulf Lindqwister, Yvonne Vigue, Frank Webb, Tom Yunck, James Zumberge, "Global Geodesy Without Fiducial Sites," *Geophys. Res. Let. v.* 19, no. *2,* pp. 131-134, January 24, 1992.

Heflin, M., M. Watkins, D. Jefferson, F. Webb, and J. Zumberge "Coordinates, Velocities, and EOP from the Jet Propulsion Laboratory Using GPS, SSC(JPL) 95 P 02 EOP(JPL) 95 P 02," *ZERS Technical Note 19*, in press, 1995, P. Charlot, ed.

Herring, T. A. and D. Dong, "Measurement of diurnal and semidiurnal rotational Variations and Tidal Parameters of the Earth," *J. Geophys. Res.*, 99(B9), 18051–18071, September 10, 1994.

Lichten, S. L., "Estimation and filtering for high-precision GPS positioning algorithms," *Manuscript Geodaetica, 14, 159–176, 1990.*

McCarthy, Dennis D., cd., *IERS Technical Note 13*, July, 1992.

Meehan, T. K., J. M. Srinivasan, D. J. Spitzmesser, C. E. Dunn, J. Y. Ten, J. B. Thomas, T. N. Munson, C. B. Duncan, 1992, *The Turbo Rogue GPS Receiver,* presented at the 6th International Geodetic Symposium on Satellite Positioning, Columbus, Ohio, March 18, 1992.

Nerem, R. S., F. J. Lerch, J. A. Marshall, E. C. Pavlis, B. H. Putney, B. D. Tapley, R. J. Eanes, J. C. Ries, B. E. Schutz, C. K. Shum, M. M. Watkins, S. M. Klosko, J. C. Chan, S. B. Luthcke, G. B. Patel, N. K. Pavlis, R. G. Williamson, R. H. Rapp, R. Biancale, F. Nouel, "Gravity Model Development for TOPEW Poseidon: Joint Gravity Models 1 and 2," *J. Geophys. Res., v.* 99, no. C12, Dec. 15, 1994.

Ries, J. C., R. J. Eanes, C. K. Shum, and M. M. Watkins, "Progress in the Determination of the Earth's Gravitational Coefficient," *Geophys. Res. Let.* , 19(6), 529–531, March 20, 1992.

Scherneck, H-G, "A parametrized solid earth tide model and ocean tide loading effects for global geodetic baseline measurements," *Geophys. J. Int.*, 106, pp. 677–694, 1991.

Watkins, M. M., J. C. Ries, R. J. Eanes, R. D. Tapley, R S Nerem, "The JGM-3 Gravity Model," Proceedings of Topex/Poseidon Precision Orbit Determination Meeting, Feb, 1994.

Webb, F. H. and J. F. Zumberge, eds., *An Introduction to GIPSY/OASIS II,* Jet Propulsion Laboratory Document D-11088, Colorado, July 1993.

Zumberge, J. F., D. C. Jefferson, G. Blewitt, M. B. Heflin, F. H. Webb, "Jet Propulsion Laboratory IGS Analysis Center Report" in *Proceedings of the 1993 IGS Workshop, G.* Beutler, E. Brockmann, eds., March 25–26, 1993, Bern, Switzerland, pp. 154-163.

Zumberge, J. F., G. Blewitt, D. Jefferson, M. B. Heflin, F. H. Webb, "Earth Orientation Parameters from the Jet Propulsion Laboratory Using GPS," *IERS Technical Note 14,* September, 1993, P. Charlot, ed.

Zumberge, J. F., D. C. Jefferson, M. B. Heflin, F. H. Webb, G. Blewitt, "Earth Orientation Results from the Jet Propulsion Laboratory Using GPS," *IERS Technical Note 17,* September, 1994, P. Charlot, ed.

Zumberge, J. F., R. E. Neilan, I. I. Mueller, "Densification of the IGS Global Network" in *Proceedings of the IGS Workshop on Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks* , May, 1995, J. F. Zumberge and R. Liu, eds.

GPS Orbit and Earth Orientation Parameter Production at NOAA for the International GPS Service for Geodynamics for 1994

G. L, Mader, M. S. Schenewerk, J. R. Ray
Geosciences Laboratory, Office of Ocean and Earth Sciences, NOS, NOAA,
Silver Spring, Maryland

W. G. Kass, P. R. Spofford, R. L. Dulaney, D. G. Pursell
National Geodetic Survey, NOS, NOAA,
Silver Spring, Maryland

Introduction

The GPS orbits and eop solutions submitted to the IGS by the National Geodetic Survey (NGS) are a joint effort between NGS and the Geosciences Laboratory (GL). The GL is responsible for the development of the processing software and techniques while NGS is responsible for the operational production. NGS and GL are both activities within the National Ocean Service (NOS) of NOAA (National Oceanic and Atmospheric Administration) which ensures a close working relationship between the two groups.

Station Network

NGS used an average of about 32 tracking stations for the GPS orbit and Earth orientation solutions that have been submitted to the IGS. This list of included stations is not static but changes occasionally to include new stations that offer a more favorable geometry or new geographical coverage and to drop stations in regions where the tracking density is greater or redundant, Generally, the number of included stations will probably be maintained between 35 and 40. Additional stations do not appear to noticeably improve the orbit solutions. This number also appears adequate to provide overall tracking network stability that is relatively insensitive to daily tracking irregularities within the total global tracking network.

Table 1 summarizes the tracking stations used during 1994. All stations that were used are listed along with the date at which their use began in order to highlight those new stations that were added during the year. The date at which stations were dropped from our daily orbit solutions are also indicated. From this list, 30 stations were used during the entire year while 7 stations were added and 3 stations were dropped. At the end of the year, 2 additional stations were dropped as the 1995 processing began.

Table 1 also shows which station positions were held fixed for the orbit and eop solutions. NGS began 1994 fixing only the 13 reference sites agreed upon by the IGS to their ITRF92 positions. All other sites were unconstrained. The effect of daily tracking dynamics on these 13 stations meant that on any given day, 1 or 2 stations were frequently missing. This had a severely deleterious effect on the orbit and eop results as shown later in this report. Consequently, in July we began also fixing all the stations that we were regularly using and for which an ITRF92 position was reported. These additional constraints, indicated in the table, had an immediate beneficial effect on the orbit and eop results.

Table 1. 1994 Selected NGS fiducial sites for precise GPS orbit computations.

Abbrev	*Ref Frame(*)*	*Station*	*Used*	*Dropped*
algo	ITRF92	Algonquin	01 JAN94	
areq	UNCONSTR	Arequipa	16AUG94	
brmu	UNCONSTR	Bermuda	01 JAN94	
cas 1	UNCONSTR	Casey Station	02AUG94	
dav1	UNCONSTR	Davis	14JUL94	
drao	ITRF92(*)	Penticton	01 JAN94	
eisl	UNCONSTR	Easter Island	15AUG94	
fair	ITRF92	Fairbanks	01 JAN94	
for-t	UNCONSTR	Fortaleza	01 JAN94	
gold	ITRF92	Goldstone	01 JAN94	
hart	ITRF92	Hartebeesthoek	01 JAN94	
hers	ITRF92(*)	Herstmonceux	01 JAN94	15AUG94
hobl	UNCONSTR	Hobart	01 JAN94	31 JUL94
hob2	UNCONSTR	Hobart	16JUL94	
kerg	UNCONSTR	Kerguelen	10 DEC94	
kit3	UNCONSTR	Kitab	21 OCT94	
kokb	ITRF92	Kokee Park	01 JAN94	
kosg	ITRF92	Kootwijk	01 JAN94	
kour	ITRF92(*)	Kourou	01 JAN94	
macl	UNCONSTR	McQuarrie Is.	02AUG94	31 DEC94
madr	ITRF92	Madrid	01 JAN94	
masl	ITRF92(*)	Maspalomas	16JUL94	
masp	ITRF92(*)	Maspalomas	01 JAN94	15JUL94
mate	ITRF92(*)	Matera	01 JAN94	
mcmu	UNCONSTR	McMurdo	15JAN94	15JAN95
mdo1	ITRF92(*)	McDonald	01 JAN94	
mets	ITRF92(*)	Metsahovi	01 JAN94	
nlib	ITRF92(*)	North Liberty	01 JAN94	15AUG94
nyal	ITRF92(*)	Ny Alesund	01 JAN94	
onsa	ITRF92(*)	Onsala	01 JAN94	
pama	UNCONSTR	Pamatai	01 JAN94	09APR94
rcm5	UNCONSTR	Richmond	01 JAN94	
sant	ITRF92	Santiago	01 JAN94	
stjo	ITRF92(*)	St Johns	01 JAN94	
taiw	ITRF92(*)	Taiwan	01 JAN94	
tidb	ITRF92	Tidbinbilla	01 JAN94	
trom	ITRF92	Tromsoe	01 JAN94	
tskb	UNCONSTR	Tsukuba	01 JAN95	
usual	ITRF92(*)	Usuda	01 JAN94	31 DEC94
wes2	UNCONSTR	Westford	01 JAN94	
wett	ITRF92	Wettzell	01 JAN94	
yarl	ITRF92	Yarragadee	01 JAN94	
yell	ITRF92	Yellowknife	01 JAN94	

Notes:
1.) REF FRAME(*) Added constraints starting on 20Jul94.
2.) Switched to ITRF 1993 (epoch 1995.0) on 01 JAN95.

Product Delivery

NGS is the primary source of precise GPS orbits for the U.S. civil surveying community. Because of their need for precise orbits as near to real time as possible, NGS has made a commitment to deliver daily orbit products no later than 6 days after any given day. This commitment to timeliness has so far precluded the use of multiday arcs that would require waiting for following data, The delivery delay of NGS orbit products to the U.S. Coast Guard Navigation Information Service Bulletin Board and to the CDDIS is shown in Figure 1. The number of days it took to deliver an orbit is plotted for each day of 1994. Figure 2 shows this same data plotted as a histogram. The mean delivery delay in 1994 was a little longer than 4 days.

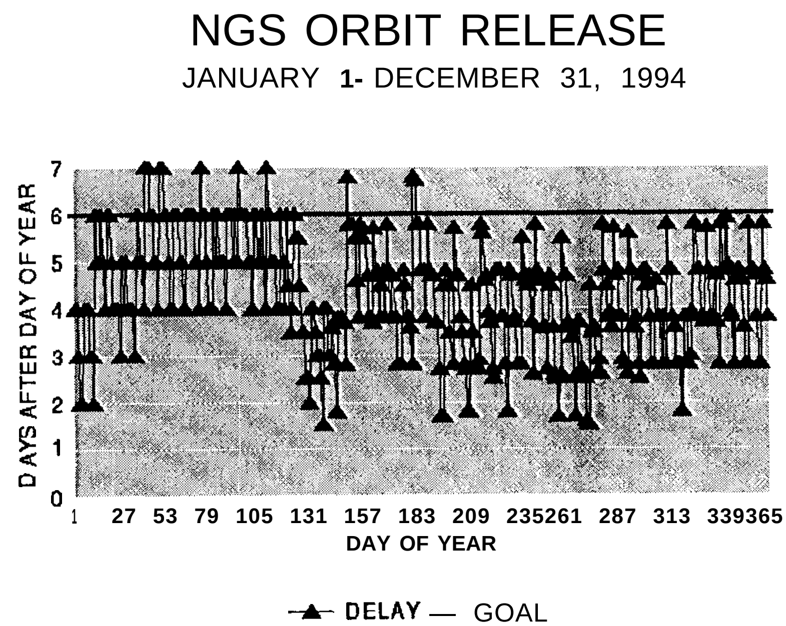


Figure 1. The number of days delay in delivering GPS ephemerides is shown for each day of the year for 1994.

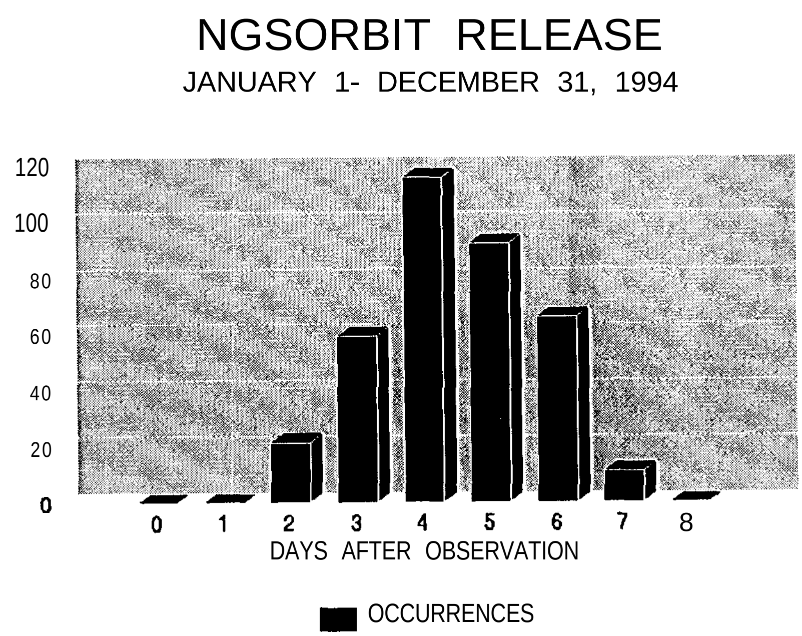


Figure 2. The frequency of occurrence of the delay for each day's orbit in 1994 is shown as a histogram. The mean ephemeris delivery time was just over 4 days.

On only 11 days (3%) were orbits delivered with a lag time greater than 6 days. Most of these delays occurred shortly after AIS was turned on requiring a greater than usual amount of manual data editing. These particular problems were solved by mid-year. The greatest factor contributing to the delay of NGS'S orbit computation is the late arrival of tracking data from stations within our computational network to the data centers, This is especially noticeable around holidays. These delays are partly responsible for certain stations being dropped from our list of usable stations. These delays are also responsible for increasing our station list to 35–40 stations while fixing about 25 stations in an effort to make the solutions less sensitive to this short but variable list of each day's missing stations.

Processing Summary

The procedures used by NGS for orbit and eop processing are summarized in Table 2. This table is reproduced and updated from that submitted to the IGS as a survey of all analysis center procedures. Changes to our processing during the year are indicated in the table.

Table 2. Analysis Center Questionnaire.

GENERAL INFORMATION

Analysis Center	National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS) SSMC3 1315 East West Highway Silver Spring, MD 20910 USA Phone: 3017133205, Fax: 3017134322
Contact Person(s)	Mark Schenewerk email: mark@ tony. grdl.noaa.gov phone: 3017132854 William Kass email: billk@buster. rigs. noaa.gov phone :3017133208 Gerald Mader email: gerry@mozart.grdl. noaa.gov phone: 3017132854 Paul Spofford email: pauls@dancer. rigs. noaa.gov phone: 3017133205
Software Used	PAGE3 developed at NOAA
IGS Products generated for GPS week 'wwww' day of week 'n' (n=0,1,...,6)	NGSwwwwn.EPH GPS ephemeris/clock files in 7 daily files at 15 min intervals in SP3 format, including accuracy codes computed from the formal orbit errors of the solution NGSwwwwn.ERP (pole estimates and a priori UT1 UTC) in 7 daily files NGSwwwwn.SUM Processing summary in 7 daily files
Preparation Date	July 18, 1994

Table 2. (cont.)

MEASUREMENT MODELS	
Preprocessing	Phase preprocessing in a baseline by baseline mode using doubledifferences. In most cases cycle slips are fixed automatically looking simultaneously at different linear combinations of LI and L2. Manual reediting is done if any baseline shows larger than normal postfit RMS statistics in the all base combined solution. At that time, bad data points are removed or new ambiguities are set up.
Basic Observable	Carrier phase, code only used for receiver clock sync. Elevation angle cutoff : 20 degrees Sampling rate : 30 seconds Weighting : Uniform
Modelled observable	Double differences, ionosphere-free linear combination.
RHC phase rotation corr.	None
Ground antenna phase center	Elevation dependent phase center corrections are applied to all antenna types.
Troposphere	A priori model: Saastamoinen "dry" zenith with the CfA 2.2 mapping function plus the Saasamoinen '(wet" with the Chao "wet" mapping function. Estimation : zenith delays in 6 hour intervals.
Ionosphere	Not modeled (ionosphere eliminated by forming the ionosphere free linear combination of L1 and L2)
Plate motions	ITRF92 station velocities fixed (see IGSMAIL#421)
Tidal displacements	Solid earth tidal displacement: Melchion (1978) Pole tide: not applied Ocean loading: not applied
Atmospheric load.	Not applied
Satellite center of mass correction	Block I x,y,z: 0.2110, 0.0000, 0.8540 m Block II/IIA x,y,z: 0.2790,0.0000, 1.0230 m
Satellite phase center calibrat.	Not applied

Table 2. (cont.)

ORBIT MODELS	
Geopotential	GEMT3 model up to degree and order 8
	GM= 398600.4418 km**3/sec**2 (Jan 1- Aug 17) 398600.4415 km**3/sec**2 (Aug 18- present)
	AE = 6378.1363 km
Third body	Sun and Moon as point masses
	Ephemeris: Generated from the MIT PEP program
	GMsun = 132712440000 km**3/sec**2
	GMmoon = 4902.7989 km**3/sec**2
Solar radiation pressure	Direct radiation: ROCK4 and ROCK42 approximations (T1O and T20) for Block I and II sat.
	Satellite masses used: all Block I = 520.0 kg all Block II= 885.0 kg
	One scale factor and the ybias estimated per arc
	Earth shadow model includes: umbra and penumbra
	Reflection radiation: not included
	New GPS satellite attitude model: not applied
Tidal forces	Solid earth tides: not applied
	Ocean tides: not applied
Relativity	Not applied
Numerical Integration	11th order Adams-Moulton Predictor-corrector
	Integration step: 22.5 minutes
	Starter procedure: Initial conditions taken from the previous day at 24:00 (from broadcast under special conditions).
	Arc length: 24 hours of data are used to adjust a 31-hour integrated arc centered on the day of interest. The 3.5-hour extensions are used in house for quality control and are removed before submission to the IGS.

Table 2. (cont.)

ESTIMATED PARAMETERS (APRIORI VALUES& SIGMAS)	
Adjustment	Least-squares algorithms
Rejection Criter.	No rejection during parameter estimation procedure. Outliers are marked during preprocessing step
Station coordinates	13 stations absolutely fixed to the ITRF92 positions as given in IGSMAIL#430, the remaining are estimated The ITRF92 velocities are used for daily coordinate updates. Other site positions defined in IGSMAIL#421.
Orbital parameters	6 element state vector at IC, solar radiation and ybias scaling factors estimated as constants for one arc. No *a priori* sigmas used.
Troposphere	Zenith delays estimated once per 6 hours for each station.
Ionospheric correction	Not estimated
Ambiguity	Estimated as real values with no *a priori* constraints
ERP	X and Ypole coordinates. *A priori values* taken from IERS Rapid Service Bull. A
Satellite clock bias	Satellite clock biases are not estimated but elimi nated by forming double differences.
Receiver clock bias	Receiver clock corrections are estimated during the preprocessing using code measurements.
Other parameters	None

REFERENCE FRAMES	
Inertial	Geocentric; mean equator and equinox of Besselian year 1950 (B1 950.0)
Terrestrial	ITRF92 reference frame realized through a set of 13 station coordinates and velocities as given in IGSMAIL #430 as well as the antenna offsets for the above stations given in /igscb/station/tie/localtie.tab available from IGS CB (igscb.jpl.nasa.gov). Beginning with data from July 20, 1994, an additional 12 sites were fixed.

Table 2. (cont.)

Interconnection	Precession: IAU 1976 Precession Theory
	Nutation: IAU 1980 Nutation Theory
	Relationship between UT1 and GMST: USNO **Circular No. 163 (IAU Resolution)**
	A priori ERP values from IERS Rapid Service Bull. A

References

Fliegel, H., T. Gallini and E. Swift (1992), Global Positioning System radiation force **model for geodetic applications,** *J. Geophys. Res.* 97(B1), pp. 559-568, January 1992.

McCarthy, D.D. (cd.) (1992). IERS Standards (1992), *IERS Technics/Note 73,* Observatoire de Paris, July 1992.

Melchion, P (1 978), "The Tides of the Planet Earth," Pergamon Press, pp. 109–1 21.

Schenewerk, M. S., MacKay, J. R., Kass, W., Miranda, C., and Mader, G., (1993), Rapid Turnaround GPS Ephemerides from the National Geodetic Survey, Proceedings of the ION GPS 93, Institute of Navigation, pp. 247-255.

Orbit and EOP Evaluation

NGS continuously monitors the quality of its GPS orbits and eop parameters by comparison with those produced by other analysis centers and the IGS combined products and by examining the repeatability of long baselines. Figure 3 shows the difference for 1994 of the x and y pole positions generated by NGS with respect to the IERS pole positions. The same figure also shows the RMS difference between the NGS orbits and the IGS combined orbits for all satellites after a 7-parameter transformation.

The RMS difference between the NGS orbits and those of the other analysis centers and the IGS combined orbits was typically 30–35 cm prior to the commencement of A/S on January 31, 1994. The onset of A/S had a significant effect on the quality of the solutions emerging from our automatic processing procedures. The typical RMS difference between the NGS and IGS combined orbit rose to about 50 cm with numerous severe outliers. In spite of these differences, NGS remained committed to its production schedule since it appeared that the orbit quality was still well within the specifications required by the surveying community. Meanwhile, efforts were simultaneously underway to modify our software and processing procedures in response to A/S. The results of these efforts were largely in place by May 1994.

The next major increment in improving the NGS orbits occurred on July 23 when we began fixing about 24 instead of the previous 13 stations. This brought the RMS difference between the NGS orbits and the IGS combined orbits to about 20 cm. The improvement seen in the GPS orbits was mirrored in the NGS polar motion results (see Figure 3). Throughout the first half of the year, the RMS residual was about 0.9 mas for the x pole and 1.1 mas for they pole. After constraining the additional stations, the polar motion performance improved by

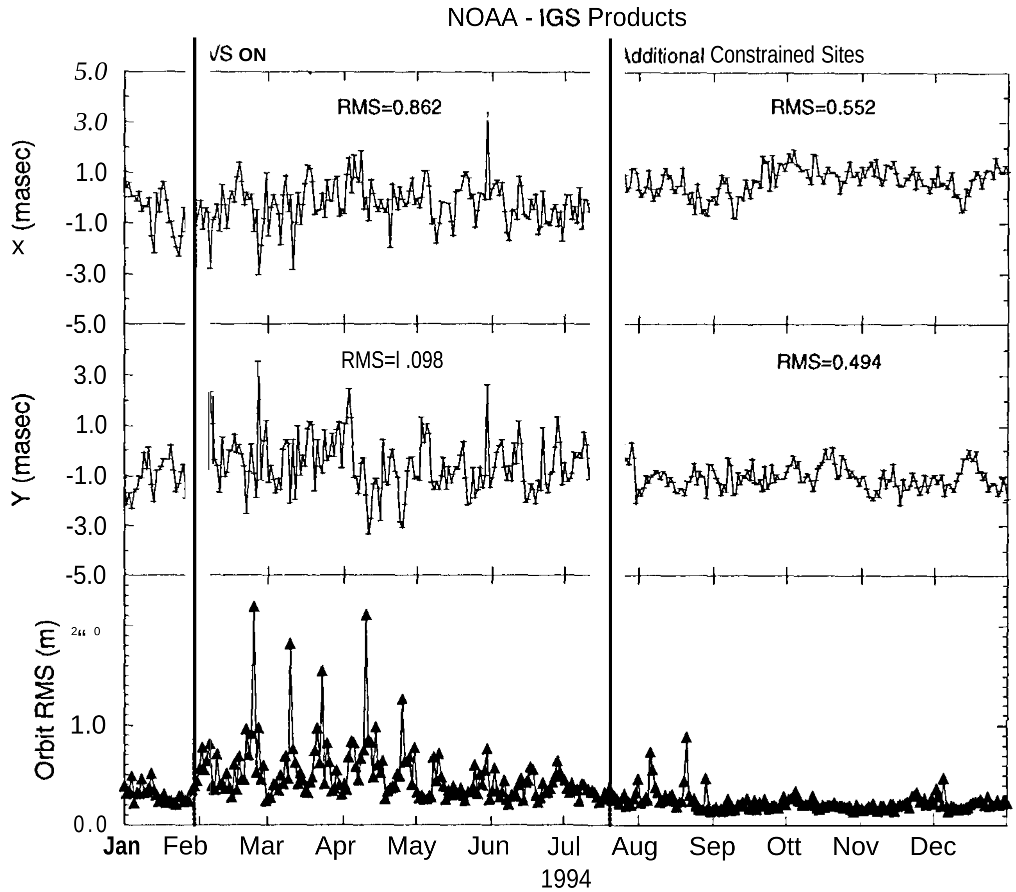


Figure** 3. **The NGS- determined x and y pole positions with respect to the IGS pole positions are plotted for each day of 1994. The overall RMS comparison between the NGS orbit and the combined IGS orbit is also shown for all 1994. The onset of A/S had a significant effect on NGS orbit quality. These problems were resolved by mid-year with a resulting 20-cm average agreement between NGS and IGS.

about a factor of two. Similar results can be seen from the weekly reports distributed by the USNO.

NGS and GL monitor the repeatability of long baselines, representative of those used within NOAA, using NGS as well as GPS orbits from other IGS analysis centers. This is done by producing daily estimates of site coordinates to assess the overall quality of GPS-derived geodetic solutions as end users would perceive it. This analysis is intended to monitor the contribution of the NGS orbits to the quality of these representative solutions by comparison with other orbits. It is not intended as a more thorough orbit analysis which would be done with longer baselines.

Three sites (two baselines) were selected for the baseline repeatability analysis presented here. These sites were chosen to meet the following requirements.

1. one baseline should be predominately north–south; one baseline should be predominately east–west.
2. reasonably reliable data should be available for all of 1994.
3. the sites should be part of the IGS network but not included in the NOAA orbit adjustments.
4. both baselines should be longer than 1000 km,

The site selection was also confined to North America to be coincident with the area containing most of NOAA's operational activities. The sites selected were Albert Head, McDonald, and JPL. Pertinent information regarding these sites, as specified in the IGS/IERS documentation and in the ITRF93 reference frame, is shown in Table 3. The baseline analysis presented here is in addition to routine baseline comparisons conducted by NGS on other baselines throughout the year. These results were compiled in early 1995 and consequently use the ITRF93 coordinates for the selected stations. All the orbits used for this analysis used ITRF92 coordinates and were downloaded from the CDDIS. Except for small deviations from the *a priori* coordinates, this difference in reference frames has no effect on the analysis.

***Table 3. Sites* Selected *for* Baseline Repeatability Analysis,**

Albert Head, Victoria, BC, Canada				
albh	x	Y	z	
	-2341332.869 m	-3539049.487 m	4745791.402 m	monument
	-0.0240 m/yr	0.0014 m/yr	-0.0103 m/yr	velocity,
JPL Mesa, Pasadena, CA, USA				
jpl1	x	Y	z	
	-2493304.112 m	-4655215.532 m	3565497.360 m	monument
	-0.0353 m/yr	0.0227 m/yr	0.0076 m/yr	velocity,
McDonald VLBA, Fort Davis, TX, USA				
mdo1	x	Y	z	
	-1329998.656 m	-5328393.385 m	3236504.241 m	monument
	-0.0166m/yr	0.0008 m/yr	-0.0041 m/yr	velocity
	x	Y	z	Length
albh-jpl1	151971.243 m	1116166.045 m	1180294.042 m	1631568.547 m
mdo1-jpl1	1163305.456 m	-673177.853 m	-328993.119 m	1383721.243 m.

The data were processed with the Geosciences Laboratory's PAGE3 software, using the indicated precise ephemeris with no further orbit adjustment. The data were edited automatically. Approximately 10% of the days required additional, hand editing. Phase biases, 1 hour piece wise, continuous, linear tropo scaling factors, and daily positions were estimated. jpl1 was used as the reference site and held fixed.

Hardware information for each site were taken from the site logs available from the Central Bureau. Pertinent changes during 1994 are:

1	01/16/94	albh	ROGUE SNR 8C replaced with ROGUE SNR 8000
2	04/14/94	albh	antenna height change: Dome Margolin B replaced with Dome Margolin T
3	05/09/94	jpl1	firmware upgrade in ROGUE SNR 8: 7.5 to 7.8
4	06/14/94	jpl1	ROGUE SNR 8 replaced with ROGUE SNR 8100
5	06/14/94	jpl1	antenna height change: Dome Margolin R replaced with Dome Margolin T
6	10/12/94	jpl1	firmware upgrade in ROGUE SNR 8100: 2.8.32.1 to 3.0
7	11/23/94	mdo1	firmware upgrade in ROGUE SNR 8000: 2.8 to 3.0

These events are indicated in Figure 4 with dashed vertical lines labeled with the number from the first column. The following events also occurred during 1994 and are noteworthy for their possible effects on baseline repeatability:

A	01/1'7/94	jpl1	Northridge earthquake
B	01131194		AIS on continuously
C	07120/94		NOAA increase number of fixed orbit tracking sites.

Figure 4 shows the north, east, and up estimated adjustments to the *a priori* site coordinates from daily solutions using the IGS precise ephemerides. The events described above are indicated with dashed lines at the appropriate epoch and labeled using the corresponding number or letter. Four days had insufficient data from these baselines to yield meaningful solutions. The period from January 31 through June 14 (A/Son through the replacement of the ROGUE at JPL) had significant data loss presumably because of the poor performance of the older ROGUE receivers with A/S on. Using a criterion of 80% of the normal number of double difference observations for a baseline (80% normal = 10,000 observations given the baseline lengths, elevation cutoff, and observation interval) 37% of the days during this period failed this criterion as compared with 10% for the other periods. This data loss predictably resulted in larger scatter and outliers. Table 4 lists the RMS scatter (weighted by the formal errors from the solution) for each baseline component using the IGS and NOAA precise ephemerides. The results for January 31–June 13, and all other days are broken out revealing the disparate receiver performance during these two periods. All values are in centimeters.

Eliminating the days with 80% or fewer observations yielded slightly improved baseline repeatabilities. Since the receiver performance in the first half of 1994 for these baselines was anomalous and not representative of current or expected future performances, in the subsequent discussion, only the June 14–December 31 period will be considered.

The June 14–December 31 data were then reprocessed using ephemerides generated by the other analysis centers. All other aspects of the processing were identical. The estimated adjustments to the *a priori* baseline components for

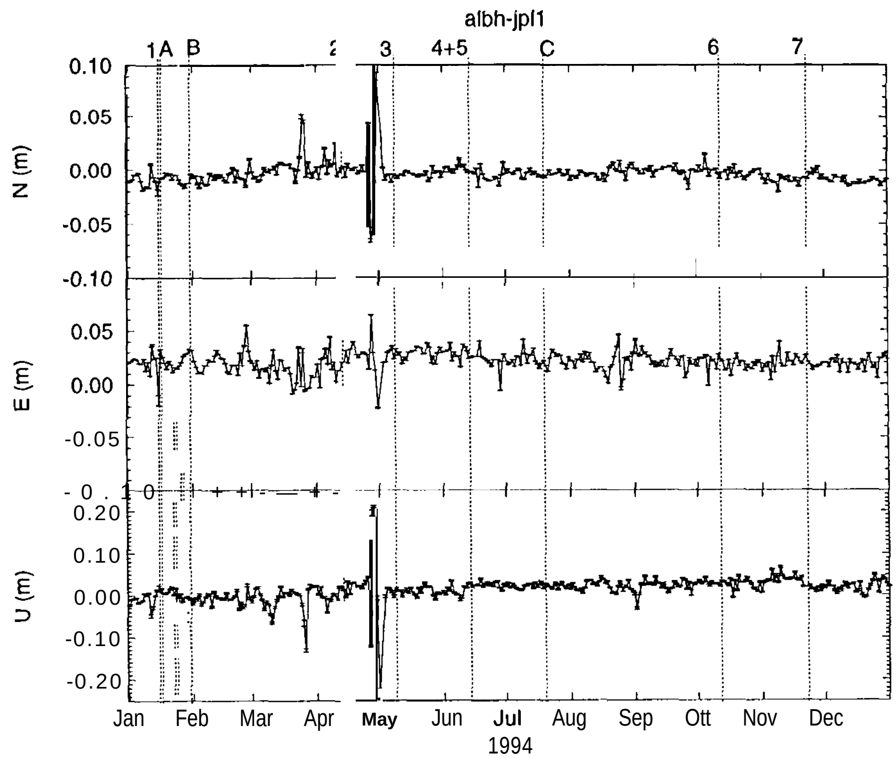


Figure 4. The displacement of the north, east, and up position of albh with respect to jpl1 from the IGS a priori coordinates is shown for each day of 1994 using the IGS combined orbits. Significant events described in the text and indicated by the dashed lines.

Table 4. Baseline Repeatability Using All Data (all **values in** *centimeters).*

EPH	DATES	albh-jpl1 N	albh-jpl1 E	albh-jpl1 U	mdo1-jpl1 N	mdo1-jpl1 E	mdo1-jpl1 u
IGS	All 1994	0.65	0.82	1.92	0.55	0.87	2.29
	Jan 31-Jun 13	0.83	1.09	2.58	0.64	0.99	3.40
	Jan & Jun 14-Dec 31	0.57	0.63	1.38	0.49	0.72	1.56
NGS	All 1994	1.06	1.14	2.12	0.61	1.58	2.19
	Jan 31 -Jun 13	1.17	1.49	3.03	0.72	1.49	3,22
	Jan & Jun 14-Dec 31	0.57	0.83	1.58	0.51	1.16	1,58

each orbit type and for each day are shown in the Figures 5–10. Each baseline component is shown separately with each Analysis Center and the IGS as sub-panels in the figure. The horizontal scales are identical in all figures; the vertical component figure scales have the same span but, by necessity, offsets from a zero mid-point. The mean displacement of albh and mdol, with respect to jpl1, from their *a priori* values and the RMS of their repeatability for each orbit type are shown in Figure 11 and summarized in Tables 5 and 6.

Conclusions

During 1994, NGS maintained an average delay for precise GPS orbit delivery of just over 4 days. The orbit processing procedure suffered significantly with the onset of AIS. Modifications to the automated software and procedures and the constraining of additional stations have produced an average agreement of about 20 cm with the IGS orbits. Baseline repeatability analyses using all the analysis center orbits as well as the combined IGS orbits do not show any significant variation between the baselines determined using NGS orbits and the other orbits. As a direct result of the analysis center questionnaire, the Geosciences Laboratory modified some of the physical constants used in the NGS processing. These modifications brought the previously large scale factor difference seen for the NGS orbits more in line with those of the other analysis centers.

In the coming year NGS and GL will examine possible revisions to some of the models and procedures used in our processing software and analysis. In particular, we expect to include the effect of Earth tides on the geopotential and to examine the production of orbits derived from multiday arcs as an additional orbit product. The current treatment of both these effects distinguishes the NGS orbit from most of the other analysis centers and maybe contributing significant factors to the differences between the NGS orbits and the IGS combined orbits. We also expect to add the effects of ocean loading using empirically determined coefficients.

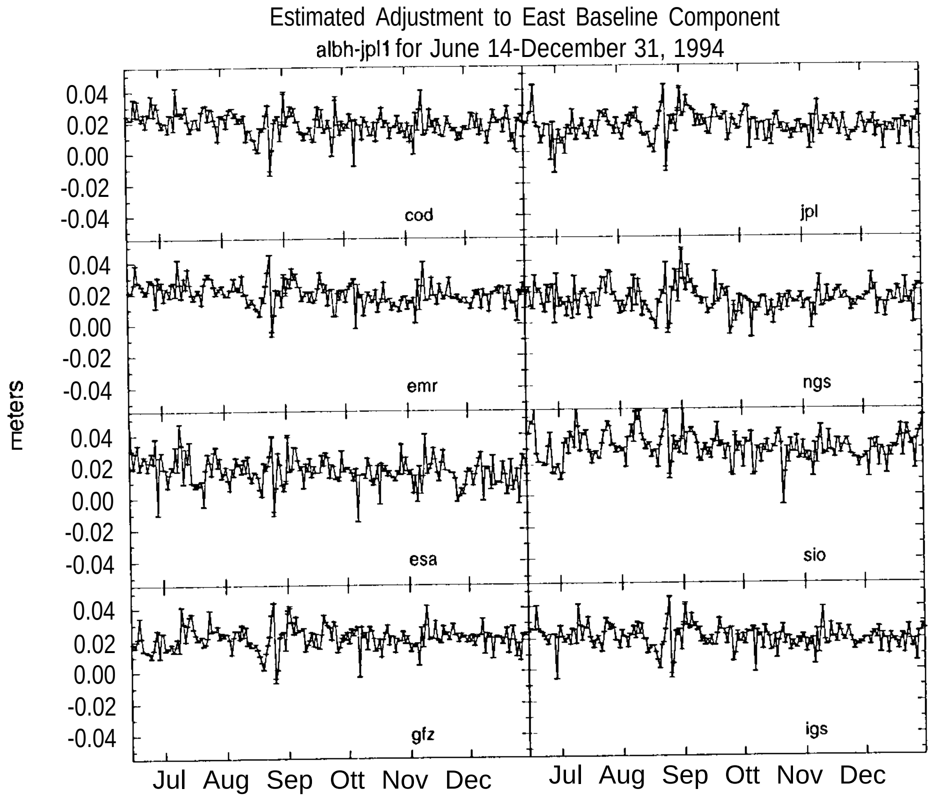


Figure 5. The east displacement of ***albh*** *from its* a priori ***value*** *from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

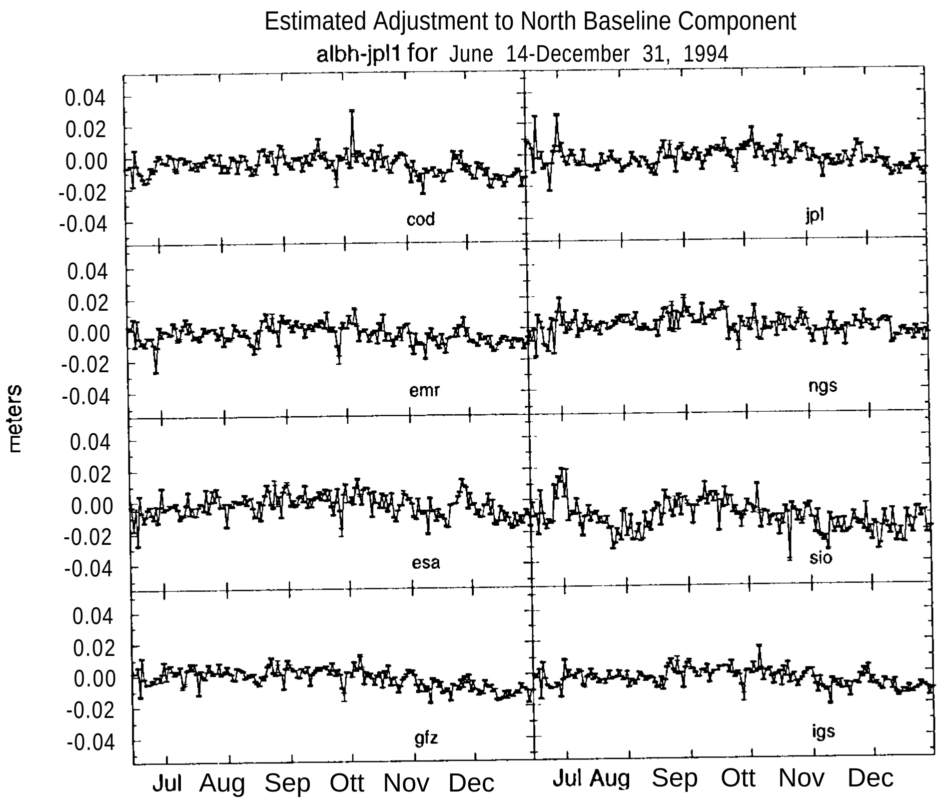


Figure 6. The north displacement of ***albh*** *from its* a priori value *from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

Figure 7. The vertical displacement of albh from its a priori *value from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

Estimated Adjustment to Vertical Baseline Component
albh-jpl1 for June 14-December 31, 1994

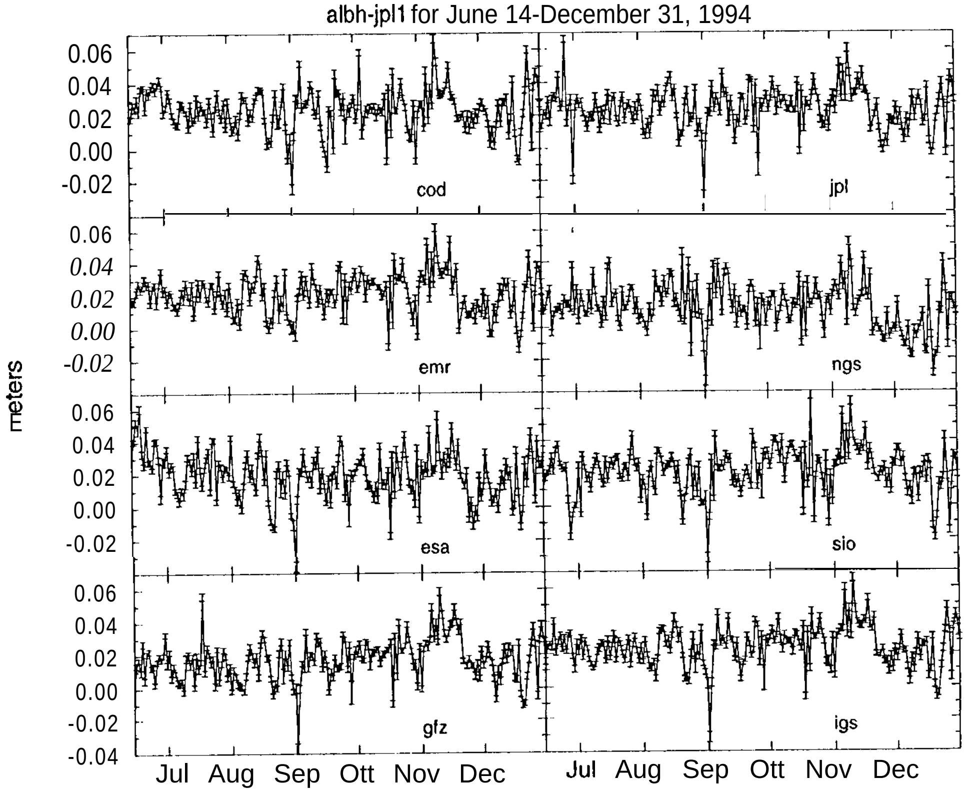
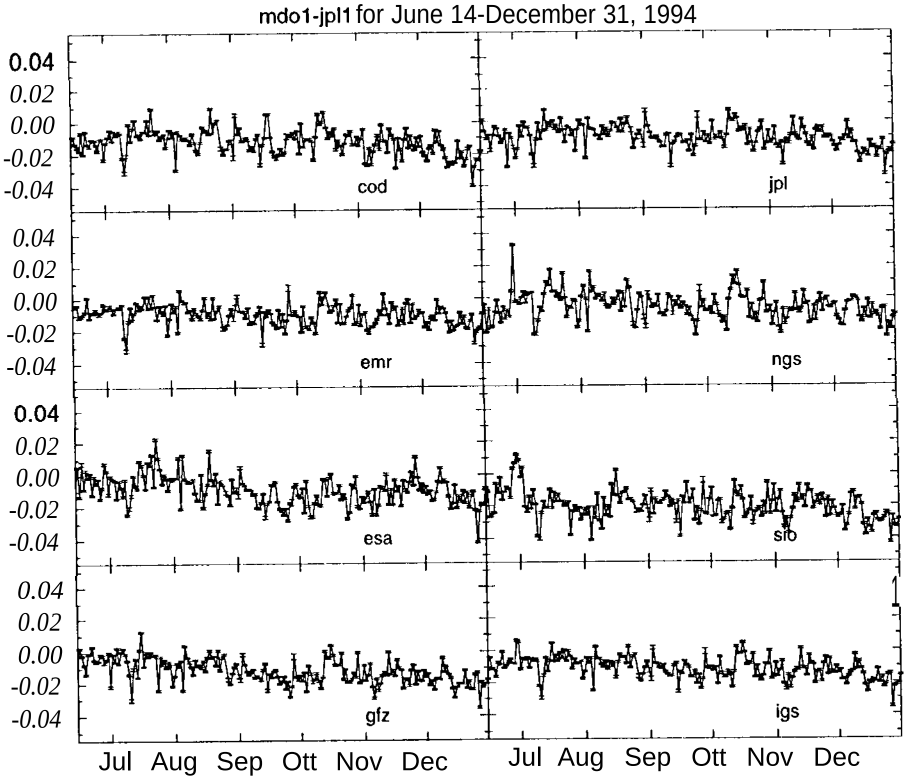


Figure 8. The east displacement of mdo 1 from its a priori *value from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

Estimated Adjustment to East Baseline Component
mdo1-jpl1 for June 14-December 31, 1994



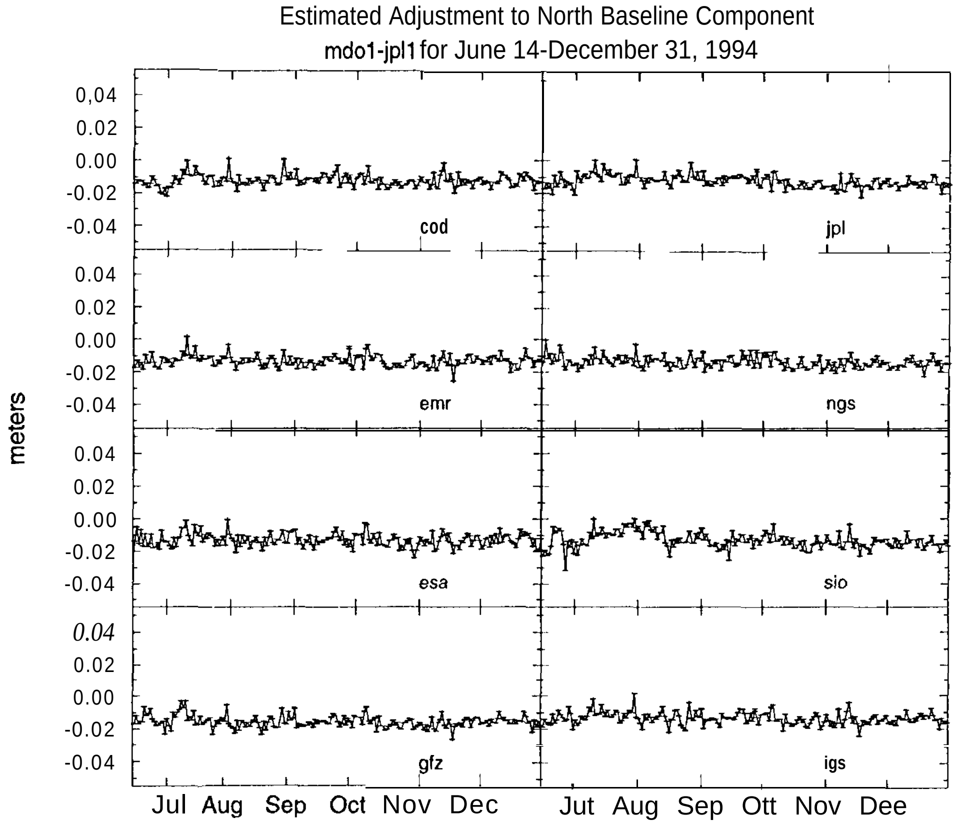


Figure 9. The north displacement of mdo 1 from its a priori *value from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

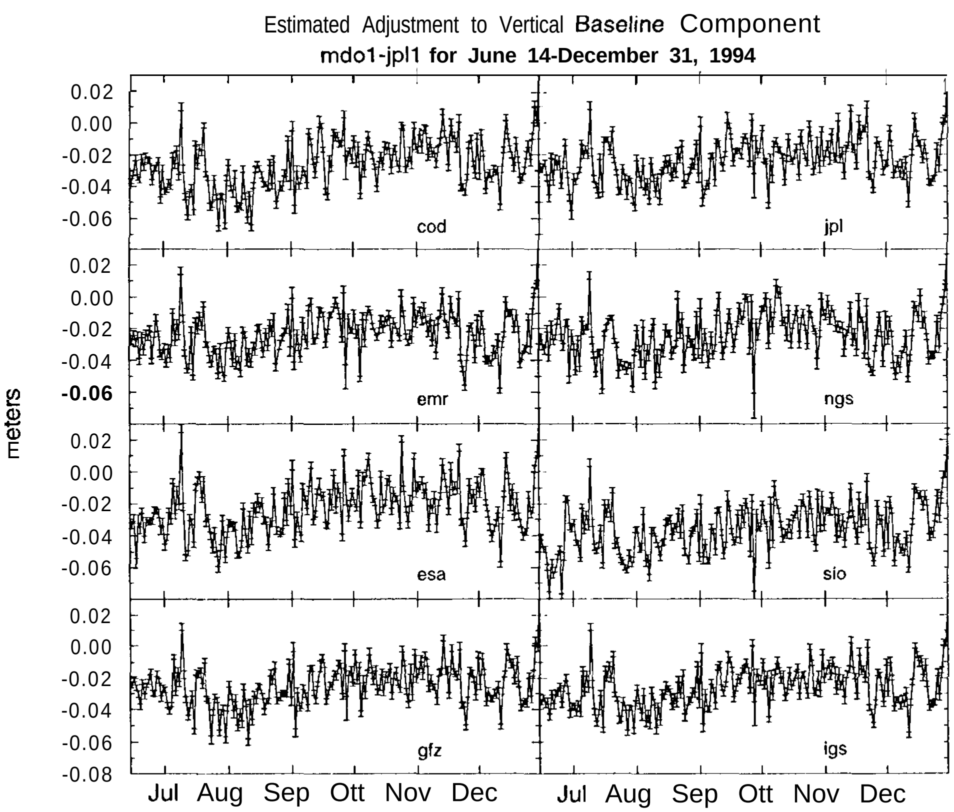


Figure 10. The vertical displacement of mdo 1 from its a priori *value from June 14 to December 31 using each orbit type. All other details of the processing are identical.*

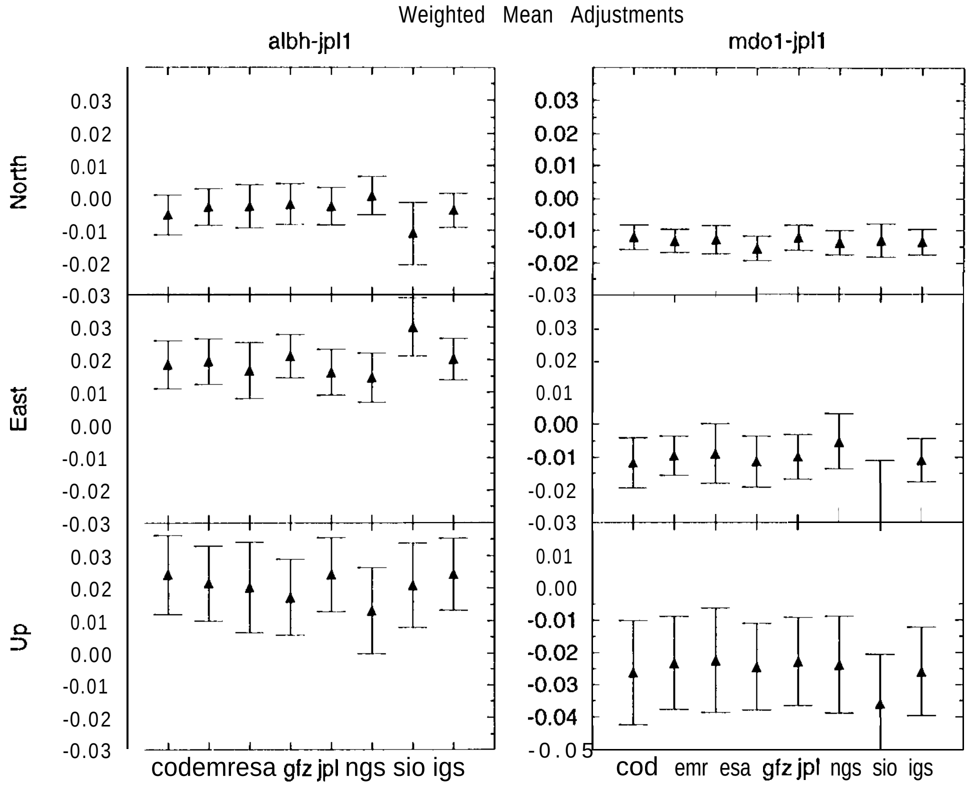


Figure 11. The mean north, east and vertical displacements for albh and mdo 1 for each orbit type. The error bars indicate the RMS repeatability for each orbit type.

Table 5. RMS Baseline Repeatability (cm).

	albh-jpl1 n	e	u	mdo1-jpl1 n	e	u
cod	***0.63***	***0.74***	***1.21***	***0.37***	***0.77***	1.61
emr	0.58	0.70	.15	0.35	0.61	1.44
esa	***0.69***	***0.87***	***.39***	***0.42***	***0.91***	1.63
gfz	0.65	0.67	.17	*0.37*	*0.79*	1.35
jpl	0.59	0.71	***.14***	***0.38***	***0.69***	1.37
ngs	0.60	0.76	***.32***	***0.36***	***0.84***	1.51
sio	0.96	0.89	***.30***	***0.50***	***0.90***	1.55
igs	0.54	0.64	1.10	0.38	0.67	1.37

Table 6. Mean Displacement (cm).

	albh-jpl1 n	e	u	mdo1-jpl1 n	e	u
cod	**-0.51**	**1.85**	**2.42**	**-1.21**	**-1.18**	**-2.62**
emr	-0.26	1.95	2.15	-1.32	-0.96	-2.33
esa	***-0.24***	1.67	***2.03***	-1.28	***-0.90***	***-2.25***
gfz	-0.17	2.12	1.72	-1.55	-1.14	-2.45
jpl	***-0.24***	1.45	***2.42***	-1.22	***-0.99***	***-2.29***
rigs	***-0.09***	1.45	1.31	-1.37	-0.53	-2.38
sio	-1.08	***3.01***	***2.09***	***-1.30***	-1.99	***-3.60***
igs	*-0.37*	*2.02*	*2.43*	-1.35	-1.09	-2.59

NRCan (EMR) Analysis Report

P. Tétreault, J. Kouba, R. Ferland, and J. Popelar
Geodetic Survey Division, Geomatics Canada, Natural Resources Canada
Ottawa, Ontario, Canada

Introduction

In August 1992, the Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) joined the IGS pilot service as its seventh analysis center known as EMR (Energy, Mines and Resources). Since then, EMR has been generating precise orbits, clocks, and EOP parameters on a daily basis. EMRs participation in IGS was a natural extension of GSD and Geological Survey of Canada (GSC) effort to create a GPS based Canadian Active Control System (CACS) (Delikaraoglou *et al.*, 1986; Kouba and Popelar, 1990). From the conception of the CACS in 1986 to the start of the Epoch92 campaign in July 1992, EMR had been contributing data to the international GPS effort by participating in several major GPS campaigns such as CASA'S, GOTEX, and GIG91 and by continuously operating the Yellowknife and Algonquin fiducial stations. By the start of the Epoch92 campaign, EMR had acquired the necessary hardware and software for the computation of precise GPS orbits. Participation in the IGS pilot service that evolved from Epoch92 was, therefore, an excellent opportunity for EMR to continue contributing to and benefiting from this international cooperative GPS effort.

In the following report, EMR's GPS analysis which includes generation of precise orbits, clocks, EOPS and station coordinates is reviewed and some of the results presented.

EMR GPS Analysis

Software

In view of EMR's limited resources and of the complexity of GPS global software, it was decided early on that an existing software had to be adapted for the CACS orbit computation. In 1989 EMR acquired the MicroCosm (Van Martin Systems Inc., 1990) and GIPSY/OASIS (Lichten, 1990; Webb and Zumberge, 1993) software packages. Initially, both packages were modified to increase operational flexibility and to accommodate new requirements. The software results for test data sets showed good agreement and provided information on achievable precision (Ferland and Lahaye, 1990). Currently EMR daily orbit computations capability is based on HP9000 UNIX platforms and the GIPSY/OASIS software.

Data

From the beginning the EMR orbit computation strategy has been to provide precise orbits optimized over Canada in the shortest time possible. To achieve this goal EMR has automated the GIPSY/OASIS procedures and used the minimum number of stations required to provide geometric network strength to process 24-hour arcs with no data overlaps.

During 1994, EMR used 6 Canadian CACS stations augmented by up to 16 global IGS sites. To enhance the data quality, given the relatively small number of stations, undifferenced pseudo-range and carrier-phase observations decimated at 7.5 minutes are used. The two types of observations are assumed independent, although the pseudo-range observations are smoothed using carrier-phase measurements. Most estimated parameters are constrained using realistic bounds corresponding to their daily variance and many parameters are sufficiently predictable to use previous day results as *a priori* values. For example, initial satellite states and stations' tropospheric delays are initialized using the previous day's solution. *A priori* values for solar pressure parameters are estimated using a moving weighted average of the previous days' solutions. Table 1 lists the parameters estimated daily, along with their *a priori* values and standard deviations.

Table 1. Summary of estimated parameters, a priori values and sigmas (as of December 1994).

Parameter	Estimation	*A priori* Value	*A priori* Sigma
Stations (X,Y,Z)	mean value	IGS/ITRF92 (of date)	see Table 2 / 50m
Pole (x,y)	mean value	IGS/USNO Bull. A	3m
DUT1	mean value	IGS/USNO Bull. A	3m / fixed
LOD	mean value	IGS/USNO Bull. A	0.5m/sec
Trop. Zenit. Delay	mean value	previous day estim.	3cm
Satellite States (X, Y, Z,dX,dY,dZ)	mean value	previous day estim.	see Table4
Sol. Rad. Press. (GX,GZ)	mean value	previous days estim.	10%
Sol. Rad. Press. (GY)	mean value	previous days estim.	0.5d-09m/s**2
Phase Ambiguity	mean value	pseudorange estim.	300000km
Tropospheric Bias	rand. walk	0.0km	0.01 m/sqrt(hr)
Station Clock	white noise	point positioning	1 sec
Satellite Clock	white noise	broadcast	1 sec

Reference Frame

As recommended by IGS, the ITRF is used in all EMRs solutions. This is realized by constraining a prescribed set of ITRF coordinates and velocities. Table 2 lists the 13 stations and the constraining standard deviations for their ITRF coordinates used since January 1994. Table 2 also gives the percentage of days since January 1994 when listed stations have not been included in EMRs daily solution due to either data unavailability or data problems. EMR's processing is typically performed within three to five days after the time of observation.

On January 1, 1995, in accordance with IGS recommendations, ITRF92 station coordinates were updated to ITRF93. This reference frame change introduced a small discontinuity in EMRs solutions. Table 3 shows the seven parameters for the 13 station ITRF92/ITRF93 transformation as well as transformations derived from EMRs daily solutions for GPS week 782. The small differences between the transformations are due to variations in data quality, fiducial stations used, and solution geometry.

Processing Strategy

The basic processing strategy (Kouba *et al.*, 1993) had been developed and implemented by October 1992, two months after EMR had commenced

Station	ITRF92 Sigma (mm)	ITRF93 Sigma (mm)	Exclusion * (%)
ALGO	**5, 5,5**	**3, 3, 3**	**3.0**
FAIR	**6,6,6**	**3,3,3**	**2.1**
GOLD	**8, 8,8**	**4, 5, 5**	**1.4**
HART	**10, 10, 10**	**4,4,4**	**10.5**
KOKB	6, 6, 6	**3,3,3**	7.0
KOSG	7,7,7	**5, 5,3**	6.0
MADR	6, 6, 6	**3,3,2**	1.4
SANT	0, 10, 10	**4,4,4**	9.8
TIDB	1,11,11	**4,4,4**	1.9
TROM	6,6,6	**4, 4,4**	2.3
WETT	6, 6, 6	**3, 3, 2**	3.5
YAR1	9,9,9	**5,5,4**	0.7
YELL	6,6,6	**3,3,4**	0.7

(*) Fiducial stations may have been excluded from EMR daily solutions due to receiver not tracking, data not available at time of estimation or data rejected. Percentage are given with respect to all days stations have been in operation from January 02, 1994 to March 04, 1995.

Table 2. Constraining sigmas (X, Y,Z) for 1994 and 1995 EMR solutions.

Transformation	T1 sig (cm)	T2 sig (cm)	T3 sig (cm)	Sc sig (ppb)	R1 sig (mas)	R2 sig (mas)	R3 sig (mas)
ITRF93 to ITRF92 for the 13 IGS fiducial stations	**2.0** **0.4**	**0.8** **0.5**	**0.3** **0.4**	**-0.1** **0.6**	**1.32** **0.18**	**0.82** **0.16**	**0.55** **0.16**
EOP and station coordinate solution based on ITRF92 and ITRF93	1.4 0.1	1.6 0.1	-0.1 0.1	0.4 0.2	1.48 0.06	0.96 0.05	0.48 0.06
Orbit solution based on ITRF92 and ITRF93	0.2 0.04	1.1 0.04	0.5 0.04	0.0 0.02	1.42 0.01	0.81 0.01	0.63 0.01

Table 3. Differences between EMR solutions based on ITRF92 and ITRF93 for GPS week 782.

contributing to IGS. The main characteristic of this strategy is to compute a 24-hour arc without data overlap and with most of the *a priori* information obtained from the previous day solution. Using properly weighted previous day orbital information ensures day-to-day solution continuity. To minimize nonlinearity problems, UT1-UTC (DUT1) estimation is reset, typically hi-weekly, to the VLBI-derived value (IERS, Bull A). For days when a reset takes place two solutions are computed, one with the old a *priori* DUT1 and one with the new. This facilitates maintenance of a continuous UT1-UTC series since January 2, 1994. The satellite state vector constraints are relaxed whenever DUT1 is reset and fixed. A summary of EMRs processing strategy is given in Appendix A.

The processing strategy has been modified on five occasions. In January 1993 the period between *a priori* DUT1 resets to Bulletin A values was extended from one to two weeks. In January 1994 EMR implemented a stochastic daily update of the orbital parameters. Since then, orbital constraints for day(n) are derived from the satellites state vector solution of day(n-1) with the corresponding variance-covariance matrix augmented using a stochastic model. Stochastic modeling of the state vectors, as described in Table 4, facilitates estimation of both DUT1 and LOD since it effectively constrains the right ascension of the ascending nodes.

Table 4. Orbit stochastic modeling employed in EMR daily analysis.

Parameter	Modeling	Steady State Sigma	DUT1
semi-major axis	randomwalk	0.1 0m/sqrt(day)	estimated
eccentricity	randomwalk	0.12m/sqrt(day)	estimated
inclination	randomwalk	0.06m/sqrt(day)	estimated
right ascencion	randomwalk	0.06m/sqrt(day)	estimated
argument of perigee	randomwalk	0.16m/sqrt(day)	estimated
mean anomaly	randomwalk	0.1 6m/sqrt(day)	estimated
dX, dY, dZ (non-eclip)	whitenoise	5. 0d-08mm/sec	estimated
dX, dY, dZ (eclipsing)	whitenoise	1.Od-07mm/sec	estimated
GX, GZ	whitenoise	1070	estimated / fixed
GY	whitenoise	0.5d-09 m/s**2	estimated / fixed
x, Y, z	whitenoise	1 km	fixed
dX, dY, dZ	whitenoise	0.1m	fixed

The activation of anti-spoofing (AS) on all GPS Block 11 satellites in February 1994 resulted in a degradation of EMRs orbit and clock solution quality. Table 5 shows the impact of AS on EMRs results. AS was especially harmful to EMRs processing because precise GPS pseudo-range observations were no longer available for clock estimation. Under AS, the older generation of Rogue receivers produced cross-correlated pseudo-range observations that were biased and up to 10 times noisier than P-code observations. Furthermore, the pseudo-range biases of the reconstructed observations were time dependent and thus could not be properly calibrated nor combined with carrier-phase observations. The AS problems were somewhat mitigated by the introduction of the Meenix 7.8 receiver software and by using stations equipped with TurboRogue receivers. AS pseudo-range observations for TurboRogues and Rogues with the Meenix 7.8 or later software were still biased by about 1 m or 20 to 50 m, respectively. The receiver hardware and software updates, however, made it possible to estimate satellite dependent biases at each station and use again both carrier-phase and properly weighted pseudo-range observations in daily processing.

In June 1994 LOD estimation was implemented."' The yaw rate attitude model (Bar-Sever, 1994) was implemented in October 1994. EMR currently does not estimate the yaw rates; instead the best available nominal values are used. Tracking data of satellites emerging from the earth's shadow, which used to be rejected, can now be properly modeled and included in EMRs estimation. At the same time, the antenna phase center offset of Block II satellites was changed from 0.952 m to 1,023 m to be consistent with the 1992 IERS standards. No

Table 5. Impact of anti-spoofing on EMR results.

GPS Week	Pseudo-Range RMS (cm)	EMR Clock RMS IGS Combination (nanosecond)	EMR Orbit RMS IGS Combination (cm)
732-733 (pre-AS)	17	0.5	10
736-737(early AS)	60	10	15
780-781	45	1	12

change in scale has been noted, indicating that the 7-cm difference is being absorbed by other solution parameters.

Two additional enhancements were introduced for the 1995 processing. Stations GUAM, EISL, and KERG, recently added to the IGS global network, have been included to provide the needed geometrical strength in the southern hemisphere. Station USUD was replaced by station TSKB in January 1995 and since February 26, 1995, IERS Bulletin A celestial pole (CP) corrections are added to the IAU 1980 a *priori* nutation model.

Clock Estimation

Precise satellite clock corrections have been included in EMRs SP3 files since August 1992. The clock corrections are estimated simultaneously with the orbital, EOP, and station parameters using both phase and pseudo-range observations. One station's clock is selected as a reference in the estimation process. The ALGO station, which is equipped with an hydrogen maser (HM), has served with few exceptions as the EMR reference clock. The ALGO HM typically drifts about 20 ns per day or less.

Since no integer phase ambiguity fixing is employed, precise pseudo-range observations are essential for clock estimation with nanosecond precision. Calibration of pseudo-range biases is required whenever AS is in effect and Cl and cross-correlated P2 observations are used. Since a single reference station clock is used, a strong network geometry is required to ensure that precise clock solutions are obtained for all GPS satellites over the 24-hour arcs. Figures 1 and 2 show typical results of station clock variations with respect to ALGO. Figure 2 also shows the effect of ionospheric disturbances on station clock estimation at YELL. The common signature is due to the ALGO HM used as the reference. Discontinuities between consecutive days are typically less than one nanosecond and represent the bias of the independent daily solutions. Other discontinuities are sometimes present within the daily solution. They may be caused by a variety of factors ranging from GPS receiver clock resets to pseudo-range bias changes when a station receiver configuration is modified or tracking is interrupted.

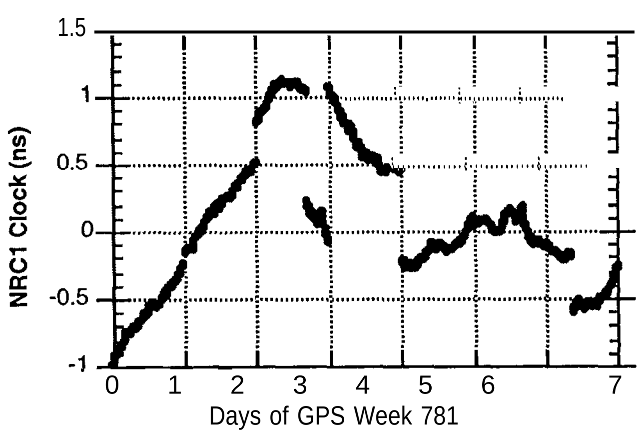
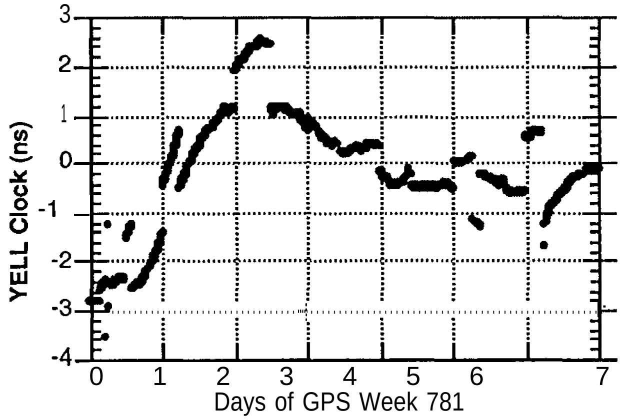


Figure 1. NRC1 hydrogen maser clock offsets with respect to AL GO obtained from EMR daily GPS solutions.

Figure 2. YELL hydrogen maser clock offsets with respect to AL GO obtained from EMR daily GPS solutions.



Combination of Daily Solutions

For 1993 and 1994 EMR has combined all daily solutions and derived new station coordinates. For 1994, EOP and station velocities were also included in the combined solution. Specifically, all the archived 1994 daily solutions were retrieved and subjected to additional statistical testing and editing to remove outliers. The *a priori* ITRF92 coordinate constraints for the 13 fiducial stations were rigorously removed and 10-m sigma introduced. Orbit state vectors and other unknowns contained in the daily solutions were also eliminated. The loosely constrained variance-covariance matrices were then combined into a single annual solution for station coordinates, velocities and daily EOP. The velocities for the 13 fiducial stations were constrained to their ITRF93 values. The combined solution produced a consistent set of station coordinates and velocities (at the epoch 1994.0) and new daily EOP, all based on ITRF93 and the 1994 EMR daily solutions only. The EMR 1994 station and velocity solutions are free of daily variations resulting from inconsistencies of data from fiducial sites.

Appendix 2 lists the coordinate and velocity differences between the EMR 1994 combined solution and the ITRF93. Table 6 lists RMS differences for both EMR 1994 EOP daily solutions, the original and the recomputed, with respect to IERS Bulletin B. In 1995 EMR has begun to combine daily solutions to produce weekly estimates of station coordinates and EOP as part of an IGS pilot project.

Table 6. Mean and RMS differences between IERS Bull Band EMR 1994 EOP estimates (original estimates submitted to IGS and recomputed estimates submitted to IERS).

Difference	Pole X mean/rms (mas)	Pole Y mean/rms (mas)	UT1 - UTC * mean/rms (ins)
Original (ITRF92)- Bull B	0.45 / 0.39	1.24 / 0.50	0.1 16/ 0.566
Recomputed (ITRF93) - Bull B	-0.20 / 0.37	-0.40 / 0.35	0.151/0.564

* DUT1 modeled as (UT1-UTC) + 455µs + 9.945µs/d * DOY

Operational Procedures

Data Acquisition and Validation

The acquisition and validation of the data for all stations used in EMRs daily analysis is highly automated and performed by the Data Acquisition and Validation group which also manages the CACS sites (Duval, 1995), RINEX files for the non-Canadian IGS sites are retrieved daily either from CDDIS or JPL. The data are validated by performing pseudo-range point positioning, generating a satellite tracking table and creating a clock file for each station. The tracking table is useful for detection of unusual events such as a AS-free Block II satellite and the clock files provide indication of the station's and satellites' clock performance. Validation data files for all stations used in EMR daily solutions are available to station operators and users.

Orbit Computation

Orbits are currently computed using one of two processing strategies, one for days when DUT1 is reset and new *a priori* EOP are input and one for all other days. Figure 3 depicts the steps performed before initiating the EMR GIPSY/ OASIS automated processing. The complete daily orbit computation including the generation of SP3 ephemeris, clock and EOP files for 25 GPS satellites using data from 22 stations takes about 6 hours on an HP9000/735 computer and requires close to 200 Mb of run-time on-line storage. Each processed day currently requires about 30 Mb of storage for archiving. Figure 4 shows the stations which have been included in EMR daily solutions since August 1992, while Figure 5 shows days when satellites were excluded or were not operational.

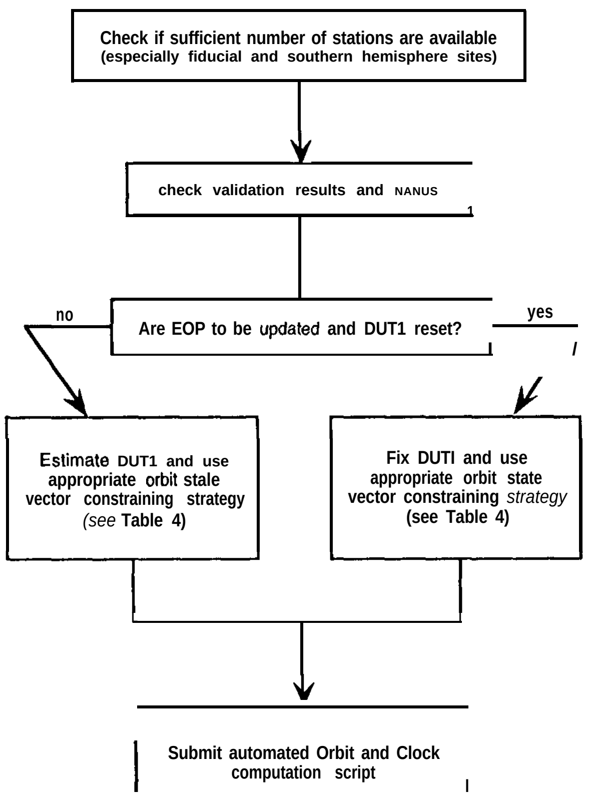


Figure 3. Processing steps performed before starting automated daily EMR GPS analysis.

Figure 4. Stations included in EMR daily solutions.

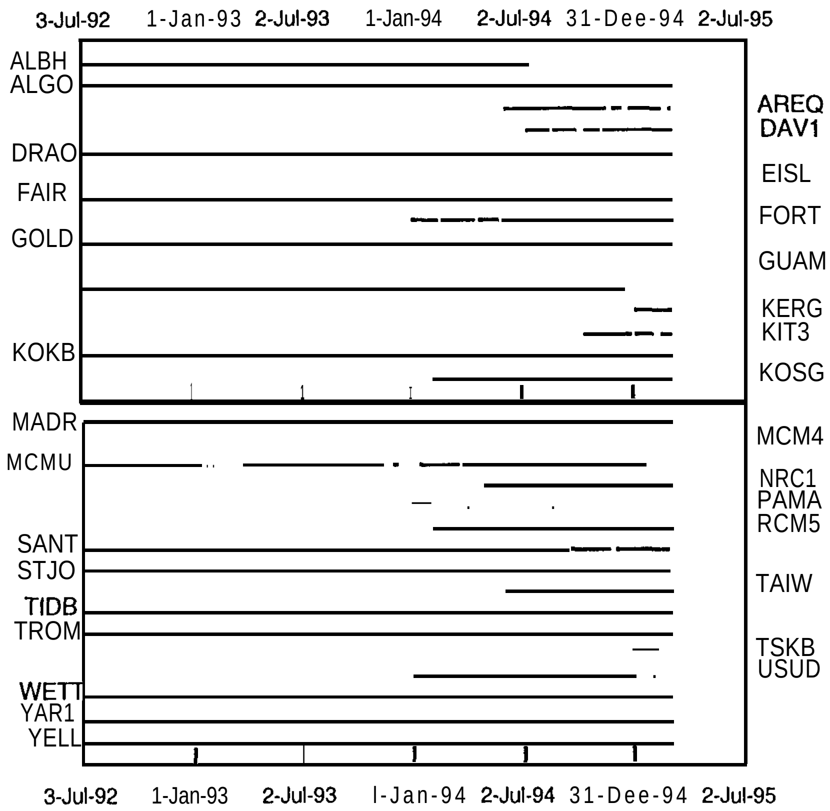
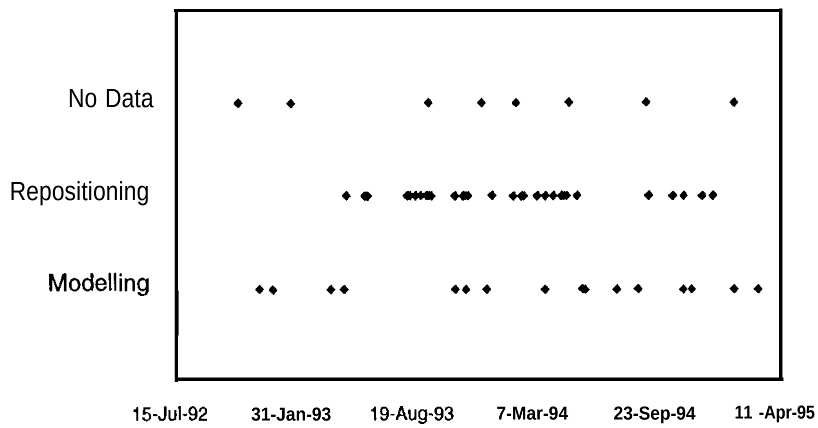


Figure 5. Days with a missing or deleted satellite in EMR daily solutions.



Quality Control (QC)

The QC is divided into pre- and post-processing verifications. Pre-processing QC includes data quality, quantity and GPS constellation status verification in order to prevent eventual problems such as satellite maneuvers. Post-processing QC, by a minimum of two EMR team members, is performed on each daily solution before it is transferred to the IGS data center. It includes verifications of the post-processing carrier-phase and pseudo-range observation residuals for stations and satellites; estimated corrections and sigmas for satellite states, station coordinates and EOP. Pseudo-range biases are also verified and updated as required. Final QC and feedback are provided weekly by the IGS orbit and clock combination and the IERS Rapid GPS EOP combinations.

Conclusions

The short history of the IGS so far, regardless of the AS setback, has been one of continuous progress and productive international collaboration. EMR participation in the IGS has also been a successful one. As of March 31, 1995 EMR had processed and submitted to the IGS 972 daily GPS ephemerides and EOP solutions, one for every day since the first contribution of August 2, 1992. In return, the Canadian Active Control System has been integrated within the ITRF. Access to a global reference frame and precise GPS satellite orbits and clocks are some of the tools EMR has acquired through its participation in the IGS. These tools are essential to provide Canadian users with a modern spatial reference system.

References

Bar-Sever, Y. O. (1994). New GPS Attitude Model, IGS Mail#591, May 09, 1994.

Delikaraoglou, D., R. R. Steeves, and N. Beck (1986). Development of an Active Control System using GPS, *Proc. of the Fourth International Geodetic Symposium on Satellite Positioning,* Austin, Texas, pp. 1189–1203.

Duval, R. (1995). NRCan Operation Centre Report, 1994 *IGS Annual Report* (this volume), Zumberge, *et al.,* eds.

Ferland, R. and F. Lahaye (1990). GIPSY and MicroCosm Comparison using the GPS Standard Set, *Proc. of the Second International Symposium on Precise Positioning with GPS (GPS'90),* Ottawa, Canada, pp. 739-756.

Kouba, J. and J. Popelar (1990). GPS Satellite Monitoring: Data Analysis, *Proc. of the Second International Symposium on Precise Positioning with GPS (GPS'90),* Ottawa, Canada, pp. 656-662.

Kouba, J., P. Tétreault, R. Ferland, and F. Lahaye (1993). IGS Data Processing at the EMR Master Control System Centre, *Proc. of the 1993 IGS Workshop* (*G.* Beutler and E. Brockmann, eds.), Berne Switzerland, pp. 123-132.

Lichten, S. M. (1990). Estimation and Filtering for High-Precision GPS Positioning Applications, *Manuscript Geodaetica, No. 15,* pp. 159-176.

Van Martin Systems, Inc., (1990). MicroCosm Systems Description Version 9005.00, Vol 1, Rockville Maryland.

Webb, F. H. and J. F. Zumberge, eds., *An Introduction to GIPSY/OASIS II Precision Software for the Analysis of Data from the Global Positioning System,* Jet Propulsion Laboratory Document D-11088, July 1993.

Appendix A

Measurement and Orbit Models used in EMR GPS Analysis

MEASUREMENT MODELS

Preprocessing	single station type, using L1-L2 phase and pseudorange data, editing most cycle slips, computes smoothed pseudoranges at requested intervals (7.5min), introduces and initializes real phase ambiguities
Basic observable	carrier phase and smoothed pseudo-range elevation angle cutoff : 15 degrees sampling rate : 7.5 minutes weighting : exponential, station/satell. specific. Rejection criteria : 5 (aposteriori) sigmas
Modelled observable	undifferenced, corrected for ionosphere (L3, P3), CA pseudoranges corrected for CA-PI biases whenever applicable
RHO Polar. phase rotation corr.	applied (Wu et al., 1993)
Ground antenna phase centre cal.	not applied
Troposphere	Zenith delay: treated as a random walk process Mapping function: Lanyi mapping function Met. data input : Global constant values
Ionosphere	not modelled (ionospheric corrections applied using dual frequency observations, see above)
Plate motions	13 ITRF93 station velocities fixed (see IGSMAIL#819)
Tidal displacement	Solid earth tidal displacement: applied (IERS, 1992) Correction applied to remove permanent tide: not applied Nominal h2 and 12 values: 0.609, 0.0852 dh periodic change (IERS, 1992, eqn. (7), p. 57): applied (IERS, 1992) Pole tide: applied (IERS, 1992) Ocean loading: Pagiatakis (1982) model
Atmospheric load.	not applied
Satellite center of mass correction	Block I x,y & z: (0.210, 0, 0.854m) Block II/IIA x,y & z : (0.279, 0, 1.0229 m)
satellite phase centre calibrat.	not applied
Relativity	periodic term applied

ORBIT MODELS	
Geopotential	GEM T3 + C21+S21 model up to degree and order 8
	GM=398600.4415 km**3/sec**2
	AE = 6378.137 km
Third-body	Sun, Moon and planets regarded as point masses
	ephemerides: JPL DE200
	GMsun = 132712439935.4842 km**3/sec**2
	GMmoon = 4902.7991 km**3/sec**2
Solar radiation pressure	direct radiation: ROCK4 and ROCK42T models for Block I and II satellites, resp. area, specularities and reflectivity used: see Tables 1,2, (Fliegel and Gallini, 1992, JGR(97)B1,P562) satellite masses used: PRN 12 519.8kg PRN 01 880.0kg PRN 21-22 883.9 02 878.2 23 972.9 14 887.4 24-31 880.0 15 885.9 04-06 972.9 16-19 883.2 07 883.9 20 887.4 09 972.9
	x,z, scale and y- radiation biases: taken into account
	Earth shadow model includes: penumbra and atmospheric refraction/attenuation effects
	reflection radiation: not applied
	new GPS satellite attitude model: applied(IGSMAIL#591) geometrical effects : applied orbit dynamic (integration) eff. : not applied yaw rates(estimated/nominal) : NOMINAL
Tidal forces	solid earth tides: frequency independent Love's number K2= 0.300
	Ocean tides: UT CSR model from Schwiderski
Numerical integration	variable (high) order Adams predictor-corrector with direct integration of second-order equations
	integration step : variable (typically < 1000s)
	starter procedure: Runge-Kutta
	arc length : 24 hours

ESTIMATED PARAMETERS (APRIORI VALUES & SIGMAS)	
Adjustment	square-root information filter (SRIF) [Bierman, 1977]
Station coordinates	13 stations constrained to the ITRF93 positions (using ITF93 sigmas) as given in IGSMAIL#819, the remaining stations estimated (50m apriori sigmas) . The ITRF93 velocities are used for daily updating of coordinates In POSTPROCESSING and station combination, Apriori station constraints are rigorously removed for input into combined station solutions (adding the reduced normal matrices)
Satellite clock bias	modelled as white noise process and solved for at each epoch. (1ms appriori sigmas, apriori values from broadcast message) . Thus each epoch solution is independent and based on both phase and pseudorange observations. WARNING: no L1-L2 **satellite calibration applied, so the satellite clocks include the** L1-L2 **calibration delays**
Receiver clock bias	a **white noise process** (with large 1 s apriori sigmas, apriori values from preprocessing) . One Hydrogen Maser clock fixed and used as a time reference, usually ALGO. Thus each epoch solution is independent and based on both phase and pseudorange observations. WARNING: no P1-P2 receiver calibration applied, so the receiver clocks include the P2-P1 cal. delays (i.e. Rogues SNR8-800)
Orbital parameters	initial position and velocity, solar radiation pressure scales in x, z and y-bias considered constant through the orbital arc. Orbit states modelled as a random walk process between adjacent 24h orbit arcs. Apriori orbits, extrapolated from previous arc are assigned the following stochastic sigmas (for convenience Keplerian elements are used, then transformed into the x,y, z frame of reference used for processing) : semi-major axis (a) : 10m/sqrt (day) eccentricity (e) : .12m/sqrt (day) inclin., node(i, RA) : . 06m/sqrt (day) perigee, M.A (P, MA) : . 16m/sqrt (day) velocity (DX, DY, DZ) : . 00005 m/s/sqrt (day) non eclipsing . 0001m/s/sqrt (day) eclipsing Gx scale : .10 (white noise) Gy scale : .10 (white noise) Gy bias : .5d-09 m/s**2 (" ")
Troposphere	estimated as a random walk with about O. 01m/sqrt (hr) sigma. Previous day solution is used as apriori value with O. 03m sigmas to initiate the random walk process.
Phase Ambiguities	real, estimated as needed with apriori values from pseudorange observation, sigmas 3. ODO 8m
EON	x & y pole, UT1-UTC and LOD. Current IERS Bulletin A, (updated every two weeks only) and used as apriori. Constant during a 24h period, solutions refer to 12:00h UT. Apriori sigmas used: x,y pole 100 mas UT1-UTC 7 ms LOD 86400 ins/day. Note: In postprocessing the EOP and station coordinate apriori sigmas can be rigorously removed or changed
Other parameters	C1-P1 Pseudorange biases periodically updated as necessary from post fit pseudorange residuals

References

Aoki, S., B. Guinot, G. H. Kaplan, H. Kinoshita, D. D. McCarthy, and P. K. Seidelman (1982). "The New Definition of Universal Time," *Astron. Astrophys.*, *105,* pp. 359-361.

IERS (1992) Standards, *IERS Technical Note 13,* Observatoire de Paris, (edited by McCarthy, D.)

Lichten, S. M. (1990). "Estimation and Filtering for high-precision GPS positioning applications." *Manuscript Geodaetica,* Vol. 15, pp. 159-176.

Tralli, D. M. and S. M. Lichten (1990). "Stochastic estimation of tropospheric path delays in global positioning system geodetic measurements." *Bulletin Geodesique,* Vol. 64, No. 2. pp. 127-159.

Severs, O. J. and J. S. Border (1990). *Observation model and parameter partials for the JPL geodetic modeling software* "GPSOMC". JPL Publication 87–21, Rev. 2, JPL, Pasadena, CA, USA.

Pagiatakis, S. D (1982). "Ocean loading, body tides and polar motion effects on very long baseline interferometry." UNB Technical rep. No. 2, Dept. of Surv. Engineering, Univ. of New Brunswick, Fredericton, N.B.

Kouba, J., P. Tétreault, R. Ferland, and F. Lahaye (1993). "IGS data processing at the EMR Master Control System Centre," *Proceedings of the 1993 IGS Workshop,* held at Univ. of Berne, Switzerland, March 1993, pp. 123–132.

WU, J. T. *et al.,* (1993). "Effects of Antenna Orientation on GPS phase," *Manuscript Geodetica (1993), 18,* pp. 91–98.

Appendix B

Differences between EMR 1994 Combined Station Coordinate/ Velocity Solutions** and ITRF93 at epoch 1994.0

Coordinate Differences

Site	X(mm)	Y(mm)	Z(mm)	N(mm)	E(mm)	H(mm)
ALBH	-19.0	55.5	-59.7	-13.1	-46.5	-68.4
ALGO	-9.0	25.6	-12,1	10.8	-3.5	-27.4
AREQ	1.3	-6.0	-7.3	-5.3	-0.7	7.9
DRAO	.6	20.7	-7.8	8.7	-9.7	-17.9
FAIR	-1.7	9.5	.2	3.4	-8.9	-1.4
FORT	-6.2	-2.4	4.9	4.6	-5.7	-3.7
GOLD	-7.1	11.1	6.7	9.3	-11.4	-1.6
HART	23.6	7.6	18.9	27.6	-4.2	13.8
KOKB	9.3	-13.0	1.6	3.1	15.4	-3.3
HOLB	-23.7	-21.2	31.1	-4.4	-5.6	43.9
KOSG	-2.4	-7.4	2.5	4.0	-7.1	.0
MADR	-4.1	-4.5	-8.4	-4.0	-4.8	-8.3
MCM2	11.7	-5.3	28.4	-6.3	2,5	-30.4
RCM5	-9.3	-30.1	43.0	26.7	-14.2	43.9
SANT	15.4	-25.4	-10.9	6.7	6.1	30.3
STJO	-10.6	11.0	-.3	11.0	-1.8	-10.5
TAIW	7.0	-22.4	35.4	41.7	5.7	-5.8
TIDB	2.0	-9.5	15.0	8.4	7.1	-14.1
TROM	-7.3	-6.0	-10.5	4.6	-3.3	-12.9
USUD	6.8	-13.8	9.7	16.2	5.8	-5.8
WETT	-2.5	-6.7	-4.6	-.1	-6.0	-6.0
YARI	-12.8	6.6	12.0	16.0	8.7	4.2
YELL	-4.9	4.7	12.8	7.9	-6.4	10.3
mean	-0.2	-2.0	6.9	9.7	-2.3	-1.0
sigma	8.7	14.2	14.2	10.6	7.3	16.6
mean*	0.1	-0.6	1.8	7.5	-1.4	-1.3
sigma*	9.9	12.6	10.3	7.5	7.7	13.3

• For the 13 IGS fiducial stations

Velocity Differences

Site	Vx mm/y	Vy mm/y	Vz mm/y	VN mm/y	VE mm/y	VH mm/y
ALBH	6.2	15.1	-0.7	11.5	-3.2	-11.2
AREQ	2.9	-17.8	-8.4	-3.0	-2.9	-19.4
DRAO	1.8	8.3	-10.2	-.6	-2.5	-13.0
FORT	21.1	-1.5	-4.8	-3.6	12.0	17.7
HOLB	-4.7	-6.3	18.9	6.0	0.2	19.6
MCM2	-11.9	-3.0	-33.2	3.6	5.6	34.7
RCM5	.5	-13.3	7.0	.7	-1.7	14.9
STJO	.6	17.7	-18.6	-2.5	11.2	-23.0
TAIW	3.2	5.4	11.1	8.9	-5.6	7.3
USUD	-22.0	-21.2	.3	-1.1	30.5	2.0
mean	-4.8	2.1	-8.4	-1.8	-0.3	2.4
sigma	12.7	20.4	22.6	5.2	17.7	28.8

• * EMR solutions obtained with ITRF93 Velocities Fixed for the 13 Fiducial Stations

Appendix C

Example EMR Weekly Reports

Analysis Report

EMR ANALYSIS REPORT GPS-WEEK 0791 Dates: 95mar05 to 95marl 1

NRCan (Natural Resources Canada, formerly Energy, Mines and Resources (EMR))
615 Booth Street, Ottawa, Canada K1 A OE9
e-mail: kouba@geod.emr.ca, pierre@geod.emr.ca
tel: (613)992-2678 (Jan Kouba)
(613)992-2218 (Pierre Tétreault)
fax: (61 3)995-321 5

PRODUCTS GENERATED:
The following products are generated and uploaded into CDDIS@NASA/GSFC

EMR07910-6.SP3	GPS ephem. files for days O-6, week #0791 in sp3 format
EMR07917.ERP	pole x,y and DUT1 solutions for week #0791
EMR07917.SUM	name of this text summary file

REMARKS on EMR's products:
1. ALGO receiver clock used as reference. In the sp3 EPH file sat. epochs with no reference (e.g. ALGO not observing a satellite) have a value of 99999,999999 microseconds. ALGO clock error & drift were about -260 ns (49781) & -22 ns/day w.r.t. GPS time,
2. PRN28 is operating in AS free mode since February 20.
3. No data for PRN28 observed on Day 02 (Mar07/95) and only a little data observed on Day 3 (Mar08/95)
4. Starling with week 0791 we have added in our ERP report the apriori corrections to the celestial pole (dpsi and deps) that are used in our orbit processing.

SOLUTION CHARACTERISTICS

1. Solution identifier	Submission 950316
2. Software used	GIPSY/OASIS II (UNIX)
3. Definition of Terrestrial frame:	
origin and orientation	Nominally ITRF93
reference epoch	current date
GM	398600.4415 km^3/s^5
gravity model	GEMT3(8,8) +C21+S21
ocean loading	Pagiatakis, global model

4. Solution characteristics:
   undifferenced phase and smoothed pseudorange data > 15 degrees @ 7.5 min.; single day (24h) arc with 6 IC and 3 rad. parameters per satellite
5. See IGS Mail#655 (June 30, 1994) and IGS Report#1488 (January 16, 1995) for more details.

CARRIER PHASE / PSEUDO RANGE STATISTICS

Note: F indicates a constrained fiducial site
E indicates an eclipsing satellite

Carrier Phase Statistics
rms (cm)/ # obs

		95mar05	95mar06	95mar07	95mar08	95mar09	95mar10	95mar11
ALBH		.42/1147	.42/1136	.00/0	.00/0	.00/0	.40/1141	.36/1144
ALGO	F	.53/1182	.56/1167	.65/1124	.67/1153	.56/1153	.57/1185	.57/1183
AREQ		.40/1013	.00/0	.37/185	.43/1036	.41/1033	.00/0	.00/0
DAV1		.49/1097	.48/904	.49/1101	.47/1085	.49/1048	.49/1050	.55/1003
DRAO		.44/1118	.39/1111	.40/1110	.43/1103	.41/1170	.47/1167	.43/1169
FAIR	F	.82/1141	.70/1182	.83/1112	.81/1025	.8611055	.79/1004	.82/1003
FORT		1.25/1054	1.32/994	1.29/1029	1.28/1061	1.25/1009	1.19/964	1.28/1031
GUAM		.60/967	.65/1088	.57/1009	.70/1077	.47/1094	.49/1062	.61/1102
GOLD	F	.55/1156	.43/1153	.43/1107	.40/1116	.46/1152	.38/970	.57/1062
HART	F	.62/1151	.56/1140	.53/1029	.55/1051	.55/1097	.55/1154	.55/1162
KERG		.57/1014	.61/1136	.61/1083	.59/1083	.51/1047	.61/1144	.60/1143
KIT3		.99/1058	.92/1109	.89/1051	.97/1058	.84/1063	.88/1087	.95/1075
KOKB	F	1.47/1066	1.13/1165	1.10/1102	1.1311080	1.03/1156	1.03/1118	1.10/1183
KOSG	F	.4711158	.43/1138	.41/1065	.42/1113	.41/1092	.37/1064	.39/1083
MADR	F	.53/1113	.56/1120	.46/1076	.5211096	.45/1089	.48/1132	.49/1022
MCM4		.45/1160	.45/1203	.54/1170	.54/1167	.56/1112	.49/1173	.58/1166
NRC1		.34/1170	.38/1167	.40/1133	.40/1174	.40/1185	.35/1175	.37/1188
RCM5		.80/1113	.84/1141	.83/1126	.99/1112	.69/1152	.73/1168	.80/1145
SANT	F	.00/0	.50/319	.48/1065	.50/1114	.49/1181	.49/1180	.48/1168
STJO		.41/1190	.54/1181	.43/1146	.4711194	.46/1171	.49/1193	.45/1182
TAIW		.51/1165	.50/1148	.49/1077	.57/1093	.54/1159	.47/1170	.57/1110
TIDB	F	.97/1068	.93/1081	1.02/1087	1.08/1083	1.04/1107	.97/1127	.96/1115
TROM	F	.79/1085	.76/1210	.80/1160	.82/1167	.79/1095	.85/1090	.88/1022
TSKB		.53/1155	.55/1152	.51/1083	.59/930	.471795	.58/1068	.61/1182
WETT	F	.22/98	.50/1146	.15/97	.49/1104	.12/58	.46/1151	.52/1153
YAR1	F	.44/1184	.42/1192	.44/1098	.46/1098	.39/998	.46/1039	.54/1037
YELL	F	.61/1011	.61/1156	.63/1052	.62/1135	.66/1132	,64/1042	.70/962
PRN01		.75/1089	.71/1149	.71/1083	.6611157	.71/1113	.5811094	.68/1132
PRN02		.70/1114	.60/1127	.64/1105	.64/1142	.59/1082	.61/1169	.67/1188
PRN04		.65/1043	.64/1154	.65/1090	.69/1152	.61/1081	.64/1217	.63/1193
PRN05		.65/1142	.63/1133	.62/1091	,67/1197	.62/1164	.59/1170	.68/1160
PRN06	E	.68/1202	,91/1113	.73/1108	.68/1148	.69/1137	.69/1182	.76/1183
PRN07	E	.71/1043	.65/1203	.69/1115	.69/1205	.68/1032	.61/1161	.70/1190
PRN09		.63/1121	.58/1126	.62/1119	.62/1168	.60/1119	.60/1161	.59/1108
PRN12		,40/1122	,40/1135	.39/1085	.4411128	.39/1063	.40/1113	.40/1060
PRN14		.72/1093	.60/1203	.64/1142	.74/1212	.62/1157	.62/1168	.68/1166
PRN15		.79/1063	.62/1166	.66/1088	.68/1189	.60/1069	.56/1121	.60/1117
PRN16		.67/1099	.72/1160	.77/1139	.97/1172	.70/1109	.76/1211	.70/1206
PRN17		.64/1150	.72/1140	.63/1122	.68/1186	.69/1140	.59/1141	.6911146
PRN18	E	.65/1123	.64/1135	.66/1013	.65/1137	.64/1067	.62/1153	.65/1073
PRN19		.62/1086	.65/1148	.64/1105	.67/1133	.63/1119	.62/1177	.67/1158
PRN20		.66/1090	.62/1096	.62/1093	.66/1121	.62/1053	.60/1108	.61/1135
PRN21		.74/1099	.67/1145	.77/1041	.70/1176	.62/1037	.70/1135	.72/1136
PRN22		.69/1188	.70/1179	.75/1156	.76/1211	.73/1188	.70/1216	.72/1209
PRN23		.57/1032	.65/1107	.65/1042	.65/1088	.61/1058	.59/1162	.80/1118
PRN24		.67/1104	.66/1138	.62/1149	.71/1226	.60/1028	.60/1168	.65/1195
PRN25		.71/1190	.69/1199	.7411164	.71/1215	.69/1169	.66/1161	.75/1216
PRN26	E	.74/1190	.76/1145	.70/1087	.79/1193	.78/1121	.73/1106	.78/1143
PRN27		.67/1155	.68/1143	.68/1152	.64/1238	.65/1141	.71/1187	.67/1214
PRN28	E	.77/1151	.63/1108	.00/0	.55/330	.60/929	.63/1041	.63/1061
PRN29	E	.62/1153	.62/1152	.70/1113	.69/1206	.72/1154	.70/1170	.70/1134
PRN31	E	.95/992	.64/1135	.7711075	.73/1178	.62/1073	.64/1126	.70/1154

Pseudo Range Statistics
rms (cm)/ # obs

		95mar05	95mar06	95mar07	95mar08	95mar09	95marl O	95marl 1
ALBH		25/1 149	27/1151	0/0	0/0	0/0	26/1 145	28/1 146
ALGO	F	31/1183	32/1 179	40/1 129	37/1 180	29/1182	32/1 187	32/1 184
AREQ		43/1 046	0/0	44/1 84	43/1 057	41/1033	0/0	0/0
DAVI		11/38	10/56	12/38	23/59	1 3/34	12/39	1 3/31
DRAO		32/1 120	33/1 118	35/1 114	32/1 104	29/1 169	32/1170	33/1 170
FAIR	F	53/1 176	56/1 193	59/1 118	56/1 040	51/1056	52/1 049	51/1056
FORT		41/1165	43/1 171	44/1 127	42/1 142	41/1133	44/1 017	41/1136
GUAM		51/1035	54/1 097	54/1 057	57/1 106	58/1 115	59/1 074	53/1 106
GOLD	F	83/1 158	78/1 156	77/1 109	85/1 119	81/1150	65/970	93/1 063
HART	F	66/1171	70/1151	71/1040	67/1061	73/1 113	67/1161	68/1 174
KERG		1 7/43	1 7/43	18/42	16/43	18/42	16143	17/42
KIT3		59/1 111	62/1131	72/1091	70/1 094	70/1 119	93/1 126	101/1105
KOKB	F	56/1 197	57/1 211	62/1 172	60/1 143	59/1200	58/1 198	57/1 222
KOSG	F	53/1 158	56/1 152	53/1 067	57/1 114	59/1 112	51/1068	60/1 083
MADR	F	63/1 120	64/1121	65/1 079	66/1 098	61/1095	63/1 133	65/1 030
MCM4		39/1 187	35/1 203	41/1174	40/1 175	38/1 122	37/1 177	35/1 170
NRCI		36/1 171	3511169	37/1 134	37/1 176	36/1 185	37/1177	35/1 189
RCM5		35/1 160	36/1 163	39/1 137	35/1 161	34/1 159	36/1 172	32/1 158
SANT	F	0/0	61/321	57/1 068	89/1 122	77/1 183	54/1 186	58/1 177
STJO		68/1 192	63/1 193	84/1 149	70/1 194	59/1 194	53/1 196	58/1 193
TAIW		65/1 174	59/1 154	1 30/1 034	69/1 125	65/1 187	57/1 177	81/1104
TIDB	F	53/1 135	52/1 118	60/1 131	53/1 122	58/1 155	57/1 174	60/1 154
TROM	F	27/48	21 /57	21/55	19/56	1 9/49	1 3/45	1 5/43
TSKB		62/1 178	67/1 193	94/1 116	1 01/933	78/800	1 00/1 070	94/1 184
WETT	F	67/98	68/1 146	58/97	70/1 104	51/58	69/1 148	67/1151
YAR1	F	36/1 197	39/1 198	46/1 098	39/1 099	36/1 005	40/1 045	42/1 053
YELL	F	34/1 119	33/1171	33/1 116	35/1 137	35/1 155	37/1 106	36/1 089
PRNO1		55/1 033	58/1 041	731966	65/1 055	66/977	5311003	63/1 026
PRN02		54/986	55/1 006	63/946	63/1013	59/960	68/1 023	68/1 041
PRN04		47/984	49/1 024	60/953	57/1041	53/983	53/1 085	53/1 082
PRN05		52/1 037	54/1 041	61/965	60/1 086	55/1 040	54/1 069	54/1 056
PRN06	E	57/1 105	54/1 034	62/1 006	60/1 064	60/1 031	54/1 075	53/1 077
PRN07	E	55/973	55/1 053	62/984	67/1 056	62/996	64/1 050	67/1061
PRN09		49/999	49/998	62/995	63/1 048	57/993	51/1034	57/1 013
PRN12		40/1 121	33/1135	34/1 072	36/1 136	42/1 053	31/1 114	35/1 061
PRN14		51/997	54/1 076	62/1015	58/1 090	54/1 081	57/1 083	60/1 076
PRN15		53/999	49/1 049	64/957	58/1 071	66/959	61/1036	61/1030
PRN16		54/1 006	5511073	66/1 094	70/1 101	61/1029	57/1 119	64/1 092
PRN17		55/1 039	58/1 034	61/979	61/1038	64/1 003	57/1 011	59/1 040
PRN18	E	51/1009	58/1 019	67/937	66/1 019	61/963	62/1 051	61/1012
PRN19		51/1010	54/1 035	66/978	65/1 057	61/1004	58/1 040	62/1 047
PRN20		51 /974	51/977	65/961	54/1 025	52/943	48/993	55/1021
PRN21		54/987	58/1 015	77/938	62/1031	61/931	60/1 006	63/1 030
PRN22		53/1 095	53/1 097	68/1 053	60/1 094	55/1 074	57/1 099	58/1 108
PRN23		53/933	56/979	71/904	521923	53/901	53/1 003	61/1015
PRN24		50/972	57/989	58/1 002	6411085	561967	56/1 036	57/1 063
PRN25		53/1 059	53/1 083	78/1 025	62/1 120	57/1 044	55/1 037	58/1 095
PRN26	E	53/1 068	54/1 075	54/991	61/1073	56/1 007	54/997	67/1018
PRN27		51/1059	4811057	62/1 027	63/1 098	60/1 025	62/1 076	60/1 098
PRN28	E	38/1051	42/1 044	0/0	30/330	40/872	40/939	44/960
PRN29	E	46/1 032	56/1 045	65/974	6411063	64/1 017	62/1 033	65/1 058
PRN31	E	59/1 001	56/1 037	64/954	59/1 047	62/952	63/1041	69/1 033

Station Clock Solutions at Ohour UTC
(microsecond)

	95mar05	95mar06	95mar07	95mar08	95mar09	95marl O	95mar1 1
ALBH	1.733	1.840	---	---	---	2.419	2.534
ALGO	REF	REF	REF	REF	REF	REF	REF
AREQ	.751	...	---	.694	.755	---	...
DAV1	...	-.267*	10.294'	23.905'	37,693*	---	65.346'
DRAO	-1.318	-1.214	-1.107	-1.004	-.893	-.782	-.669
FAIR	-.506	-.516	-.524	-.532	-.540	-.549	-.560
FORT	.190	.229	.269	.309	.349	.389	.430
GUAM	---	..-	...	---	...	---	---
GOLD	-.745	-.731	-.716	-.699	-.682	-.664	-.646
HART	-.302	-.032	.375	.752	.899	1.089	1.153
KERG	10.870	8.721	6.767	4.379	3.124	.370	-2.729
KIT3	---	...	...	...	...	---	...
KOKB	1.894	1.776	1.657	1.538	1.418	1.296	1.173
KOSG	.847	.929	1.029	1.199	1.397	1.638	1.896
MADR	-2.750	-2.721	-2.689	-2.655	-2.623	-2.591	-2.562
MCM4	---	...	...	...	...	...	---
NRC1	-1.049	-1.036	-1.022	-1.007	-.993	-.979	-.965
RCM5	.512	.523	.536	.552	.565	.576	.587
SANT	---	---	-5.163	-5.111	-5.064	-5.013	-4.963
STJO	39.685	69.898	100.059	130.287	160.534	190.960	221.484
TAIW	2422.103	2481.754	2541.429	2601.139	2660.921	2720.724	2780.492
TIDB	.067	.076	.086	.097	.109	.120	.129
TROM	1124.693	1132.811	1140.968	1149.175	1157.405	11 65.733*	1173.969
TSKB	71.256	71,306	71.361	71.417	71.474	71.533	380.837
WETT	1.922*	2.117	2.338'	2.536	2.745	2.952	3.074
YARI	3.664	3.695	4.315	4.344	4.361	4.364	4.357
YELL	-.070	-.096	-.120	-.144	-.173	-.201*	-.233

Note: * indicates a non-0hour UTC epoch

EOP Report

SUMMARY OF CANADIAN EMR SOLUTION

1. Analysis center : Geodetic Survey Division (GSD), SMRSS, EMR
2. Solution identifier : Submission 950315
3. Software used : GIPSY/OASIS II (UNIX)
4. Definition of Terrestrial frame:
   - origin : Nominally ITRF93
   - orientation : " "
   - reference epoch : current date
   - velocity of light : 299792458 m/s
   - GM 398600.4415 km^3/s^5
   - gravity model : GEMT3(8,8) +C21+S21
   - permanent tide corr: None
   - ocean loading : Pagiatakis, global model
5. Adjusted parameters:
   - undifferenced phase and smoothed pseudorange data > 15 degrees @ 7.5 min.;
     single day (24 h) arc with 6 IC and 3 rad. parameters per satellite
   - trop. zenith delay corr. parameter augmented with random walk stoch. process;
     initial phase ambiguity parameters (1 for each satellite/station pass or initial phase);
   - station positions X,Y,Z, up to 23 stations. ALGO, FAIR, GOLD, HART, KOSG, TROM, WETT, YELL, MADR, MCMU, SANT, TIDB and YAR1 are constrained;
     x, y pole position, once a day (DUT1 fixed/solved; DUT1 ,x,y *a priori* sigma = 3m), LOD *(a priori* sigma 86400 ins/day);
     station clock biases once per each epoch/station (except for ALGO h. maser which provides the time reference) with sigma 1 s;
   - **satellite clock biases once per each epoch/satellite with 1 ms sigma.**

EOP SOLUTION

MJD	X	Y	UT1-UTC	LOD	Xsig	Ysig	UTsig	LODsig	Nr	Nf	Nt	Xrt	Yrt	dpsi	deps
	(10**-5")		usec	us/d	(1 O* ● -5)		usec	us/d				10**-5"/d		10**-5"/d	
49781.50	-4572	53741	227360	2882	9	11	29	11	26	12	25	322	114	-2331	-620
49782.50	-4225	53841	224542	2766	9	10	14	10	26	13	25	318	103	-2312	-634
49783,50	-3891	53945	221823	2591	8	10	17	**11**	**26**	**13**	**24**	**313**	**93**	**-2299**	**-645**
49784.50	**-3644**	**54078**	**219206**	**2527**	**8**	**10**	**19**	**11**	**26**	**13**	**25**	**306**	**80**	**-2292**	**-652**
49785.50	**-3379**	**54226**	**216586**	**2602**	**8**	**10**	**21**	**12**	**26**	**13**	**25**	**299**	**67**	**-2289**	**-657**
49786.50	**-3164**	**54314**	**213901**	**2672**	**8**	**10**	**22**	**10**	**26**	**13**	**25**	**296**	**58**	**-2286**	**-659**
49787.50	**-2964**	**54381**	**211159**	**2762**	**8**	**10**	**23**	**11**	**26**	**13**	**25**	**296**	**52**	**-2279**	**-657**

Scripps Orbit and Permanent Array Center Report to the IGS—1995

Peng Fang and Yehuda Bock
Scripps Institution of Oceanography, University of California San Diego
La Jolla, California

Introduction

The Scripps Orbit and Permanent Array Center (SOPAC) at Scripps Institution of Oceanography has been providing precise GPS satellite ephemerides and Earth orientation parameter (EOP) estimates on a daily and weekly basis since August 1991. The motivation for this activity is the development and support of regional GPS permanent arrays for geophysical applications, in particular, the Southern California Integrated GPS Network (SCIGN) which includes the regional-scale Permanent GPS Geodetic Array (PGGA) and a dense array in the Los Angeles Basin. One of our primary goals is the development of a very-near-real-time system for monitoring crustal deformation, atmospheric processes, engineering structures, and moving geophysical platforms.

SOPAC functions as both an IGS Global Data Center and Global Analysis Center in our role as the UNAVCO Orbit Facility. We work closely with the MIT group (R. W. King, T. A. Herring and S. McClusky), including the development of the GAMIT/GLOBK software and orbit-determination strategies.

In this report, we emphasize recent progress towards a very near real time system including rapid orbits, rapid polar motion, rapid tropospheric mapping and global ionospheric TEC mapping.

Global and Operational Data Center

SOPAC is one of the three Global Data Centers, along with CDDIS and IGN, archiving IGS products and a complete set of RINEX data for the global tracking network. In addition, it serves as a Regional Data Center, archiving and analyzing all continuous GPS data collected in southern and Baja California (Figures 1-2) for the Southern California Earthquake Center (SCEC). SOPAC is responsible currently for the operations and data downloading of 19 SCIGN/PGGA/DGGA stations, in collaboration with the U.S. Geological Survey Office in Pasadena (K. Hudnut). Furthermore, SOPAC archives data from the northern California Bay Area Deformation Array (BARD) and the Continuously Operating Reference Stations (CORS) network operated by the U.S. National Geodetic Survey.

SOPAC distributes by electronic mail a weekly data bulletin which catalogs the tracking data in the archive as well as provides a rudimentary quality check indicator. An example of a recent week is given in Table 1. A World Wide Web (WWW) Home Page also provides access to these bulletins (http://jon.ucsd.edu). The SOPAC archive has a three-tiered hierarchical structure as indicated in Figure 3 with a total of 120 Gb available for on-line data storage.

Figure 1. Southern California ***Integrated*** *GPS Network. Map of southern California permanent GPS array for near* ***real-*** *time monitoring of* ***crustal*** *deformation. See Figure 2 for a complete site map of Los Angeles Basin stations.*

Southern California Integrated GPS Network (SCIGN)

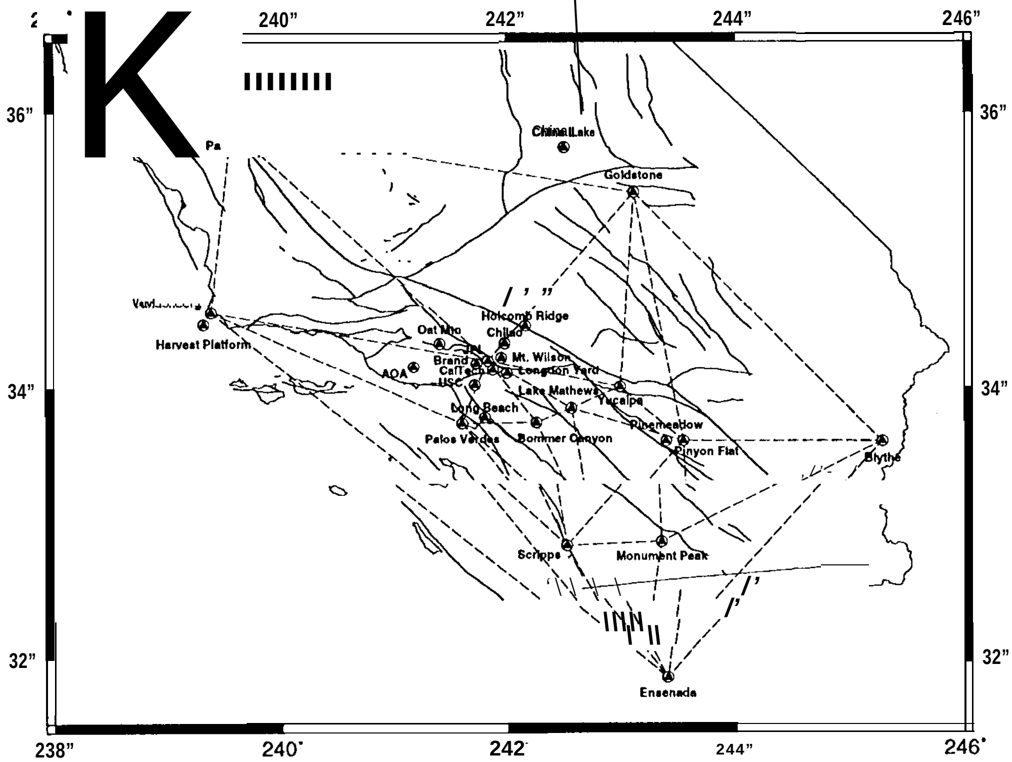


Figure 2. Dense GPS Geodetic Array in the Los Angeles Basin. Sites operational as of May.

Dense GPS Geodetic Array (DGGA) - Los Angeles Basin

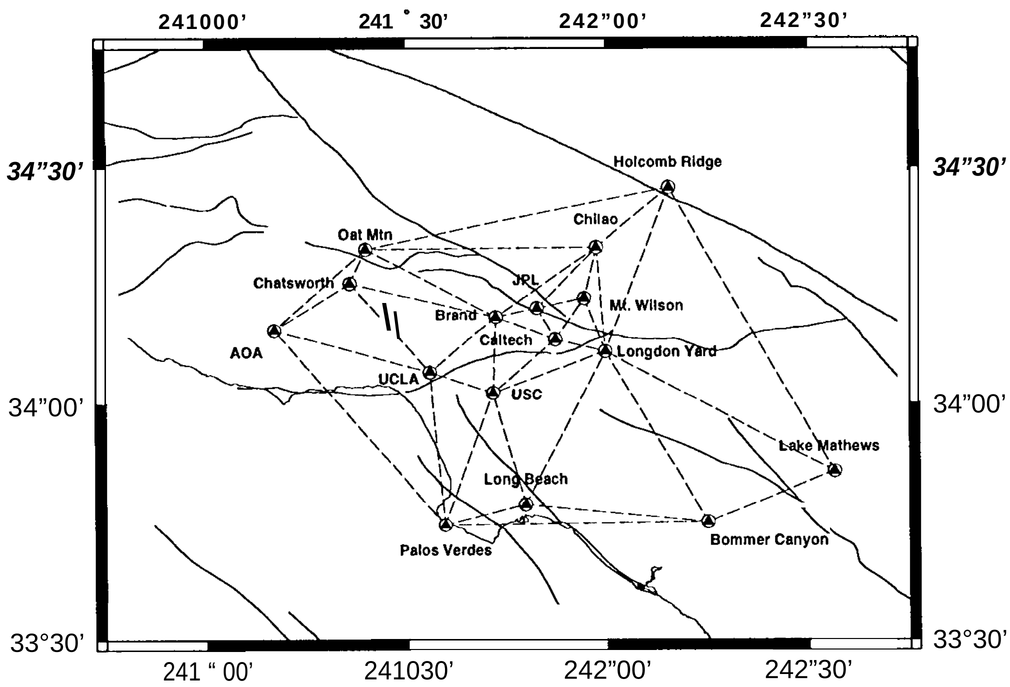


Table 1. SOPAC Global Data Center Report — GPS Week 0810.

Submitted by: Yehuda Bock, Jeff Behr and Peng Fang
Scripps Orbit and Permanent Array Center (SOPAC)
Institute of Geophysics and Planetary Physics (IGPP)
Scripps Institution of Oceanography (S10)
University of California, San Diego (UCSD)
La Jolla, CA 92093-0225 USA
e-mail : bock@pgga . ucsd. edu; behr@pgga. ucsd. edu
fax: (619) 534-9873
Geodesy lab tel: (619) 534-7692

To access SOPAC GARNER archive:
ftp toba. ucsd. edu (132.239.152.80)
login: anonymous
password: your name
directories: rinex, raw
Direct problems to: pgga@pgga. ucsd. edu

Data Holdings as of 07/26/95 03:49:11 UTC

P G G A & G L O B A L T R A C K I N G D A T A
(GPS DATA ARCHIVED AT SOPAC)

GPS WEEK #810 — Jul 16,95 - Jul 22,95 — DOY 197 - DOY 203

SITE_NAME	S10 CODE	IGS CODE	TYPE OF RECEIVER	Day Number 197	198	199	200	201	202	203
Blythe [PGGA] , CA, USA	blyt	blyt	ASHTECH Z-X113	B	B	B	B	B	B	B
Yucaipa [PGGA], CA, USA	crfp	crfp	ASHTECH Z-X113	B	B	B	B	B	B	B
Lake Mathews [PGGAI , CA, uSA	math	math	TRIMBLE 4000 SSE	B	B	B	B	B	B	B
Monument Peak [PGGA] , CA, USA	monp	monp	ASHTECH Z-XI 13	R5	B	B	B	B	B	B
Pinyon 1 [PGGA] , CA, USA	pin1	piny	ASHTECH Z-X113	B	B	B	B	B	B	B
Pales Verdes [PGGA] , CA, USA	pvep	pvep	TRIMBLE 4000 SSE	B	B	B	B	B	B	B
Scripps 3 [PGGA] , CA, USA	sio3	sio3	ASHTECH z-X113	B	X	B	B	B	B	B
Bommer Canyon [PGGA] , CA, USA	trak	trak	ASHTECH Z-X113	B	X	B	B	B	B	B
Vandenberg [PGGA] , CA, USA	vndp	vndp	ASHTECH Z-X113	B	B	B	B	B	B	B
Brand Basin [DGGA] , CA, USA	bran	bran	ASHTECH LPZ-XI ID	BBR6		-	-		-	-
Brand Basin [DGGA] , CA, USA	bran	bran	ROGUE SNR-8000	-	-	-	B	B	B	B
Chilao [DGGA] , CA, USA	chil	chil	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Claremont [DGGA] , CA, USA	clar	clar	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Firecamp 9 [DGGA] , CA, USA	cmp9	cmp9	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Pearblossom [DGGA] , CA, USA	hole	hole	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Hollydale [DGGA] , CA, USA	help	help	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Mt. Lee [DGGA] , CA, USA	leep	leep	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Longdon Yard [DGGA] , CA, USA	long	long	ASHTECH LPZ-XI ID	B	B	B	B	B	B	B
Rocketdyne [DGGA] , CA, USA	rock	rock	ASHTECH LPZ-XIID	B	B	B	B	B	B	B
Allen Osborne [DGGA] , CA, USA	aoal	aoal	ROGUE SNR- 8000	X	x	x	x	x	x	x
Parkfield [PGGA] , CA, USA	carr	carr	ROGUE SNR-8000	X	x	x	x	x	x	x
Mammoth Lakes, CA, USA	casa	casa	ROGUE SNR- 8000	X	X	X	X	X	9	X
Catalina Island [DGGA] , CA, USA	cat1	catl	ROGUE SNR -8000	-	-	-	-	x	x	x
Enseneda [PGGA] , BC, Mexico	cice	cice	ROGUE SNR- 8000	X	x	x	x	x	x	x
Cal tech [PGGA] , CA, USA	cit1	citl	ROGUE SNR- 8000	xxx		x	x		x	x
Goldstone [PGGA] , CA, USA	ds10	gold	ROGUE SNR- 8	X	9		6	9		XXX
Harvest Platform [PGGA] , CA, USA	harv	harv	ROGUE SNR- 8000	X	x	x	x	x	x	x
JPL Mesa [PGGA] , CA, USA	jpl1	jplm	ROGUE SNR-800 0	X	X	X	X	X	1	6
Long Beach [DGGA] , CA, USA	lbch	lbch	ROGUE SNR-8000	X	x	x	x	x	x	x
Oat Mt new [DGGA] , CA, USA	0at2	0at2	ROGUE SNR-800 0	X	x	x	x	x	x	x
Quincy [PGGA] , CA, USA	quin	quin	ROGUE SNR - 8000	xxx		x	x		x	x
Saddle Peak [DGGA] , CA, USA	spkl	spkl	ROGUE SNR-8000	2	7	3	2	4	6	6
UCLA [DGGA] , CA, USA	uclp	uclp	ROGUE SNR- 8000	x	x		xx		x	xx
USC [DGGA] , CA, USA	usc1	usc1	ROGUE SNR- 8000	X	x	x	x	x	x	x
Whittier College [DGGA] ,CA, USA	whc1	whcl	ROGUE SNR-800 0	X	x	x	x	x	x	x
Whittier Library [DGGA] , CA, USA	whil	whil	ROGUE SNR-8000	x	9	5	8	9	9	8
Mt. Wilson [DGGA] , CA, USA	wlsn	wlsn	ROGUE SNR- 8000	X	x	x	x	x	x	x
Briones [BARD] , CA, USA	brib	brib	ASHTECH Z-XI 13	X	x	x	x	x	x	x
Chabot [BARDI , CA, USA	chab	chab	ASHTECH Z-X113	X	x	x	l	x	x	
Columbia [BARDI , CA, USA	cmbb	cmbb	ASHTECH Z-XI 13	X	x	x	x	x	x	x
Farallon [BARD I , CA, USA	farb	farb	ASHTECH Z-X113	X	x	x	x	x	x	x
Molate [BARDI , CA, USA	mola	mola	TRIMBLE 4000 SSE		x	x				
Nunes [BARD] , CA, USA	nune	nune	TRIMBLE 4000 SSE		x	x				
Tiburon [BARDI , CA, USA	tibb	tibb	ASHTECH Z -XI 13	X	x	x	x	x	x	x
Winton [BARDI , CA, USA	wint	wint	ASHTECH Z-X113	x		xx	2		xx	
Denver [CORS] , CO, USA	dent	dent	TRIMBLE 4000 SSE	X	x	x	x	x	x	x
Hillsboro [CORS] , KS, USA	hbrk	hbrk	TRIMBLE 4000 SSE							
Haskell [CORS] , OK, USA	hklo	hklo	TRIMBLE 4000 SSE	X	x	x	x	x	x	x
Lament [CORS] , OK, USA	lmno	lmno	TRIMBLE 4000 SSE	X	x	x	x	x	x	x

Platteville [CORS] , CO, USA	pltc	pltc	TRIMBLE 4000 SSE	X x x x 9 X X
Sterling. [CORS], CO, USA	strl	strl	ROGUE SNR-800 0	X x x x x x x
Table Mt. [CORS] , CO, USA	tmgo	tmgo	ROGUE SNR - 8000	X x x x x x x
Vici [CORS] , OK, USA	vcio	vcio	TRIMBLE 4000 SSE	X x x x x x x
Wallops. [CORS] , CO, USA	wlps	wlps	ROGUE SNR-8000	X x x x x x x
white Sands [CORS] , NM, USA	wsmn	wsmn	TRIMBLE 4000 SSE	X x x x x x x
Albert Head, Victoria B.C.	albh	albh	ROGUE SNR - 8000	X x x x x x x
Algonquin, Canada	algo	algo	ROGUE SNR-8000	X x x x x x x
Arequipa, Peru	arel	areq	ROGUE SNR-8000	X x x x x x x
Bogota, Colombia	bogt	bogt	ROGUE SNR-8000	X x x x x x x
Borowiec, Poland	borl	borl	ROGUE SNR-8000	X x x x x o x
Brasilia, Brazil	braz	braz	ROGUE SNR- 8000	X x x x x x x
Bermuda	brmu	brmu	ROGUE SNR- 8000	x x x x x6 x
Brussels, Belgium	brus	brus	ROGUE SNR- 8000	X x x x x x x
Casey, Antarctica	casl	casl	ROGUE SNR-810 0	8 7x x
Davis, Antarctica	dav1	dav1	ROGUE SNR-810 0	3 2 1 2
Easter Island, Chile	eisl	eisl	ROGUE SNR - 8000	X x x x x x x
Fairbanks, AR, USA	fair	fair	ROGUE SNR-8000	x 3 4 X X X X
Fortaleza, Brazil	fort	fort	ROGUE SNR-8000	x 7 X x x x x
Goddard SFC, MD, USA	gode	gode	ROGUE SNR-8100	X x x x x x x
Graz, Austria	graz	graz	ROGUE SNR - 8	X x x x x x x
Guam, USGS Observatory	guam	guam	ROGUE SNR- 8000	1 4 2 1 x x x
Hartebeesthoek, S. Africa	hart	hart	ROGUE SNR- 8	X x x x x x x
Herstmonceux, UK	hers	hers	ROGUE SNR- 8A	X x x x x x x
Hobart [Tasmania] , Australia	hob2	hob2	ROGUE SNR- 8100	
Bangalore, India	iisc	iisc	TRIMBLE 4000 SSE	
Jozefoslaw, Poland	joze	joze	TRIMBLE 4000 SSE	x x x x x x6
Kerguelen Islands	kerg	kerg	ROGUE SNR- 8c	X x x x x x x
Kiruna, Sweden	kiru	kiru	ROGUE SNR-8100	x
Kitab, Uzbekistan	kit3	kit3	ROGUE SNR- 8000	x X x x x x
Kokee Park, HI, USA	kokr	kokb	ROGUE SNR- 8000	X x x x x x x
Kootwi jk Obs. , Netherlands	kosg	kosg	ROGUE SNR- 8000	X x x x x x x
Kourou, Fr. Guyana	kour	kour	ROGUE SNR- 8 C	x x x x x
Lhasa, Tibet	lhas	lhas	ROGUE SNR- 8000	X x x x x x x
La Plata, Argentina	lpgs	lpgs	ROGUE SNR-800 0	X x x x x x
Macca, Antarctica	macl	macl	ROGUE SNR-8100	X X 9 X
Madrid DSN, Spain	ds60	madr	ROGUE SNR-8	x x 9 9 X X X
Maspalomas, Canary Is.	masl	masl	ROGUE SNR-810 0	X x x x x x x
Matera, Italy	mate	mate	ROGUE SNR- 8	X x x x x x
McDonald Obs, TX, USA	mdo 1	mdo1	ROGUE SNR- 8000	X x x x x x x
McMurdo, Antarctica new	mcm4	mcm4	ROGUE SNR- 8000	X x x x x x x
Metsahovi, Finland	mets	mets	ROGUE SNR- 8C	X x x x x x x
North Liberty, Iowa, USA	nlib	nlib	ROGUE SNR - 8000	X x x x x x x
NY Alesund, Norway	nail	nyal	ROGUE SNR - 8	X x x x 8 x x
O'Higgins, Antarctica	ohig	ohig	ROGUE SNR-8000	
Onsala, Sweden	onsa	onsa	ROGUE SNR- 8000	x 9 9 9 X 8 X
Pamatai, Tahiti	pama	pama	ROGUE SNR- 800	2 x x x3
Penticton, Canada	drao	drao	ROGUE SNR- 8000	X x x x x x x
Perth, Australia	pert	pert	ROGUE SNR- 8100	o
Pie Town, NM, USA	piel	piel	ROGUE SNR- 8000	X x x x x x x
Pot sdam, Germany	pots	pots	ROGUE SNR-800 0	X x x x x x x
Richmond, FL, USA	rcm5	rcm5	ROGUE SNR-8000	9 X X X X 9 X
Santiago, Chile	sant	sant	ROGUE SNR-8	x l 7 0 3 0
Saint John's, Canada	stjo	stjo	ROGUE SNR- 8000	X x x x x x x
Shanghai Observatory, China	shao	shao	ROGUE SNR-8100	X x x x x x x
Taiwan, Taipei	taiw	taiw	ROGUE SNR-8000	8 x x x x x
Thule, Greenland	thu1	thu1	ROGUE SNR-8000	
Tidbinbilla, Australia	ds42	tidb	ROGUE SNR-8	X X 6 X 8 X X
Tromso, Norway	trom	trom	ROGUE SNR-8	X x x x x x x
Tsukuba-Kashima, Japan	tskb	tskb	ROGUE SNR-8000	X x x x x x x
Usuda, Japan	usu3	usual	ROGUE SNR-8000	X x x x x x x
Villa franca, Spain	vill	vill	ROGUE SNR-8100	x 7
West ford, MA, USA	wes2	wes2	ROGUE SNR-8000	X x x x x x x
Wettzell, Germany	wtz1	wett	ROGUE SNR-8000	X x x x x x x
Yarragadee, Australia	yar1	yarl	ROGUE SNR-8	X x x x x x x
Yell owkni f e, Canada	yell	yell	ROGUE SNR-8000	X x x x x x x
Zimmerwald, Switzerland	zimm	zimm	TRIMBLE 4000 SSE	X x x x x x x
Zwenigorod, Russia	zwen	zwen	ROGUE SNR - 8000	x x x

1. The following 19 sites are downloaded by SOPAC: BLYT, BRAN, CHIL, CHTP, CLAR CMP9 , CRFP, HOLC, HOLP, LEEP, LONG, MATH, MONP, PIN1 , PVEP, ROCK, S103 , TRAK, VNDP .
2. All other data are copied from CDDIS/JPL/NOAA/ CIC/AUSLIG/IGN/EMR
3. From GPS week 747, we record above the approximate percentage of data for each file computed by a RINEX file checker (e.g. 9 = 85-95%)
4. PGGA is the acronym for the southern California Permanent GPS Geodetic Array. It is now the regional component of the Southern California Integrated GPS Network (SCIGN) operated by SOPAC, USGS and JPL and which includes a

dense array in the Los Angeles Basin referred to as the DGGA (Dense GPS Geodetic Array) . SCIGN is administered under the umbrella of the Southern California Earthquake Center (SCEC) .

5. BARD (Bay Area Regional Deformation Array) is the acronym for the Northern California permanent GPS array. RINEX data can be also accessed from tbe Northern California Seismic Data Center (NCSDC) via anonymous ftp [login: brkseis20. Berkeley. edu (128.32.146.106) 1 cd /pub/ gps/rinex/YYYY/ YYYY. DDD (YYYY= current year, DDD. Jul ian day)
6. CORS (Continuously Operating Reference Stations) is tbe acronym for tbe U. S National GPS Network. RINEX and meteorological data can also be accessed from the National Geodetic Survey (NGS) , Silver Spring, MD via anonymous ftp [login: proton .ngs. noaa. gov (140.90.111.134)1 SOPAC archives both RINEX and meteorological data (e.g. , vici1550.95m) .
7. Ashtech Low Power z-12 is indicated by LPZ-XII3 .
8. Ashtech z-12 series receiver in combination with new Ashtech Dome Margolin with choke ring antenna is indicated by a trailing 'D' , i .e. , Z-XII3D.
9. Receiver change at BRAN on day 199, Ashtech replaced by TruboRogue SNR-8000.
10. New DGGA site on Catalina Island from day 201.
11 .S103 & TRAK raw data lost on day 198 due to operator error.
12. CARR & CASA data are a mix of 30 second and 1 second sampling on day 200.

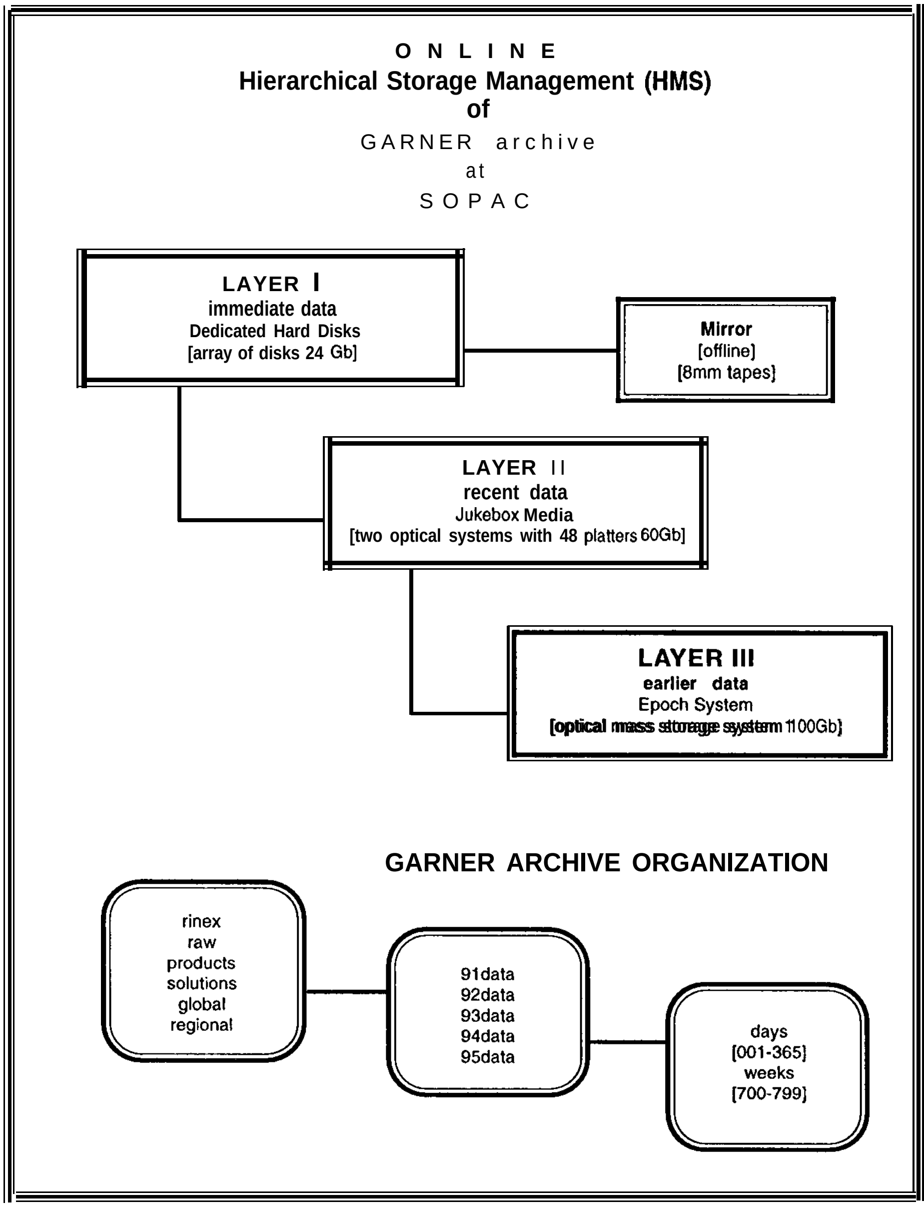


Figure 3. Hierarchical Structure of the SOPAC GARNER Archive.

SOPAC Global Analysis Center

SOPAC Rapid Products

Due to increasing demands for near real time applications, SOPAC has been generating rapid orbit and Earth orientation estimates since the beginning of GPS week 0783 (8 January, 1995). These products in standard IGS format are generally available over anonymous ftp within 18 hours of the end of a 24-hr observation collection window (0-24h UTC). In addition, we compute our regular daily and weekly orbits and Earth orientation estimates. The weekly products are contributed currently to the IGS combined orbit. In addition we have been experimenting with a predicted orbit which is extrapolated 24 hours by numerical integration of the daily rapid orbits. We rely on HP700 series workstations to meet the increasing demand on data analysis. The procedure that we follow for the rapid orbital products are outlined in the next section.

In order to cope with the heavy computational load problem with processing an increasing number of global stations, SOPAC has conducted some experiments with distributed solution schemes, which have proven very successful in regional applications (Zhang *et al.,* 1995). In one of these schemes, we divide the global stations into two groups so that the stations are interleaving. In order to strengthen the connection between the two networks, 3 stations are chosen to be common to both subnetworks. In another scheme, we divide the network into northern and southern subnetworks (P. Tregoning, personal communication). With these schemes, the computation load can be distributed and the efficiency is greatly increased. Moreover, a longer observation time span can be used and more unknown parameters (e.g., zenith delays) can be estimated without an increase in computational time.

Temporal variations in atmospheric refraction are of interest to geodesy and atmospheric physics. SOPAC has begun mapping global total electron content (TEC) and plans to provide TEC maps, time series, and/or spherical harmonic coefficients as additional rapid products. Initial results and procedures are given in the results section. SOPAC has already begun producing rapid precipitable water maps for the U.S. CORS/NOAA stations.

Analysis Procedures

Daily and Weekly Regular Orbit Service. An automatic ftp procedure retrieves RINEX observation files from various data-collecting agencies around the world every 4 hours. Within 4-7 days after data retrieval, an analysis procedure is initiated using 24 hours of data (0-24h). This procedure first performs a series of checks for adequate global station coverage and observation length. When an individual RINEX file is less than 50% of normal size, it is excluded. At present, 32-36 global stations are used in each 24-hour solution. The procedure then sets up auxiliary files and converts the RINEX files into GAMIT (King and Bock, 1994) internal format. A driver program generates a set of batch jobs running sequentially according to a predefine strategy. In the case of the IGS daily solution, parameters to be solved for include station positions, satellite orbits (8 initial conditions: satellite state vector, direct solar radiation pressure and y-bias for each satellite), polar motion position and rate, UT1 rate, tropospheric zenith delays (piecewise continuous once every 2 hours per site), and phase ambiguities. We use the ionosphere-free linear combination of phase sampled at 2-minute intervals. The data processing starts with the best available satellite ephemerides, normally from our rapid solution, *a priori* Earth orientation parameters from the IERS rapid service, *a priori* tracking station coordinates according to the ITRF93 specification (Boucher, Altamimi, and Duhem, 1994), and previous SOPAC solutions. Among the *a priori* values, only the best known station coordinates and UT1 are tightly constrained. The data processing is iterated on a model-clean-solution cycle 3 times. The solution is of the weighted least squares type. Data cleaning is a crucial step in the process. Bad observation rejecting, cycle slip fixing, and phase ambiguity flagging are performed by an automatic cleaning procedure that relies on the progressively improved (orbital) modeling during the iterations. In the final stage of the processing, a loosely constrained (of all parameters) solution (SINEX-like) file is produced, of which the full covariance matrix will be saved for later weekly solution use.

A weekly solution of 7 daily solutions (according to GPS week) are carried out with the GLOBK (Herring, 1994) software package which is of Kalman filter type. The *a priori* and constrained setups in the weekly solutions are identical to that of daily solutions. A forward filter solution computes a weekly estimate of station coordinates. These are fixed in a back solution which estimates daily orbital initial conditions and earth orientation parameters (pole, pole rate, UT1 rate).

Orbit and EOP estimates from the SOPAC regular weekly solution are reported regularly to the IGS AC coordinator and USNO. The SOPAC orbits agree with the rapid IGS orbits to about 20 cm after a 7-parameter similarity transformation (rotation, translation, and scale). S10 pole-x/y position series agree with IERS Bulletin B to about 0.13 miliarcseconds (Gambis) after offsets are removed.

Daily Rapid Service. The basic procedure for the rapid solution is very similar to the regular daily solution described above. The data processing is launched by computer automatically 13 hours (6am local time) after the end of data collection time (00:00 UTC). According to our experience, most of the key stations, typically 20 at least, will become available at this time. If the total number of stations is less than 18, the rapid processing will sleep for 30 minutes, then wake up to check data availability until enough data are ready. This processing uses the predicted orbit from the previous day, or from the broadcast ephemerides if one of the satellites was repositioned on the previous day. The major difference between rapid processing and regular processing is that the automatic cleaning procedure is more strict, that is, any observations of poor quality or in question are removed to assure full automation. When cleaning in the strict mode, about 10% more data are excluded compared to the regular editing. The total processing time is about 6 hours.

These differences are in an absolute sense, that is the no translation, rotation, or offset are taken into account. There are some high values around day 20 to 50, that indicate the solution suffer from tightly constrained a *priori* UT values which are predictions and in error. Such errors lead to the serious rotation in the orbits. Figure 4a shows the S10 rapid orbit and EOP estimate availability time after data collection ending time (at end of a day in GMT time). The dark horizontal time represents the nominal processing starting time (13 hours after data collection end time). Except for the first 10 days, those delayed ones are normally due to external data source down and occasionally our local network or computer system problem. Figure 4b shows the number of stations included in the rapid solution. On the average, about 26 stations are available for the rapid solutions. Figure 5 shows the rms and offset of SOPAC rapid pole-x and pole-y comparing with USNO-A. Figure 6 compares the SOPAC rapid orbits and the IGS “rapid” orbits. Figure 7 shows baseline precision obtainable with the SOPAC rapid orbits.

Figure 4. SOPAC Rapid Orbit Statistics. Solution availability time and the number of stations included in the rapid SOPAC orbit and EOP solutions. The solid horizontal line in the upper graph represents the nominal processing start time. The first 10 days were later processed for evaluation purposes. Typical reasons for delays are network and computer facility problems.

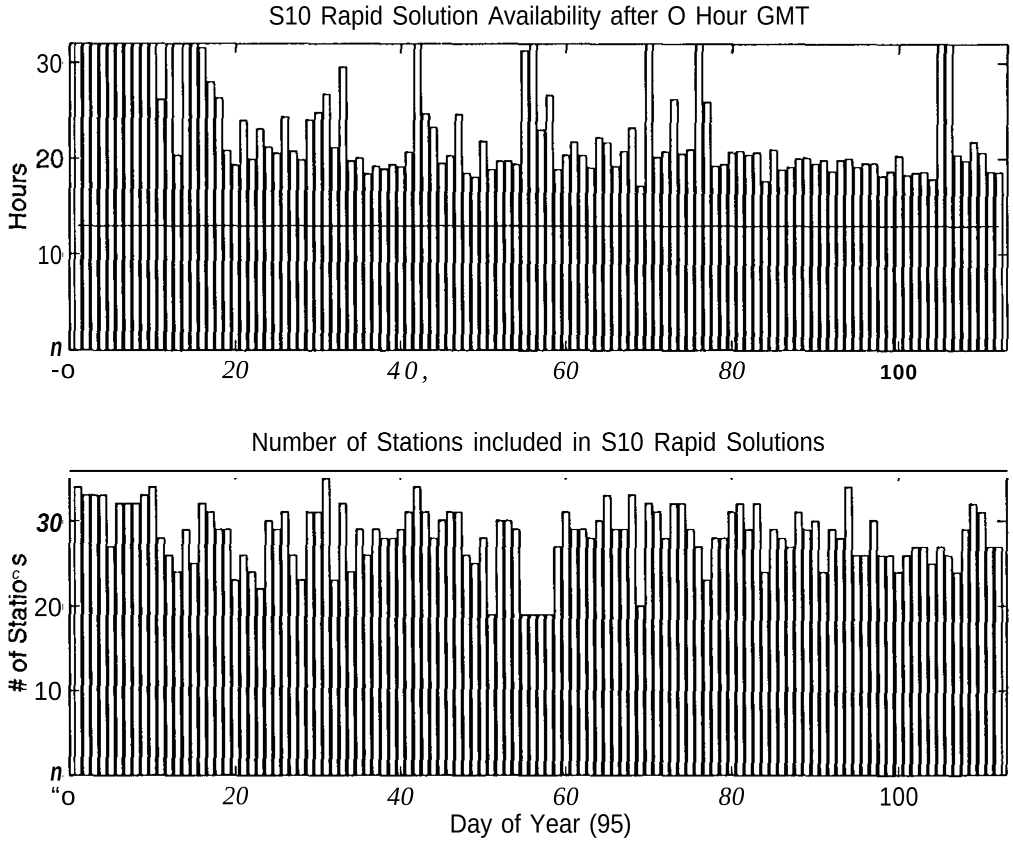
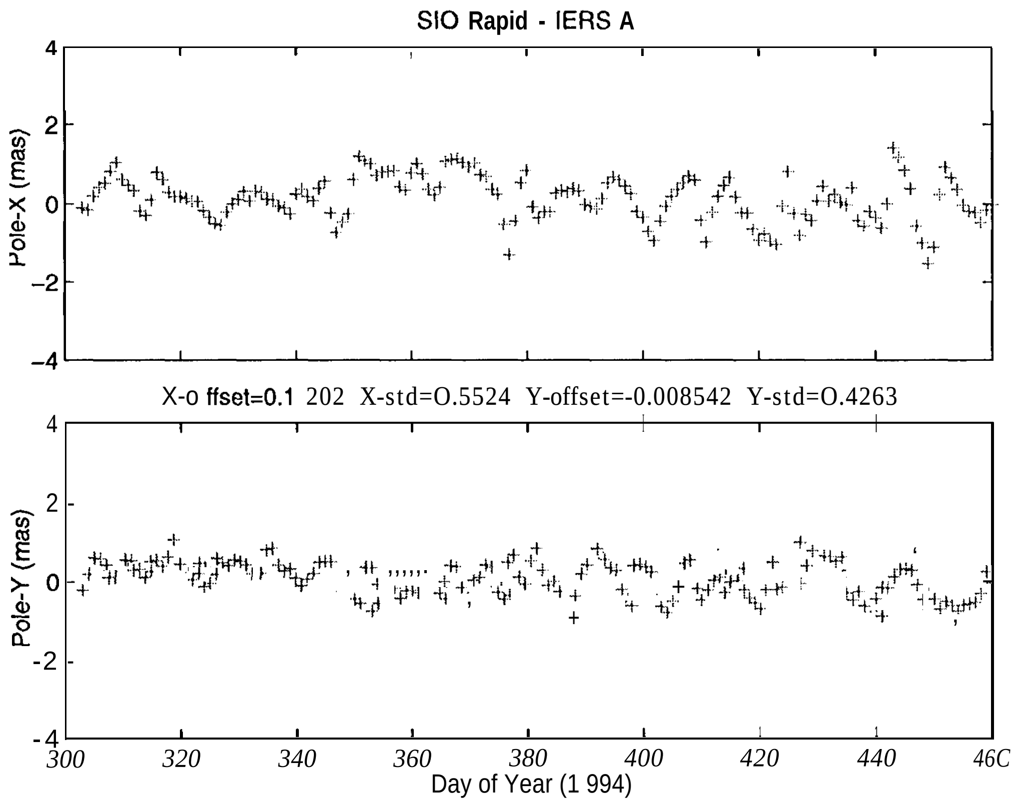


Figure 5. Comparison of SIO rapid polar motion and IERS Bulletin A.



24 Hour Orbit Overlap Difference between SIO Rapid& IGS

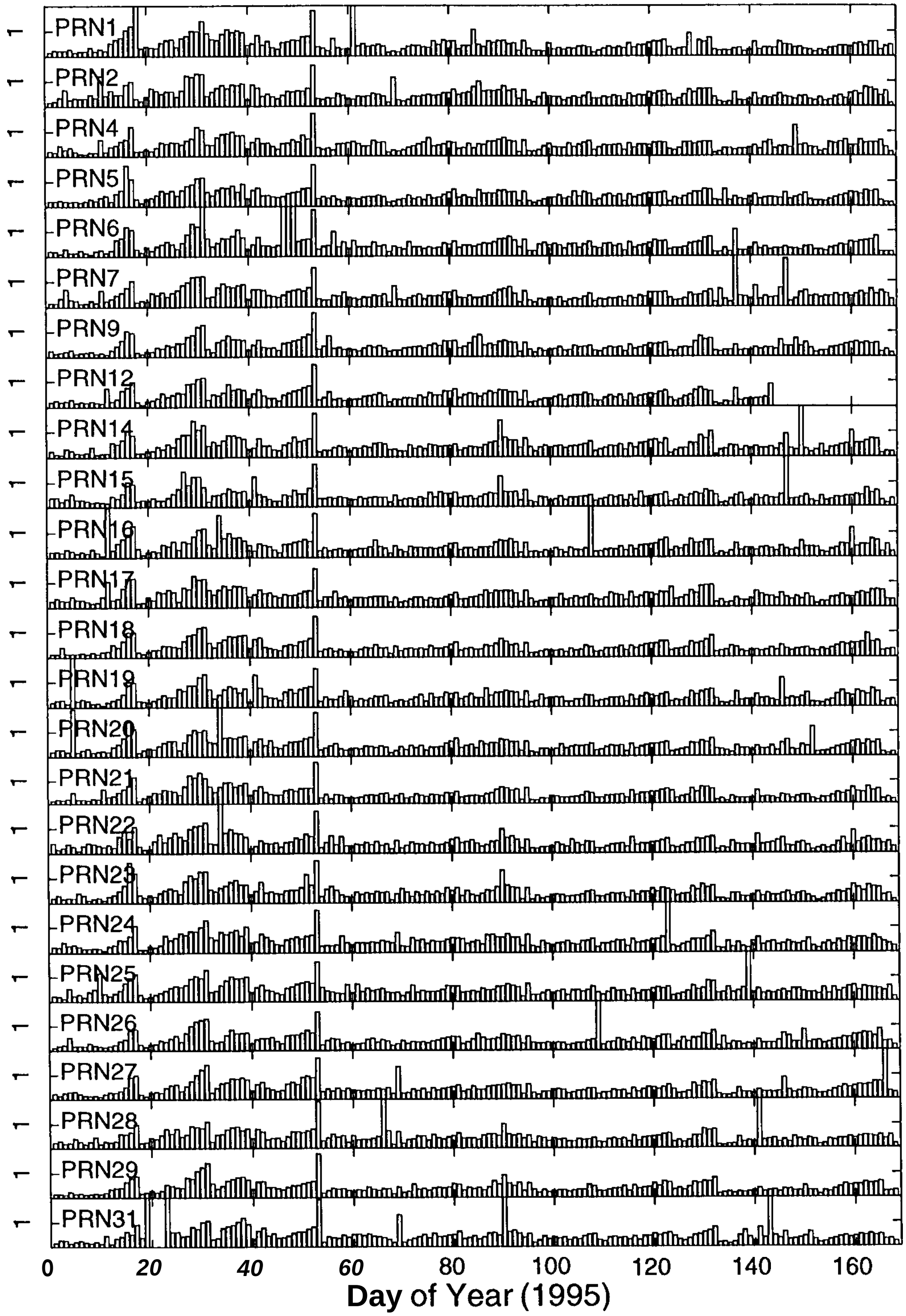
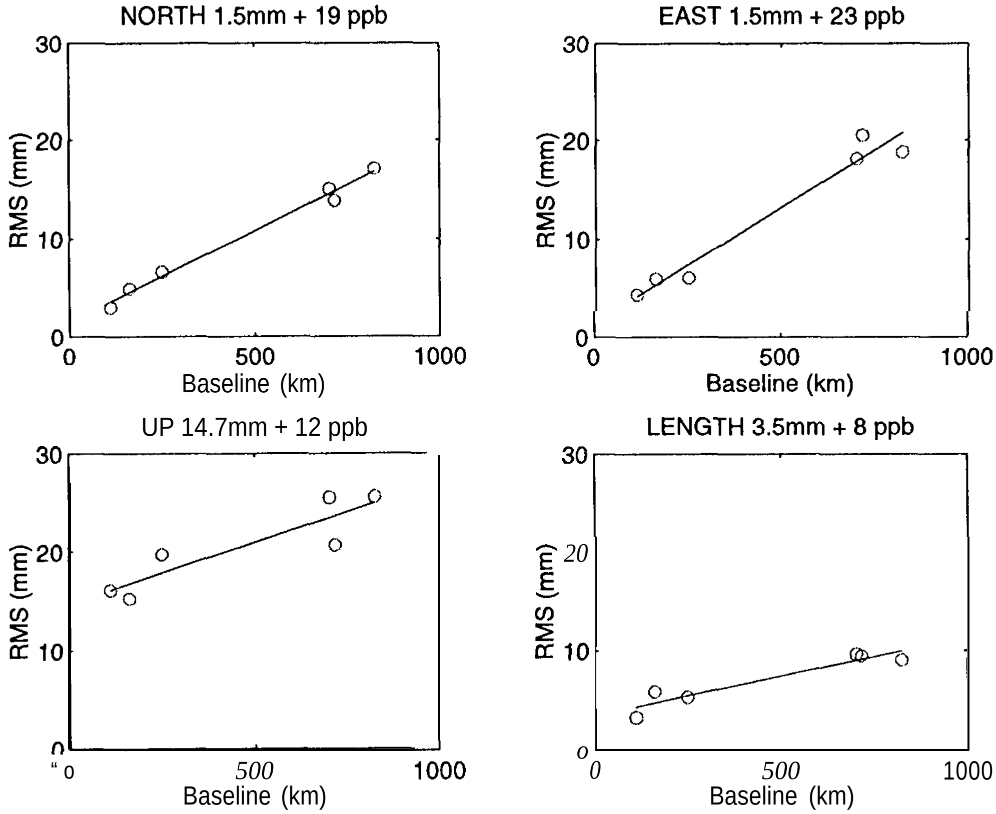


Figure 6. Comparison of SOPAC rapid orbits with IGS. Time series of absolute overlap differences for 24-hour periods between S10 rapid orbits and combined IGS orbits.

Figure 7. Baseline precision using SIO rapid orbits. The rms of individual components are based on 120 days of 24-hour solutions of 4 California stations with no overlapping stations with IGS.



Mapping Global Total Electron Content

Mapping global TEC is carried out with conventional methods using GPS L1 and L2 carrier phase observable assisted by PI and P2 pseudoranges for resolving ambiguities. The TEC can be estimated from pseudorange in an absolute sense but the noise level is very high (Figure 8 upper graph) while TEC can be estimated from phase with very high accuracy in a relative sense. By offsetting the phase estimates, absolute TEC at high precision can be obtained (Figure 8 middle graph). The scatter over smooth-fitting lines is about 10-16e/m2 level in TEC. Figure 8 shows the obvious nighttime low and daytime high. The TEC curves do not overlap at a given time because they are different estimates in space (Figure 9). These points are computed assuming that the centroid height of ionosphere is 350 km on the Earth with mean radius of 6371 km. As shown, the TEC estimates cover a very wide region which makes the global mapping possible. Figure 10 shows a series of 2-hour averaged TEC global maps over a 24-hour period. It can be clearly seen that the solar-activated high TEC region (light area) is moving westwards in time.

Mapping Rapid Tropospheric Precipitable Water

We have begun to routinely produce daily, rapid precipitable water estimates for the NOAA CORS stations equipped with meteorological sensors. All North American IGS stations (only Goldstone in California), including the CORS stations are analyzed using the GAMIT software as soon as the SOPAC rapid

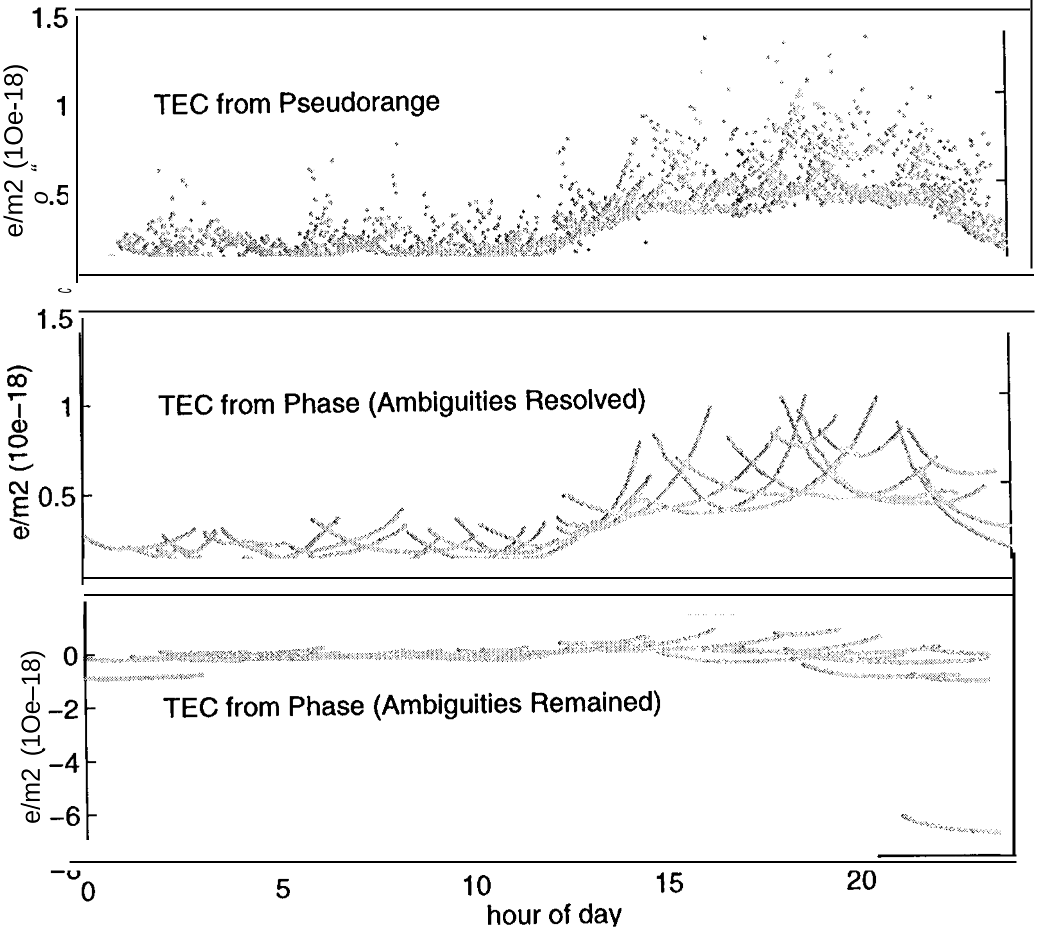


Figure 8. TEC estimates at ALGO. Time series of TEC estimates over a 24-hour period from all satellites observed at station ALGO.

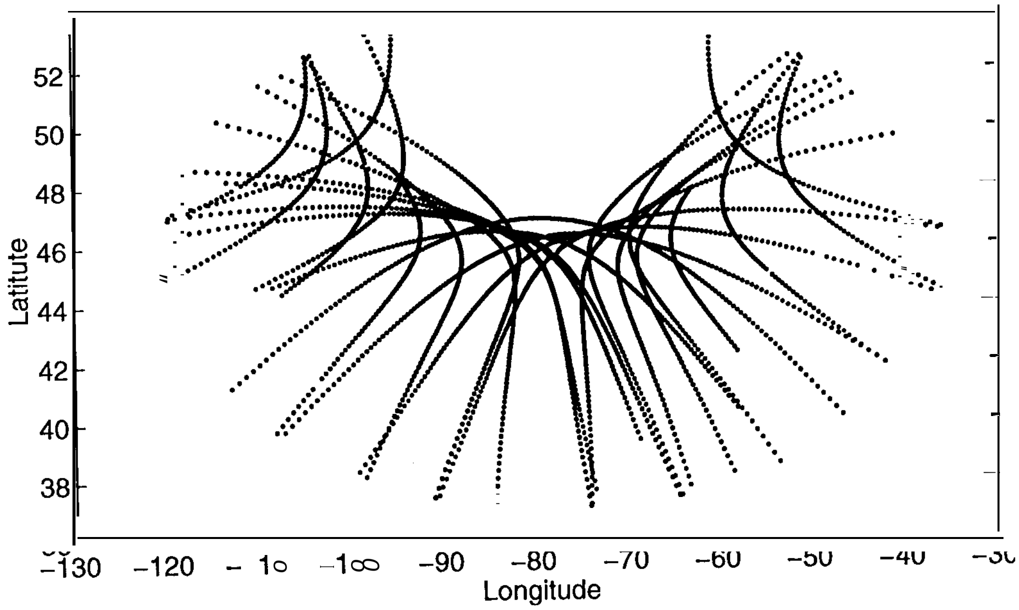
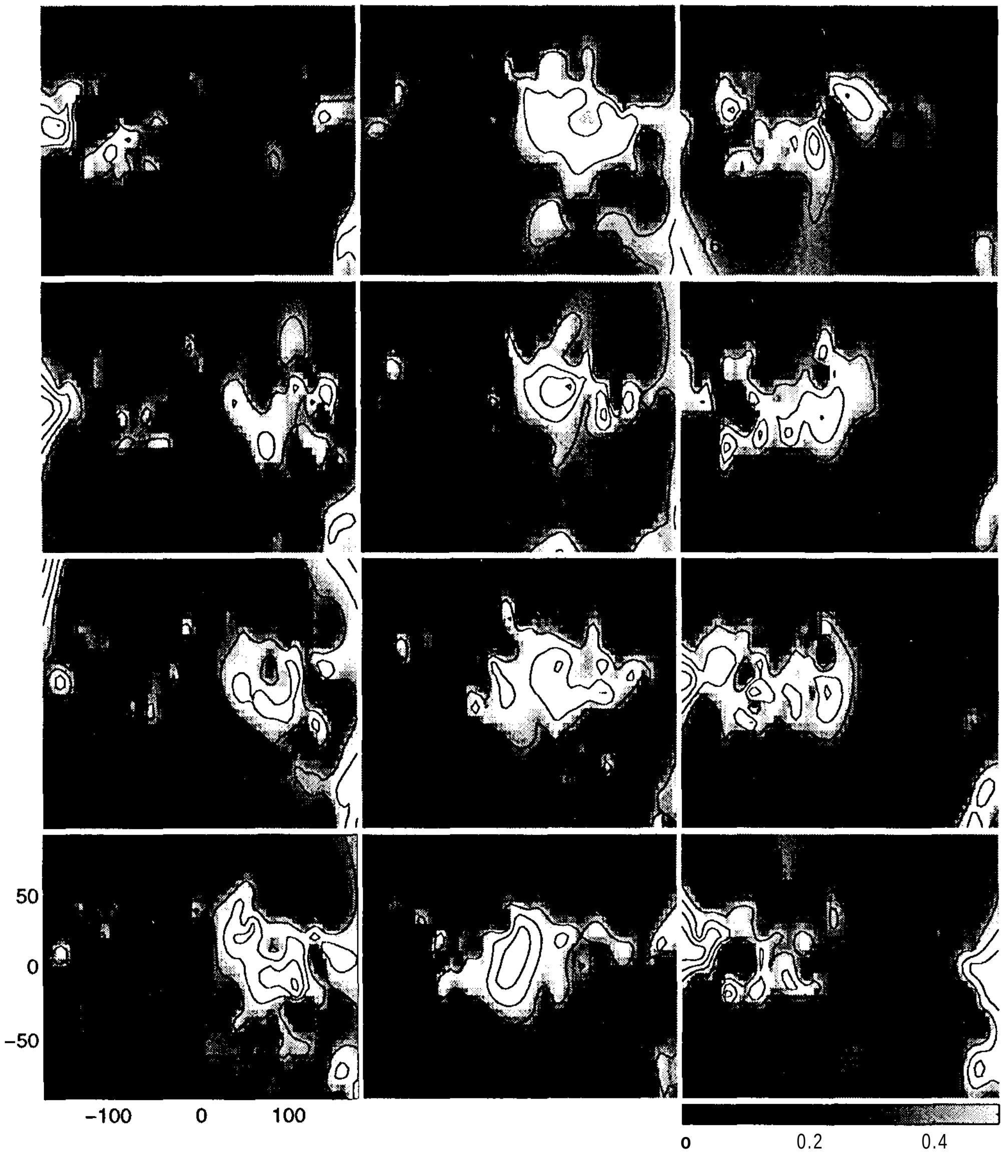


Figure 9. Subionsophere points at ALGO. Subionosphere points during a 24-hour period at station ALGO.

Figure 10. Two-hour averaged global TEC mapping. X-axis is longitude and Y-axis is latitude. Gray scale is in 10^{18} e/m^2.



orbit is generated. The station coordinates and satellite orbits are tightly constrained. Total zenith delay parameters (ZND - zenith neutral delay) are estimated under the assumption that they behave as a first-order Gauss-Markov process. The process correlation time is set to 100 hours, the process standard deviation to 2.5 mm, and the ZND is estimated every 30 minutes at each station. We use the CfA mapping function [Davis, *et al.*, 1985]. The zenith wet delay (ZWD) is recovered from the ZND estimates by subtracting the ZHD time series computed using surface pressure measurements. The ZWD estimates are then transformed into PW estimates as described in Duan *et al.* [1995]. The uncertainty in the PW estimate derives almost entirely from the uncertainty in the earlier estimate of ZWD [Bevis *et al.*, 1994].

Figure 11 shows a 30-day time series of PW for the CORS/NOAA site in Denver, Colorado using the rapid SOPAC orbits and the procedure just described, including a comparison with water vapor radiometer (WVR) determinations of PW. The differences in PW when using the rapid and regular SOPAC orbits is

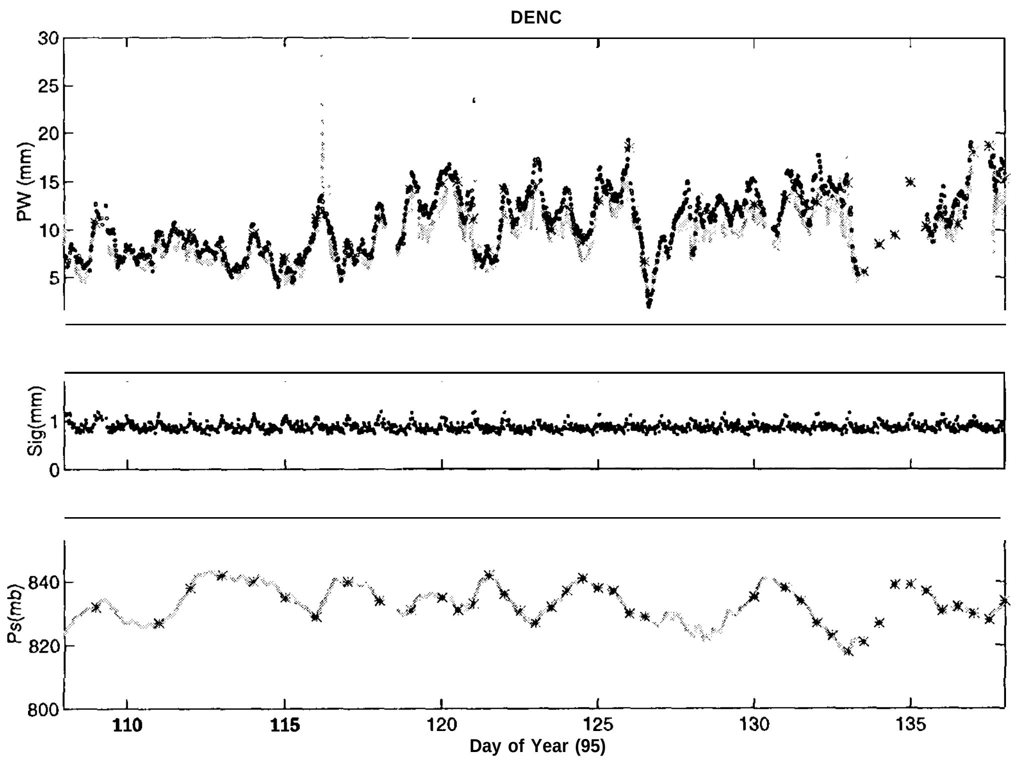


Figure 11. GPS PW series at Denver NOAA CORS station. Solid circles are GPS estimates using 'pure GPS approach' with SOPAC near-real-time orbits. Light dots are WVR estimates. The '' are balloon sounding (radiosonde) estimates. Note that there is a small offset (under 1 mm) between WVR, GPS, and Radiosonde measurements. This is probably due to miscalibration of WVR.*

generally below the l-mm level. These results indicate that PW can be monitored rapidly and automatically using GPS meteorology with about 1–2-mm accuracy.

Acknowledgments

We would like to acknowledge the contributions of Jeff Behr, Burt Oral, Shelley Marquez, Paul Tregoning, and Jie Zhang at Scripps, Tom Herring, Bob King and Simon McClusky at MIT, Mike Bevis, Steve Businger, Steve Chiswell and J.P. Duan at Univ. of Hawaii, and S. Gutman at NOAA. Supported by grants from the National Aeronautics and Space Administration (NASA NAG 5-1917) the Southern California Earthquake Center (SCEC 14-08-00001-A0899 (USC PO 569930)), the U.S. Geological Survey (USGS 1434-92-G2196), and the U.S. National Science Foundation (NSF EAR 9208447, NSF EAR-9416338 and SCEC NSF EAR 89 20136),

References

Bevis, M., S. Businger, T. Herring, C. Rocken, R. Anthes and R. Ware, GPS meteorology: Remote sensing of atmospheric water vapor using the Global Positioning System, J. Geophys. Res. 97, 15,787-15,801, 1992.

Bevis, M., S. Businger, S. Chiswell, T. Herring, R. Anthes, C. Rocken and R. Ware, GPS Meteorology: Mapping zenith wet delays onto precipitable water, J. Appl. Met. 33,379-386, 1994.

Blewitt, G., Y. Bock and G. Gendt, Regional clusters and distributed processing, Proc. IGS Analysis Center Workshop, J. Kouba, cd., Int. Assoc. of Geodesy, Ottawa, Canada, 61-92, 1993.

Blewitt, G., Y. Bock and G. Gendt, Global GPS network densification: A distributed processing approach, Manuscript Geodaetica, in press, 1995. Bock, Y., Crustal deformation and earthquakes, Geotimes, 39, 16-18, 1994.

Boucher, C., Z. Altamimi, and L. Duhem, Results and Analysis of the ITRF93, IERS Technical Note 18, Central Bureau of IERS, Paris, October, 1994.

Calais, E. and J.B. Minster, GPS detection of ionospheric perturbations following the January 17, 1994, Northridge earthquake, Geophys. Res. Lett., 22, 1045-1048, 1995.

Duan, J. , M. Bevis, P. Fang, Y. Bock, S. Chiswell, S. Businger, C. Rocken, F. Solheim, T. Van Hove, R. Ware, S. McClusky, T. Herring, and R. W. King, GPS Meteorology: Direct Estimation of the Absolute Value of Precipitable Water, submitted to J. Appl. Met., 1995.

Gambis, D., Summary of Contributed Earth Orientation Parameters Series, IERS-Bulletin B, Central Bureau of IERS, Paris, (issued monthly).

Gurtner, W, RINEX-The Receiver-Independent Exchange Format, GPS World, July 1994, v.5, no. 7.

Herring, T.A. Documentation of the GLOBK Software v.3.3., Mass. Inst. of Technology, 1995.

King R.W. and Bock, Y., Documentation of the GAMIT GPS Analysis Software v. 9.3, Mass. Inst. of Technology and Scripps Inst. of Oceanography, 1995.

Kouba, J., Orbit Combination and Evaluation Statistics, IGS Electronic Report, NRCan GS Division, Ottawa, (issued weekly).

Rocken, C., R. Ware, T. VanHove, F. Solheim, C. Alber, J. Johnson, M. Bevis and S, Businger, Geophys. Res. Lett. 02,2631 (1993)

Rocken C., T. Van Hove, J. Johnson, F. Solheim , R. Ware, M. Bevis, S. Chiswell and S. Businger submitted to J. Atmos. Oceanic Tech., 1995.

Wessel, P. and W. H. F. Smith, Free software helps map and display data, EOS, Trans. AGU, 72, pp. 445-446,1991.

Zhang J., Y. Bock and P. Fang, Surface Displacements of the 1992 Landers Earthquake from a Distributed Analysis of Global and Regional Continuous GPS Data, Geophys. Res. Lett., in preparation, 1995.

The SIRGAS Project

Luiz Paulo Souto Fortes
IBGE/Departmento de Geodesia
Rio de Janeiro, Brazil

Melvin Jesus Hoyer Romero
Consejo Nacional de Cartografia, Universidad del Zulia
Maracaibo, Venezuela

Walter Humberto Subiza Piña
Servicio Geografico Militar
Montevideo, Uruguay

Hermann Drewes
Deutsches Geodaetisches Forschungsinstitut
Muenchen, Germany

The SIRGAS Project was established during the International Conference on the Definition of a South American Geocentric Datum, during the period October 4–7, 1993, in Asuncion, Paraguay, by an invitation of the sponsoring entities: International Association of Geodesy (IAG), Pan-American Institute of Geography and History (PAIGH), and United States Defense Mapping Agency (DMA). Representatives of each sponsoring entity and of almost all South American countries participated in that Conference.

The objectives established for the project are the following: to define a reference system for South America; to establish and maintain a reference network; and to define and establish a geocentric datum. The goals to be achieved are: to reach the defined objectives in 1997 coinciding with the Scientific Assembly of the International Association of Geodesy (with the exception of maintenance that has a permanent character); to promote and coordinate the work of each South American country in order to get the defined objectives; to establish a high precision GPS network; to concentrate the attention at the beginning on the Horizontal Datum; and to facilitate the connection of pre-existing networks.

Objectives related to the definition of the reference system and of the geocentric datum for the continent have been achieved in the Asuncion Conference, the plenary having chosen the following:

- SIRGAS reference system: IERS (International Earth Rotation Service) Terrestrial Reference Frame (ITRF);
- geocentric datum: coordinate axes based on the SIRGAS reference system and parameters of "Geodetic Reference System (GRS) of 1980" ellipsoid.

The development of the SIRGAS Project encompasses the activities needed for the adoption on the continent of a reference network of precision compatible with the up-to-date positioning techniques, mainly those associated with the Global Positioning System (GPS). Considering the proliferation of GPS utilization, to tie these new surveys to an existing geodetic structure, basically carried out by the use of classical methods (triangulation, traverse, trilateration, etc.), whose precision is at least ten times worse than that easily obtained with the GPS, implies at least a waste of resources. Besides, the multiplicity of classical geodetic systems, adopted by the South American countries, makes the solution of technically simple problems, such as the definition of international borders, very difficult. On the other hand, the adoption of the ITRF as reference system, besides guaranteeing the homogenization of the results internally to the continent, will allow the consistent integration with the networks of other continents, contributing more and more to the effective developing of a "global" geodesy.

During 1994, important progress was achieved towards the establishment of a geocentric reference system for South America. From this point of view, the first meeting of the Working Group II "Geocentric Datum", held during the period 20 through 22 April 1994, in Bogota, Colombia, and the first one of the Working Group I "Reference System" and the second one of the Working Group II, both held during the period October 24–28, 1995, in La Plata, Argentina, have contributed a lot. During the WG I meeting, the SIRGAS GPS campaign was scheduled for May 26 to June 4, 1995, when about 52 stations (Table 1), which will form the SIRGAS reference network, will observe the GPS satellites 24 hours per day. From this high precision frame, the WG 11 will integrate the GPS networks available in each country, using and encouraging the establishment of the necessary international ties. The classical network integration, as Resolution No. 2 of the first WG II meeting, will occur according to the interest of each country. It is important to mention that, among those 52 stations, around eight are IGS stations already functioning in South America, which will guarantee the necessary tie between the SIRGAS reference network and IGS (Figure 1).

Besides the meetings mentioned above, two other events where resolutions that specifically deal with and support the SIRGAS project were adopted should be emphasized: Meeting XXX of the PAIGH Directing Council, through Resolution No. VIII, and Meeting XI of the Directors of South American, Spanish and Portuguese Geographic Institutes, through Resolution No. 8.

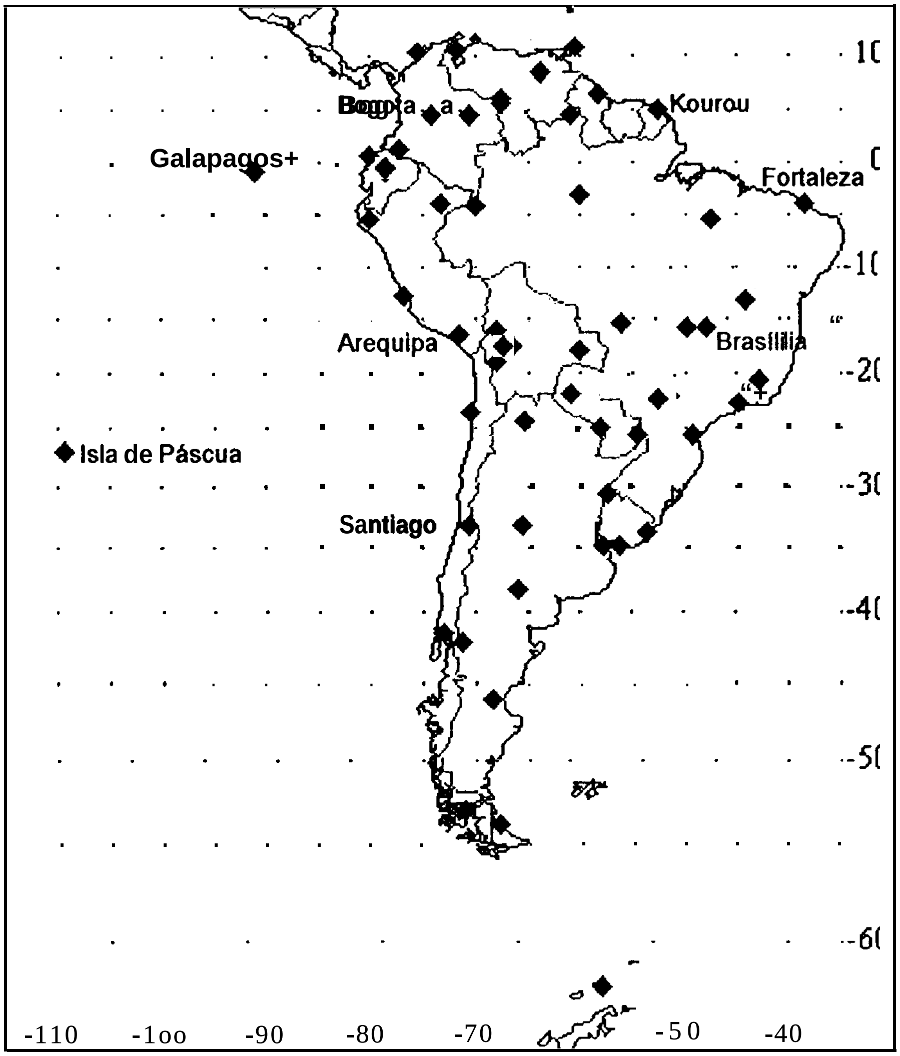
The efforts that have been carried out by various groups and project collaborators, including the sponsoring entities and the IGS community, besides the steps that were already carried out by the Working Groups, have been generating a continually greater participation of various South American countries, establishing the necessary conditions for the achievement of the project objectives.

Detailed information about the project structure, composition, Working Group I and II meetings, including data and processing centers can be found in SIRGAS Project Newsletters #1 and #2, available upon request or under f tp. dgf i. badw-muenchen. de or deged. ibge. gov. br (name: anonymous, passwd: <own e-mail address>, directory: pub/ gps / sirgas).

SIRGAS stations (10.Jan.1 995)				Instr.	Institution
ISLA REY JORGE	Antarctica	-62,3	-58.	(Z12/SSE)	IGM Chile
CHURCAL	Argentina	-24.31	-65.34		Univ. Tucuman
EL MAITEN	Argentina	-42.01	-71.21	Leica	Cat. Rio Negro
LA PLATA	Argentina	-34.91	-57,93	T. Rogue	Ohs. La Plata/GFZ
LOTE 10B	Argentina	-46.04	-66.47	(SSE/Z12)	Cat. Chubut
LOTE 24	Argentina	-38.13	-66.09	SSE	UAGG Mendoza
MORRO	Argentina	-33.27	-65.48	Z12	UAGG Mendoza
PUERTO IGUAZU	Argentina	-25.60	-54.59		IGM Argentina
RIO GRANDE	Argentina	-53.79	.67.75	T. Rogue	Oba. La Plata / GFZ
AZANAQUES	Bolivia	-19.	-66.	SSE	IGM Bolivia
EL ALTO	Bolivia	-16.	-66.	SSE	IGM Bolivia
SURUTUVIA	Bolivia	-16.	-60.	SSE	IGM Bolivia
VILLA TUNARI	Bolivia	-17.5	-66.5	SSE	IGM Bolivia
BOM JESUS LAPA	Brazil	-13.25	-43.42	(SSE/Z12)	·
BRASÍLIA	Brazil	-15.95	-47.66	T. Rogue	IGS (IBGE / JPL)
CACHOEIRA	Brazil	.22.69	-44.96	(SSE/Z12)	·
CUIABÁ	Brazil	-15.55	-56.07	(SSE/Z12)	·
CURITIBA	Brazil	-25.45	-49.23	(SSE/Z12)	·
FORTALEZA	Brazil	.03.66	-36.43	T. Rogue	IGS
IMPERATRIZ	Brazil	-05.50	-47,47	(SSE/Z12)	' - {IBGE/IfE/
MANAUS	Brazil	-03.12	-60.06	(SSE/Z12)	/UFPR/USP/
PRES. PRUDENTE	Brazil	-22.12	-51.41	(SSE/Z12)	/UNESP/UFV/
VIÇOSA	Brazil	-20.75	-42.90	(SSE/Z12)	UFPE}
ANTOFAGASTA	Chile	-23.5	-70.5	T. Rogue	IGM Chile/GFZ
ISLA DE PASCUA	Chile	-26.99	-109.36	T. Rogue	IGS
PUERTO MONTT	Chile	-41.5	-73.	T. Rogue	IGM Chile/GFZ
PUNTA ARENAS	Chile	-53.	-71.		IGM Chile
SANTIAGO	Chile	.33.15	-70.67	T. Rogue	IGS
BOGOTA	Colombia	+04.64	-74.06	T. Rogue	IGS
CARTAGENA	Colombia	+10.5	-75.5	Leica	Agustin Codazzi
LETICIA	Colombia	-04.1	-69.9	Laica	Agustin Codazzi
PASTO	Colombia	+01 .2	-77.2	Leica	Agustin Codazzi
PTO. CARRENO	Colombia	+06. 1	-67.5	Leica	Agustin Codazzi
GALAPAGOS	Ecuador	-01.	-91.	T. Rogue	IGS
LATACUNGA	Ecuador	-01.0	-76.6		IGM Ecuador
MUISNE	Ecuador	+00.6	-60.		IGM Ecuador
KOUROU	Fr. Guiana	+05.13	-52.62	T. Rogue	ESA / IGS
TIMEHRI	Guyana	+06.51	-56.26		Lands & Surv. Dept.
ASUNCIÓN	Paraguay	-25.	-5B.		DSGM Paraguay
M ESTIGARRIBIA	Paraguay	-22.	-61.		DSGM Paraguay
AREQUIPA	Peru	-16.45	-71.48	T. Rogue	IGS
IGUITOS	Peru	-03.9	-73.3	(SSE)	" - {IGN Peru/
LIMA	Peru	-12.8	-76.8	(SSE)	/Univ. FA RFA)
PIURA	Peru	-05.3	-60.2	(SSE)	·
TOBAGO	Trinidad	+11.	-60.5		
CERRO VIGIA	Uruguay	-33.72	-53,58	Z12	{SGM Uruguay/
MONTEVIDEO	Uruguay	-34.06	-56.27	Z12 + Leica	/Fac. Ing
YACARE	Uruguay	-30.60	-57.42	Z12	Univ. de la Rap.)
LA CANOA	Venezuela	+8.57	-63.85	Leica	{DCN/
MARACAIBO	Venezuela	+10.77	-71.67	Leica	/EIG/
PTO. AYACUCHO	Venezuela	+05.7	-67.6	Leica	/DIGECAFA/
STA. ELENA	Venezuela	+04.7	-61.	Leica	/DGFI}

Table 1. Stations of the SIRGAS Reference Network.

Figure 1. Stations of the SIRGAS Reference Network (the IGS ones are named)



The Contribution of the EUREF Subcommission to IGS

E. Gubler
Federal Office of Topography
Wabern, Switzerland

The EUREF Subcommission (EUropean REference Frame) is a body within the IAG Commission X, "Continental Networks". Its task is to establish and maintain a three-dimensional geometric reference frame for the whole of Europe. Starting in 1989 the subcommission has covered the major part of Europe with a GPS network. While the older parts have an accuracy of 3 to 5 cm horizontally and somewhat worse vertically, the new campaigns reach centimeter accuracy. The subcommission, or more specifically its Technical Working Group, has formulated strict rules on how to process the campaigns and how to establish and operate permanent GPS stations, to be accepted as EUREF stations. The EUREF Subcommission has expressed its will to establish a regional densification of the IGS network in Europe and endorsed this with resolution 3 of the Helsinki meeting:

> The IAG Subcommission for the European Reference Frame *endorses* the guidelines for a EUREF network of permanent GPS stations presented by the EUREF Technical Working Group, asks the EUREF Technical Working Group to implement and co-ordinate such a permanent network, *requests* the EUREF members to take the necessary actions to support these activities and *proposes* to the International GPS Service for Geodynamics (IGS) that the EUREF network be the regional densification for Europe of the global IGS network.

AUSL G Associate Analysis Centre

Martin Hendy
Austral ın Surveying and Land/formation Group
Belconnen, Australia

Summary for the IGS Annual Report 1994

AUSLIG Geodesy has been doing global GPS solutions using about 20 IGS sites. Station coordinates, pole position, and eight satellite parameters are estimated. A comparison of the GPS satellite trajectories—generated from the estimated GPS orbit parameters—with the ephemeris produced by the individual IGS Analysis and the IGS combined ephemeris is currently underway. The estimated coordinates of the IGS core sites show very good agreement with the ITRF values.

Regional solutions are being done for the Australian Regional Network (Australia & Antarctica). These computations are performed using both the locally determined satellite orbits and the IGS combined orbit.

The global GPS sites being processed are: Fairbanks, Yellowknife, Algonquin, Goldstone, Kokee Park, Pamate, Easter Island, Santiago, Fortaleza, Madrid, Maspalomas, Ny Alesund, Metsahovi, Hartebeesthoek, Kerguelen, Kitab, Yaragadee, Taipei, Usuda, Tidbinbilla, McMurdo, Casey, and Davis.

Plans are to continue this work in preparation to function as a Type-1 Associate Analysis Centre.

SLR data are being routinely processed.

The Central European Initiative and Its Relation to IGS

Peter Pesec
Institute for Space Research, Dept. Satellite Geodesy,
Austrian Academy of Sciences
Graz, Austria

Introduction

At present, the following eight countries are members of the Central European Initiative (CEI): Austria, Croatia, Czech Republic, Hungary, Italy, Poland, Slovakia, and Slovenia. Within the framework of CEI, the Committee of Earth Sciences section C looks after the field of geodesy. Based on earlier proposals, the Central Europe Regional Geodynamics Project (CERGOP), initiated by Hungarian and Polish scientists, can be considered as a logical continuation of earlier geodynamic activities in the Central European area, now based on modern space techniques and *on* a flexible and reliable organization. CERGOP was approved by the CEI Section C conference in Ksiaz Castle, Poland in May 1993. A detailed concept of CERGOP was introduced during the last IGS workshop in Potsdam (Pesec, 1995). The following condensed summary is given.

The Main Objectives of CERGOP

The main objectives of CERGOP are described in detail in Sledzinski (1994a). They can be summarized as follows: (1) collection of satellite, geodetic, astronomical and gravimetric data for the analysis and interpretation of the geodynamic interactions in the region of Central Europe; (2) investigation of geodynamic processes and geotectonic features in the Central European region, in particular the Teisseyre-Tornquist zone and the Carpathian and Subalpine Orogeny; (3) provision and monitoring of a precise geodetic reference in order to accomplish these tasks; (4) collection of materials for providing a geoid map with centimeter accuracy for Central Europe.

Concept and Realization

The scientific concept of CERGOP is based on the *merging* of on-going national activities in the field of geodynamic research which are supplemented by international projects. Specifically this means that most of the financial burden has to be carried by the national institutions. By now three additional countries have joined the project: Germany, Romania, and Ukraine. Each country is represented by a National Investigator (NI). They constitute the International Project Working Group (IPWG), headed by the CERGOP Management Group (NIs of Germany, Hungary, Italy, and Poland).

The tasks of IPWG include the organization of observation campaigns, the supervising of the study groups' activities, the performance control of the data center and the processing centers, and the liaison with overlapping international projects. Besides the overall project tasks, the members of IPWG disseminate information, and keep and establish contacts with existing international projects and organizations (e.g., IGS, EUREF, WEGENER, IDNDR, EUROPROBE, Baltic Sea Level Project, Extended SAGET, and others). IPWG is chaired by the NI of Hungary and co-chaired by the NI of Poland.

One of the first important steps was the establishment of a Central European GPS Geodynamic Reference Network, which serves as the common basis for all scientific projects. It consists not only of the mere sites but also of the complete infrastructure which enables a proper operation (instrumentation, maintenance, communication, observing personnel). Financial support for covering part of the maintenance of CEGRN during the next three years was given by the European Community.

During the last year altogether 11 CERGOP study groups (CSGs) were proposed by the national representatives. They are formed by the collaboration of scientists from two or more member countries and are designed for carrying out research in a particular field. This field may cover objectives directly related to CERGOP (co-research) or only linked to CERGOP (associated research). Some CSGS have started their work recently, and some are just in the stage of being developed (Sledzinski, 1994b).

The CERGOP working group meets twice a year at different places in the member countries. Detailed summaries of the national activities are supplemented by the reports of the data center, the processing centers, and the individual study groups. All reports are compiled and published (presently in the "Reports on Geodesy" of the Warsaw University of Technology).

Central European GPS Geodynamic Reference Network (CEGRN)

In order to keep the number of sites at a reasonable level IPWG decided to appoint-after consultation—to each member country a restricted number of stations which are served within CERGOP—even if they are upgraded to a permanent station. At present CEGRN comprises 31 sites (Pesec, 1995), which are obliged to take part in a five-day epoch campaign every year.

The data center at Graz is responsible for archiving all incoming data (permanent stations, epoch campaigns), checking and distributing the data to other organizations, and providing continuous access to the stored data sets. It is organized similar to the IGS data centers and can be queried via anonymous FTP and dial-up modem. Up to 3-GByte disc memory is at disposal for data storage; older data are stored on magneto-optical discs.

By now four processing centers are in operation:

- Institute of Geodesy and Geodetic Astronomy, Warsaw, Poland;
- Institute for Space Research, Graz, Austria;
- Research Institute of Geodesy, Zdiby, Czech Republic;
- FOMI Satellite Geodetic Observatory, Pent, Hungary.

IFAG Frankfurt indicated its interest to act as an additional processing center in the future.

The main task of the processing centers is to compute an annual set of coordinates for all CEGRN stations. All processing centers are currently using the Bernese software package; CSG 4 determines and recommends the official set of coordinates. In addition, the determination of daily coordinate sets for the permanently recording stations is on the schedule.

The products placed at disposal by the data center for further use are station descriptions (including receiver types and eccentricities), relevant sets of coordinates and the respective covariance matrices, and in future, specific data of the station environment like 4-D meteorological data and multipass information.

Possible Relations of CERGOP to IGS

CEGRN can be regarded as a regional reference frame, which was established according to the guidelines of IGS. A considerable part of the reference stations was observed during the IGS Epoch'92 campaign giving a first link to the global IGS frame. CEGRN contains the VLBI/SLR/GPS fundamental station Wettzell (FRG) and the SLR/GPS stations Graz (Austria), Borowiec (Poland) and Potsdam (FRG) operating as European core stations of IGS as well. In addition, the permanently operating stations Jozefoslaw and Lamkowko (Poland), Pecny (Czech Republic), Padova (Italy) and Hafelekar (Innsbruck, Austria) make their data available—via Internet or Modem—to the CERGOP data center at Graz, which transfers all collected data to the regional IGS data center at IFAG Frankfurt on a daily basis. At present, altogether eight stations of the CEGRN network monitor the CERGOP reference frame on a permanent basis; their data are included in the daily solution of the IGS orbit determination center CODE at the University of Berne.

It should be stressed that, according to the present plans, some more stations will receive a permanent status in the near future (after solving some communication problems). Daily solutions computed at the CERGOP processing centers and referred to ITRF will be routinely available. At least one complete set of coordinates per year is at disposal for all CEGRN stations which can be incorporated into regional and global solutions.

Conclusions

The Central Europe Regional Geodynamic Project takes a considerable part of national geodynamic investigations of 11 countries under a common umbrella. Mutual assistance promotes the use of modern space techniques for attaining accuracies of coordinates in the sub-centimeter region which is required for geodynamic research. Through accepted procedures the products can be incorporated in continental and global solutions. The activities are controlled by the International Project Working Group. However, the main tasks have to be fulfilled and financed by the underlying national organizations. Some financial support has been given by the European Community within "Copernicus" for the next three years,

References

Pesec, P., CERGOP and Its Relation to IGS; Presented at the IGS Workshop in Potsdam, May 1995.

Sledzinski, J., *et* al., Proceedings of the 1st CEI CERGOP Working Conference Warsaw, Poland, February 1994; Reports on Geodesy No. 2 (10), 1994a, Special Issue.

Sledzinski, J., *et* al., Proceedings of the 2nd CERGOP Working Conference Pent/ Budapest, Hungary, November 1994; Reports on Geodesy No. 5(13), 1994b, Special Issue.

Lamkowko Satellite Observatory

Lubomir W. Baran
Olsztyn University of Agriculture and Technology
Olsztyn, Poland

The Satellite Observatory of the Olsztyn University of Agriculture and Technology was established in 1961 on initiative of the Committee for International Geophysical Cooperation of the Polish Academy of Sciences. The Observatory was located at the area of the University Campus Kortowo, in the southern part of Olsztyn. It was registered in COSPAR as an International Satellite Tracking Station, number 1151.

In the years 1961–78 visual observations of artificial Earth satellites were carried out, at the beginning only in the framework of the Ephemeridal Service, and since 1964 also within international programs of study of the upper parts of the Earth atmosphere (INTEROBS, EUROBS, ATMOSPHERE). Observations of low satellites were carried out with special telescopes having large fields of view (AT-1, TZK) as their feature. Specially adopted theodolites were used for this purpose. Also a digital theodolite TEOSAT was built at the Observatory to meet these requirements.

In 1978 the Observatory was moved to the little village of Lamkowko, located nearly 30 km to the northeast of Olsztyn. At the *new* location, a camera, AFU-75, for photo observations of artificial Earth satellites was installed. The observations performed with it were used for realization of the research programs ATMOSPHERE and PHOTODOPPLER, coordinated by INTERCOSMOS.

In the 1980s, theoretical and then also practical activities took place at the Observatory, aiming at application of the Doppler observations to regional geodynamic studies as well as to realization of various engineering tasks. The observations were performed taking advantage of the Doppler receiver DOG-3, designed and constructed in Poland.

The Satellite Observatory in Lamkowko got its own GPS receivers (ASHTECH MD-XII) in February 1991. Thanks to that the Observatory was able to take part in the first IGS observational campaign (July 25–August 8, 1992) as a Fiducial Station. In the years 1992 through 1994 the Observatory participated in many other observational campaigns connected, for example, with extending the EUREF network to the territory of Poland and Baltic States (EUREF-POL and EUREF-BAL), as well as with regional geodynamical studies (projects: Baltic Sea Level, Central Europe Regional Geodynamics Project, Geodynamics of Ukrainian Carpathians).

Since 1994 the Observatory has owned a Turbo Rogue SNR-8000 receiver. It enabled permanent observations to start from 1 December 1994 in the framework of the International GPS Service for Geodynamics.

Support of the CNES GPS Tracking Network to the IGS

Loic Boloh
Centre National d'etudes Spatiales
Toulouse, France

Introduction

Since 1991, CNES, the French Space Agency, has been contributing to the International GPS Service for Geodynamics. Through its Toulouse Operational Center, CNES currently manages four stations which are part of the International Network:

- Grasse, France
- Hartebeesthoek, Rep. of South Africa
- Kerguelen Islands, Southern Indian Ocean
- Pamatai, Tahiti Island, French Polynesia

CNES sites are equipped with permanently installed receivers, which are dedicated to continuous GPS satellites tracking.

Toulouse Operational Center

An Operational Center at CNES in Toulouse performs Network management, which includes tasks such as data management, network maintenance, and users' interface.

The four CNES stations have access to direct communications links with the Toulouse Operational Center. GPS raw data, along with meteorological surface measurements (HART and PAMA), are transmitted daily to Toulouse. The data are also stored at each site for backup. CNES personnel in Toulouse:

- overview data transfer from the stations to Toulouse,
- assess performance of the data taken by the stations of the network,
- ensure data are made available to the users within the proper time delay,
- meet special requirements from the users in term of data availability,
- manage data storage at the Toulouse Operational Center.

At the Toulouse Operational Center, data are uncompressed and rinexed; data completeness is checked and a quality control is performed. Rinexed data are then stored on a workstation to be retrieved by users. Every day data are transferred from Toulouse to the IGN Global Data Center in Paris which provides on-line access to the community.

Besides data formatting and validation, the Toulouse Operational Center performs Network maintenance:

- to assist station personnel for first-level maintenance,
- to perform diagnosis on GPS receivers in case of anomalies,
- to direct and coordinate equipment shipment if maintenance cannot be performed on-site,

. to provide the interface between the network and the industrial maker when required to perform maintenance actions,

- to ensure that the necessary equipment to perform first-level maintenance is available or can be secured for each station.

Grasse

In February 1995 a Turbo Rogue (SNR-81OO) was installed near Grasse, southeast of France, at the Calern Observatory which is part of Observatoire de la Côte d'Azur (OCA). It is collocated with SLRS and LLRs; the GPS antenna, which is stationed close to a mobile VLBI mark, is mounted on a dedicated concrete pillar on bedrock with forced centering plate.

The GPS receiver is operated and monitored by OCA personnel; data are retrieved daily by the Toulouse Operational Center through the Internet.

Hartebeesthoek

The Rogue SNR-8 at Hartebeesthoek, Rep. of South Africa, has been continuously tracking GPS satellites since January 1991. The receiver is set up at the CNES satellite tracking station, near the radio observatory of Hartebeesthoek, which provides a VLBI reference point.

This GPS station was part of the 6-station Global Network for the TOPEX-Poseidon project. It is operated and monitored by Satellite Applications Center personnel from CSIR, who also staff the CNES satellite tracking station 24 hours a day. Raw data are transferred daily to Toulouse through a permanent link set up for satellite tracking applications. The allocated bandwidth for GPS data is 9600 bps.

Kerguelen

A Rogue SNR-8C (mini-rogue) has been operational since mid-November 1994 in the Kerguelen islands, in the southern Indian Ocean. The site is located on the main island, at Port-aux-Français, in IFRTP (Institut Français pour la Recherche et la Technologies Polaires) facilities and close to a CNES satellite tracking station.

The receiver is operated and monitored by IFRTP personnel from the Geophysics Laboratory. Raw data are transferred daily to Toulouse through a permanent link set up for satellite tracking applications. The allocated bandwidth for GPS data is 9600 bps.

Pamatai

The Rogue SNR-800 at Pamatai on the French Polynesian island of Tahiti has been continuously tracking GPS satellites since January 1992. The receiver is set up in the facilities of the CEA (Commissariats à L'Énergie Atomique) Geophysics Laboratory (LDG).

The receiver is operated and monitored by LDG personnel. Raw data are transferred daily to Toulouse through a NUMERIS type link (64 bps). NUMERIS is a service for data transfer offered to general customers by France Telecom.

Receiver Tracking Performance

During the year 1994, two major anomalies occurred, which degraded network tracking performance.

The first anomaly occurred in July at Pamatai when the receiver software was upgraded to Meenix 7.8; 7 days of tracking were lost. The second anomaly occurred in December at Hartebeesthoek, when lightning struck and damaged the GPS antenna. Tracking was interrupted on December 17 and resumed after the antenna was changed on January 27.

No anomaly was recorded at Kerguelen from mid-November to December 31, 1994. For 1994, the overall tracking success rates are the following:

HARTEBEESTHOEK	95.6 %
KERGUELEN	***100 %***
PAMATAI	97,6 %

Contribution from GPS Station in Brussels (BRUS)

Carine Bruyninx
Observatoire Royal de Belgique
Brussels, Belgium

The Royal Observatory of Belgium (ROB) has a long tradition of collaboration in astronomical and geodetic international campaigns. The ROB participated in the BIH observations for time and latitude determinations and in the first European geodetic network (WEST) developed for satellite observations, from 1966 to 1971. From 1972 to 1993, as a station of the DMANTC TRANET network, permanent tracking of Transit satellites was conducted at ROB. From 1989, GPS measurements were carried out in the frame of the international EUREF89, EUREF-NORTH, EPOCH92, EUREF-L-D-B94 campaigns and different national GPS campaigns.

A TurboRogue receiver, permanently operating at the ROB in Brussels, has been included in the IGS network since November 1993. The data are processed by the CODE processing center.

In support of the deployment of a GPS zero-order geodetic network (30 stations), by the Belgian Geographical Institute, and due to a growing interest of the Belgian GPS user community, three more permanent TurboRogue receivers were installed in Belgium during 1994. All four receivers are now operating permanently and the data are processed daily at the ROB with the Bernese software and self-developed programs. Besides the objective defined above, the principal goals are the study of the ionosphere and the determination of precise station coordinates in an international reference frame, allowing the study of correlations between the coordinate variations and other geophysical phenomena.

The IGS station in Brussels is very interesting from a geophysical point of view because of the collocation with other geophysical instruments, A TRANET station was operating on the same site from 1972 to October 1993, showing better than 90% agreement between ionospheric disturbances calculated from Doppler measurements and earlier GPS measurements. A superconducting gravimeter has been continuously recording at the ROB and until now absolute gravity measurements were carried out twice a year. In 1996 an absolute gravimeter is expected to be operating on a regular basis. Ground water level variations are monitored and seismic measurements are continuously made on site. At the same site, the Belgian Royal Meteorological Institute measures the meteorological parameters which influence the GPS signal several times a day. Precise frequency is made available to the GPS receiver by an H-maser.

Until now the three permanent stations (beside Brussels) have only been included in the EUREF-L-D-B-94 network; the calculation of precise ETRF89 coordinates is in progress. In the meantime all four sites were included in the national densification of ETRF89 (1994). In this way the four permanent stations are the backbone of the Belgian national zero-order geodetic network based on GPS measurements. Thanks to their permanent character the calculation of their ITRF coordinates and associated changes are now in progress.

The Belgian fundamental point for leveling is located at the ROB and the GPS station is a fundamental part of the national zero-order GPS network.

In this way the GPS station at the ROB combines the national and international aspect of GPS and offers collocation with a variety of other geophysical instrumentation.

University of Padova (UPAD)

Alessandro Caporali
University of Padova
Padova, Italy

The station UPAD started tracking activities at the experimental level in January 1994, with the official start of the IGS. The antenna of the Trimble 4000SSE receiver was originally mounted above the dome of an unused astronomical observatory in downtown Padova, on the roof of the University's main building. This site was selected because of its unobstructed horizon, nominal quality of the GPS data and logistic facilities provided by the University. The site was assigned the DOMES number 12750M001.

Late in 1994 the radio frequency environment worsened to the extent that the data became unusable. Fortunately it turned out that it was sufficient to move the antenna just few meters apart from the DOMES 12750M001 location to re-establish normal tracking conditions. The new site was monumented and a new site description was submitted to the IGS. The DOMES number of this new site, in effect since January 1995, is 12750 MO02.

In 1994 extensive work was done to improve communications. The receiver was interfaced to a PC via an RS232 port at 38.4 Kbaud. From the PC the data were originally sent to the VAX of the University Computer Center, via modem connection through the local phone network of the University. The download process required almost two hours daily but proved reliable and gave a lot of experience on automating procedures via modem. Late in 1994 an Ethernet connection with the VAX was cabled up to the receiver and data download improved in speed considerably. It was decided to keep the modem procedure as a backup.

As of February 1995 we considered the experimental phase concluded. Daily RINEX files are compressed in accordance with the IGS standards, are checked with the QC program of UNAVCO, and are sent to the regional Data Center of the Italian Space Agency in Matera, where they arrive normally between 00:30 and 00:45 UTC. From there they are relayed to IfAG in Frankfurt.

Besides the contribution to the IGS, support to local projects is provided in the following fields:

- applied geology: in the Euganei Hills, about 15 km from Padova, water pumping results in subsidence. A structural model of the deformation uses height changes determined by a local network of GPS receivers which make reference to the IGS site UPAD;
- cadastral survey: roving single-frequency GPS receivers are used by surveyors to map borders of plots of land. Updated measurements of the areas are obtained in support of the management of agricultural resources. The UPAD station serves as unique reference for all local surveys;
- aircraft navigation: two single frequency stations are operated in cooperation with the Local Command of the Air Traffic Control to experiment on the procedures for monitoring the integrity of the GPS signals by repeated computation of the baselines joining the receivers to the UPAD site.

Future plans include the improvement of the capability to provide, at the UPAD site, GPS related services to the local community, such as GPS data and ephemeris, gravity, trigonometric and leveling data, geoidal undulations and digital terrain models.

GL/NOAA Operational Data Center

Miranda Chin
National Oceanic and Atmospheric Administration
Silver Spring, Maryland

BERMUDA

4_Char_Id: BRMU IERS DOMES Number: 42501S004

Geographical Location: The station is located at the Bermuda Biological Station for Research of Bermuda Island.

Operation Agency: GL/NOAA Operational Data Center (GODC)

Site Description: The GPS station is located in the Wright Hall building. The tracking system was established on March 12, 1993.

GPS Tracking System Configuration

Receiver (type: Rogue SNR-8000, serial #: T307, firmware: 3.2)
Antenna (type: Dome Margolin T, serial #: 148)
PC (type: 386)
Uninterrupted power supply (UPS)
High speed modem (type: Telebit Trailblazer+)

System Installation

Antenna Installation: The antenna is mounted on the roof of the Wright Hall building.

Receiver Installation: The receiver is located inside an office of the building and is connected to a UPS unit, The operation remote control and the data communication to the receiver are provided by a PC which directly connects to the receiver via an RS232 cable.

```
                                    Operation Remote Control
1---------1        1-----1              1-----1
|antenna|--||---|  U P S  |---|    |-------|modem|----------|
1---------1  |  |  1-----1   |  |         1-----1           |
     |----------         1---------1
     | receiver  <----->| On_site |                    1---------1
     1----------   RS232  | PC      1--------------------[ GODC |
                         1---------1     Internet        1---------1
                                    Data Communication Route
```

Tracking Configuration

The *receiver* is operating in fixed position mode and is continuously recording measurements every 30 seconds onto the flash card. The clock steering capability is enabled.

Data Communication

The daily tracking data are downloaded from the receiver to the on-site PC at 00:10 UTC; then the data are forwarded to GODC for rinexing and distribution.

```
1----------1 00:10 |------------| Inter |---------|Inter 1-------1
| Receiver |------->| on_site  PC  |<------| GODC |----->| CDDIS |
1---------1 RS232 1------------1  Net  1---------1  Net  1-------1
```

Data Availability

On-line data sets: Copies of the raw and RINEX data sets are available on-line through GODC; the access information can be found inthe GODCreport.

Off-line data sets: Two copies of data sets collected more than 200 days prior are stored on optical disks and DAT tapes.

Other Geodetic Measurements

Mobile Laser, Mobile VLBI

FORTALEZA

4_Char_Id: FORT IERS DOMES Number: 41602M001

Monument Inscription: SAT92009

Geographical Location: The station is located at the Instituto National de Pesquisas Espaciais (INPE) site in Eusebio which is approximately 22.7 km southeast of the city of Fortaleza in the state of Ceara on the Atlantic coast of northeastern Brazil.

Operation Agencies: The daily operation is provided by INPE at Fortaleza, Brazil and by GL/NOAA Operational Data Center (GODC).

Site Description: The GPS site was established on May 13, 1993. A local control survey was conducted in September 1993. In this survey vectors between the GPS monument, the VLBI reference point, and four additional geodetic control points were determined.

GPS Tracking System Configuration

Receiver (type: Rogue SNR-8000, serial #: T119, firmware v: 2.8)
Antenna (type: Dome Margolin T, serial #: 119)
PC (type: Compaq 386/20)
External frequency standard (type: Hydrogen maser)
Uninterrupted power supply (UPS)
High speed modem (type: Telebit Trailblazer+)

System Installation

Monument location and description: The monument is a standard IBGE disk star-drilled in the concrete roof of the eastern-most observatory building. It is about 0.4 m south of the north edge of the building and 0.4 m east of the west edge of the building.

Antenna Installation: The Dome Margolin T chokering antenna is located on top of an aluminum platform. The platform is supported by two sides of the building and a pole. A fiber plastic cone shape dome is used for covering the antenna.

Receiver Installation: The Rogue SNR-8000 is located inside the main office building. A 5-MHz output from a maser clock is connected to the receiver lpps input. The data communication is provided by a PC which directly connects to the receiver via an RS232 cable.

```
                                   1-----1
                                ---|UPS |-----|
     1---------1                |    |-----|    |
     | antenna |-------1        |               |
     1---------1       1----------1 RS232 1-------1      1-----1
                       | receiver |<------>|on_site|---->|modem|
                       1----------1        | PC    |     1-----1
       |-------               | lpps       1-------1
       | maser  --------                   Data Communication
       |-------|  5MHz
```

Tracking Configuration

The receiver is operating in fixed position mode and is continuously recording measurements every 30 seconds onto the flash card. The digital potentiometer is disabled.

Data Communication

Step 1. The daily tracking data are downloaded from the receiver to the on-site PC at 00:10 UTC. Then the data are forwarded to the computer at the Federal University of Ceara in Fortaleza (UFC) via a high speed modem.

```
1----------1  00:10 l------------l        1-----1
| Receiver |------->| on_site PC|------>| UFC |
1----------1  RS232 1------------1 modem |-----|
```

Step 2. The computer at ATSME/INPE gets the data from UFC and then transfers them to the HP 755 computer at GODC via the Internet for data processing and distribution.

```
|------| Internet |----------|Internet |---------|      1-------1
| UFC |<--------- |ATSME/INPE| -------->| GODC    |---->| CDDIS |
1------1          1----------1          1---------1      1-------1
```

Data Availability

On-line data sets: Copies of the raw and RINEX data sets are available on-line through GODC; the access information can be found in the GODC report.

Off-line data sets: Two copies of data sets collected 200 days prior are stored on optical disks and DAT tapes.

Other Geodetic Measurements

VLBI, Absolute Gravity

RICHMOND

4_Char_Id: RCM5   IERS DOMES Number: 40499S018

Geographical Location: The station is located at the U.S. Naval Observatory Time Service Substation in Perrine which is approximately 25 miles south of Miami, Florida.

Operation Agency: GL/NOAA Operational Data Center (GODC)

Site Description: A number of GPS systems have been installed at this station since February 1988. The current system was established on October 11, 1993.

GPS Tracking System Configuration

Receiver (type: Rogue SNR-8000, serial #: T160, firmware: 3.0.32.2)
Antenna (type: Dome Margolin T, serial #: 148)
PC (type: 386)
External frequency standard (type: cesium)
Uninterrupted power supply (UPS)
High speed modem (type: Telebit Trailblazer+)

RCM5 *System Installation*

Monument location and description: The monument is located at the east end of the main office building and is a combination of a ground plane and a galvanized pipe. The ground plane is made of a one meter square plate of aluminum. A punch hole in the center marks a permanent location for mounting the antenna. This ground plane is mounted on top of a galvanized pipe. The pipe is held by two brackets to the wall of the building, set in cement in the ground.

Antenna Installation: The antenna is held in place by a 48-cm stainless steel ring. A spike is used to position the antenna to the punch hole in the center of the ground plane. Then the ring is held onto the ground plane by three stainless steel studs which are also used to level the antenna. In addition, four tabs are used to reinforced the antenna onto the ring.

Receiver Installation: The receiver is located inside the main office building. A 5-MHz line from a cesium clock is connected to the receiver 1pps input. The operation remote control and the data communication to the receiver are provided by a PC which directly connects to the receiver via an RS232 cable.

```
                                   -----|          Operation  Remote  Control
                               ---  UPS|-- --|              1-----
 1---------1                   |    -----|   |        |-----|modem -----|
 | antenna  1------   --- |    |             |        |     |-----
 1---------1          ----------   RS232   ---------- |                1---------1
                      receiver    <------>  on_site PC |                | GL/NOAA |
                      ----------            1----------1                1---------1
  1-------1                |  lpps
  |cesium  1-----------                               |-------------------|
  1-------1  5MHz                                           Internet
                                                  Data  Communication  Route
```

Tracking Configuration

The receiver is operating in fixed position mode and is continuously recording measurements every 30 seconds onto the flash card. The clock steering capability is disabled.

Data *Communication*

The daily tracking data are downloaded from the receiver to the on-site PC at 00:10 UTC; then the data are forwarded to GODC for rinexing and distribution.

```
1----------1 00:10 |------------| Inter |--------- |Inter 1-------1
| Receiver |------->| on_site PC |<------| GODC    |----->| CDDIS |
1----------1 RS232 1------------1 Net 1---------1 Net 1-------1
```

Data Availability

On-1ine data sets: Copies of the raw and RINEX data sets are available on-line through GODC; the access information can be found in the GODC report.

Off-line data sets: Two copies of data sets collected more than 200 days prior are stored on optical disks and DAT tapes.

Other Geodetic Measurements

VLBI – From December 1983 to August 1992.
Absolute Gravity – Measurements were taken in 1989, 1990, and 1991.
SLR - Mobile Laser
DORIS

WESTFORD

4_Char_Id: WES2 IERS DOMES Number: 40440S020

Geographical Location: The station is located at the Haystack Observatory in Westford which is about 48 km northwest of Boston, Massachusetts.

Operation Agency: GL/NOAA Operational Data Center (GODC)

Site Description: The GPS station is on the right side of the road after entering the Observatory. Various GPS systems have been installed at the site since October 1986. The current system was established on February 8, 1993; the antenna position, WES2, was surveyed to the local control points and also determined by the global GPS tracking network.

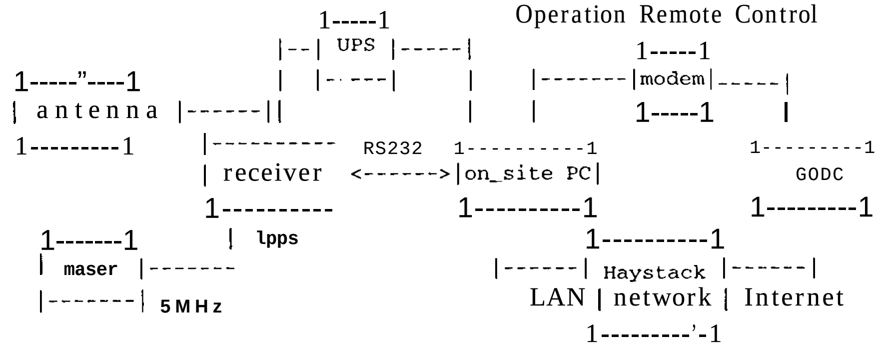
GPS Tracking System Configuration

Receiver (type: Rogue SNR-8000, serial #: T109, firmware: 3.0.32.2)
Antenna (type: Dome Margolin T, serial #: 145)
PC (type: COMPAQ 386)
External frequency standard (type: maser)
Uninterrupted power supply (UPS)
High speed modem (type: Telebit Trailblazer+)

System Installation

Antenna Installation: The antenna was mounted on a steel tower about 60 m away from the northeast corner of the Westford VLBI office building.

Receiver Installation: The receiver is located inside the Westford office building. The 5-MHz output from a maser is plugged into the lpps input in the back of the receiver panel. The data communication and the operation monitoring of the receiver are provided by the PC which directly connects to the receiver via an RS232 cable.



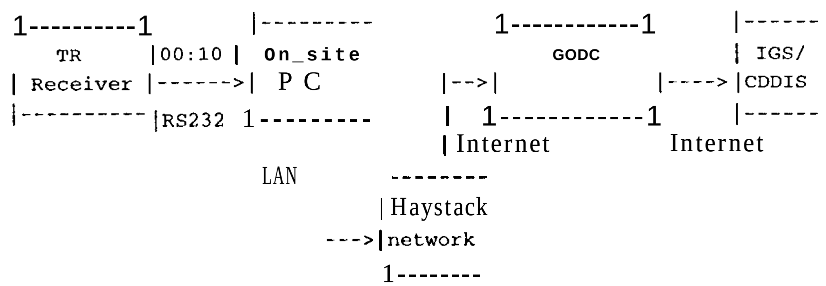
Data Communication Route

Tracking Configuration

The receiver is operating infixed position mode andiscontinuously recording measurements every30 seconds ontotheflash card. The clock steering capability is disabled.

Data Communication

The daily tracking data are downloaded from the receiver to the on-site PC at 00:10 UTC. From the PC the data are transferred to a Haystack computer then forwarded to GODC for processing and distribution.



Data Availability

On-1ine data sets: Copies of the raw and RINEX data sets are available on-line through GPDC; the access information can be found in the GODC report.

Off-line data sets: Two copies of data sets collected more than 200 days prior are stored on optical disks and DAT tapes.

Other Geodetic Measurements

VLBI, Absolute Gravity, Mobile Laser

NRCan (GSD) Operational Stations

Robert Duval
Geodetic Survey Division, Natural Resources Canada
Ottawa, Ontario

Algonquin

Station:	ALGO
Full Name:	ALGONQUIN
GSD No:	883160
Domes No:	401 O4MOO2
CDP No:	N/A
Location:	Algonquin Park, Ontario, Canada
Lat:	N 45°57'20.8"
Long:	W 78°04'16.9"
Agency:	Geodetic Survey Division Natural Resources Canada 615 Booth Street Ottawa, Ontario Canada K1A OE9
Contact:	Robert Duval
Telephone:	(613) 947-2786
E-mail:	duval@geod.nrcan.gc.ca

ALGO is collocated with the permanent VLBI installation (46-m dish) located on the property of Algonquin Space Complex in the Algonquin Park approximately 160 km west of Ottawa, Ontario. The GPS station has been in operation since January 1991. In addition to GPS observations and VLBI experiments, Satellite Laser Ranging and absolute gravity observations have been carried out at the site. ALGO is located on the North American plate.

The GPS reference mark consists of a brass plate with a forced centring stainless steel bolt embedded on top of a 2-m concrete pier, 40 cm in diameter. The concrete pier is anchored to exposed bedrock by a steel casing to a depth of 10 m.

A local reference network of 14 points within a 200-m radius is used to monitor the offsets between the GPS marker and the collocated system markers as well as for studies of the site stability through periodic resurvey. These surveys are carried out by conventional surveying techniques according to special order specifications. This local network is linked to four stations within a 10-km radius that provide connection to the Canadian Geodetic control network for monitoring of regional stability.

As of March 1995 ALGO is equipped with a dual-frequency, eight-channel AOA SNR-8000 TurboRogue GPS receiver. The Dome Margolin antenna with choke rings is mounted to the reference mark using a 10-cm-high anodized aluminum cylinder. This mount provides a constant height above the reference mark and also allows the antenna to be oriented. Reference frequency is provided by an external Hydrogen Maser frequency standard shared with the VLBI installation. A meteorological sensor unit records data every 15 minutes.

Data communication to the site is provided through the wide-area Anikom 200 satellite link operated by Telesat Canada using CCITT standard X.25

asynchronous packet data communications. At the site, a X.25 packet assembler disassembler (PAD) interfaces with the receiver and the met sensor unit. From Telesat facilities in Ottawa data is routed to GSD via DATAPAC, a public packet switching network.

Technical Summary

As of March 31, 1995:

GPS Receiver:	ROGUE SNR-8000 Rcvr s/n 226
Firmware:	Version 3.0.32.2
Antenna:	AOA Dome Margolin T s/n 173
Antenna Height:	0.100 m (from reference mark to base of antenna assembly)
Clock:	Hydrogen Maser
Meteorological data:	Temperature, humidity and pressure recorded every 15 minutes
Collocation:	VLBI (CDP no 7282, DOMES no 40104S001, GSD no 683100) SLR (CDP no 7410, GSD no 933000) Absolute Gravity (Geological Survey of Canada)

St. John's

Station:	STJO
Full Name:	ST. JOHN'S
GSD No:	920000
Domes No:	401 O1MOO1
CDP No:	N/A
Location:	St. John's, Newfoundland, Canada
Lat:	N 47°35'42.8"
Long:	W 52°40'39.9"
Agency:	Geodetic Survey Division Natural Resources Canada 615 Booth Street Ottawa, Ontario Canada KIA OE9
Contact:	Robert Duval
Telephone:	(613) 947-2786
E-mail:	duval@geod.nrcan.gc.ca

STJO is located at the Geological Survey of Canada (NRCan) geomagnetic observing station in St. John's, Newfoundland. The GPS station has been in operation since May 1992. STJO is located on the North American plate.

The GPS reference mark consists of a brass plate with a forced centring stainless steel bolt embedded on top of a 1.5-m concrete pier, 40 cm in diameter. The concrete pier is anchored to exposed bedrock by stainless steel reinforcing bars to a depth of 3 m.

A local reference network of three points within a 150-m radius is used for monitoring the local stability of the site through periodic resurvey. These surveys are carried out by conventional surveying techniques according to special order specifications.

As of March 1995 STJO is equipped with a dual-frequency, eight-channel AOA SNR-8000 TurboRogue GPS receiver. The Dome Margolin antenna with choke rings is mounted to the reference mark using a 10-cm-high anodized aluminum cylinder. This mount provides a constant height above the reference mark and also allows the antenna to be oriented. Reference frequency is provided by an external Rubidium frequency standard.

Data communication to the site uses high-speed modems over terrestrial data lines.

Technical Summary

As of March 31, 1995:

GPS Receiver:	ROGUE SNR-8000 Rcvr s/n 161
Firmware:	Version 3.0.32.2
Antenna:	AOA Dome Margolin T s/n 171
Antenna Height:	0.100 m (from reference mark to base of antenna assembly)
Clock:	AOA Rubidium frequency standard s/n 116
Meteorological data:	None
Collocation:	Geomagnetic observatory (Geological Survey of Canada)

Yellowknife

Station:	YELL
Full Name:	YELLOWKNIFE
GSD No:	889201
Domes No:	40127MO03
CDP No:	N/A
Location:	Yellowknife, N. W. T., Canada
Lat:	N 62°28'51.2"
Long:	W 114°28'50.4"
Agency:	Geodetic Survey Division Natural Resources Canada 615 Booth Street Ottawa, Ontario Canada K1A 0E9
Contact:	Robert Duval
Telephone:	(613) 947-2786
E-mail:	duval@geod.nrcan.gc.ca

YELL is collocated with the semi-permanent VLBI installation (MV-1 mobile unit, 9-m dish) located at the Geological Survey of Canada Geophysical Laboratory (Seismic Station) in Yellowknife, N.W.T. The GPS station has been in operation since January 1991. In addition to GPS and VLBI installations, a DORIS transmitting station, an absolute gravity station, a permanent geomagnetic observatory and a seismic array are located at the site. YELL is located on the North American plate.

The GPS reference mark consists of a brass plate with a forced centring stainless steel bolt embedded on top of a 1.8-m concrete pier, 40 cm in diameter. The concrete pier is anchored to exposed bedrock by steel reinforcing bars to a depth of 50 cm.

A local reference network of 12 points within a 350-m radius is used to monitor the offsets between the GPS marker and the collocated system markers as well as for studies of the site stability through periodic resurvey. These surveys are carried out by conventional surveying techniques according to special order specifications. This local network is linked to the Canadian geodetic control network.

As of March 1995 YELL is equipped with a dual-frequency, eight-channel AOA SNR-8000 TurboRogue GPS receiver. A Dome Margolin antenna with choke rings is mounted to the reference mark using a 10-cm-high anodized aluminum cylinder. This mount provides a constant height above the reference mark and also allows the antenna to be oriented. Reference frequency is provided by an external Hydrogen Maser frequency standard shared with the VLBI installation. A meteorological sensor unit records data every 15 minutes.

Data communication to the site is provide through the wide-area Anikom 200 satellite link operated by Telesat Canada using CCITT standard X.25 asynchronous packet data communications. At the site, a X.25 packet assembler disassembler (PAD) interfaces with the receiver and the met sensor unit. From Telesat facilities in Ottawa data is routed to GSD via DATAPAC, a public packet switching network.

Technical Summary

As of March 31, 1995:

GPS Receiver:	ROGUE SNR-8000 Rcvr s/n 302
Firmware:	Version 2.8.32.1
Antenna:	AOA Dome Margolin T s/n 273
Antenna Height:	0.100 m (from reference mark to base of antenna assembly)
Clock:	Hydrogen Maser
Meteorological data:	Temperature, humidity and pressure recorded every 15 minutes
Collocation:	VLBI (CDP no 7296, DOMES no.40127MO04, GSD no 909012) VLBI (CDP no.7285, DOMES no.40127M001, GSD no 829098) DORIS Absolute Gravity Seismic Array Geomagnetic Observatory

Sites in Kitab and Potsdam

Roman Galas and Christoph Reigber
Department of Kinematics and Dynamics of the Earth, GeoForschungsZentrum
Potsdam, Germany

Kitab

The Kitab (Uzbekistan) IGS Core Station (KIT3) has been jointly operated by GFZ and the Kitab Latitude Station since October 2, 1994. The GPS antenna is placed a few meters apart from the Visual Zenith Telescope, which was operated in the International Polar Motion Service for about 80 years and was used, together with four other stations, for the definition of the CIO 1900-05.

Two other satellite tracking systems are permanently colocated with the GPS, a PRARE ground station and a DORIS beacon.

The station is equipped with:

- Turbo Rogue SNR 8000 receiver, S/W Version 2.8.32.1X
- Automatic meteorologic sensor
- Inmarsat A Mobile Terminal
- Computer with modems and software for automatic data download and for HSD (64k) transfer via Inmarsat A service.

In 1994 the station was operating nearly automatically. A permanently running program on the Inmarsat-computer downloads the GPS data (CONAN Binary Format) every midnight. After compression, they are routed to the Inmarsat Earth Station in Eik (Norway). From there the data reach the Base Station in Potsdam through ISDN. The transfer of one day's data, including establishing the connections, takes about 1 minute. After decoding and converting the data, in the GFZ Operational Data Center to the RINEX format, the daily files are sent to the Regional Data Center in IfAG (Frankfurt) and to the Global Data Center CDDIS (Greenbelt).

Potsdam

The IGS station in Potsdam (POTS) is located in the campus of the GeoForschungsZentrum on the Telegrafenberg, and has also been operating in the IGS since October 2, 1994.

The station is equipped with:

- TurboRogue receiver, SNR-8000
- PC computer with interface to the LAN of GFZ.

The GPS antenna is placed on the geodetic pillar (old triangulation point on the roof of old Geodetic Institute (Building A17). The station operates in a fully automatic mode. Every midnight the data from the previous day is downloaded (CONAN Binary Format) and the RINEX daily files are sent through the Internet to the IGS Data Centers.

An SLR (7836) and PRARE system are also operating permanently, near the GPS, with known differential coordinates to the GPS Mark.

Some construction work on the geodetic/GPS pillar caused the station to be out of service between days 287 and 300 of 1994, and the antenna height was changed as follows:

Between the days 275–286:	h = 0.168 m
From day 301 onwards:	h = 0.046 m

In December 1994 the receiver software version was updated:

Between the days 275–353:	2.8.32.1X
From day 354 onwards:	***3.0***

Since October 2, 1994 the data from both stations, Kitab and Potsdam, are available at the CDDIS, IfAG, and IGN Data Centers with average delay of 1 day. Starting with day 275 of 1994 RINEX files are also available directly from Potsdam. The GFZ Operational Data Center is easily accessible through anonymous ftp at the Internet address 139.17.1.7 under the directory pub/home/kg/gpsdata.

The GPS Receiver Network of ESOC: Maspalomas, Kourou, Kiruna, Perth, and Villafranca

C. Garcia-Martinez, J. M. Dow, T. Martin-Mur, J. Feltens, and M. A. Bayona-Perez
European Space Operations Center
Darmstadt, Germany

ESOC is currently involved in the establishment of a network of high-precision geodetic receivers on ESA ground sites. So far, five installations have been carried out at the sites of Maspalomas, Kourou, Kiruna, Perth, and Villafranca. The establishment of this network is one of the objectives of the ESA GPS-TDAF (Tracking and Data Analysis Facility). Figure 1 shows the geographical distribution of the receivers.

ESOC GPS RECEIVERS

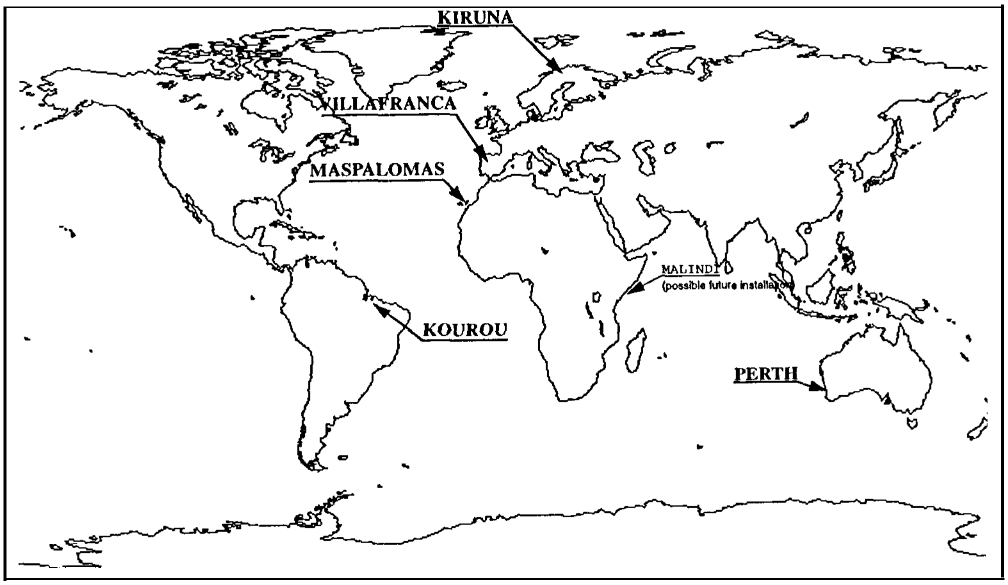


Figure 1.

Location of the Receivers

The ESOC receivers are being installed at the ESA ground stations. In this way they can take advantage of the facilities that the stations provide. They are integrated in racks in rooms with temperature and humidity control, connected to the frequency standards of the stations and to the permanent communication links between the stations and the control center at ESOC. They also provide, along with the rest of the GPS-TDAF, several additional services. Examples are the monitoring of the behavior of the timing system, the 1PPS output, and the ionosphere monitoring over the station.

Maspalomas

The GPS receiver is installed at the Maspalomas ground station, the property of the Spanish institute INTA. It is located in the southern part of the Gran Canaria Island, municipal district of San Bartolome de Tirajana, Spain. The site is approximately 1750 m from the coast.

Kourou

The GPS receiver is installed at the ESA Kourou Diane station located about 27 km from the town of Kourou, in French Guiana.

Kiruna

The GPS receiver is installed in the ESA Kiruna ground station, located at Salmijarvi, 38 km east of Kiruna in northern Sweden.

Perth

The receiver is located at the ESA Perth station, approximately 20 km north of the city of Perth on the western coast of Australia. The station is situated on the Perth International Telecommunications Centre Complex, operated by Telstra Corporation Limited,

Villa franca

The receiver is situated in the Villafranca (VILSPA) ground station, located in Villafranca del Castillo, 30 km west of Madrid, Spain.

History and Evolution

The development of the network started at the beginning of 1992 when two MiniRogues (SNR-8C), the most advanced receiver then, were ordered from AOA. After a period of testing in ESOC, the first installation was completed in the week before the start of the IGS campaign at Maspalomas. Data were available from June 22, 1992. The antenna was mounted on a monument, belonging to the Spanish IGN, that participated in several geodetic campaigns with the marker name MPA1. For IGS the selected marker name was MASP.

ESOC constructed another monument and on April 11, 1994 installed a new GPS system with a TurboRogue SNR-81OO. Both systems were operated in parallel for several weeks until the decommission of the old receiver. The marker name of the new monument is MAS1 and the IERS DOMES Number 31303MO02 was assigned to it.

The second of the MiniRogues was installed late July 1992 at Kourou. Initially the data were downloaded directly from the receiver to ESOC using Telebit modems, Unfortunately the quality of the public telephone lines between Europe and French Guiana were very irregular. The data were obtained for a period of 10 days in August, and sporadically thereafter. Attempts made from Pasadena to dial up the Kourou modem were also unsuccessful. The low transfer rates and the irregular quality of the telephone lines made very problematic the completion of the file transfers using XMODEM. A new solution had to be implemented. It was based on the permanent links between the station and the control center ESOC shared by several ESA projects. The regular operation of the receiver started on October 18, 1992 when the connection to the new data link was completed. During the period when communications were not possible, a permanent concrete monument was constructed for the antenna there (see IGS mail No. 144). The antenna was moved by about -3.0 m, -1.1 m, 1.1 m in longitude, latitude, and height, respectively, from its previous position. The software of the MiniRogue was upgraded to version 7.8 on October 6, 1994. The receiver has been operated permanently without hardware problems for almost two-and-a-half years.

Another set of five receivers, this time TurboRogues, was ordered at the end of 1992. After the testing period in ESOC, the first receiver was dispatched to Kiruna and installed in July 1993. The receiver was placed in a building several meters away from the main building of the station. From here the distance to the monument is shorter. The monument is on top of a slope surrounded by trees.

The second TurboRogue installation was performed on August 13, 1993 at Perth. Unfortunately, a few days after the beginning of the operation, the receiver was damaged during a lightning storm on September 3, 1993. A new receiver was immediately delivered. The grounding of the antenna has been improved to avoid the same problem happening again. The original receiver and antenna were repaired and reinstalled on April 27, 1994.

The last installation was Villafranca, on November 12, 1994. At this site the cabling from the monument to the racks of the main building, where the receiver is integrated, is about 150 meters long. This is 50 m longer than the standard setup of the receiver. This made necessary the installation of an additional line amplifier close to the antenna. With this modification the signal level has nominal values.

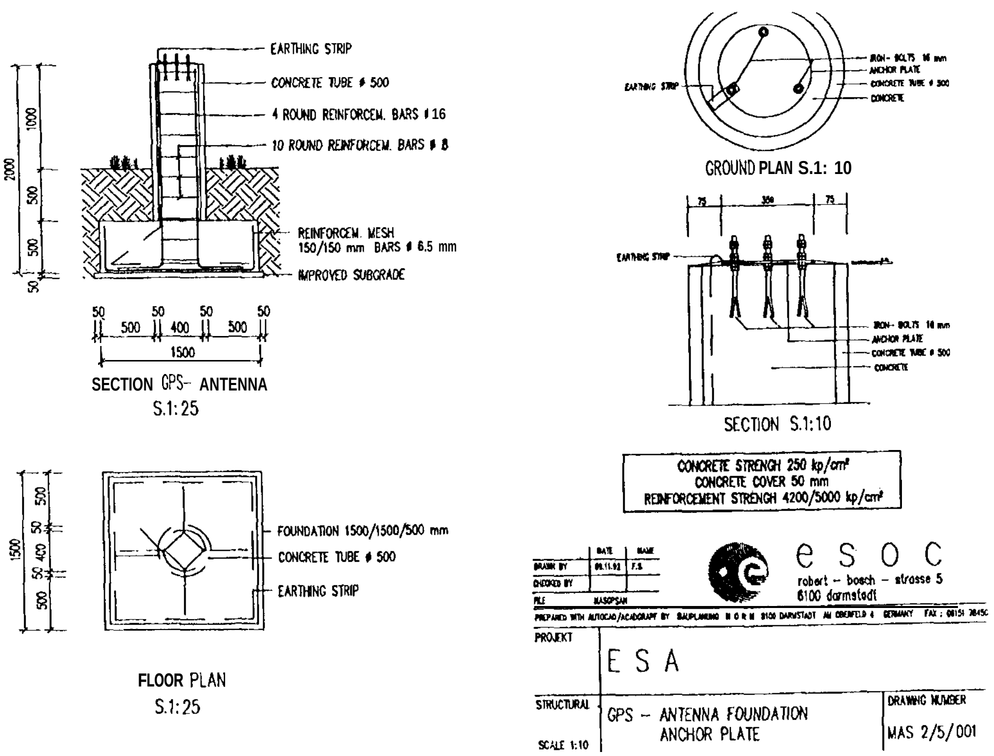


figure 2.

Monumentation

Figure 2 shows the monument specially developed for the GPS-TDAF. It is basically a reinforced concrete cylinder 50 cm in diameter that is situated over a foundation. On top of the cylinder there is an embedded horizontal metal plate. The marker is the center of this plate, on the upper surface.

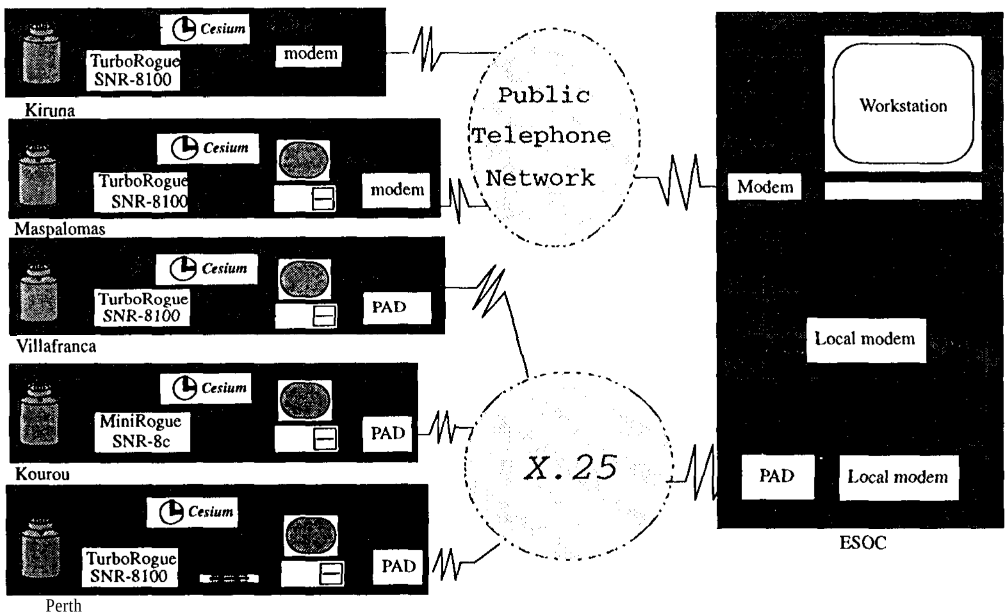
Three iron bolts fix the antenna mounting in a horizontal position. The antenna is screwed to the mounting.

Equipment

The physical configuration of all the equipment involved in the remote stations part of the GPS TDAF is summarized in Figure 3. The remote stations are continuously tracking the GPS satellites. The antenna is connected to the receiver normally with a standard 100-m RG-214 coaxial cable. Only Villafranca has a cable 150-m long, as remarked in the last section.

Figure 3.

GPS TDAF Pilot System Configuration



The timing system of the stations use a 5-MHz reference frequency. They are cesiums manufactured by OSCILLOQUARTZ with long-term drift controlled by timing GPS system.

There are two different receivers in the ESA stations. The MiniRogue SNR-8C, currently only at Kourou, and the TurboRogue SNR81OO at the rest of the stations. An effort is made to try to update them with the latest well-tested software releases. All the TurboRogues are currently (March 1995) running software version 2.8. The MiniRogue of Kourou runs Meenix 7.8 and Ruse 4.2.

One of the serial ports of the receivers is connected to a device that provides for communications and optionally for data storage. This device is a PC that runs a script of a communications package. Shortly after 00:00 UTC the PC downloads the data from the receiver with the XMODEM protocol, waits the remainder of the day for the call from the ESOC control center and allows the remote control of the computer.

There are two main reasons for the necessity of the intermediate device. First it buffers data. Several months of data can be stored on the disk. In addition it allows the data transfer to ESOC using a wide range of protocols. The XMODEM protocol, the only one supported by the receivers, is not suitable for the packet-switched networks that are sometimes involved in the communications with the control center. It also provides flow control with the DCE (Data Communication Equipment).

The communication with the receiver uses the same line that is used for data downloading. The commands are sent to the PC that stores them and immediately changes the active comm port to the one connected to the receiver, sends them, waits for the answer, and stores it. The active port is swapped, again to the one connected to the communication device and the answer of the receiver is echoed. Several attempts have been made with a secondary line (PAD or modem) connected to the free port of the receiver for interaction with it in terminal mode, but the system has been shown to be more reliable without this secondary link.

For the communications with ESOC the permanent links between ESOC and the stations are used whenever possible. They are very reliable and do not introduce additional costs due to the small amounts of data involved.

At ESOC there is one workstation with two serial ports. One is attached to a Telebit modem and the other to an internal LAN of ESOC that gives access to the ESA ground station via X.25/PAD. This workstation retrieves, decompresses, reformats, validates, archives, recompresses, and distributes the data automatically every day. The nominal time when all the processes are finished is 02:00 UTC.

The data are available to the IGS community in RINEX format via the official data centers.

In Maspalomas the receiver is a TurboRogue SNR-81OO. The antenna, Dome Margolin T, is mounted over a monument located several meters east of the main equipment room. The antenna height is 0.033 m. The data retrieval is performed with a Telebit T2500 modem. A PAD (Packet Assembler-Disassembler) that runs over a 64-Kbit/s line has been used in the past.

Kourou is the only one of the ESA stations with a MiniRogue SNR-8C. The antenna is Dome Margolin B with a height of 0.132 m and is located about 25 *m* from the main control room building.

Kiruna has a TurboRogue SNR-81OO and a Dome Margolin T antenna with a height of 0.062 m. The communications are performed with a Telebit T2500 that is directly connected to the TurboRogue. There are future plans for using a PAD and a remote PC as in the other ESA stations.

The TurboRogue of Perth is connected to a Dome Margolin T antenna with a height of 0.0595 m. The communications are carried out by means of a PAD that is situated in a different building of the station. To overcome this problem, two local modems had to be used. They provide for communications between PC and PAD.

Villafranca has also a TurboRogue with a Dome Margolin T antenna. The antenna height is in this case 0.0437 m.

Plans for the Future

There are currently three ESA sites that offer possibilities for future installations. They are Malindi (Kenya), Odenwald (Germany), and Redu

(Belgium). Because of its geographical position Malindi is the most interesting one for IGS. Nevertheless the other two sites, located in Europe, are also quite interesting for ESA. Currently there are very encouraging plans for the improvement of the communications with Malindi and a test with a receiver is being planned for May 1995.

References

GPS TDAF Stations Configuration Manual, Version 1.0, March 1993, ESOC.

Tsukuba

Yuki Hatanaka
Geographical Survey Institute
Tsukuba, Japan

Station Name: Tsukuba

4 char ID: TSKB
IERS DOMES Number: 21730S005

Site Specifications
- GPS Receiver
  - Receiver Type: Rogue SNR-81OO (TurboRogue)
  - Serial Number: 102
  - Firmware Version: 2.8
- GPS Antenna
  - Antenna Type: Dome Margolin T (with filter)
  - Serial Number: 105
- Vertical Antenna Height: 0.0 m (Dee.15,1993-)
- Antenna Reference Point: Bottom of preamplifier
- Frequency Standard: Cesium 5 MHz
- Address: Kitasato-1, Tsukuba-shi, Ibaraki-ken, 305 Japan

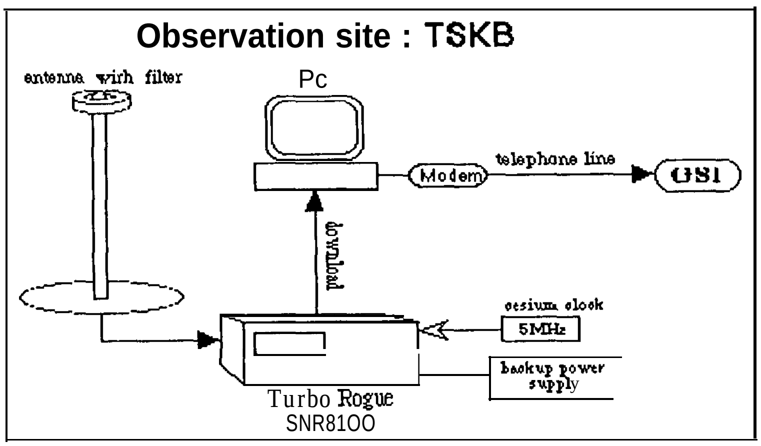


Figure 1.

Site problems in 1994

date	doy	description	IGS mail No.
Aug. 14–15	226–227	Antenna failure	0707
Oct. 22–23	295–296	Outage	0724

Point of Contact
Agency: Geographical Survey Institute
Contact: HATANAKA, Yuki
Address: Kitasato-1, Tsukuba-shi, Ibaraki-ken 305, Japan
Telephone: 81-298-64-1111 ex.4357
E-mail: gps@geos.gsi-mc.go.jp
Fax: 81-298-64-1802

AUSLIG Operational Data Center

Martin Hendy
Australian Surveying and Land Information Group
Belconnen, Australia

GPS Site at Casey Station in Antarctica

A permanent GPS receiver was installed at the Australian Antarctic Research Station Casey, in Wilkes Land, Antarctica in 1994. The monument *is* a concrete pad set in rock at ground level, 200 m west of the nearest station building. The site was chosen using aerial photography and station plans, such that the antenna had the best possible horizon, was away from any potential multipath from station buildings, was free of any potential snow drifts, and was within feasible distance of a building that could house the receiver and associated equipment. This is a permanent installation and was installed by AUSLIG field staff with the assistance of the Australian Antarctic Division.

The GPS antenna is permanently located on the new monument and is covered with an acrylic dome. Low-loss heliax antenna cable was used. The GPS system consists of a PC running the Linux operating system, a modem, and multiplexer. The PC logs data from the GPS receiver continuously and sends them back to Canberra using tcp/ip protocols over the Antarctic Division satellite link. Data are also stored on the receiver flashcard as per usual.

The remote system is fully automated and except for occasional firmware upgrades and system maintenance does not require human intervention. It is housed in the communications room at Casey and is supported by the station UPS system.

Due to the remote location of this site, and the infrequent resupply of the site, GPS receiver firmware upgrades and other system maintenance can only be done once a year during the Antarctic summer.

Station information as was submitted by email to IGS in July 1994 is as follows:

Station Information

Installation Date: July, 1994
Monument Mark: 16 mm stub in center of stainless steel plate set in concrete
Receiver Type: Rogue SNR-81OO (Turbo Rogue rackmount)
Receiver Software: V2.8.1.2
Frequency Reference: external rubidium
Antenna Height: 0.001 m (arp = base of antenna)
Approximate Station Coordinates:
(ITRF from an unconstrained global solution)

```
Lat:  S 66” 17’ 00.0840”
Long: E 110” 31' 10.9385"
Ht :  22.741 m
x :  -901776.2558 m
Y :   2409383.7338 m
Z:   -5816748.5915 m
```

Data Availability

Data for this site are available from:

```
ftp.auslig.gov.au
user = ftp
passwd = email address
cd gps/nnn          where nnn is the day of the year (1...366)
```

The site identifier is casl and the files are held in UNIX compressed format on a Sun Workstation.

GPS Site at the Australian Research Station Davis, Antarctica

A permanent GPS receiver has been installed at the Australian Antarctic Research Station–Davis, in Princess Elizabeth Land Antarctica. The monument is a stainless steel platform set in rock and raised off the rock by approximately 12 cm to prevent any drifting of snow. The GPS antenna is a permanent installation and is covered by an acrylic dome. It is located on a hill 60 m from the Atmospheric Physics Laboratory. Since the antenna is within a magnetic quiet zone due to the proximity of a sensitive magnetometer, the antenna platform was fabricated using a special high-grade stainless steel.

The site was chosen using aerial photography and station plans, such that the antenna had the best possible horizon, was away from any potential multipath from station buildings, was free of any potential snow drifts, and was within feasible distance of a building that could house the receiver and associated equipment. This is a permanent installation and was installed by Australian Antarctic Division expeditioners for AUSLIG.

RG214 antenna cable was used and is protected by above ground conduit. The GPS system consists of a PC running the Linux operating system, a modem and multiplexer. The PC logs data from the GPS receiver continuously and sends them back to Canberra using tcp/ip protocols over the Antarctic Division satellite link. Data are also stored on the receiver flashcard as per usual.

The remote system is fully automated and except for occasional firmware upgrades and system maintenance does not require human intervention. It is housed in the Atmospheric Physics Laboratory at Davis and is supported by the station UPS system.

Due to the remote location of this site, and the infrequent resupply of the site, GPS receiver firmware upgrades and other system maintenance can only be done once a year during the Antarctic summer.

Brief station information follows and a site report has been submitted to IGSCB.

Station Information

Installation Date: July 1994
Monument Mark: stainless steel plate set in concrete pillar
Receiver Type: Rogue SNR-8100 (Turbo Rogue rackmount)
Receiver Software: V2.8.1.2
Frequency Reference: external rubidium
Antenna Height: 0.0035 m (arp = base of antenna)
Approximate Station Coordinates:
(ITRF from an unconstrained global solution)

Lat: s 68" 34' 38.3552"
Long: E 77" 58' 21.4245"
Ht: 44.696 m
x: 486854.441 m
Y: 2285099.620 m
Z: -5914955.885 m

DataAvailability

Data forthis site are available from:

ftp.auslig.gov.au
user = ftp
passwd = email address
cd gps/nnn where nnn is the day of the year (1 . ..366)

Thedata areheld on a Sunworkstation inUNIXcompressed RINEX files.

GPS Site at MacQuarie Island Research Station in the Sub-Antarctic

A permanent GPS receiver has been installed at the Australian Sub-Antarctic Research Station on MacQuarie Island, in the Southern Ocean. MacQuarie island is located at the boundary of the Australian and Antarctic plates. It is a small island with a very high rainfall and maritime climate.

The monument is a concrete pillar 1.2 m high and approximately 30 m from the Atmospheric Physics Laboratory. This is a permanent location.

The GPS antenna failed during 1994 due to corrosion damage and a new one was installed in June 1995 on a stainless steel mount which covers the top 200 mm of the pillar and which locates the GPS antenna precisely over the existing survey mark. The antenna will be protected by an acrylic dome and RG214 antenna cable was used.

The GPS system consists of a PC running the Linux operating system, a modem and multiplexer. The PC logs data from the GPS receiver continuously and sends them back to Canberra using tcp/ip protocols over the Antarctic Division satellite link. Data are also stored on the receiver flashcard as per usual.

The remote system is fully automated and except for occasional firmware upgrades and system maintenance does not require human intervention. It is housed in the Atmospheric Physics Laboratory and is supported by a UPS system.

Due to the remote location of this site, and the infrequent resupply of the site, GPS receiver firmware upgrades and other system maintenance can only be done once a year during the Antarctic summer.

Brief station information follows and a site report has been submitted to IGSCB.

Station Information

Installation Date: July 1994
Monument Mark: 16 mm stub in centre of stainless steel plate set in concrete pillar
Receiver Type: Rogue SNR-81OO (Turbo Rogue rackmount)
Receiver Software: V2.8.33.2

Frequency Reference: external rubidium
Antenna Height: 0.0675 m (arp = base of antenna)
Approximate Station Coordinates:
(ITRF from an unconstrained global solution)

Lat: S 54° 29' 58.3197"
Long: E 158" 56' 8.9915"
Ht: -6.590 m
X: -3464038.4828 m
Y: 1334172.9560 m
Z: -5169224.5040 m

Data Availability

Data forthis site are available from:

ftp.auslig.gov.au
user = ftp
passwd = email address
cd gps/nnn where nnnisthedayofyear (1 . ..366)

The data are held on a Sunworkstation in UNIXcompressed RINEX files.

GPS Site at Hobart, Tasmania, Australia

A permanent GPS receiver has been installed at the Mt. Pleasant VLBI observatory in Hobart, Tasmania, Australia. This receiver is approximately 150 m away from the previous CIGNET antenna location and the VLBI dish.

The site was chosen to minimize multipath effects from the VLBI dish and observatory, such that the antenna had the best possible horizon, and was within feasible distance of a building that could house the receiver in close proximity to the hydrogen maser clock. This is a permanent installation and was installed by AUSLIG field staff in collaboration with the Departments of Physics and Surveying at the University of Tasmania.

The GPS antenna is permanently located on the new monument and is covered with an acrylic dome. Low-loss heliax antenna cable was used. The GPS system consists of a PC! running the Linux operating system, a modem, and multiplexer. The PC logs data from the GPS *receiver* continuously and sends them back to Canberra using tcp/ip protocols over a national Internet network. Data are also stored on the receiver flashcard as per usual.

The observatory is located approximately 30 km from the University of Tasmania which is the nearest Internet node, and a dedicated data landline is leased to connect the observatory and the university. Data are transferred from the observatory to the university from where they are transferred using the Internet to Canberra.

The remote system is fully automated and except for occasional firmware upgrades and system maintenance does not require human intervention. It is housed in the observatory control room and is supported by a UPS system. Remote control of all parts of the system is possible.

Brief station information follows and a site report has been submitted to IGSCB.

Station Information

Installation Date: June 1994
Monument Mark: stainless steel plate set in concrete pillar
Receiver Type: Rogue SNR-81OO (Turbo Rogue rackmount)
Receiver Software: V3.0.33.2
Frequency Reference: external hydrogen maser
Antenna Height: 0.000 m (arp = base of antenna)
Approximate Station Coordinates:

Lat: S 42” 48’ 16.9846”
Long: E 147” 26’ 19.4293”
Ht: 41.249 m
x: -3950071.268 m
Y: -2522415.236 m
z: -4311638.625 m

DataAvailability

Data forthis site are available from:

ftp.auslig.gov.au
user = ftp
passwd = email address
cd gps/nnn where nnnisthedayofthe year (1 . ..366)

Thedata areheld on a Sunworkstation running SunOS 4.1.3 and the files are UNIX compressed RINEX files.

GPS Station in Borowiec, Poland

Waldemar Jaks
AstroGeodynamical Observatory
Space Research Centre, Polish Academy of Sciences
Kornik, Poland

The Observatory was founded in 1955 to begin astronomical observations for Earth rotation research. Observations started in the International Geophysical Year 1957 using Transit Instruments and Visual Zenith Telescopes. In the 1980s, the astronomical observations were replaced with satellite methods. The Observatory takes part in several international projects including: DOSE, IGS, WEGENER, and IERS.

SLR Station Borowiec (12205M001) started operating in May, 1988. The main instrument is the third generation laser transmitter CONTINUUM PY-62-1O which is able to achieve about 3 cm accuracy. From 1981 to 1991 the observatory handled measurements using Doppler methods of the TRANSIT system in international campaigns and researches: WEDOC-1, WEDOC-2, MERIT, MEDOC, FINPOLDOC, and ICDOC.

The permanent GPS observations started in September 1993 using TurboRogue SNR-8000 on the BOR1 marker. The receiver is linked to the cesium frequency standard EUDICS 3020 and to the automatic meteorological measurement system HPTL3A (NAVI Ltd., Poland). The Borowiec GPS station has been participating as a permanent IGS project since June 1994. Observations are checked by Quality Check v 3.0 and sent to the Graz IGS Data Center using the Internet. The Observatory computes and analyzes observations gathered in almost all international campaigns. Results of the Baltic Sea Level 1990 and 1993 campaigns were calculated using BERNESE 3.4 software. Coordinates of BORO (EUREF 0216) and BOR1 markers were computed from the EPOCH 1992 project. The Time Laboratory of Borowiec Observatory has carried the GPS comparisons to BIPM time scale since 1991. Currently, there are two cesium frequency standards: EUDICS 3020 and the XSC (Rhode & Schwartz).

Status Report of the IGS GPS Station at Metsahovi

Matti Paunonen
Finnish Geodetic Institute
Helsinki, Finland

A permanent GPS receiver has been in continuous operation at the Metsahovi Geodetic Observatory since May 1, 1991. The present MiniRogue SNR-8C receiver started up on April 30, 1992 and it has delivered data also to the IGS (International GPS Service for Geodynamics) from the very beginning in June 1992. The antenna is mounted on top of a 20-m steel tower using an electrically isolated, vertically floating mount.

The height of the antenna is kept fixed by an invar bar anchored to the bedrock (Paunonen, 1993). A 5-MHz external frequency from a hydrogen maser feeds the receiver. Statens Kartverk, Norway, retrieves the data directly from the receiver by a modem. An archive copy is kept at the observatory. The system has operated without physical changes, excluding receiver firmware updates. The height of the antenna has been found stable within 1 mm in all inspections. For monitoring the horizontal position, a 20-m plumb line inside a tube was permanently installed in the tower in September 1993, and regular checks have been made since then. The mean position has remained within 1 mm and its rms variation well within 1 mm in 187 determinations. As expected, direct sunshine has some effect on the position because of uneven elongation of the guy wires due to variable illumination conditions. The worst case movement, 3 mm, happened during a hot (26 degrees C), clear day in July 1994.

The MiniRogue has shown increased susceptibility to pseudo-range multipath effects (1-2 m) after the implementation of anti-spoofing. This is not due to the GPS environment around the tower, because unaffected satellites still give less than 20-cm multipath. Code measurements have sometimes shown irregularities which disturb ionospheric studies. In April 1995 the present receiver will be replaced by a TurboRogue SNR-81OO receiver. The GPS receiver has close site connections to a satellite laser rangefinder (50 *m),* a mobile VLBI point, and a DORIS orbitography beacon (about 3 km) (Paunonen, 1993 and 1994). A superconducting gravimeter, GWR TT70, started operation at the observatory in August 1994.

Paunonen, M., Height-stabilized 20-meter antenna mounting system of the CIGNET GPS station at Metsahovi, Newsletter of Space Geodetic Measurements Sites Subcommission (SGMS), IAG, IUGG, International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG), Vol. 4, No. 1, May 1993, pp. 7–10.

Paunonen, M., Comparison of globally and locally determined site ties for the Metsahovi GPS station, Proc. of the 1993 IGS Workshop (Eds. G. Beutler and E. Brockmann), IAG, IUGG, International GPS Service for Geodynamics (IGS), March 25–26, 1993, Astronomical Institute, University of Bern, Switzerland, pp. 310-317.

Paunonen, M., Evaluation of the site tie between the IGS GPS station and the mobile VLBI point at Metsahovi. A poster paper presented at it the IERS and IGS Workshop in Paris and Saint Mande, March 21–28, 1994.

The IGS Station Graz-Lustbuehel—Status Report

Peter Pesec
Institute for Space Research
Dept. Satellite Geodesy Austrian Academy of Sciences
Graz, Austria

Introduction

The observatory Graz-Lustbuehel represents the basic Austrian geodynamic reference point, First optical satellite measurements were initiated in 1967, in the framework of the West European densification network. Starting in 1976 the observatory served as the primary Austrian Doppler reference site during various Doppler campaigns on the European scale. From 1979 to 1983 continuous Doppler observations were carried out and gave valuable contributions to the establishment of WGS-84 and the Austrian Geoid. During the years 1979 to 1982 a precise satellite laser ranging facility was built up; this has been in continuous operation since that time and shows up, presently, as one of the most accurate SLR systems all over the world. GPS was introduced in 1986 (TI-41OO) and permanent observations started in early 1990 (with short interruptions). The observatory has contributed to the IGS since June 1992 without any interruptions.

Geodynamic Observatory Graz-Lustbuehel (GRAZ)

The geodynamic observatory Graz-Lustbuehel (GRAZ) (Latitude: N 47”04’; Longitude: E 15030’; Height: 483 m) is located in the eastern outskirts of the city of Graz at a height of about 130 m above the city level consisting of tertiary sediments with a thickness of about 400 m. The basement rock is formed by the “Graz Paleozoic” of the Eurasian plate. The central marker is fixed to the roof of a stable concrete building; local control is maintained by monitoring the ties to the laser pillar of l-m diameter, which extends 12 m below the ground surface. Further control is maintained by local ties to three fiducial points fixed in bedrock at distances of about 16 km (measured every year) and five adjacent sites of the Austrian Geodynamic Reference Frame (AGREF) at distances of about 40 km, being remeasured every 3 years.

The department currently operates the most accurate European Satellite Laser Ranging System. Capable of observing all types of satellites up to geo-stationary orbits; it has a leading position in multi-color SLR techniques. The time laboratory TUG (operated by the Institute of Wave Propagation and Communications) provides the required reference frequencies. The central marker is connected to the national height system by precise leveling, and absolute gravity measurements will be carried out at the observatory during the current year (at present only a relative connection to the absolute gravity point situated at the Graz University of Technology exists).

Starting with June 1992 (IGS pilot campaign) GPS observations have been continuously carried out on the main reference point (GRAZ) of the observatory. Data have been acquired by a MiniRogue SNR-8C receiver connected to the time laboratory TUG. Its ownership is shared by the Federal Office for Metrology and Surveying in Vienna and the Institute for Space Research (Department of Satellite Geodesy). The excellent reliability of this receiver is revealed by the fact that, altogether, only about 12 days of observations are missing from the start, corresponding to an efficiency of 99%. The main reasons were internal receiver software problems during weekends, which could not be corrected immediately, as well as logistic gaps (hardware replacements, for example).

The whole system is monitored by a PC-based automatic time-scheduling menu, which simply defines and sets the timely order of the specific independent tasks. It operates in close connection with an IBM workstation (5 GByte, connected by thin-wire ethernet), which acts as the local data center and FTP server for international access. In this context it should be mentioned that this menu also monitors data downloading and data transfer of additional remotely controlled GPS stations in Austria (see chapter 3) as well as the control and protection of data currently coming in from five permanent stations of the CEI (Central European Initiative).

The downloading of GRAZ GPS data is carried out twice a day at 12:01 UTC and 00:01 UTC. If possible, binary data are immediately transferred to JPL via FTP (unfortunately the access to JPL is frequently blocked by lacking memory/ connection resources). The binary data are saved, converted to Rinex format, merged to a daily file, and transferred to the workstation, which distributes the data set of specific stations to the regional data center IFAG Frankfurt via FTP at 03:00 UTC. In addition, all data collected during the last ten days are available via anonymous FTP (129.27.194.14) on the directory cei/outdata/LAST-TEN.DAYS. All data of the GRAZ local data center are stored on magneto-optical discs for later use.

Meteorological data for GRAZ are likewise available. At present, dry temperature and humidity are automatically collected in half-hour samples. The installation of a precise remotely controlled pressure-sensor is under way. Starting in August 1995 GRAZ will transfer meteorological data in Rinex format together with the daily data files.

Further Potential IGS Stations in Austria

Following the concept of the total coverage of the Austrian territory by permanently recording GPS stations with mutual distances of not more than 200 km the establishment of four additional stations is foreseen.

The geodynamic site Hafelekar (HFLK) (near Innsbruck; Lat: N 47018'; Len: E 11023'; H: 2335 m) is located on top of the Hafelekarspitze north of Innsbruck. Comprehensive safety precautions shelter the antenna from storms (up to 200 km/h) and keep the equipment (Rogue SNR-8C) from lightning and other influences. Regular observations started end of January 1995. Data are collected via Trailblazer modem on a daily basis and transferred to IFAG Frankfurt.

The geodynamic site Reisseck (GRMS) (Grosser Muehldorfer See; (Lat: N 46"54'; Len: E 13021'; H: 2287 m) hopefully will start its operation during autumn 1995 (Rogue SNR-8000). It is accessible by an inclined hoist, followed by a short railway line and 15 minutes on foot. The layout of the station will correspond to the site Hafelekar.

The geodynamic site Hutbiegl (HUTB) (Lower Austria) (Lat: N 48"39'; Len: E 15"36'; H: 411 m) is located in Lower Austria and serves as the main height reference point of Austria. The pillar is connected to bedrock (gneiss). The site is accessible by car. However, no electricity is available which complicates the logistics for permanent observations. Despite this, the possibility of making this station permanent during 1996 is being investigated.

Finally, the site Pfaender in Vorarlberg which is shared, as a first order triangulation point, by Austria, Germany and Switzerland is a potential candidate.

NRCan (GSC) Operational Stations

Michael Schmidt
Geological Survey of Canada, Natural Resources Canada
Sidney, British Columbia

Albert Head

STATION:	ALBH
GEODETIC MARK	927000
FULL NAME:	Albert Head
CLASS:	WCDA, CORE2
DOMES No.:	40129-M003
CDP No.:	n/a
LOCATION:	Victoria, B. C., Canada
COORDINATES:	Latitude N 48° 23'23.2" (prelim. 93/01/07)
	Longitude E 236°30'45.1" (prelim. 93/01/07)
	Ellipsoid Height 32.01 m (prelim. 93/01/07)
	Orthometric Height 50.05 m (prelim. 93/01/07)
COLLOCATION:	Mobile VLBI - CDP No.: 7289
	- DOMES No.: 40129-M001
	- Geodetic Mark: 907001

ALBH is located on the property of Canadian Forces Base Albert Head south of the city of Victoria (Vancouver Island), British Columbia, Canada. ALBH is one of seven GPS trackers in the Western Canada Deformation Array (WCDA) operated by the Geological Survey of Canada (GSC). ALBH is also part of the Canadian Active Control System (ACS) as well as the provincial (B. C.) ACS. Mobile VLBI, absolute gravity, precise tri-lat and precise levels have been carried out at ALBH in addition to the GPS observations. ALBH is located on the North American plate.

ALBH was the second permanent GPS tracker established by the GSC in western Canada. The first crustal dynamics measurements took place in 1990 (VLBI); the GPS tracker commenced operation in May 1992; absolute gravity measurements have been carried out three times (1992, 1994, and 1995). All markers on site (GPS, VLBI and local references) are tied into local vertical control through special order leveling surveys carried out by the Geodetic Survey Division (GSD), Geomatics Canada. Between 1990 and 1992 the VLBI marker was utilized as a GPS base station for the GPS surveys of several crustal strain networks on Vancouver Island as well as the first MAGEX (Marine Geodetic Experiment)—a cooperative project between S10, JPL, GSC.

Instrumentation As of July 1995 ALBH is equipped with a dual-frequency, eight-channel AOA SNR-8000 TurboRogue GPS receiver. The antenna is attached to a brass forced-centered plate (embedded in the concrete pier) via a 10-cm-high anodized aluminum base. This base provides a constant height above the brass plates and also permits the antenna to be referenced to north. The antenna and choke-ring assembly are protected by an acrylic dome. The reference frequency is provided by an external cesium beam frequency standard. The GPS equipment uses local grid power backed up by an uninterruptible power supply (UPS) capable of sustaining the site for up to 45 minutes. Two high-speed modems are used (1) to access the receiver for instrument control and data recovery and (2) to access the UPS to monitor and control power to the GPS instrumentation. The current (March 1995) data rate is 30 seconds.

Monumentation The AOA TurboRogue GPS antenna is located on top of a high concrete pier anchored to bedrock with steel reinforcement bars. The internal reference network consists of four markers surrounding the pier; these are used to monitor long-term stability of the GPS pier as well as to maintain the offsets between the GPS marker and the VLBI marker through periodic resurvey(s) of the reference network. An external GPS reference network is maintained and consists of four stations within a 10-km radius of ALBH. These four sites also belong to the joint GSC-USGS Juan de Fuca crustal strain network spanning the Strait of Juan de Fuca.

Data Handling The GPS data from all WCDA sites are retrieved automatically from a central data collection and validation platform located at the Pacific Geoscience Centre (PGC) in Sidney, B.C. Data retrieval commences at 00:00 hrs UTC daily and relies on high-speed modems over local telco data lines. Upon completion of downloads the data are validated using two routines developed at GSD, GIMP8, and DCRAP7. The validation routines issue both warning and error flags. In the event of an error condition the data are automatically downloaded again and validated. The IGS Quality Assurance program is run on the RINEX files. Any warnings or errors are captured in a daily log file along with summaries from all data validation programs. Both native CONAN Binary and RINEX files are available from a public FTP directory. The GSD (Ottawa) currently retrieves the GPS data files from the PGC FTP site, validates and forwards RINEX files to CDDIS.

ALBH Station Summary March 31, 1995:

```
GPS RECEIVER:     - 95/01/11 (95.011) 22:15UT ROGUE  SNR-8000  Rcvr s/n 292
FIRMWARE :        - 95/07/21 (95.202) 19:26UT Vers. 3.2  link  1995/03/09
                                              12:37:24 G050 JPL
ANTENNA :           95/06/07 (95.158) 20:52UT AOA Dome Margolin T p/n 7490582-1
                                              s/n 95-174 (with acrylic dome)
ANTENNA HEIGHT :  - 95/01/11 (95.011) 22:15   0.100 m   (10 cm)
                    vertical distance measured to antenna reference point(ARP)
CLOCK:              95/01/23 (95.023) 20:54UT HP 5061A Cesium s/n 2340 A02226
STATUS :          - 92/05/04 (92.125)   Operational
AGENCY :          Geological Survey of Canada, NRCan
CONTACT :         Michael Schmidt
                  Pacific Geoscience Centre
                  Geological Survey of Canada
                  PO Box 6000, Sidney, B.C. , Canada, V8L 4B2
                  TEL (604) 363-6760
                  FAX (604) 363-6565
                  INTERNET schmidt@pgc.nrcan.gc.ca or schmidt@pgc.emr.ca
```

Penticton

STATION ID:	DRAO
GEODETIC MARK	887006
FULL NAME:	DRAO WCDA ACP
CLASS:	WCDA, CORE1
DOMES No.:	401 O5-MOO2
CDP No.:	nJa
LOCATION:	Dominion Radio Astrophysical Observatory (DRAO) Penticton, B. C., Canada
COORDINATES:	Latitude N 49"19'21.4" Longitude E 240°22'30.1" Ellipsoid Height 542.5 m
COLLOCATION:	Mobile VLBI - CDP No.: 7283 - DOMES No.: 401 O5-MOO1 - Geodetic Mark: 837030

DRAO is located on the property of the Dominion Radio Astrophysical Observatory (DRAO), south of the town of Penticton, B. C., Canada. DRAO is one of seven GPS trackers in the Western Canada Deformation Array operated by the Geological Survey of Canada (GSC). DRAO is also part of the Canadian Active Control System (ACS) as well as the provincial (B. C.) ACS. Mobile VLBI, absolute gravity, precise tri-lat and precise levels have been carried out at DRAO in addition to the GPS observations. DRAO is located on the North American plate.

DRAO was the first permanent GPS tracker established by the GSC in Western Canada. The first crustal dynamics measurements took place in 1984 (VLBI: MV-2) followed by repeated VLBI occupations in 1985 and 1990; a TI-4100 GPS receiver was run at the current GPS pier for the GIG '91 experiment. The GPS tracker commenced operation (Rogue SNR-8) in February 1991; absolute and precise relative gravity measurements are carried out at regular intervals. All markers on site (GPS, VLBI and local references) are tied into local vertical control through special order leveling surveys carried out by the Geodetic Survey Division (GSD), Geomatics Canada. A broadband seismometer is collocated at the site.

Instrumentation As of July1995 DRAO is equipped with a dual-frequency, eight-channel AOA SNR-8000 TurboRogue GPS receiver. The antenna is attached to a brass forced-centered plate (embedded in the concrete pier) via a 10-cm-high anodized aluminum base. This base provides a constant height above the brass plates and also permits the antenna to be referenced to north. Reference frequency is provided by an external cesium beam (super tube) frequency standard. The GPS equipment uses local grid power backed up by an uninterruptible power supply (UPS) capable of sustaining the site for up to 45 minutes. Two high-speed modems are used (1) to access the receiver for instrument control and data recovery and (2) to access the UPS to monitor and control power to the GPS instruments. The instrumentation is enclosed in a special RFI / EMI-shielded cabinet in order to eliminate any potential interference disruptive to the radio astronomy program at DRAO. The current (March 1995) data rate is 30 seconds.

Monumentation The AOA TurboRogue GPS antenna is located on top of a concrete pier anchored to bedrock with steel reinforcement bars. The internal reference network consists of four markers surrounding the pier; these are used to monitor long-term stability of the GPS pier as well as to maintain the offsets between the GPS marker and the VLBI marker through periodic resurvey(s) of the reference network. An external GPS reference network is maintained and consists of six stations within a 10-km radius of DRAO.

Data Handling The GPS data from all WCDA sites are retrieved automatically from a central data collection and validation platform located at the Pacific Geoscience Centre (PGC) in Sidney, B.C. Data retrieval commences at 00:00 hrs UTC daily and relies on high-speed modems over local telco data lines. Upon completion of downloads the data are validated using two routines developed at GSD, GIMP8, and DCRAP7. The validation routines issue both warning and error flags. In the event of an error condition the data are automatically downloaded again and validated. The IGS Quality Assurance program is run on the RINEX files. Any warnings or errors are captured in a daily log file along with summaries from all data validation programs. Both native CONAN Binary and RINEX files are available from a public FTP directory. The GSD (Ottawa) currently picks up the data from the PGC FTP site, validates them and forwards RINEX files to CDDIS.

DRAO Station Summary April 12, 1995

```
GPS RECEIVER:    - 95/04/12 (95.102) 17:05UT ROGUE SNR 8000 Rcvr S/n 347
FIRMWARE :       - 95/07/17 (95.198) 17:23UT 3.2 link 1995/03/09 12:37:24
                                             G050 JPL
ANTENNA :          95/04/12 (95.102) 17:05UT AOA Dome Margolin T p/n 7490582-1
                                             s/n 95-172
ANTENNA HEIGHT : - 95/04/12 (95.102) 17:05UT 0.100 m (10 cm)
                   vertical distance measured to antenna reference point (ARP)
CLOCK :            94/01/04 (94.006) 23:07uT HP 5061B 003 004 Cesium Super Tube
                                             s/n 2624 A00154
STATUS :         - 91/02/27 (91.058)         Operational
AGENCY :         Geological Survey of Canada, NRCan
CONTACT :        Michael Schmidt
                 Pacific Geoscience Centre
                 Geological Survey of Canada
                 PO Box 6000, Sidney, B.C. , Canada, V8L 4B2
                 TEL (604) 363-6760
                 FAX (604) 363-6565
                 INTERNET schmidt@pgc.nrcan.gc.ca or schmidt@pgc.emr.ca
```

Herstmonceux GPS ROGUE Receiver General Site Description

Andrew Sinclair
Royal Greenwich Observatory
Cambridge, England

The site of the GPS Rogue receiver at Herstmonceux, England, is in the grounds of Herstmonceux Castle, and is located about 3 km from the village of Herstmonceux and about 8 km from the south coast of England. It is the former site of the Royal Greenwich Observatory, until it moved to Cambridge in 1990. The site is now owned by Queen's University of Canada, and is used as an international study center and conference center. The principal geodetic instrument operated at the site is the UK Satellite Laser Ranging System. This has been in continuous operation since October 1983. It was decided not to move it to Cambridge when the Observatory moved, and it is now operated by a local team of 6 people as an outstation of the Royal Greenwich Observatory, with a further 2 people at Cambridge for management and data analysis activities. An SNR-8A mini-ROGUE GPS receiver was put into operation at the site in September 1991, and the receiver was replaced by an SNR-8C in March 1992, which has been in operation since then.

The local site manager is Dr. Roger Wood, based at Herstmonceux, and the overall manager of the project is Dr. Andrew Sinclair, based at Cambridge.

Report on IGS Global Station Jozefoslaw

Janusz Sledzinski
Institute of Geodesy and Geodetic Astronomy
Warsaw University of Technology
Warsaw, Poland

The IGS station Jozefoslaw (JOZE) is located at the Astrogeodetic Observatory of the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology established in 1959. At present three permanent services are maintained at this station:

- Astrometric latitude observations have been carried out since 1959 in the frame of international cooperation with BIH and IPMS; now the observations are being used by Shanghai Observatory (international coordinator of the optical astrometry) and GOSTSTANDARD, Moscow. These observations are also used for the analyses of the time variations of the plumb line.

- Gravimetric permanent tidal measurements using LaCoste & Romberg mod. G gravity meter have been carried out since November 1993. The Observatory Jozefoslaw is one of the fundamental points of the Polish national gravimetric network; many absolute gravity determinations have been performed. A special meridional gravimetric baseline, 26 km long, was established at the observatory in 1976; periodic observations are made four times a year. The observations are used jointly with astrometric determinations for studies of the changes in the vertical.

- GPS permanent service has been maintained since August 1993. The station participated earlier in the IGS Epoch'92 campaign. The Trimble 4000SSE receiver serial No. 3249A02090, antenna Trimble Geodetic L1/L2 N0.3247A66429 is used. Three rubidium frequency standards are available at the station; one of them is used as an external standard for IGS service. On January 1, 1995 the second GPS receiver, a TurboRogue SNR 8000, serial No. 339, antenna type Dome Margolin T No. 439, was installed at the station. The permanent GPS IGS service will be maintained by both receivers (Trimble 4000SSE and TurboRogue SNR 8000). The Trimble 4000SSE will serve as the main receiver and its observations will still be transmitted to the international data centers. The observations of the TurboRogue SNR 8000 receiver will be soon available upon request for all interested centers for scientific research.

Monumentation of the reference point was made according to the IGS standards. Control points are available. Due to the geological situation the pillar could not be monumented on the bedrock. Station Jozefoslaw is the reference point of several international GPS networks: EUREF, EXTENDED SAGET, CEGRN (Central European GPS Reference Network), and BSL (Baltic Sea Level). The eccentricity of the EUREF point with respect to that of other campaigns is: X = 0.079 m, Y = 0.030 m, Z = 0.108 m. Since the 1960s the

Observatory has also participated in other international astrometric and satellite campaigns (photographic, Doppler, GPS).

The IGS Associate Analysis Centre was organized at the Institute with the aim of processing data from IGS and other GPS campaigns in Central Europe used for geodynamic studies of the Teisseyre-Tornquist contact zone, the Carpathian and Subalpine regions. The day-to-day coordinates of several IGS permanent stations from Central Europe are computed at the Centre in the cooperation with the CODE Berne Centre. Also IGS products, e.g., GPS satellite orbits and Earth rotation parameters, are archived. The Centre is also responsible for daily data transmission from the Astrogeodetic Observatory Jozefoslaw to the international data centers.

JPL-Supported Permanent Tracking Stations

G. Franklin, B. Iijima, P. Kroger, U. Lindqwister, T. Lockhart, A. Mikolajcik, M. Smith, and K. Stark
Jet Propulsion Laboratory
Pasadena, California

The following sites are permanent installations currently operated or supported by JPL. Latitude and longitude are in degrees, heights are in meters.

AREQ — NASA Laser Tracking Station, Arequipa, Peru
Lat: -16.4655
Long: 288.5070
Ht.: 2496.421

The TurboRogue at Arequipa is collocated with the Satellite Laser Ranging station in Arequipa. The original installation was done in January 1994 at an existing monument and was moved to a new installation in March of that year.

BOGT — INGEOMINAS, Bogota, Columbia
Lat: 4.64
Long: 285.91
Ht.: 2573.0

The TurboRogue receiver at Bogota shares an office phone line in order to transfer the data back to JPL.

BRAZ — IBGE, Brasilia, Brazil
Lat: -15.9474
Long 312.1219
Ht.: 1106.1887

The TurboRogue receiver at Brazil is currently uploaded using a standard phone line, but it will soon switch over to using the Internet to transfer the data to JPL.

CASA — Mammoth, California
Lat: 37.6446
Long: 241.1034
Ht.: 2384.8

The TurboRogue Receiver was installed as part of a DOSE funded project headed up by Frank Webb, Tim Dixon, and Marcus Bursik, to measure uplift in the Mammoth Lakes region. It is located at the United States Geological Survey offices in Mammoth.

CICE — CICESE, Ensenada, Mexico
Lat: 31.8712
Long: 243.3326
Ht.: 96.0994

This site was installed by the University of Miami, UNAVCO, JPL and CICESE in early 1995. It uses radio data modems to offload the GPS data.

EISL — Easter Island, Chile
Lat: –27.1482
Long: -109.3832
Ht.: 116.9770

Easter Island is located off of the coast of Chile. The TurboRogue installed there is collocated with the Satellite Laser Ranging facility on the island.

FAIR — NASA Fairbanks Observatory, Fairbanks, Alaska
Lat: 64.9780
Long: 212.5011
Ht.: 320.3149

Big Red, as the monument at Fairbanks is often called, is installed at the Gilmore Creek observatory in Fairbanks. A Rogue SNR-8 is currently in operation at this site.

GODE — Goddard Space Flight Center, Maryland
Lat: 39.0217
Long: 283.173
Ht.: 19.81

The TurboRogue Receiver at the Goddard Space Flight Center is using a steel pillar monument. It is using an external maser frequency standard.

GUAM — Guam Seismic Observatory, Dededo, Guam
Lat: 13.5893
Long: 144.8683
Ht.: 204.9137

The TurboRogue receiver is installed at the Observatory along with an IRIS/USGS seismometer.

HARV — Harvest Oil Platform, California
Lat: 34.4694
Long: -120.6821
Ht.: 19.1620

The Harvest Oil Platform is located 8 km off the coast of Vandenberg Air Force Base in Southern California. Data communications to the TurboRogue receiver at Harvest are accomplished using commercial cellular communications to the platform.

KOKB — Kokee Park, Kokee, Hawaii
Lat: 22.1262
Long: 200.3354
Ht.: 1189.9162

The Rogue SNR-8 at Kokee is located on top of a small concrete building at the Kokee Park Observatory. It is using an external Hydrogen Maser frequency reference.

MCM4 — McMurdo, Antarctica
Lat: -77.8383
Long: 166.6693
Ht.: 102.3635

There are two sites that have been used at McMurdo. There is currently a TurboRogue receiver operating at the MCM4 mark, There is a local Macintosh that uploads the receiver at the site. The data are offloaded from the Macintosh using Internet.

MDO1 — McDonald Laser Observatory, Fort Davis, Texas
Lat: 30.6805
Long: 255.9849
Ht.: 2094.9

Table 1. Data Access Information.

Short Name:	JPL
Institution:	Jet Propulsion Laboratory
Function within IGS:	Special Data Center
Mail Address:	4800 Oak Grove Drive Pasadena, CA 91109, USA
Contact:	Keith F. Stark
Telephone:	(81 8) 3545922
Fax:	(81 8) 3934965
E-Mail:	stark@logos.jpl.nasa.gov (internet)
Telnet Access:	None
FTP Access:	bodhi.jpl.nasa.gov (128.149.70.66) anonymous
Computer Operating System:	HP 9000/715 HP-UX, VAX/VMS
Amount of data on line:	120 days
Access to off-line data:	Special arrangements

Table 2. Directory Structure.

Directory	Subdirectory	Description
directory specifications are for our guest computer BODHI.		
pub		top level
	/rinex	rinex area indexed by day of year
	/raw	raw data area indexed by day of year
	/docs	supporting documentation and IGS MAIL
	/software	supporting software
	/topex	Topex orbit data

The TurboRogue at McDonald Laser Observatory uses a steel pillar monument located on the grounds of the Observatory.

NLIB — North Liberty VLBA Station, North Liberty, Iowa
Lat: 41.7716
Long: 268.4252
Ht.: 216.635

This installation is collocated with the VLBA site in North Liberty. The monument is comprised of a steel pillar on a concrete mount placed in the ground just outside of the VLBA compound. The TurboRogue receiver is using the VLBA maser as a clock reference.

PIE1 — Pie Town VLBA Station, Pie Town, New Mexico
Lat: 34.3015
Long: 251.8814
Ht.: 2353.50

This installation is collocated with the VLBA site in Pie Town. The monument is comprised of a steel pillar on a concrete mount placed in the ground just outside of the VLBA compound. The TurboRogue receiver is using the VLBA maser as a clock reference.

QUIN — Mobile Laser Tracking Station, Quincy, California
Lat: 39.9746
Long: 239.0559
Ht.: 1080.3

The TurboRogue receiver at Quincy is located at the Mobile Laser Tracking Station (Moblas) #8 in Northern California.

SHAO — Shanghai Observatory, Shanghai, China
Lat: 31.0996
Long: 121.2004
Ht.: 23.16

The TurboRogue receiver at Shanghai is hosted by the Chinese Academy of Science at the Shanghai observatory. The receiver is using the local maser as its clock reference.

THU1 — Thule, Greenland
Lat: 76.5372
Long: 291.2120
Ht.: 94.7687

This receiver is a 12-channel TurboRogue to ensure ample channel availability for the increased number of visible low elevation GPS satellites.

YAR1 — Mobile Laser Tracking Station, Yaragadee, Australia
Lat: –29.0376
Long: 115.3487
Ht.: 2165.49

The Rogue SNR-8 at Yaragadee has been operating there since late 1990.

DSN sites ***and TOPEX***

GOLD — Goldstone DSN Station, California
Lat: 35.4252
Long: -116.8892
Ht.: 986.7163

The monument and antenna used by the Rogue SNR-8 receiver at Goldstone is installed on the top of a Microwave tower at the Deep Space Network station. The data is transferred back from the site using the NASCOM lines back to JPL.

MADR — Madrid DSN Station, Spain
Lat: 40.4292
Long: -4.2497
Ht.: 829.4512

The Rogue SNR-8 receiver located here uses an monument mounted on the roof of a building at the Madrid Deep Space Network facility. The data are transferred back from the site using the NASCOM lines back to JPL.

SANT — University of Chile, Santiago, Chile
Lat: –33.1502
Long: –70.6682
Ht.: 725.6814

This installation uses a Macintosh computer in Santiago to upload the data from the Rogue SNR-8 receiver. The data are then transferred back to JPL via the Internet.

USUD — Usuda, Japan
Lat: 36.1331
Long: 138.3621
Ht.: 1504.5

The monument at Usuda is mounted on the roof of the two-story control room at the Usuda Tracking Station. The TurboRogue receiver is using an external frequency.

TIDB — Tidbinbilla DSN Station, Australia
Lat: –35.3992
Long: 148.98
Ht.: 665.4018

The Rogue SNR-8 receiver at Tidbinbilla uses an antenna mounted on JPL-style reinforced concrete pillar monument. The data are transferred back from the site using the NASCOM lines back to JPL.

Southern California

The following sites were installed as a part of the Southern California Integrated GPS Network (SCIGN), which uses a regional array of permanent GPS receivers for seismic studies in Southern California. SCIGN is currently composed of 30 permanent sites operated by various agencies in Southern

California. JPL currently retrieves data from the following 12 sites which are equipped with TurboRogue receivers:

AOA1 — Allen Osborne Associates, Westlake Village, California
Lat: 34.1575
Long: 241.1697
Ht.: 249.1509

Allen Osborne Associates, the manufacturer of the TurboRogue receiver, hosts this TurboRogue installation on the roof of their offices in Westlake Village.

CARR — Parkfield, California
Lat: 35.8883
Long: 239.5693
Ht.: 466.2229

Parkfield, California has long been known as one of the most seismically interesting places on earth due to its history of regularly repeating earthquakes. A TurboRogue receiver is permanently operating on a site with a long history of campaign occupations.

CIT1 — Caltech, Pasadena, California
Lat: 34.1367
Long: 241.8727
Ht.: 216.877

Located only a few miles south of JPL, Caltech is closely tied with the operation of the Laboratory. The TurboRogue receiver installed at Caltech is located on the roof of the North Mudd building on the Caltech campus.

JPLM — Jet Propulsion Laboratory, Pasadena, CA
Lat: 34.2050
Long: 241.8266
Ht.: 461.1171

The site here at JPL is located on the mesa directly north of the JPL Oak Grove complex in Pasadena. This receiver is one of the longest permanently operating receivers, having been installed in early 1990. A TurboRogue has replaced the Rogue SNR-8 that was originally installed there.

LBCH — Long Beach, California
Lat: 33.7877
Long: 241.7966
Ht.: 44.0

The TurboRogue receiver here uses a roof-mount monument on the Electronic System Communication building at the Bureau of Public Services.

OAT2 — ATT Microwave Facility, Oat Mountain, California
Lat: 34.3301
Long: 241.3986
Ht.: 1016.1

The name of the original site, OATT, included the acronym for the operators of the facility where it was located. The name change to OAT2 was required when the monument used by the TurboRogue receiver was moved from the ground to the roof of the facility in early 1995.

SPK1 — Fire Camp 8, Saddle Peak, California
Lat: 34.0592
Long: 241.3539
Ht.: 438.6513

Saddle Peak is located in the hills north of Malibu and currently has a TurboRogue receiver installed there.

UCLP — University California at Los Angeles, Westwood, California
Lat: 34.0691
Long: 241.5581
Ht.: 113.0

The TurboRogue receiver and the roof mount monument are installed at a building on the University of California at Los Angeles campus.

USC1 — University of Southern California, Los Angeles, California
Lat: 34.024
Long: 241.715
Ht.: 31.205

This TurboRogue installation consists of a steel pillar monument located at a power vault on the campus of the University of Southern California.

WHC1 — Whittier College, Whittier, California
Lat: 33.97
Long: 241.96
Ht.: 68.14

The TurboRogue receiver and the roof mount monument are installed at a building on the Whittier College Campus.

WHI1 — Whittier Library, Whittier, California
Lat: 33.97
Long: 241.97
Ht.: 68.14

The TurboRogue receiver and the roof mount monument are installed on the Whittier Library.

WLSN — Mt. Wilson Observatory, Mt. Wilson, California
Lat: 34.2261
Long: 241.9441
Ht.: 1695.1

The TurboRogue receiver is located at the NRL/MIT interferometry site northeast of JPL in the San Gabriel Mountains.

References

Additional information about the GPS Global Tracking Network and the SCIGN Network maybe obtained via the World Wide Web at the following addresses:

1. JPL's Global GPS Time Series Data:
   http://sideshow.jpl .nasa.gov/mbh/series .html

2. JPL's contribution to the Southern California Dense Array:
   http://milhouse.jpl.nasa.gov/

The KOSG IGS Station

Danny Van Loon
Kootwijk Observatory for Satellite Geodesy
Delft University of Technology
Delft, Netherlands

The KOSG IGS-station (acronym for Kootwijk Observatory for Satellite Geodesy) is located in the eastern part, while the Delft University of Technology itself, owner of KOSG, is in the western part of the Netherlands. KOSG has operated its ROGUE SNR-8 GPS receiver since the start of IGS after a successful GIG-91 campaign. An external HP rubidium frequency standard is connected to the receiver, while a PC takes care of the automatic download of the data in the compressed (crop) Rogue data format, using the Procomm Plus communication software. This takes place every day at 00:00 UTC. The PC is inserted in a local network of which its HP-server is connected to the Internet.

At 01:00 UTC the Kootwijk data handling job at the Delft University of Technology is started. The start is scheduled using the UNIX "crontab" command. The first action is an ftp to Kootwijk to download the Rogue data file. This file is checked for its size and after approval it is copied to the anonymous ftp account at Delft (dutlru6.tudelft.nl or 130.161.164. 175) in the directory /pub/rogue. Also it is sent (using ftp) to the Jet Propulsion Laboratory (JPL). If no cmp file was found at Kootwijk or if the size is not large enough, the data handling stops and sends an e-mail message to both the operators at Kootwijk and Delft.

After successful download of the data file the conversion to RINEX starts. Here care is taken to concatenate the navigation file to contain only messages between 0:00 and 24:00 UTC of this day. The observations always span from 0:00 to 24:00 hours UTC so no special actions are required here. After the RINEX conversions, using the Bernese RGRINEX program for the IBM-RS6000 AIX, the RINEX file is also copied to the Delft anonymous ftp account. Furthermore the data are distributed, using ftp, for the IGS to the IfAG data center. In case of an ftp error when transmitting the file to IfAG the data will be put to the CODE IGS Analysis Center in Berne. In case of any errors during the ftp sessions an e-mail message will be sent to both operators.

After conversion of the raw Rogue data, the RINEX data are processed using parts of the Gipsy and Bernese software. With both softwares an orbit integration is performed to see if anything is wrong with the navigation messages. Up to now no errors have been detected here in over two years of operation. The observation data are run through the "ninja" program of the Gipsy software with the TurboEdit algorithm, to get an idea of the data quality. From the Bernese software we use the program "RxSTATUS" and "RNXGRA" to get a graphical overview of the observations. Furthermore, a single-point-positioning solution is made using the code observations. Here both the observation and the navigation files are used. This code single-point positioning is done twice; once estimating only a clock offset and a clock drift and once estimating a clock offset for every epoch. The difference between the sigmas of the residuals of these two runs gives us an idea of the quality of the external frequency used in Kootwijk. Furthermore the rms of the residuals is a control on the quality of the code observations.

Finally the log sheet of the data processing is sent by e-mail to both operators and the output of the RNXGRA program (pseudo graphic of the RINEX observations) is put to Kootwijk using ftp.

Italian Space Agency

Francesco Vespe
Italian Space Agency
Matera, Italy

Matera Core Station

The activities of the Matera Core Station are now completely automated. The GPS fixed-station Rogue SNR-8 was installed in 1990. In 1992 our station was included among the core stations of the IGS service. The operational mode of the Rogue receiver is the following:

- Time acquisition: 24 hour/day
- Sample rate: 30 sec
- Elevation cutoff 15°
- 5-MHz external reference on Hydrogen Maser

The collected data are sent daily through the Internet in raw format to JPL/NASA and in Rinex compressed format to IfAG. In Figure 1 we show the data flow configuration used.

The Raw and RINEX compressed data are also archived at CGS.

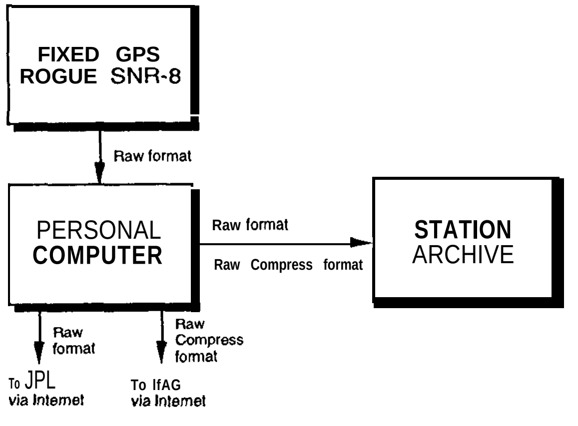


Figure 1. Data flow configuration of the GPS fixed station at Matera.

A New Fixed GPS Station at Padova

The University of Padova, in collaboration with CGS, installed a fixed station last October. The-data are collected on a daily basis and through modem are sent to CGS. As for the core stations, the data are then distributed to IfAG (RINEX) and to JPL (raw).

Following is a summary of the main features of the new GPS fixed station in Padova:

Type of Receiver:	Trimble 4000 SSE
Frequency Standard:	Internal
Coordinates of the site:	45°24’25” N 11°40’52” E 90 m
Vertical antenna height:	1.962 m (on bottom of Preamplifier)
On site point of contact:	Prof. Caporali, Dr. Galgaro Dept. of Geology and Geophysics, University of Padova

The Permanent GPS Tracking Station Zimmerwald

Urs Wild
Federal Office of Topography
Wabern, Switzerland

Introduction

The Federal Office of Topography has been operating a permanent GPS receiver since the beginning of the IGS Test Campaign (June 1992) at the SLR station Zimmerwald of the Astronomical Institute of the University of Berne (AIUB).

The station is located 10 km south of Berne at an altitude of about 900 m. The station consists of the old astronomical and the newer SLR dome and a building with offices and accommodations for the SLR observers. The GPS antenna is installed on top of a 9-m steel mast.

Local ties have been established between the axis intersection point of the SLR telescope, the GPS antenna on the mast, older GPS points on the roof of the main building, and a first-order triangulation point in the vicinity of the station. All local surveys were carried out by the Swiss Federal Office of Topography with an accuracy at the l-mm level.

Permanent GPS Tracking

The technical specifications of the GPS receiver in Zimmerwald are:

Receiver type	Trimble Geodetic System Surveyor 4000SSE
NP software	Version 6.10
SP software	Version 1.26
Internal memory	2.5 MB
Number of channels	9 + 9
Observable	L1 and L2 phase / P-code on L1 and L2 / Cross-correlation under AS
RTCM	Output (used for DGPS service)
1 PPS	Installed (used for SLR)

The Trimble 4000SSE is connected to a laptop computer, which is connected through a LAN to the station computer (VAXStation 4000/90). The receiver and the steering laptop computer are protected against power failure with a 24-V DC power supply and may be operated up to 6 hours independently from the AC current.

A special setup for the permanent GPS tracking has been chosen because Zimmerwald is not only an IGS station, but is also a reference station for national surveys and for high-precision aircraft navigation for airborne photogrammetry. It was therefore our goal not to be limited to the 30-s sampling rate commonly used for the IGS.

On the laptop computer (running under MS-DOS) the program DESQview has been installed in order to have multitask capability. Three programs are running permanently on the laptop:

- Data Logging (using the program LOGST from TRIMBLE)
- FTP server (allowing file transfer from/to the laptop)
- CRON (Job Scheduler)

The program LOGST downloads data to the laptop continuously, i.e. no data is stored in the internal receiver memory. The sampling rate is 1 s.

Every full hour the data are converted from the disk-image format to the Trimble raw data format (DAT/EPH/ION/MES). The data are automatically reduced from 1-s to 30-s data rate, unless 1-s data are explicitly requested (i.e. in a time table) for special applications such as photogrammetric flights.

Producing l-h files would also allow hourly distribution of RINEX files (even at a higher data rate than 30 s) over the Internet, in order to achieve the near real-time requirements in the future.

Every day all l-h data files are concatenated and converted to the RINEX format. The original Trimble raw data files are compressed (PKZIP) into one file. All data of the last 24 h are then downloaded to the station computer (VAXStation 4000/90), where the RINEX files are compressed and sent to the IGS European Data Center (IfAG, Frankfurt) and to CODE (Center for Orbit Determination in Europe) at the AIUB. Normally the files (in the RINEX format) are available at IfAG and CODE within a few hours after midnight.

Twenty-one days of data are available on-line from the station computer; data older than 21 days are automatically deleted from the disk every day. Data backup is performed on a magneto-optical disk (with a capacity of approximately one year of tracking data).

The quality of the tracking data is checked daily using the QC program (UNAVCO) and by computing a single-point positioning solution.

Swiss GPS Information System

The Swiss GPS Information System was installed on the station computer at Zimmerwald. The information system maybe accessed by computer networks (Internet) or by telephone modem. The use of the system is free of charge.

The main options are:

- The **GPS-Status files of the USNO GPS Information system** are downloaded daily and may be displayed.

- The status of the permanent GPS receiver in Zimmerwald may be displayed (Table 1). The same file (updated half hourly) is also available at the IGS Central Bureau Information System.

- Different types of **orbit data** are available: for campaign planning purposes the actual EPH files of the Trimble receiver are available; for high-precision GPS applications the precise orbits of the CODE maybe obtained.

- **Application programs:** Coordinate transformations between WGS-84 / ITRF and the national coordinate system (and others) maybe computed. Another program allows the computation of the deflections of the vertical and geoidal heights (for the Swiss geoid) of sites within Switzerland.

Table 1. Permanent GPS tracking status at Zimmerwald.

```
Date / Time            1995/05/26      15:04 UT
Day of the Year :    146       GPS - Week:     802
```

Tr	SV	Azi	El	AS	URA	H	Tr	SV	Azi	El	AS	URA	H
	1			Y	32.0	H	*	19	314	11	Y	32.0	H
	2			Y	32.0	H		20			Y	32.0	H
	4			Y	32.0	H	*	21	154	40	Y	32.0	H
	5			Y	32.0	H	*	22	200	57	Y	32.0	H
	6			Y	32.0	H	*	23	98	49	Y	32.0	H
	7			Y	32.0	H		24			Y	32.0	H
	9			Y	32.0	H		25			Y	32.0	H
	12			N	2.8	U	*	26	46	5	Y	32.0	H
	14			Y	32.0	H		27			Y	32.0	H
	15			Y	4.0	H	*	28	308	66	N	4.0	H
	16			Y	32.0	H		29			Y	32.0	H
*	17	56	34	Y	32.0	H	*	31	292	23	Y	32.0	H
	18			Y	32.0	H		–					

Tr: Tracking flag (*: satellite tracked)
Sv: Satellite Number
Azi: Azimuth
El : Elevation
AS: Y: AS on / N: AS off
URA : User Range Accuracy
H: Satellite Health (H: healthy, U: unhealthy)

DGPS Service (Pilot project)

The Swiss Federal Office of Topography and the SwissTELECOM are establishinga nationwide DGPS service over FM/RDS (Radio Data System) using the RTCMcorrections generatedbythe Trimble4000SSE ofthePermanent Tracking Station Zimmerwald. During the pilot project (September 1995-1997) the RTCM corrections are broadcasted over four major FM stations which cover about 70% of the more densely populated area of Switzerland.

First field tests have shown accuracies of 1 to 5 meters in real-time, depending on the receiver type used.

Pine Meadow PGGA

Frank Wyatt
Scripps Institution of Oceanography
San Diego, California

Form

Prepared by (full name)	: Frank Wyatt, Hadley Johnson, and Yehuda Bock
Date	: November 21, 1994
Report type	: NEW

Site Identification of the GPS Monument

Site Name	: Pinemeadow PGGA
4 char ID	: ROCH
Monument Inscription	: None

Threaded stainless steel rod (2 cm diameter, 9 cm long), set vertically in hole drilled in large granite outcropping on side of hill. Rod set in granite with epoxy.

IERS DOMES Number	40486MO01
CDP Number	None
Date	April 19, 1991 (installed)
Additional information	PGGA - Permanent GPS Geodetic Array

Site Location

Town	Pinemeadow
Country	California, USA
Tectonic Plate	Pacific-North America plate boundary
Additional information	ITRF92 coordinates (m) —
	X -2382183.199
	Y -4755085.173
	Z 3511367.704
	Epoch 1993.000

GPS Receiver

a-c)	Type	Trimble 4000 SST
	Serial Number	0496
	Firmware Version	4.11
	Date	April 19, 1991
	Note	First measurements

```
          Trimble:  4000ST  L1/L2 GEOD

                        ----+----                          <-- 0.070 L1
                      /     +     \                        <-- 0.068 L2
++--------------+-------------- +---------------++         <-- 0.063  TGP
++-------------+--------------- -+--------------++         <--  0.060  BGP
                |                 |
                                 |
                 |
                  +------x------+                       <-  0.000   ARP=BPA

                  <--  0.140 -->                               BPA
              <--      0.155      -->                          TPA
 <--                   0.467                     -->           NOTCHES
<--                    0.483                       ->          EOGE
```

Figure 1. Antenna graphics.

Pine Meadow PGGA

Frank Wyatt
Scripps Institution of Oceanography
San Diego, California

Form

Prepared by (full name)	: Frank Wyatt, Hadley Johnson, and Yehuda Bock
Date	: November 21, 1994
Report type	: NEW

Site Identification of the GPS Monument

Site Name	: Pinemeadow PGGA
4 char ID	: ROCH
Monument Inscription	: None

Threaded stainless steel rod (2 cm diameter, 9 cm long), set vertically in hole drilled in large granite outcropping on side of hill. Rod set in granite with epoxy.

IERS DOMES Number	40486MO01
CDP Number	None
Date	April 19, 1991 (installed)
Additional information	PGGA - Permanent GPS Geodetic Array

Site Location

Town	Pinemeadow
Country	California, USA
Tectonic Plate	Pacific-North America plate boundary
Additional information	ITRF92 coordinates (m) —

X -2382183.199
Y -4755085.173
Z 3511367.704
Epoch 1993.000

GPS Receiver

a-c) Type	Trimble 4000 SST
Serial Number	0496
Firmware Version	4.11
Date	April 19, 1991
Note	First measurements

GPS Antenna

a) Type : Trimble 4000ST L1/L2 GEOD
Serial Number : 0038
Vertical Antenna Height : 0.2465 m
Antenna Reference Point : BPA (Bottom of Preamplifier)
Date : April 19, 1991

b) Type : Trimble 4000ST L1/L2 GEOD
Serial Number : 0038
Vertical Antenna Height : 0.2475 m
Antenna Reference Point : BPA (Bottom of Preamplifier)
Date : May 15, 1991

c) Type : Trimble 4000ST L1/L2 GEOD
Serial Number : **0038**
Vertical Antenna Height : **0.2440** m
Antenna Reference Point : BPA (Bottom of Preamplifier)
Date : July 3, 1992

Note: Antenna always oriented to true North

Frequency Standard

Frequency Standard : Internal
Other (specify) : Rogue SNR-8 uses external rubidium standard
Date : April 19, 1991

Collocation

Other GEOPHYSICAL Instrumentation (specify): Continuous strain, tilt and gravity instruments, seismic array

Other (specify) : Environmental sensors

On-site, Point of Contact Agency Information

Agency : Scripps Institution of Oceanography
Contact : Frank Wyatt / Hadley Johnson
Address : IGPP 0225, Scripps Institution of Oceanography
9500 Gilman Drive, La Jolla, CA 92093-0225
Telephone : (619) 534-2411,534-2019
E-mail : fwyatt@ucsd.edu, hjohnson@ucsd.edu
Fax : (619) 534-5332

```
                 Trimble: 4000ST  L1/L2 GEOD

                        ----+----                        <-- 0.070 L1
                     /      +      \                     <-- 0.068 L2
++----------------- -----------------+ ----------------++ <-- 0.063  TGP
++---------------+ -----------------+ ----------------++ <-- 0.060  BGP
                 |                   |
                  |                 |
                   |               |
                    +------x------+                   <--0.000  ARP=BPA

                    <--  0.140 -->                         BPA
                 <--     0.155       -->                   TPA
 <--                     0.467                  ->         NOTCHES
<--                      0.483                  -->        EDGE
```

Figure 1. Antenna graphics.

International GPS Service for Geodynamics

Association Internationale de Géodésie
Union Géodésique et Géophysique Internationale

International Association of Geodesy
International Union of Geodesy and Geophysics

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

JPL Publication 95-18 9/95