IGS

INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

1994 ANNUAL REPORT

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IGS Central Bureau

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Preface

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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!

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Introduction to the 1994 IGS Annual Report

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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

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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.

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The Organization of the IGS

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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

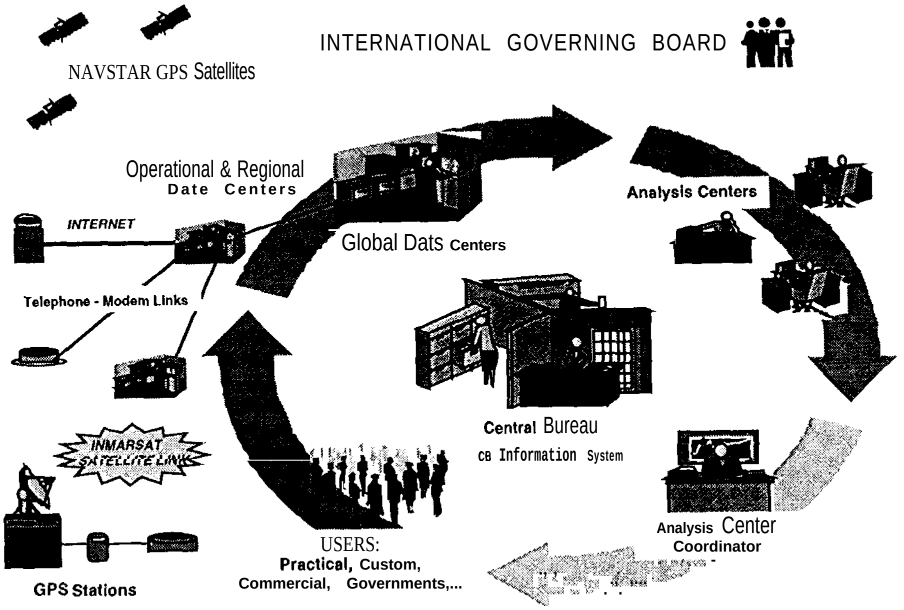


Figure 1. The organization of the International GPS Service for Geodynamics.

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.

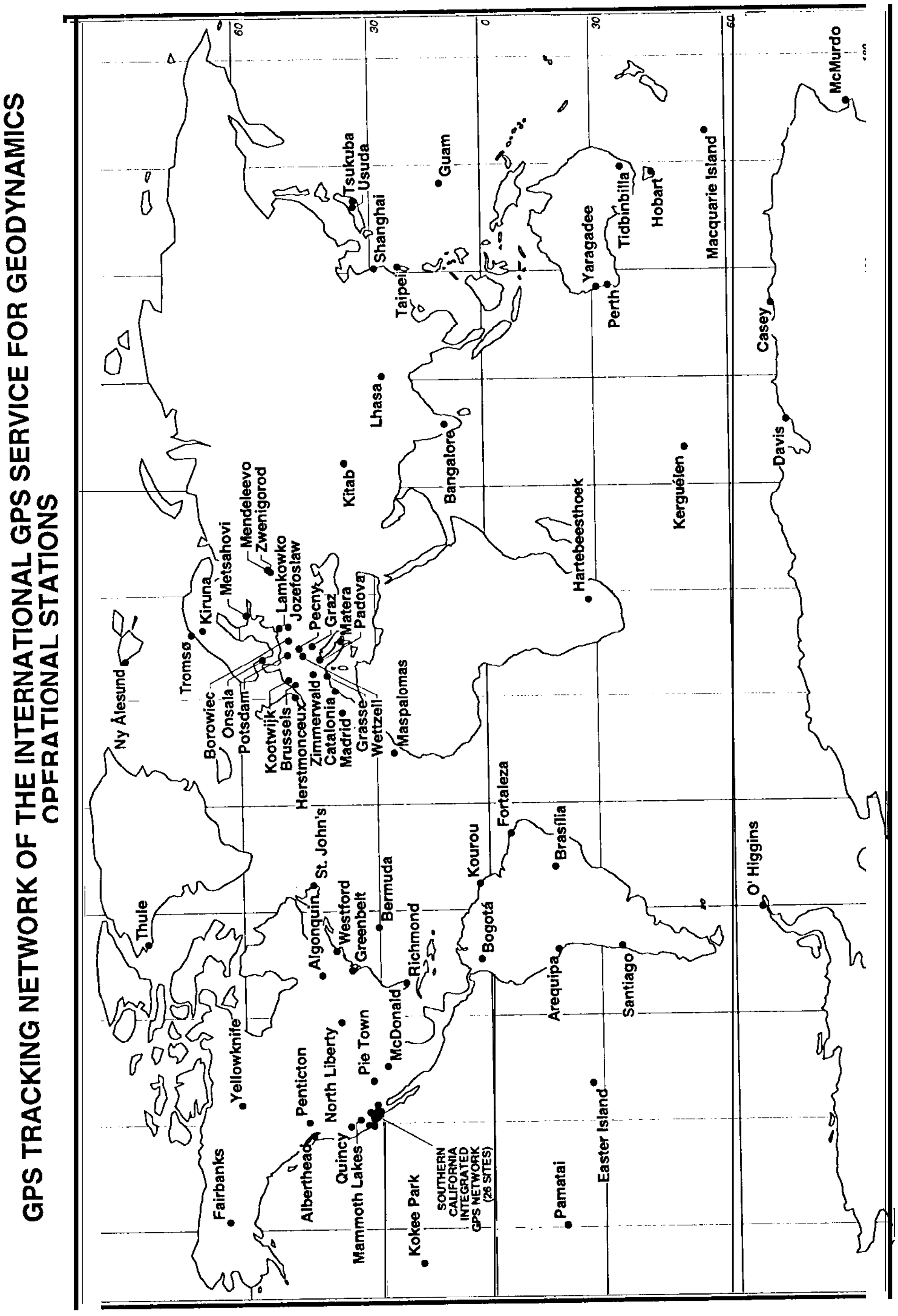
Network Stations

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 Space 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.



igure 2. The operational tations of the IGS etwork, 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.

Table 3. IGS global data centers.

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

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.

Table 4. The seven analysis centers of the IGS.

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

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.

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

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

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.

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

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/specifications 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
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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

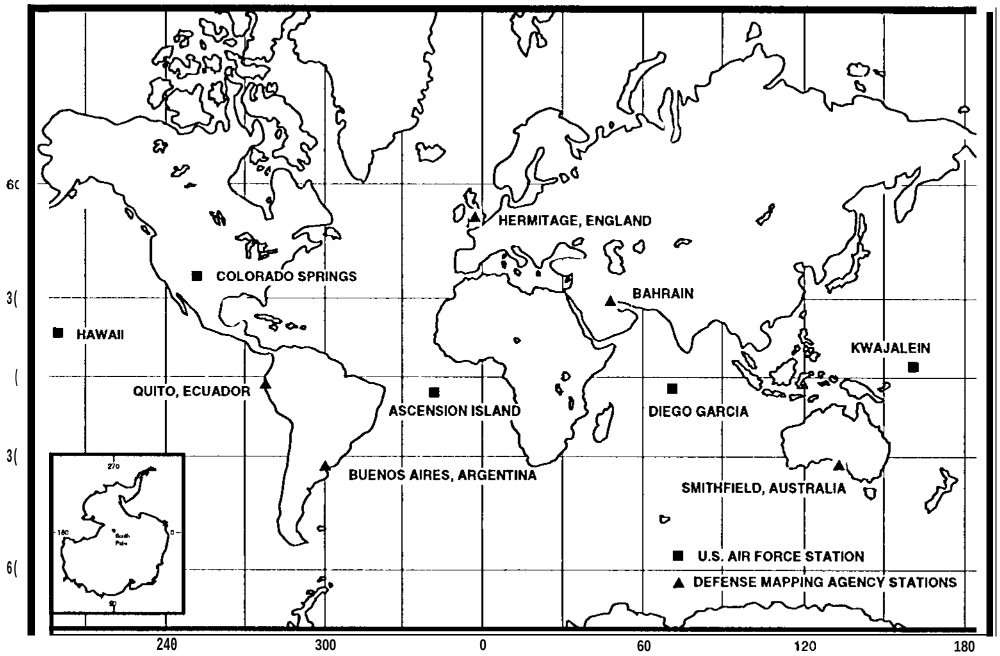
While the orbits produced from the U.S. DoD GPS ground segment were available to certain groups in the early 1980s, the simulations and post-processing of GPS data by civilian groups indicated a need for increasing precision, especially as scientific groups began to look at the GPS as a way to monitor 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

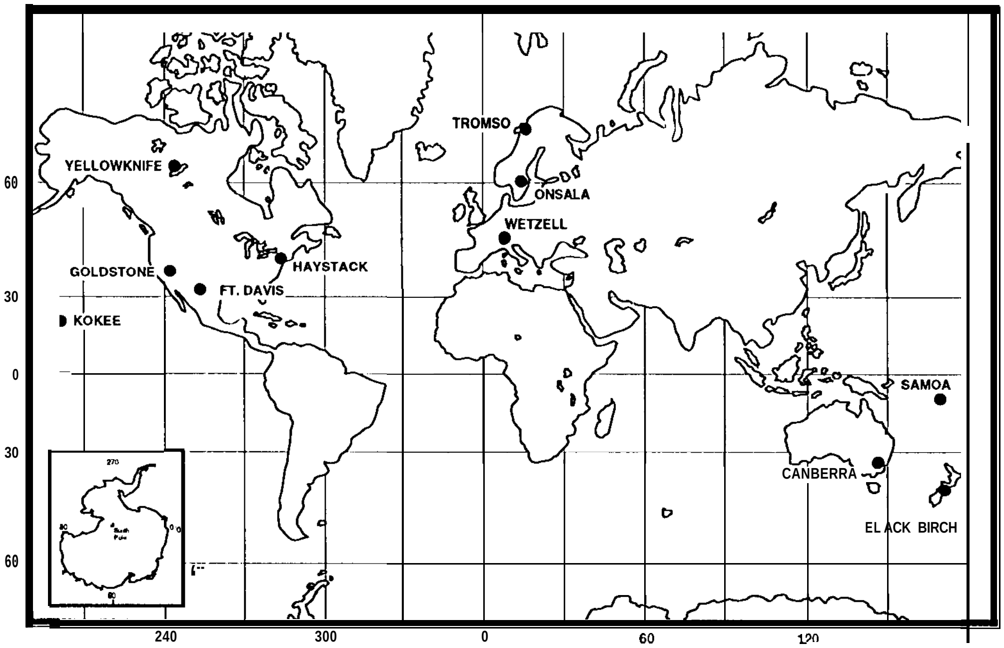
Figure 1. U.S. Air Force and Defense Mapping Agency GPS Tracking Network. The Operational Control Segment of the Global Positioning System. The operational capability was established in May 1985.

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.

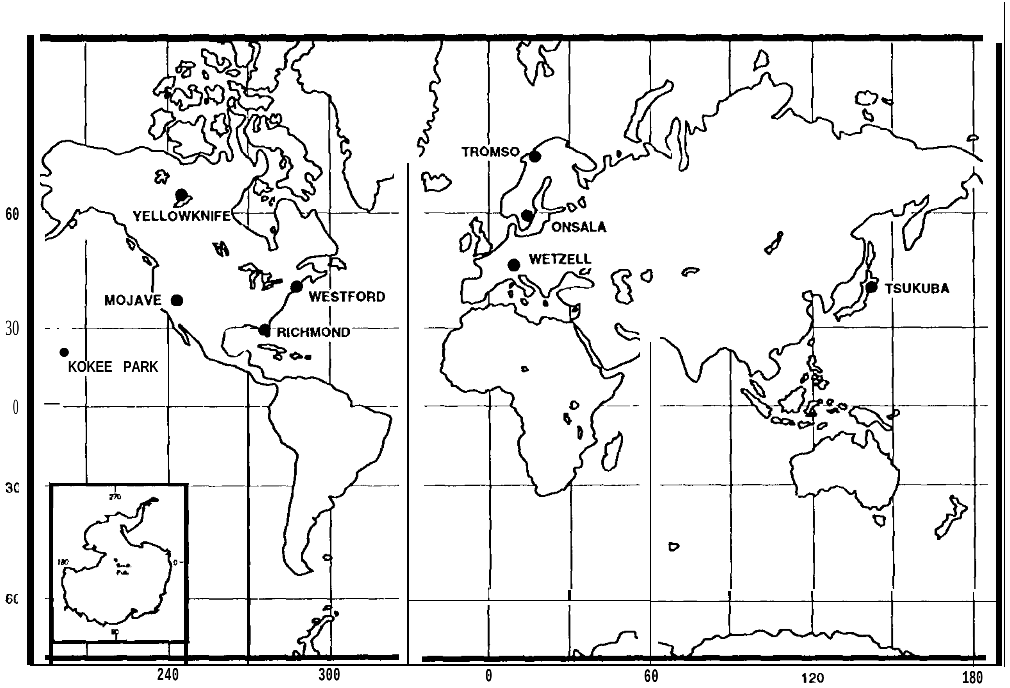
Tracking Network Development

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



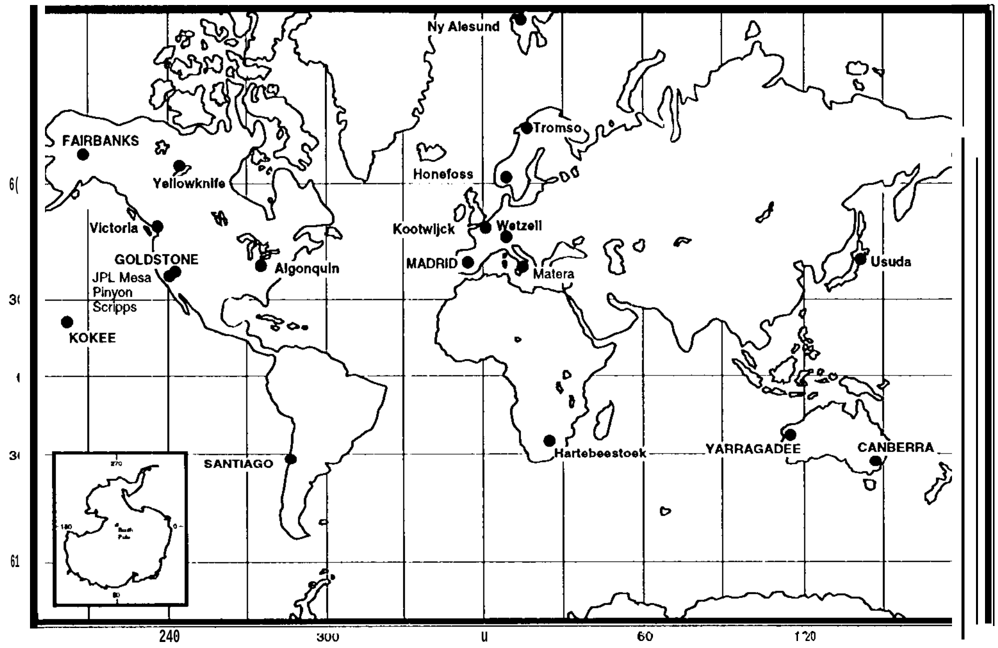
● *CIGNET* **Tracking Sites, January 1989**

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.

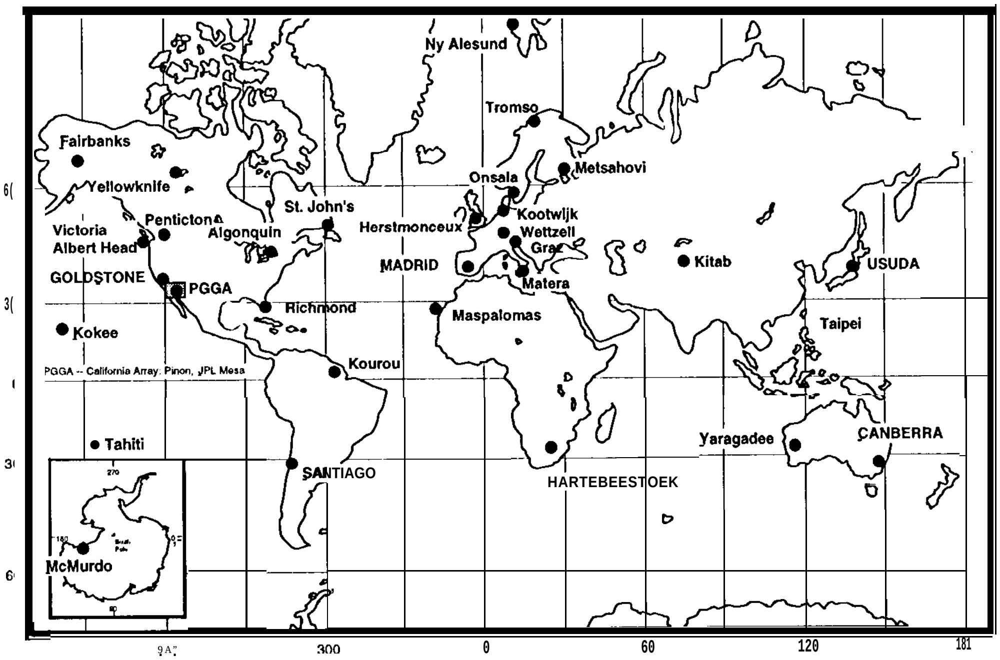


Figure 5. Tracking Network Configuration during the IGS Demonstration Campaign, June 211992-September 22, 1992. All precision P-code instrumentation.

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!

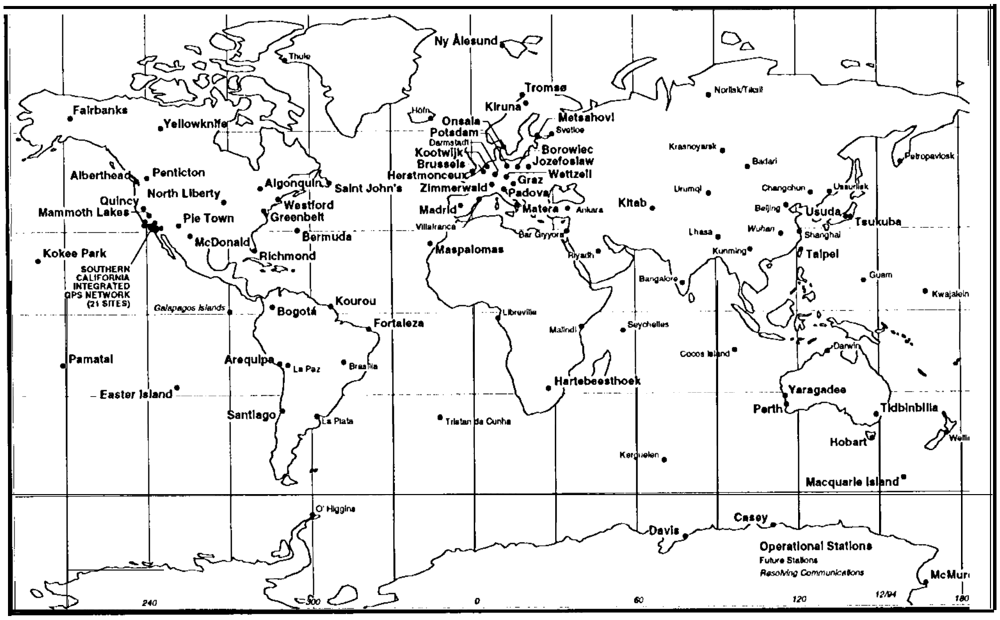


Figure 6. GPS Network at the close of 1994, the first fully operational year of the IGS.

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	Alberthead		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	-1O$.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
90	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		29.7 9	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.

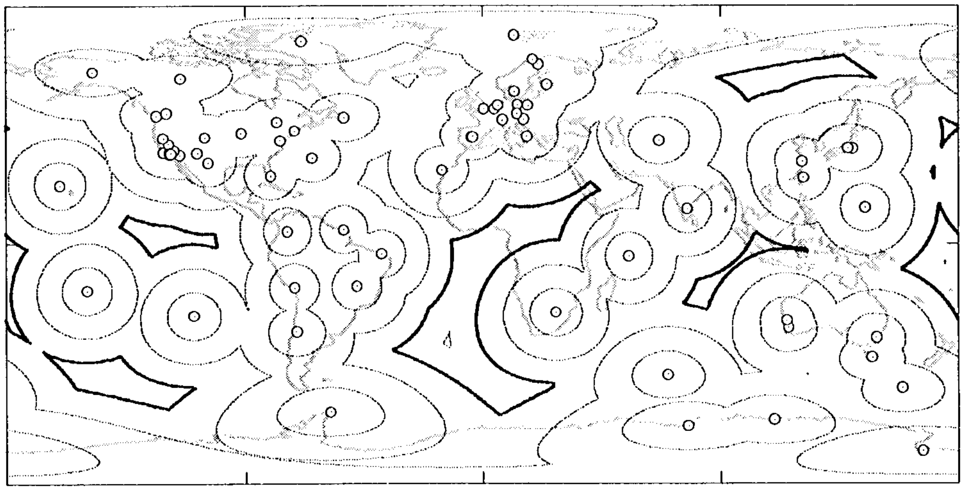


Figure 7. This map depicts the 1000-km contour isolation interval, and helps to indicate where increased GPS coverage would greatly enhance the global network **(from Zumberge, 1995).**

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.

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Status of the IGS Regional Initiative

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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

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Status and Activities of the Central Bureau

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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

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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	*OperationalCenter descriptions*
data	**format**	rinex2 . txt	*RINEX format specifications*
		sp3 txt	*SP3 orbitformat 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*
	net work	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	*IA G symposia/meetings*
mail	address	cddis. adr (.Z)	*CDDIS SGP address catalog*
		directory .txt	*IGS Colleague Directorytext*
		dose. adr	*DOSE Mail distributionlist*
		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	bullet inb.'nn'	*IERS earth orientation*
		eop90c04.'yy'	*IERS earth rotation parameters*
software	cbi s	**dos, unix, vms**	*CBIS browsing/ftp program*
	compress	**dos, vms**	*compression/decompression programs*
	qc	**aux, dos, unix, vms**	*quality check program for GPS data*
stat ion	**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	local tie, 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.

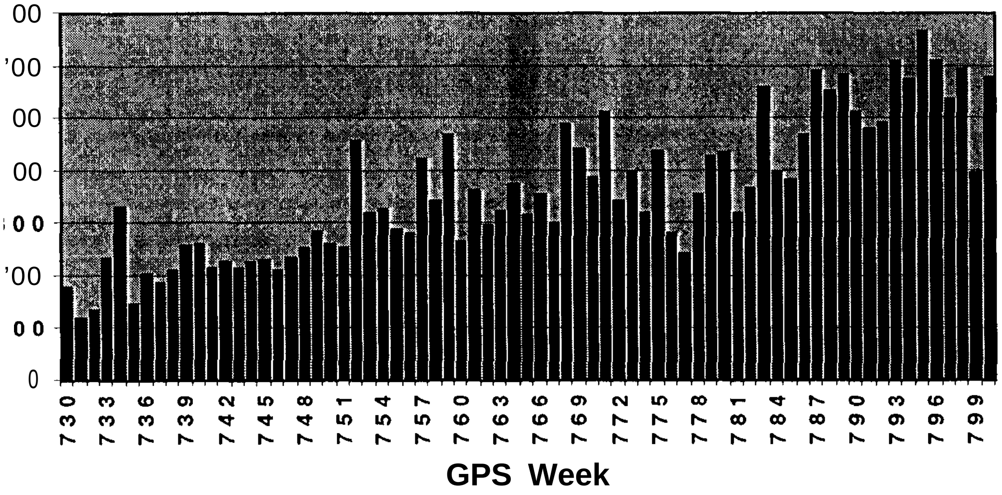

Figure 2. Logins to the CBIS by week since January, 1994.

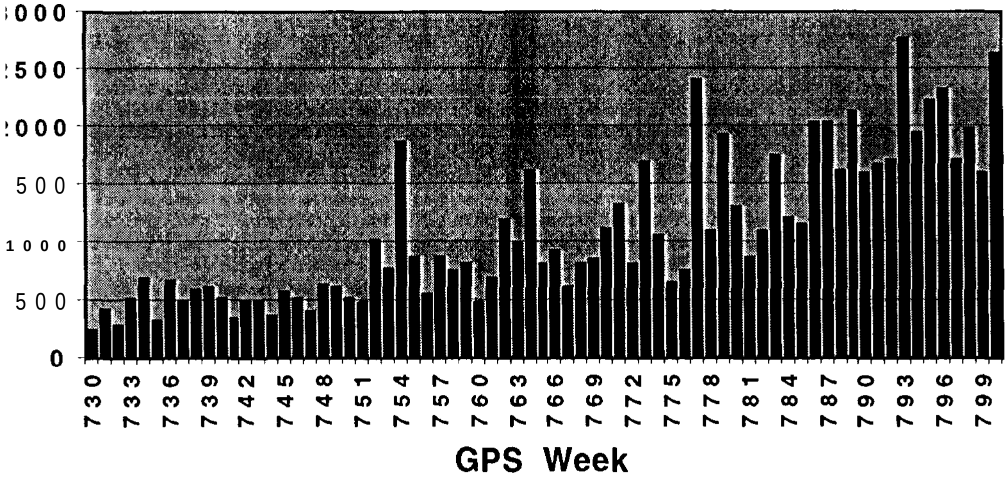

Figure 3. File retrievals from the CBIS by week since January, 1994.

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	Y SY	Z Sz	Vx SVX	VY SVY	Vz SVZ	
				m			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
13504MOO3	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	SITE	FILE	X	Y	Z	VX	VY	VZ
NUMBER	NAME	NAME	5X	SY	Sz	SVX	SVY	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

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

Technique	Solution	N	WSP cm	WSU cm
VLBI	SSC(GIUB 94 R 01	7	0.6	0.8
	SSC(GSFC) 94R01	109	0.4	0.7
	SSC(NOAA) 94 R 01	106	0.4	0.9
GPS	SSC(CODE) 94P 01	38	0.7	1.3
	SSC(EMR) 94P 02	16	0.7	1.8
	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

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		Y		Reference
		sin	Cos	sin	cos	
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.

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Analysis Coordinator Report

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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.

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).

DOMES NUMBER	IGS NAME	x mm	Y mm	z mm	Vx	VY	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)

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):

field	contents/HEADER	comment
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):

field	contents/HEADER	comment
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	Stations used fixed	Orbit hours	Observation int.	Observation 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	VY mm/y	Vz
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
501O3M1O8	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.

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Appendix I
1994 IGS Orbit/Clock Combination and Evaluation

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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 $\left(P_{cent}^{sat}\right)$ 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:

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

where

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

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

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

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

and the absolute deviation is

$$P'^{sat}_{cent} - \overline{P}^{sat} = X'^{sat}_{cent} - \overline{X}^{sat} + Y'^{sat}_{cent} - \overline{Y}^{sat} + Z'^{sat}_{cent} - \overline{Z}^{sat} \tag{2}$$

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

$$\overline{P}_w^{sat} = \frac{\sum_{cent}^{Ncent^{sat}} {}^{\prime}cent^{\prime}\%}{\sum_{cent}^{Ncent^{sat}} W_{cent}} \tag{3}$$

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:

$$W^{sat} = \left(\frac{Ncent^{sat}}{\sum_{cent}^{Ncent^{sat}} \sum_{i}^{Nepoch_{cent}^{sat}} \frac{\left\| P_{cent}^{\prime sat} - \overline{P}^{sat} \right\|_i^2}{3 \cdot Nepoch_{cent}^{sat} - 7}} \right) \qquad (4)$$

where

$$\left\| P_{cent}^{\prime sat} - \overline{P}^{sat} \right\| = \sqrt{\left(X_{cent}^{\prime sat} - \overline{X}^{sat}\right)^2 + \left(Y_{cent}^{\prime sat} - \overline{Y}^{sat}\right)^2 + \left(Z_{cent}^{\prime sat} - \overline{Z}^{sat}\right)^2} \qquad (5)$$

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

$$\overline{P}_{comb}^{sat} = \frac{\sum_{cent}^{Ncent^{sat}} W_{cent} P_{cent}^{\prime\prime sat}}{\sum_{cent}^{Ncent^{sat}} W_{cent}} \qquad (6)$$

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:

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

$$WRMS_{cent} = \sqrt{\sum_{sat}^{Nsat_{cent}} W_{cent}^{sat} \cdot \left(RMS_{cent}^{sat}\right)^2} \qquad (8)$$

where $\left(RMS^{sat}_{cent}\right)$ and $\left(W^{sat}_{cent}\right)$ 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^{sat}_{cent}) is computed from the accuracy codes provided by the Analysis Centers in their submitted SP3 files. They are computed as:

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

$$W^{sat}_{cent} = \frac{\sigma^{sat^{-2}}_{cent}}{\sum\limits_{sat}^{Nsat_{cent}} \sigma^{sat^{-2}}_{cent}} \tag{lo}$$

where $\left(\sigma^{sat}_{cent}\right)$ 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:

$$\sigma^{sat} = \sqrt{\frac{\sum\limits_{cent}^{Ncent^{sat}} W_{cent} \cdot \left(RMS^{sat}_{cent}\right)^2}{\left(Ncent^{sat} - 1\right) \sum\limits_{cent}^{Ncent^{sat}} W_{cent}}} \tag{11}$$

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:

$$W_{c_{cent}} = \frac{ABS_{cent}^{-2}}{\sum_{cent}^{Ncent} ABS_{cent}^{-2}} \tag{12}$$

where

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

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:

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

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 $\left(\Delta t_{cent}^{\prime sat} \right)$.

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:

$$\overline{\Delta t}_{comb}^{sat} = \sum_{cent}^{Ncent^{sat}} W_{c_{cent}} \Delta t_{cent}^{\prime sat} \qquad (15)$$

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:

$$RMS_{c_{cent}} = \sqrt{\frac{\sum_{sat}^{Nsat_{cent}} \sum_{i}^{Nclk_{cent}^{sat}} \left(\overline{\Delta t}_{comb}^{sat} - \Delta t_{cent}^{\prime sat} \right)_i^2}{\left(\sum_{sat}^{Nsat_{cent}} Nclk_{cent}^{sat} \right) - 2}} \qquad (16)$$

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.

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

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,

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.

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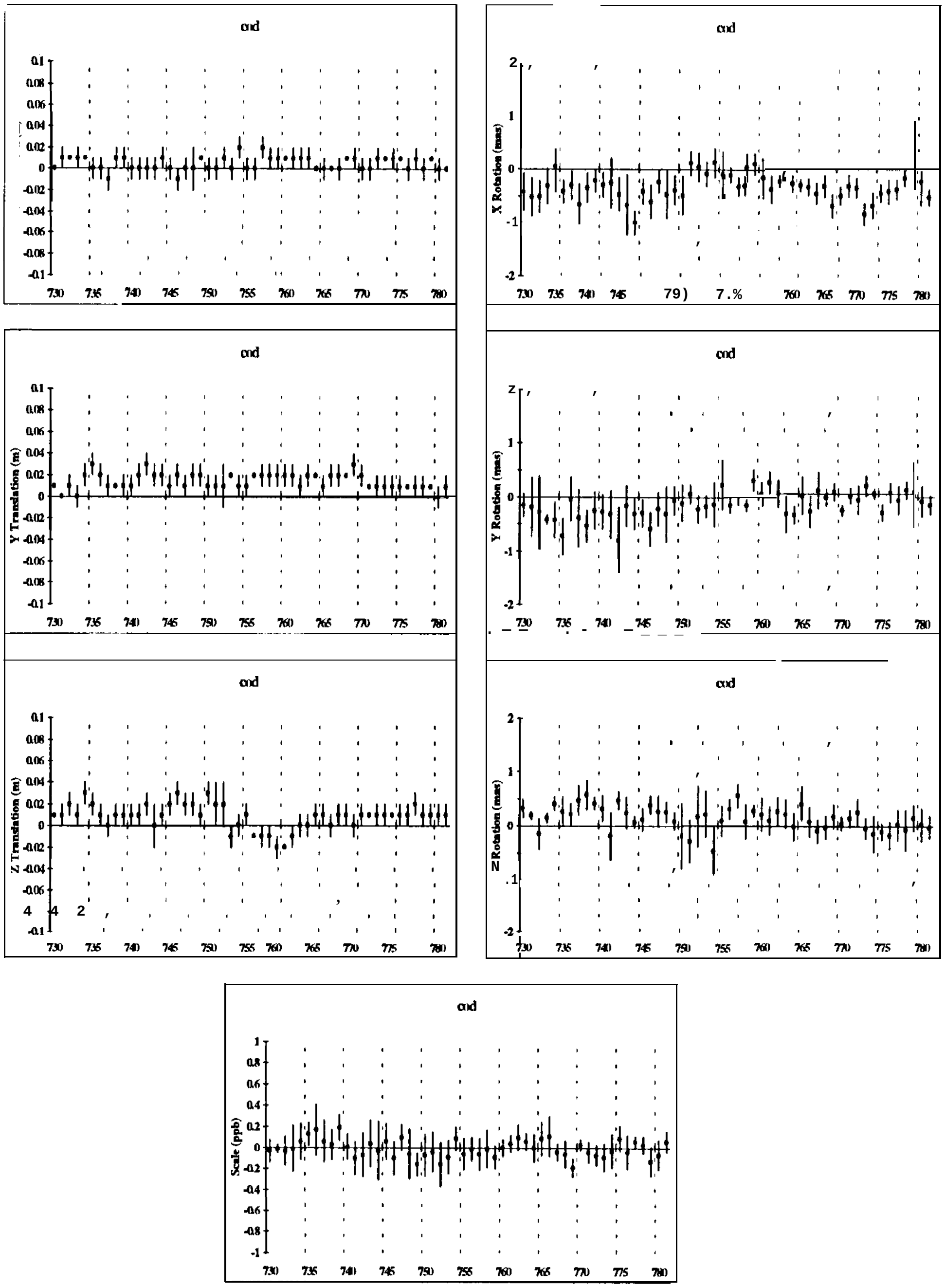
Figure 1. COD 1994: Weekly Mean 7-Parameter Helmert Transformations.



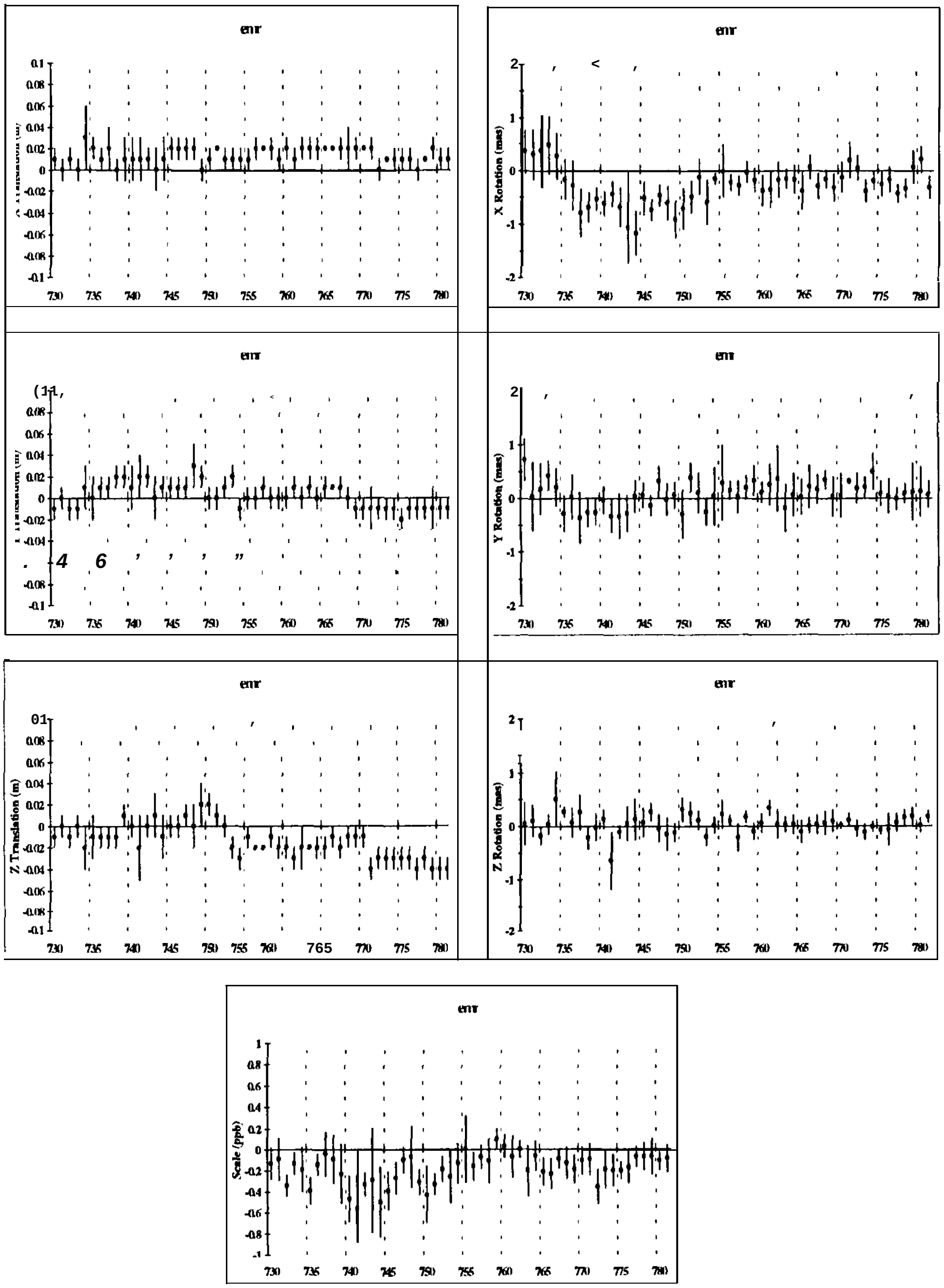


***Figure 2.** EMR 1994: Weekly Mean 7-Parameter **Helmert** Transformations.*

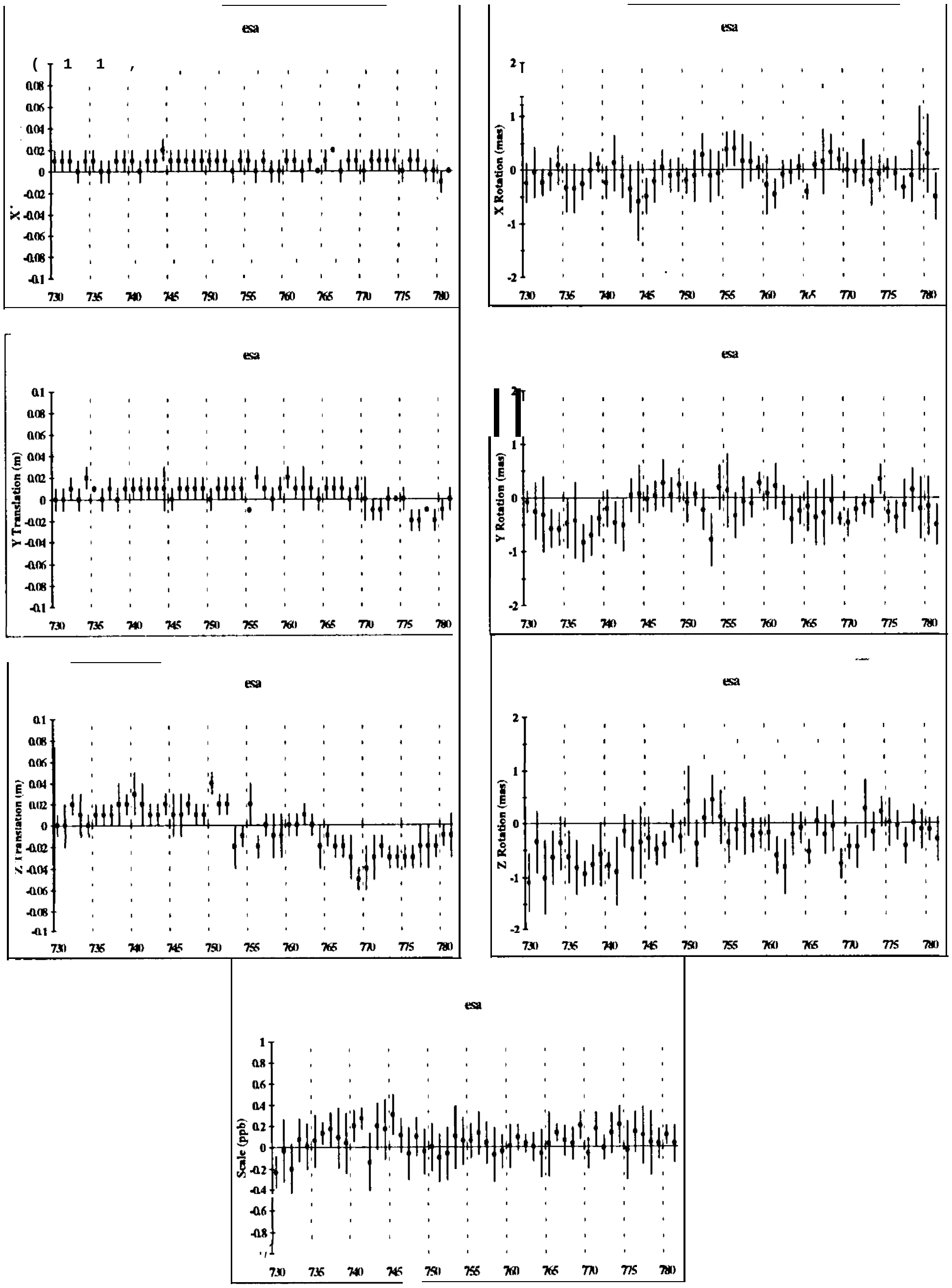


Figure 3. ESA 1994: Weekly Mean 7-Parameter Helmert Transformations.

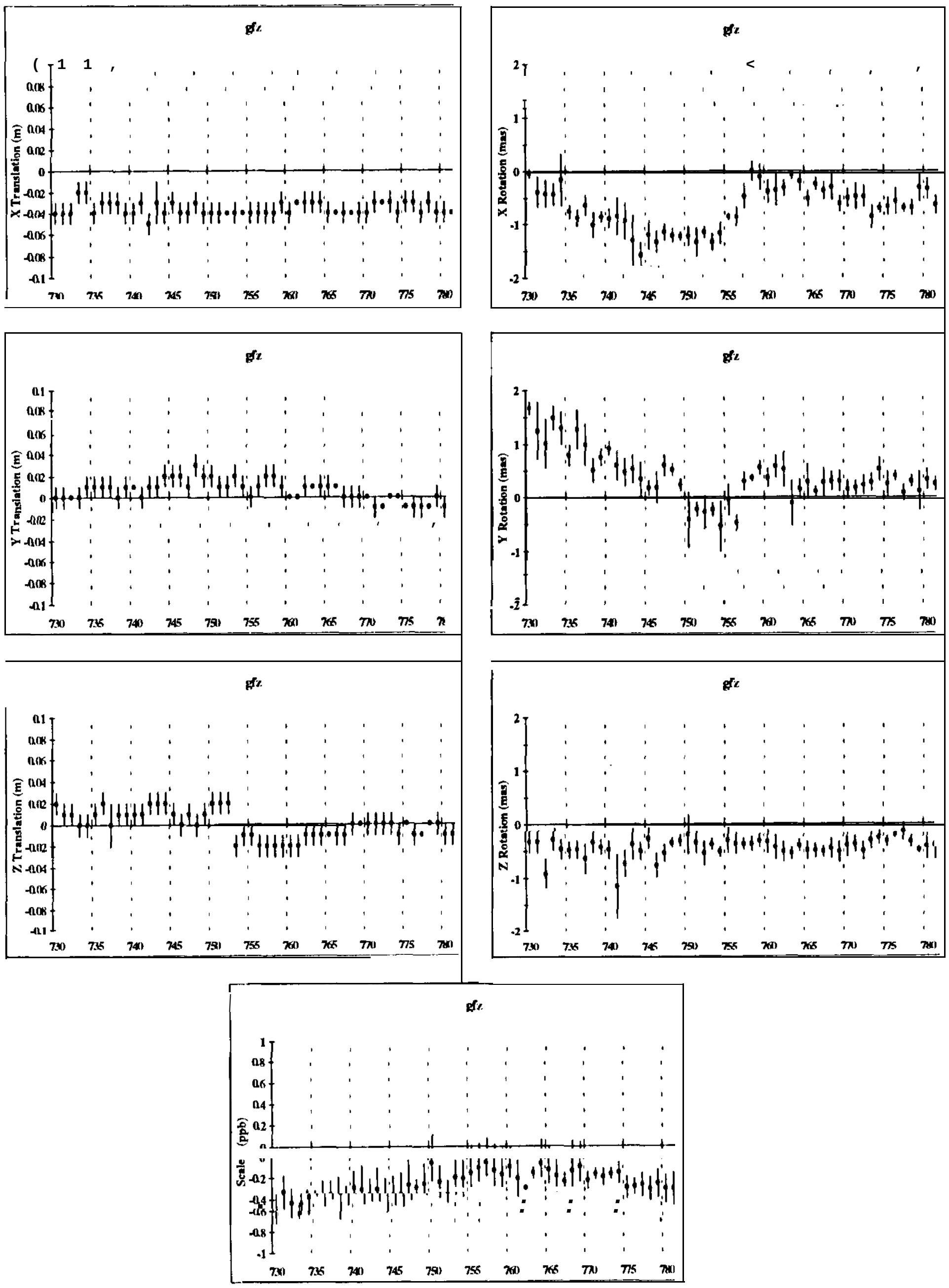
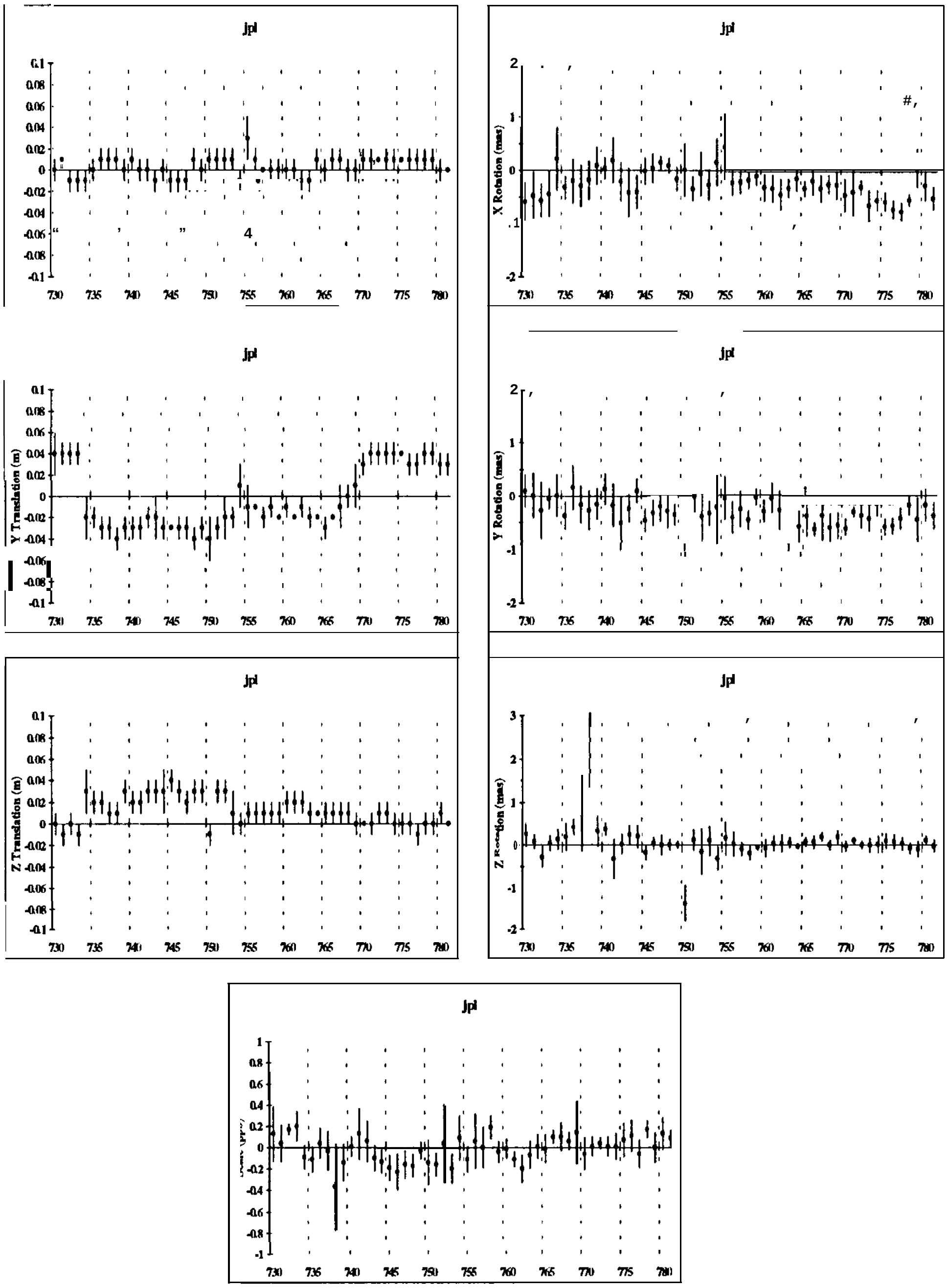


Figure** 4. GFZ 1994: Weekly Mean 7-Parameter* ***Helmert *Transformations.*

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



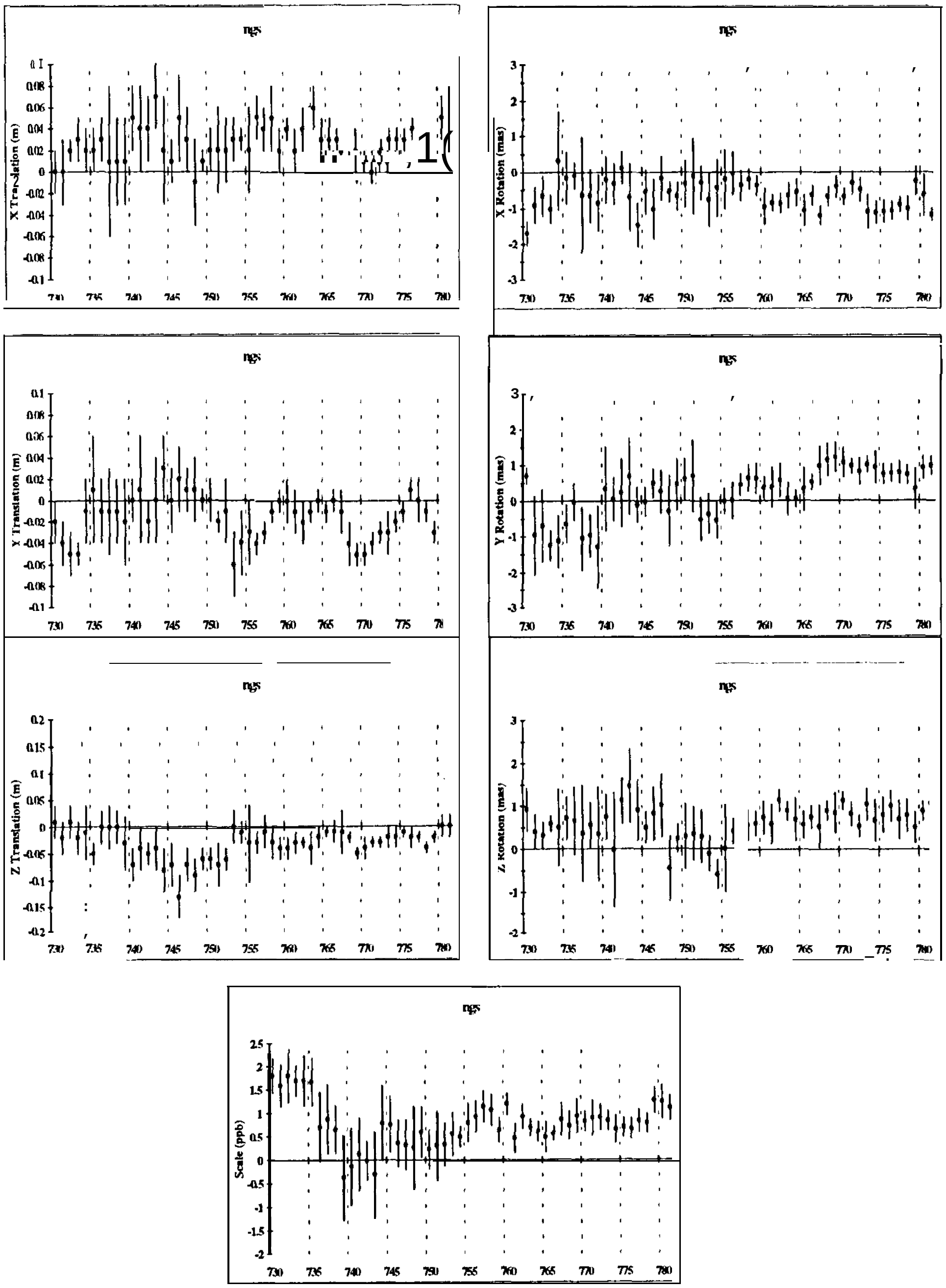
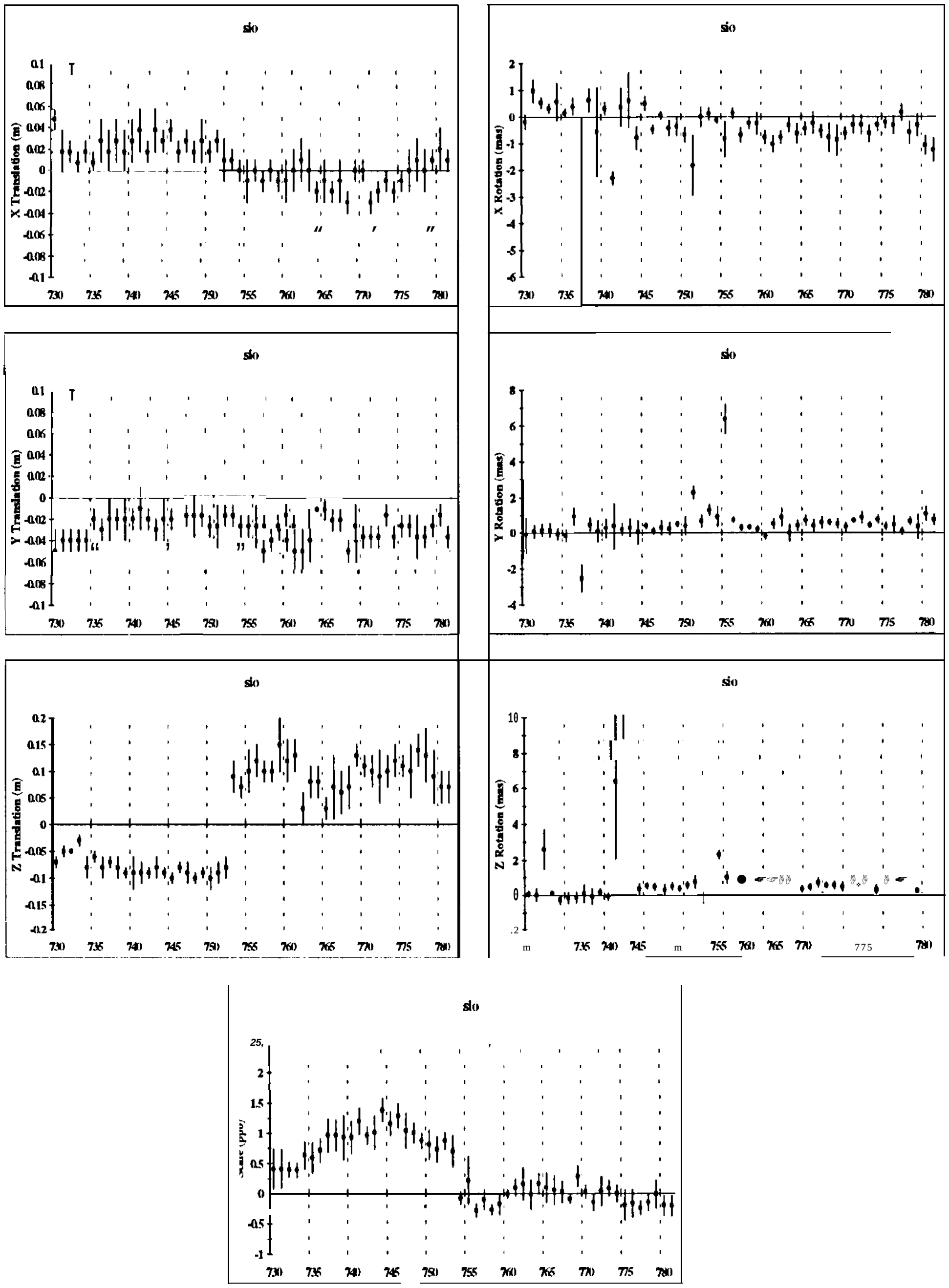


Figure 6. NGS 1994: Weekly Mean 7-Parameter ***Helmert*** *Transformations..*

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



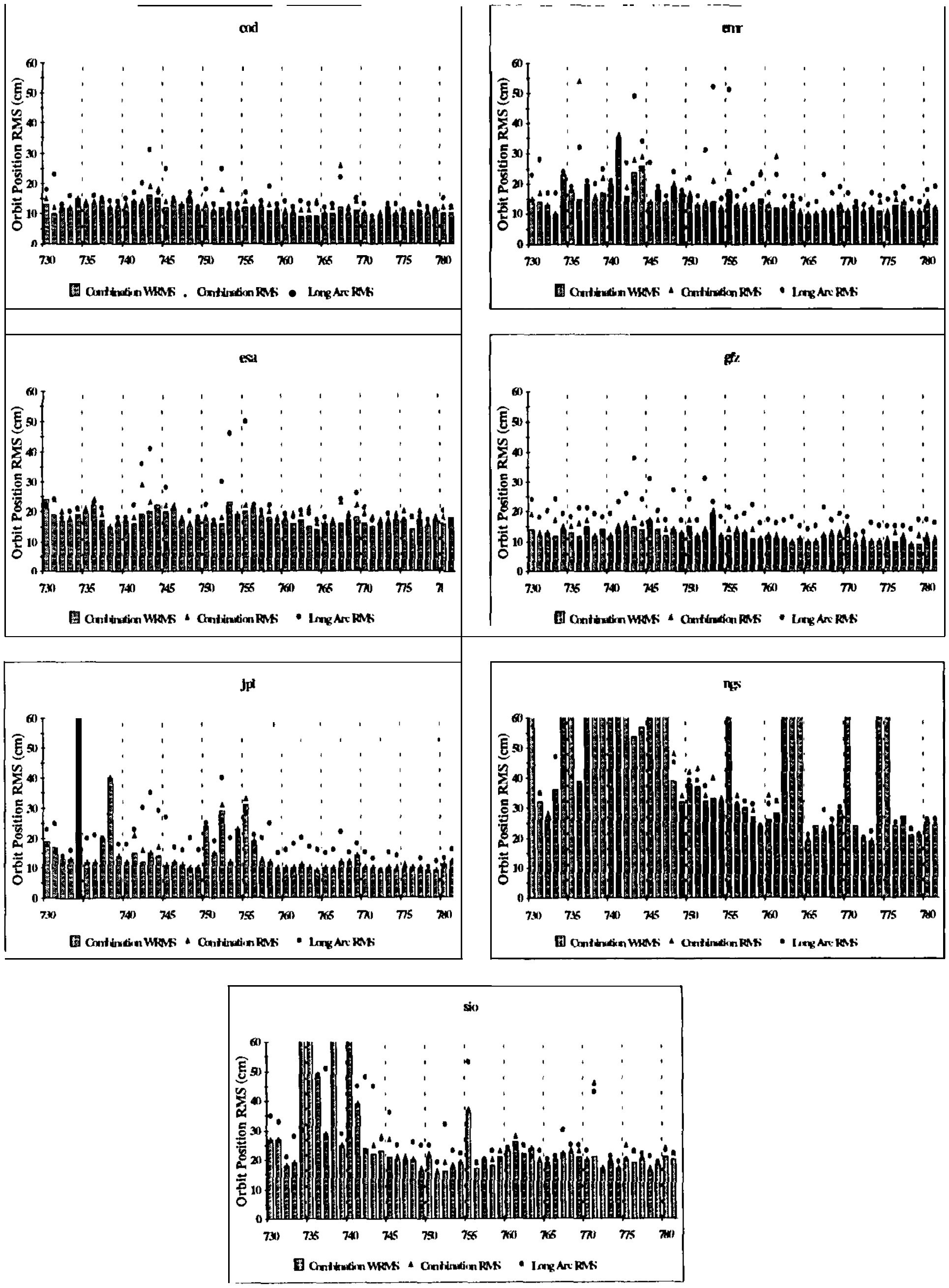
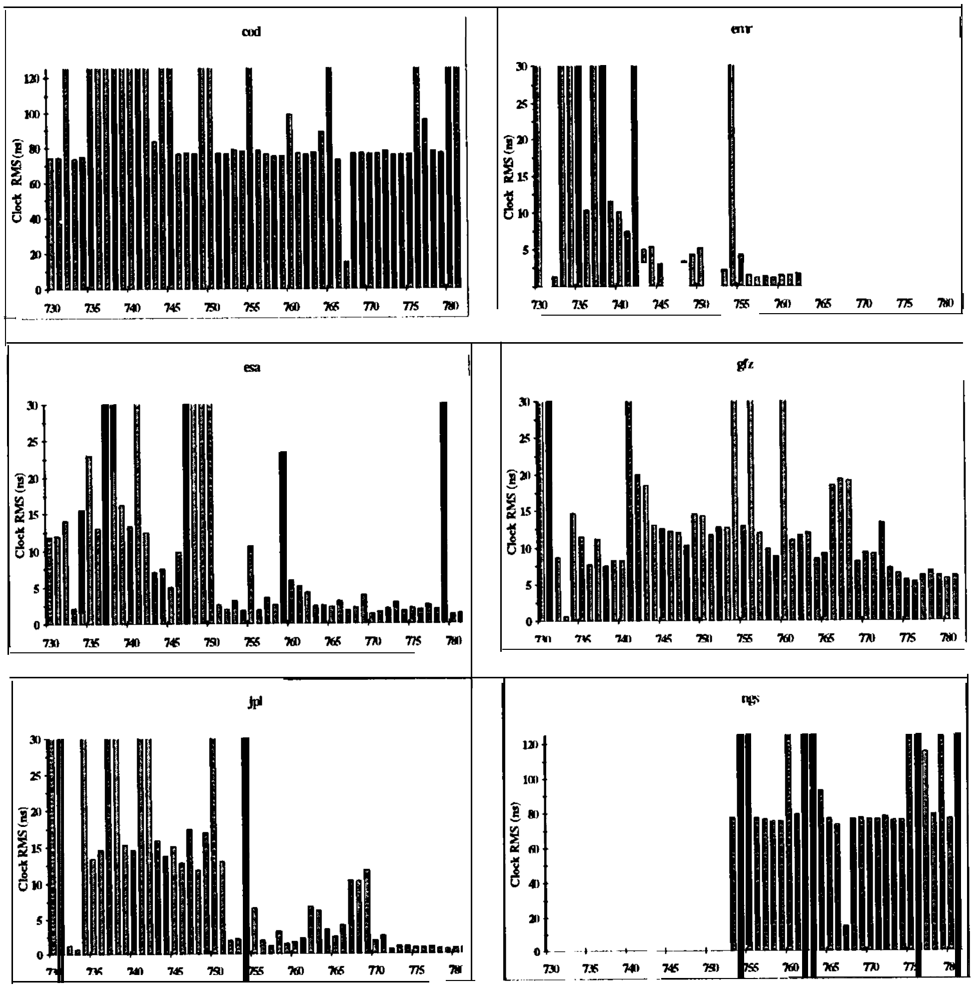


Figure 8. 1994 Weekly Mean Orbit Position RMS (all Analysis Centers.

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.

Example of Table 1.gpsweek.a.

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).

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.gpsweek.b.

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

	Day of GPS week							
PRN	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

Example of Table 2.gpsweek.day.

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

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
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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

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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

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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 online access.

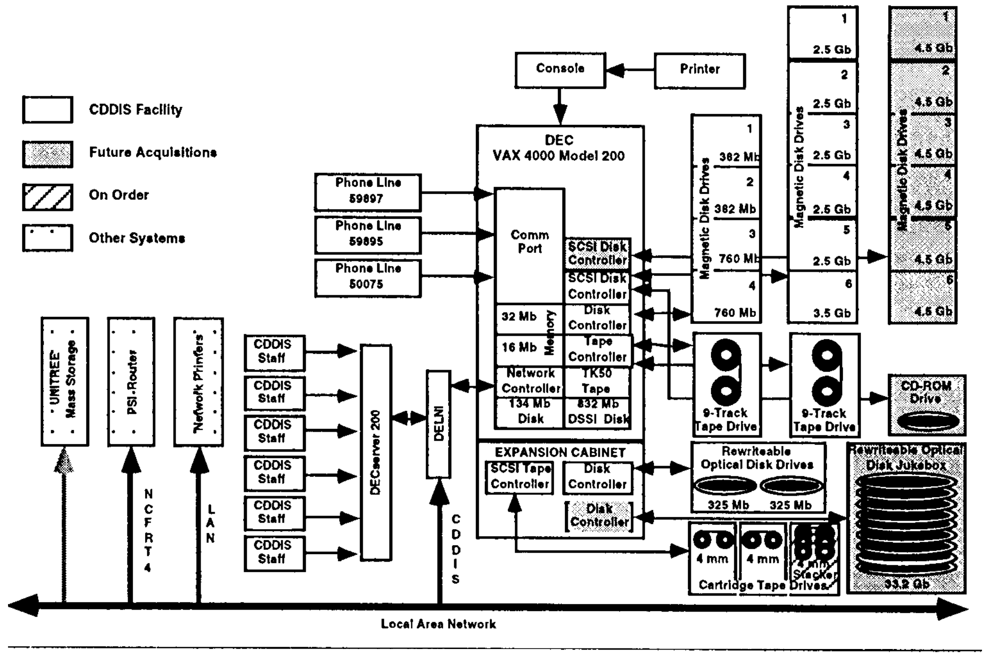


Figure 1. CDDIS Computer System Configuration.

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 301-286-4000	Autobaud 300,1200,2400 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:

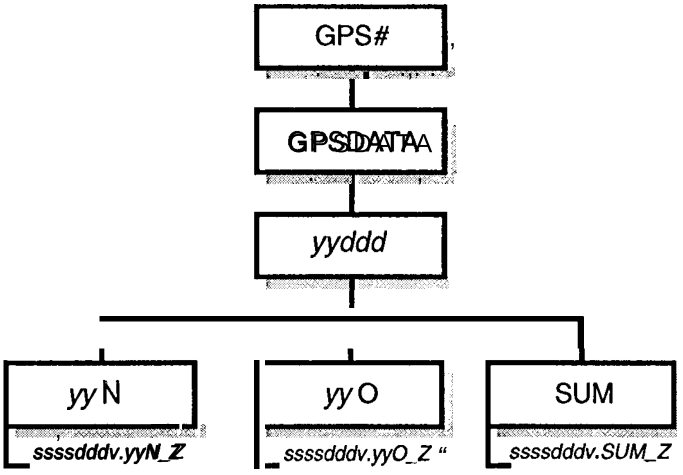
DEVICE:[DIRECTORY.SUBDIRECTORY]FILENAME.EXTENSION;VERSION

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.



Disk Number (#=1, 2,5, 6)

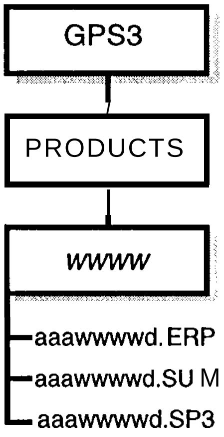
Main Data Directory Level

Daily Subdirectory Level (*yy*=year, *ddd*=day of year)

Data Type Subdirectory Level (*yy*=year)

File Level (*ssss*=IGS site, *ddd*=day of year, *v*=sequence number, *yy*=year)

Figure 3. Directory Structure on CDDIS for GPS Products.



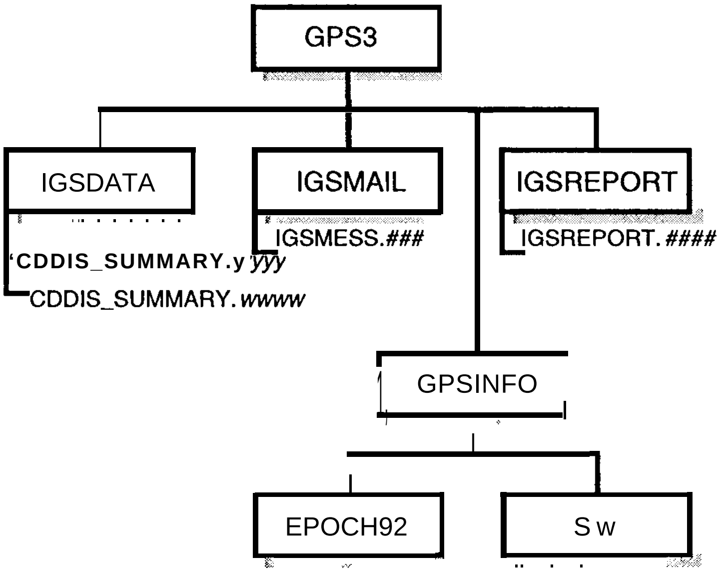
Disk Location

Main Products Directory Level

GPS Week Subdirectory Level (*wwww*=GPS week number)

File Level (*aaa*=analysis center, *wwww*=GPS week number, *d*=day of week)

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



Disk Location

Report Type Directory Level

File Level (*####*=message number, *wwww*=GPS week number, *yyyy*=year)

Ancillary Information Directory

Subdirectory Level

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.)

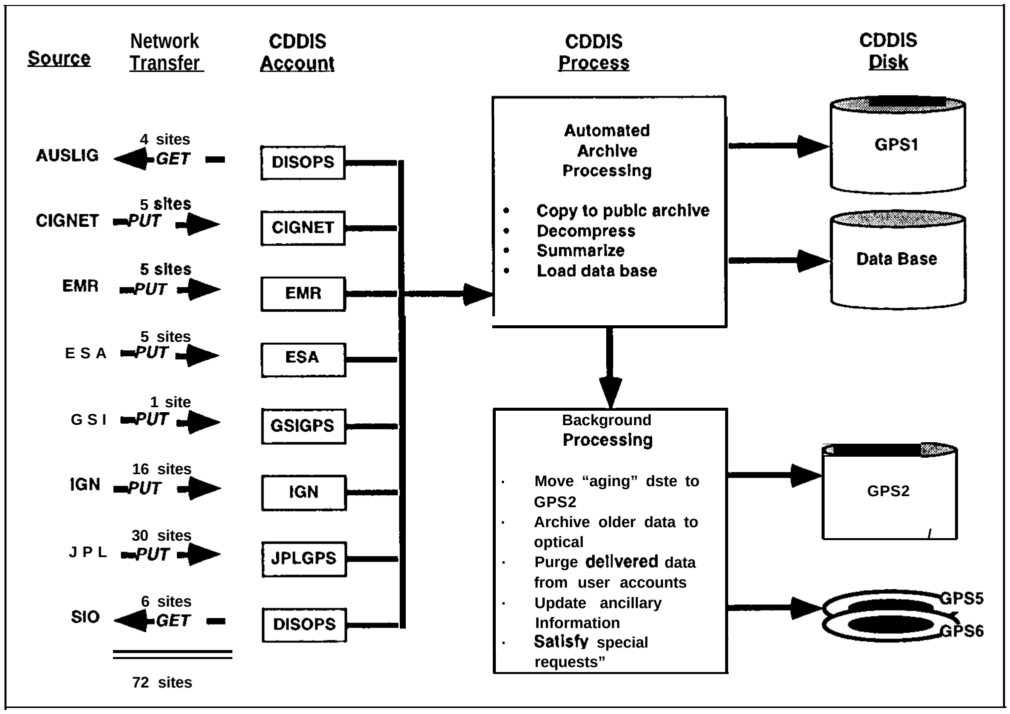
Lake Mathews, CA	33"52'	-117°27'	MATH	s	Trimble 4000SSE	01-Jan-94	—	342
Long Beach, CA	33028'	-118°09'	LBCH	J	Rogue SNR-8000	26-Jul-94	—	158
Los Alamos, NM	35°47'	-106°15'	LOSA	v	Rogue SNR-8000	08-Jan-94	01-Feb-94	11
Macquarie Isl., Australia	-54°30'	158"56	MAC1	A	Rogue SNR-81OO	05-Jul-94	—	176
Madrid, 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.

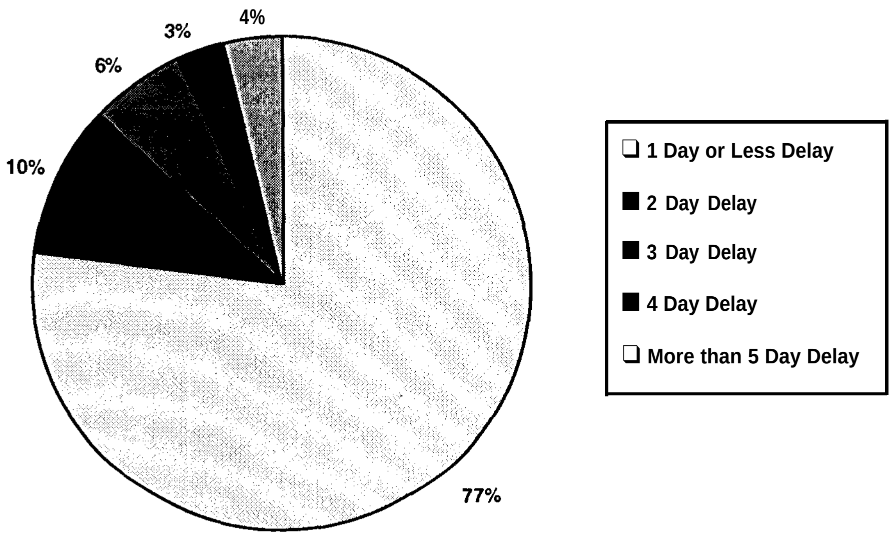


Figure 6. CDDIS GPS Data Availability Statistics.

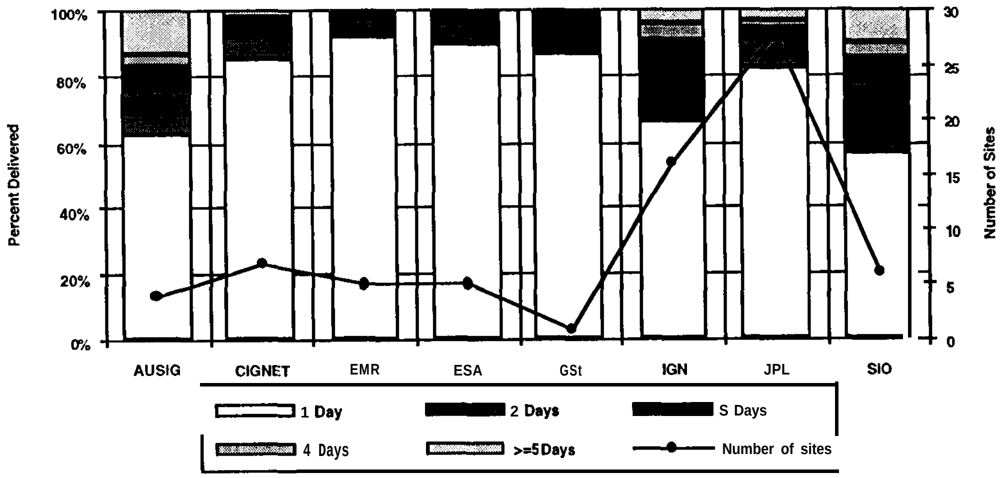


Figure 7. CDDIS GPS Data Availability Statistics (by Source).

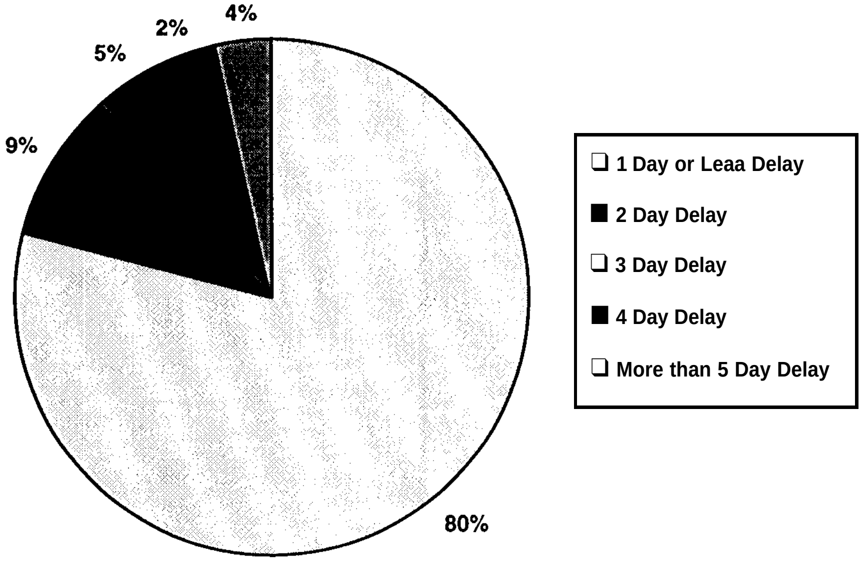


Figure 8. CDDIS GPS Data Availability Statistics (Global Stations Only).

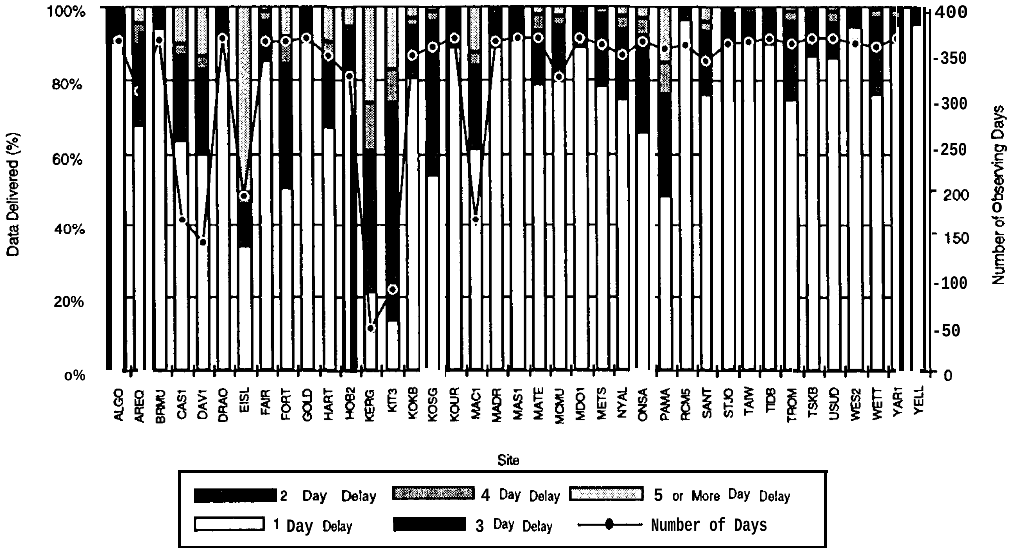


Figure 9. CDDIS GPS Data Availability Statistics by Site (Global Stations Only).

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.

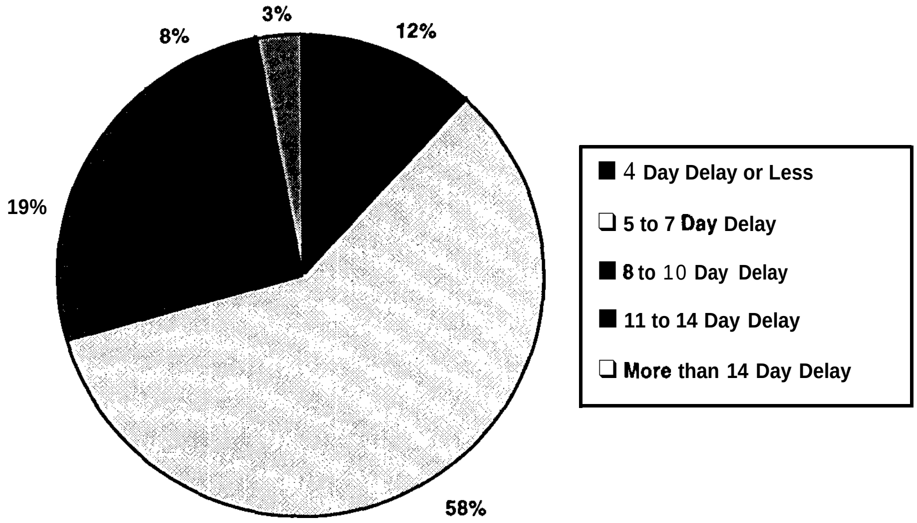
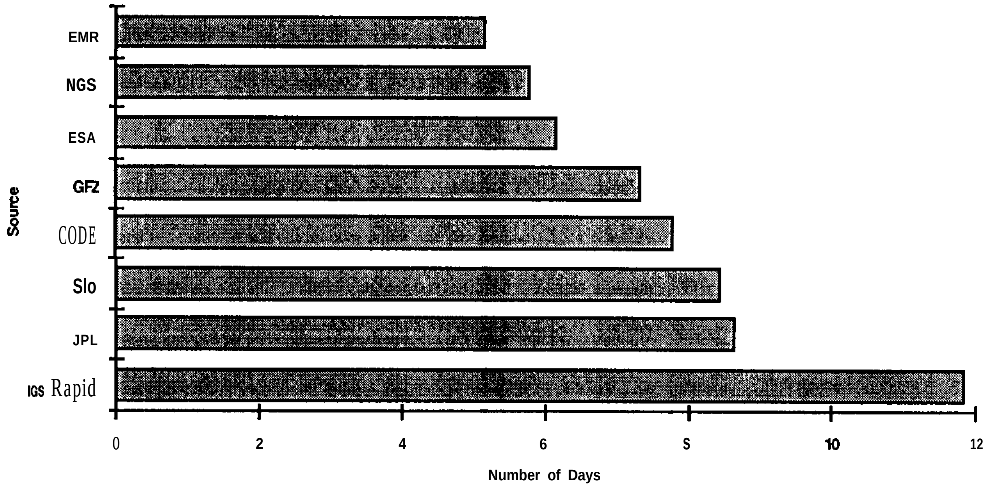


Figure 10. CDDIS GPS Product Availability Statistics.

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.

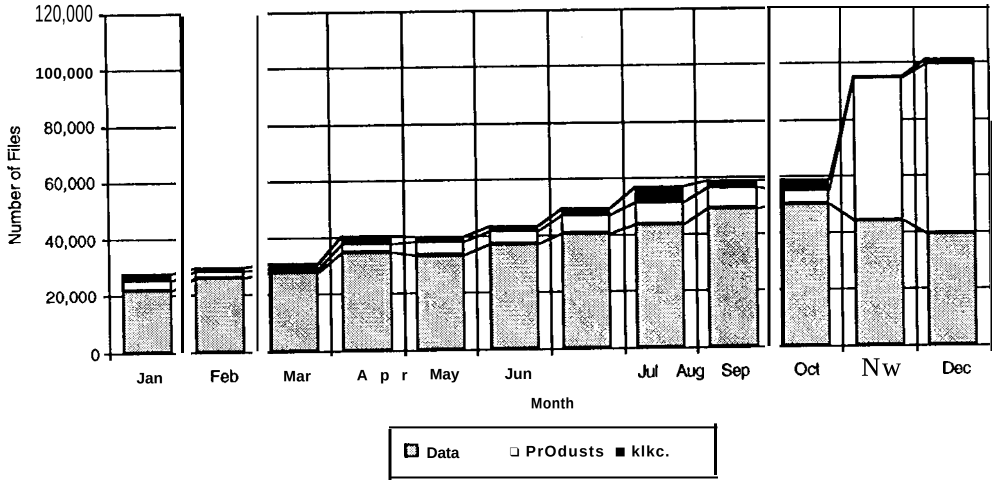


Figure 12. Number of Files Transferred During 1994 in Support of the IGS.

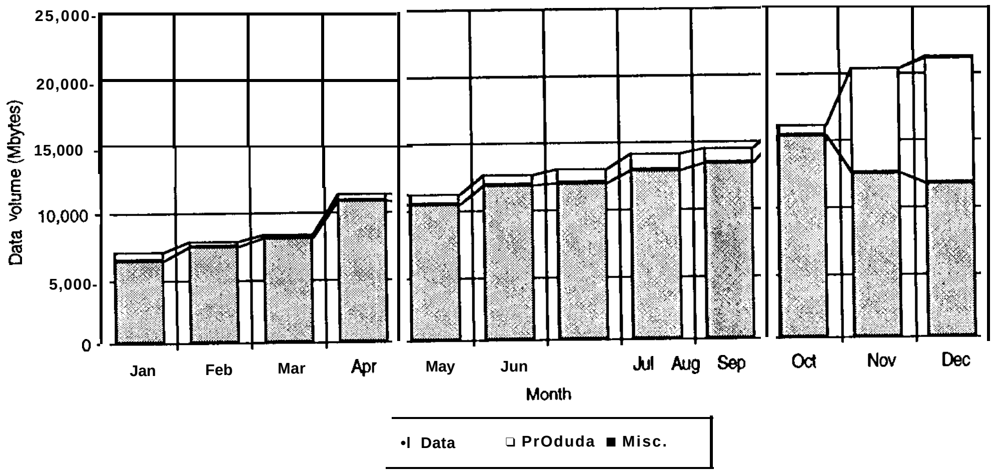


Figure 13. Volume of Data Transferred During 1994 in Support of the IGS.

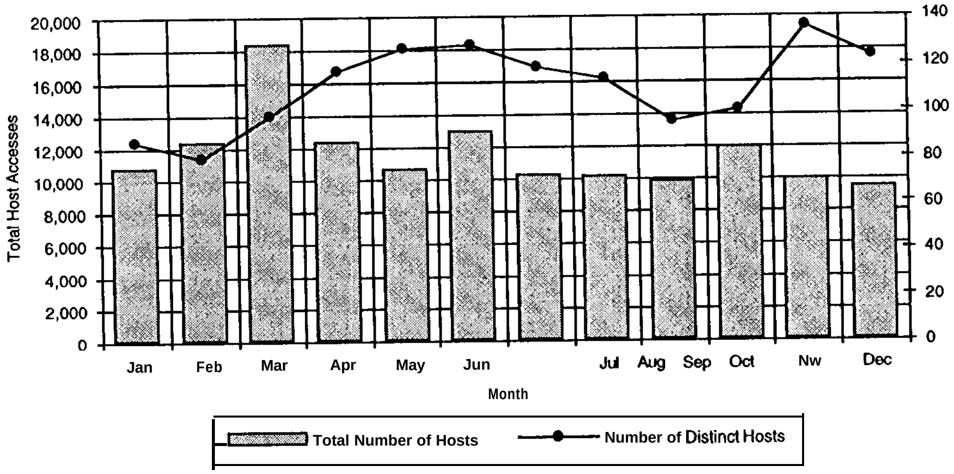


Figure 14. Number of Hosts Accessing the CDDIS in 1994 in Support of the IGS.

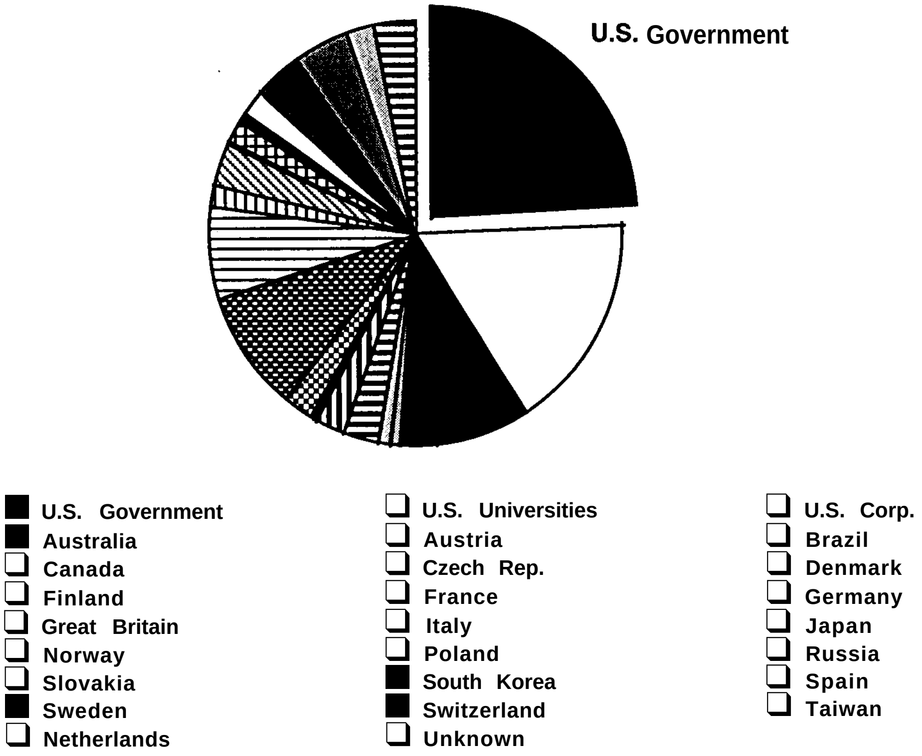


Figure 15. Distribution of IGS Users of the CDDIS.

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

†-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.

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European Regional IGS Data Center

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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.

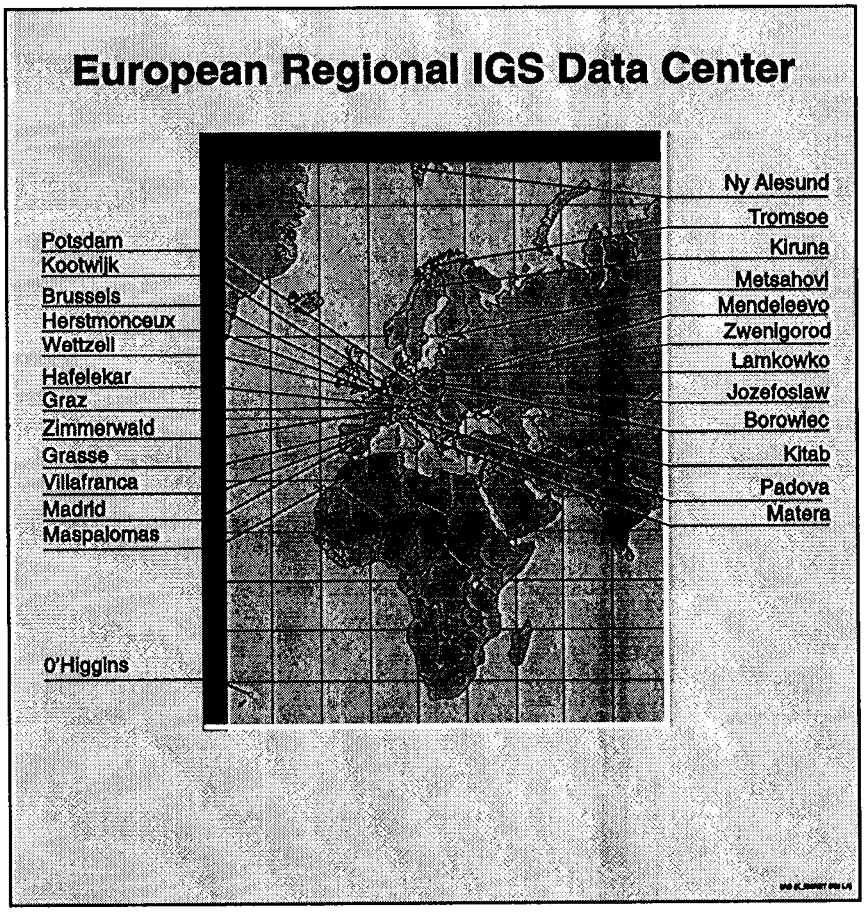

Figure 1. GPS Tracking Network.

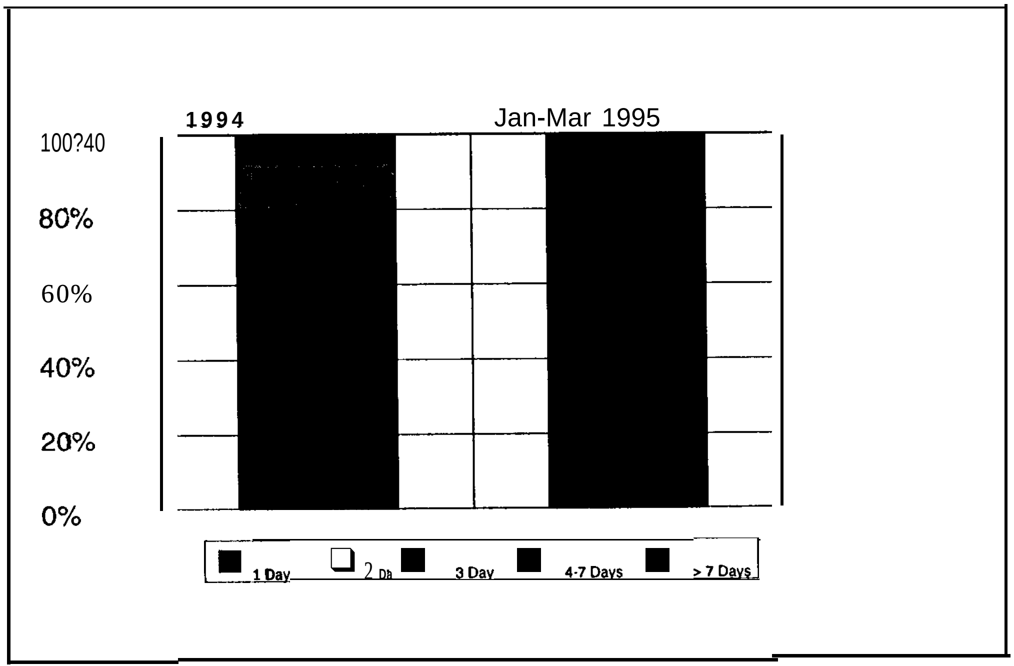

Figure 2. Data Delivery Statistic.

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-8100	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-8100	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-8100	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
Padova	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,
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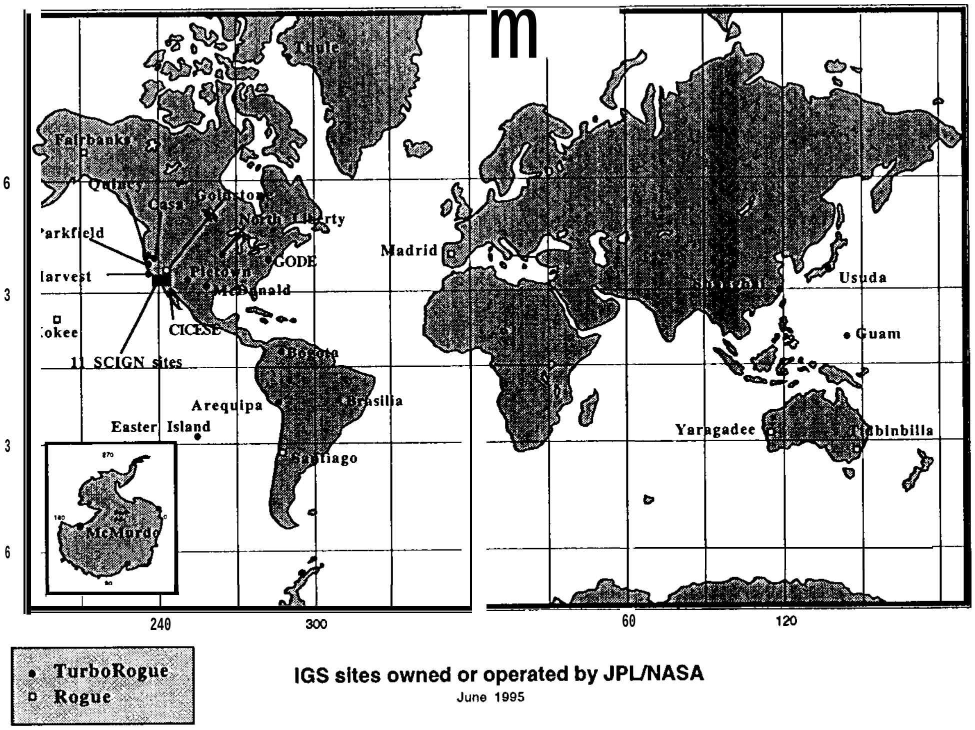
Pasadena, California

Introduction

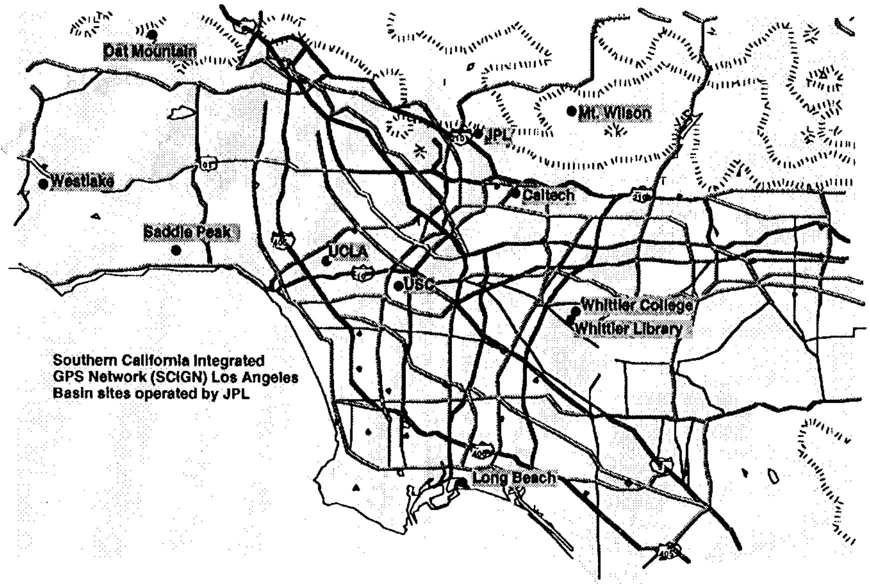
JPL/NASA has been installing and operating permanent GPS stations for more than 5 years, starting with the deployment of the 6-station TOPEW POSEIDON ground tracking network. This permanent Network was installed during the early 1990s in support of the Topex oceanographic mission in collaboration among 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.

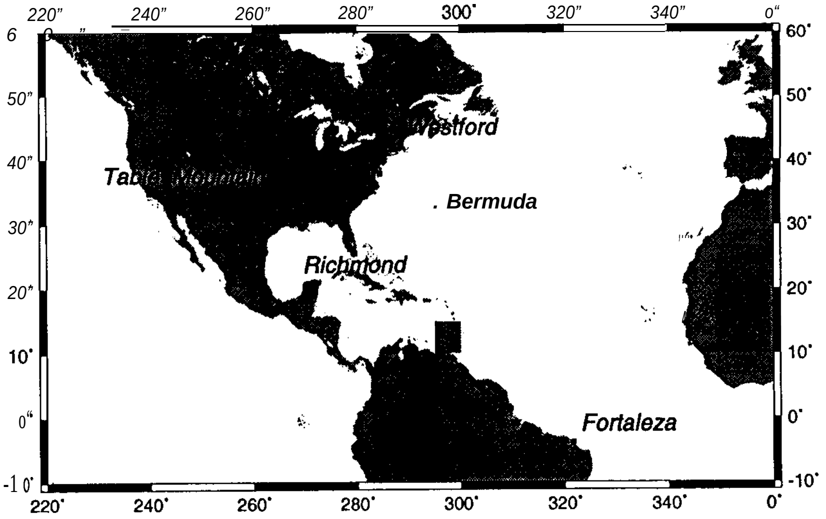
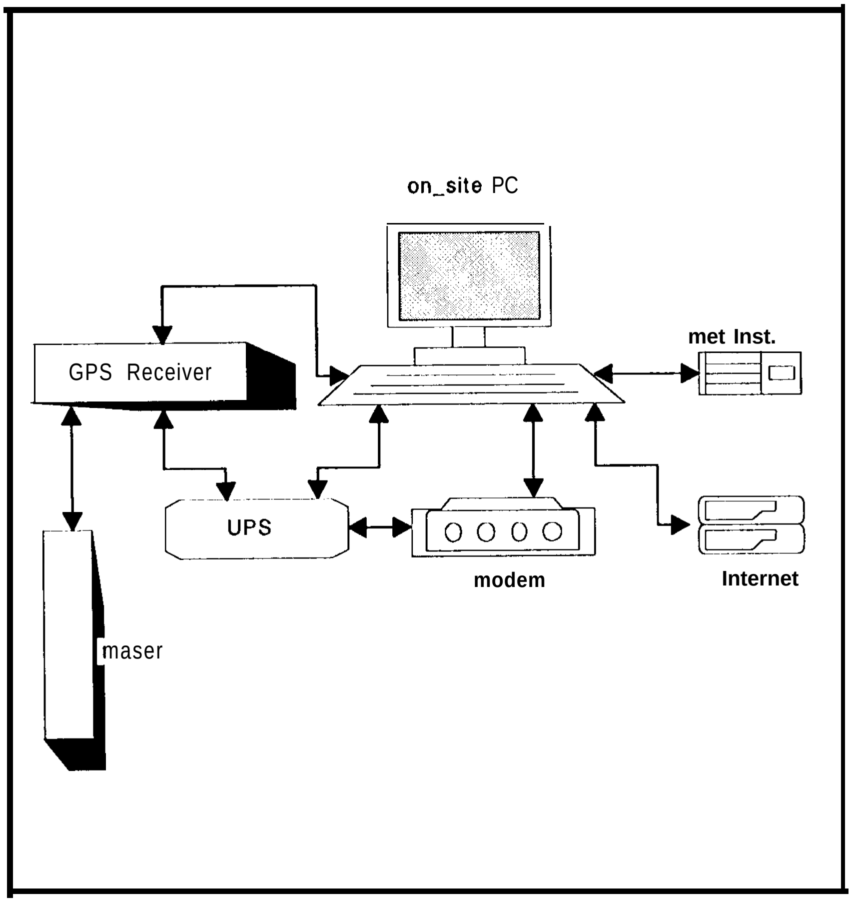


Diagram 1. GU NOAA GPS Tracking System Layout.



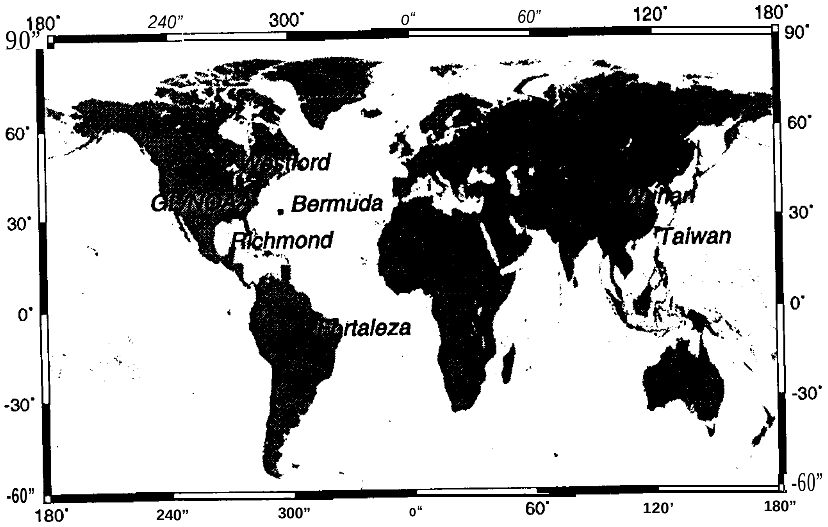


Figure 2. GL/ NOAA GPS Data Communication Network.

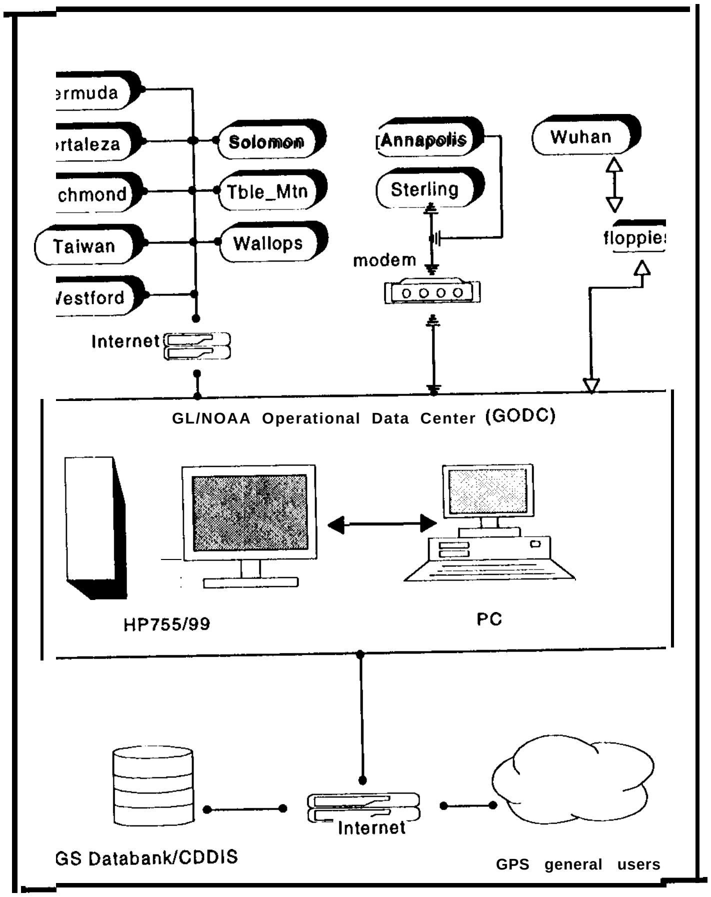


Diagram 2. Data Acquisition, processing and Distribution.

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.

Information 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: anonymous/anonymous
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).

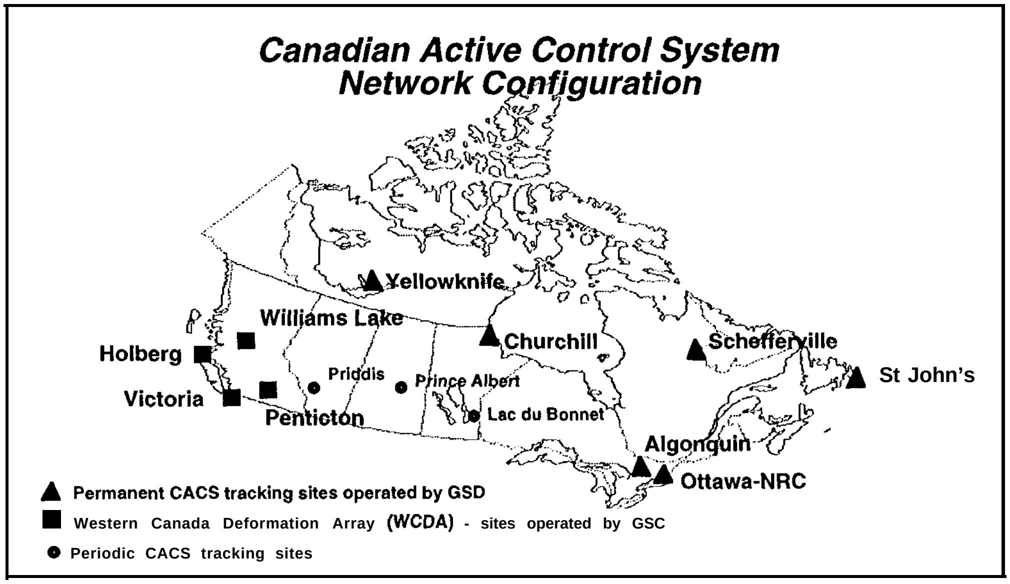
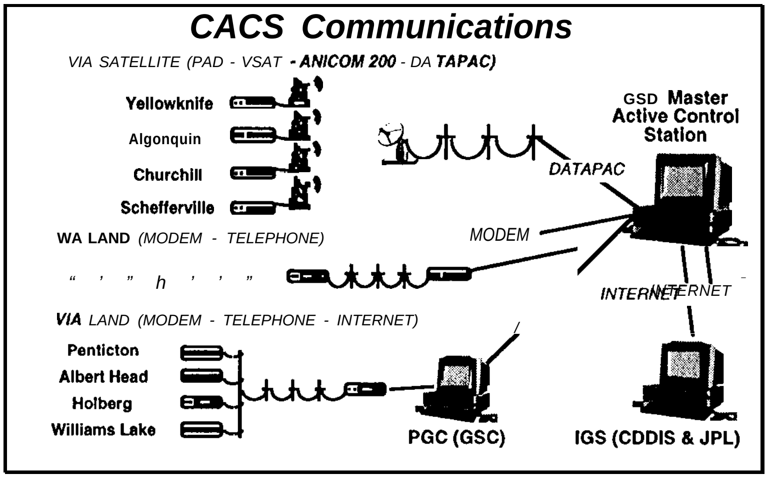


Figure 1.

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.

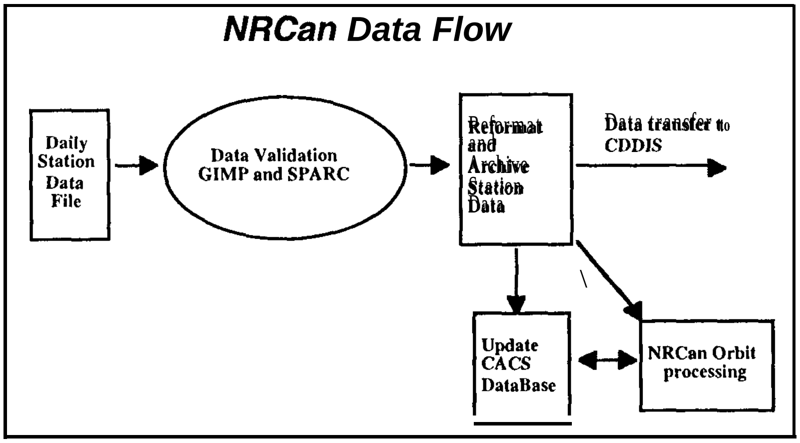


Figure 3.

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.

	Data made available within:						No data
STATION	1 day	2 days	3 days	4 days	5 days	6 days	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      START         END         #OBS.  #GAP  #C. S.   IONOSPHERIC          MULTI  PATH
PRN #    TIME          TIME                              VARIATIONS         INTVL    ARc
      (hh:mm:ss)   (hh:mm:ss)                            (cm. ) (mm. /s,)    (m. )   (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                            xxxxxxxxxxxxxxxxxxxxx
  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
     888999899877865666767998788898799888778677767777876677787777677778788789

-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-
     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  111111111111111110000000000
     7777777799  666666666666666666  0000000000000  888888888888888887777777777

  3  2222222222222222222  0000000000000000111111111111122  2222222222222222  22
     4444444444444444444  9999999999999999444444444444455  7777777777777777  44

  4  ooo222222222  1111111111  llllll2222222222222222222       111111111111110
     2229    0000000077777777777777777555555555555555555       555555555555555

  5   lllll22ooooooooooooooo222222oooooooooooooooooooollllllllllllllllllloooooo
     222229966666666666666888888555555555555556666666666999999999999999444444

  6  00000000000000     2222222222222222222  222222222222222222     2211111111
     44444444444444     3333333333333333333  222222222222222222     6622222222

  7  111121111111111111111111  000000000000000000002222222222222222    1111111
     444496666666666666666666  111111111111111111118888888888888888    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      RNs      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'
	SSSSDDDO 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' (l-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 ionospheric 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

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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.

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

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

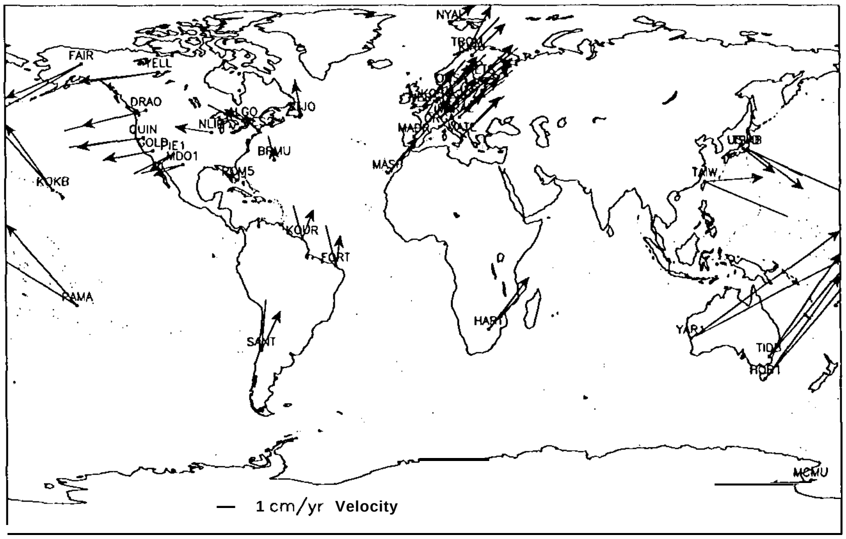


Figure 1. Station velocities estimated by CODE based on the solutions April 1993-February 1995 (arrows: CODE estimates, lines: ITRF values).

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).

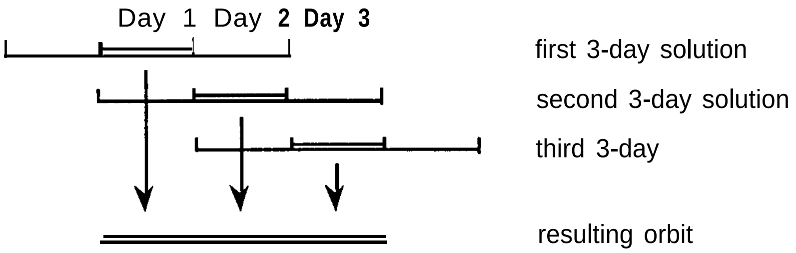


Figure 2. Processing in overlapping three-day intervals at CODE.

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 ≥ 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

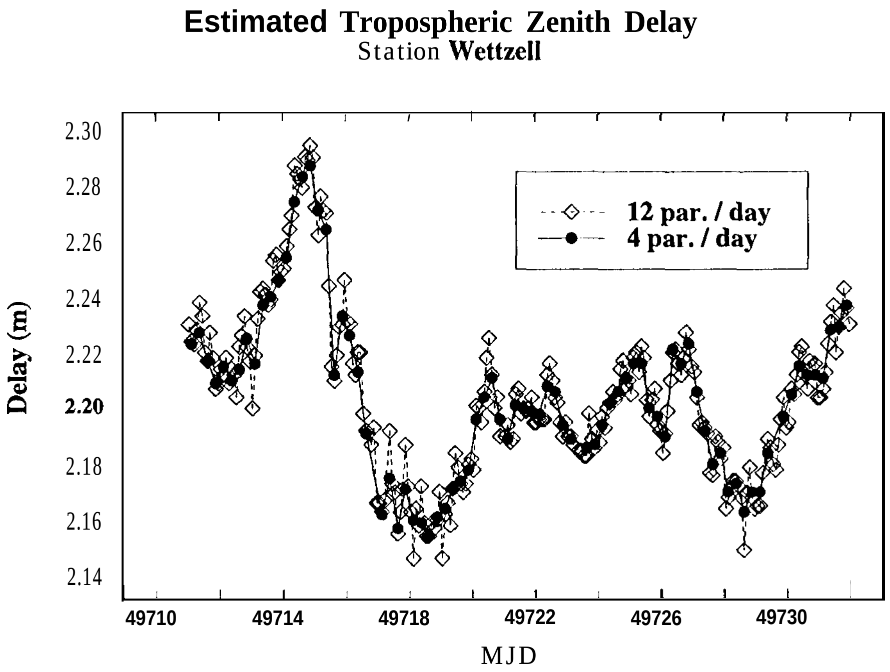


Figure 3. 4 vs. 12 troposphere parameters per day for Wettzell, weeks 781-783.

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

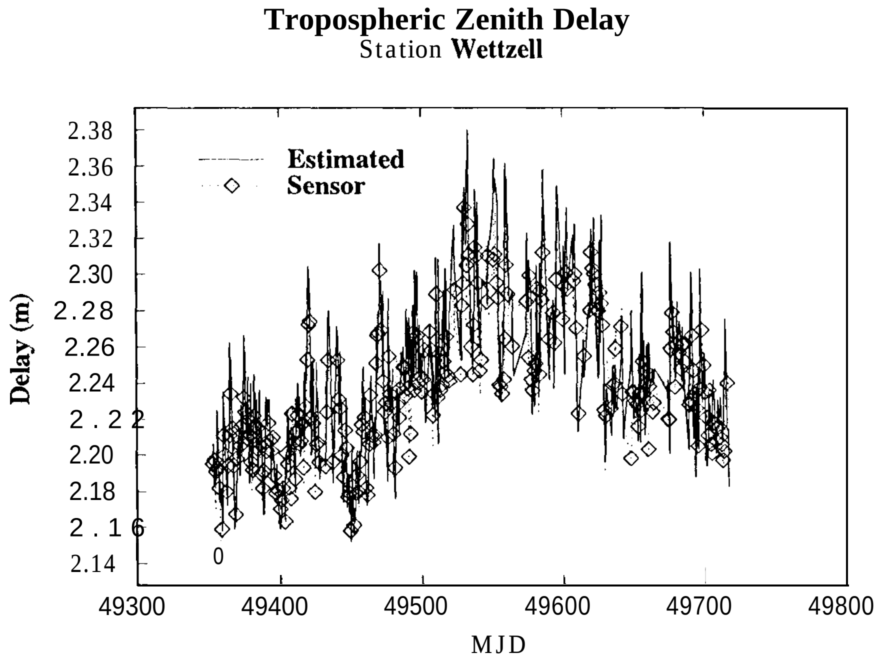


Figure 4. Tropospheric refraction from surface meteorological data and from GPS estimates for Wettzell in 7994.

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 $q=0$, 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

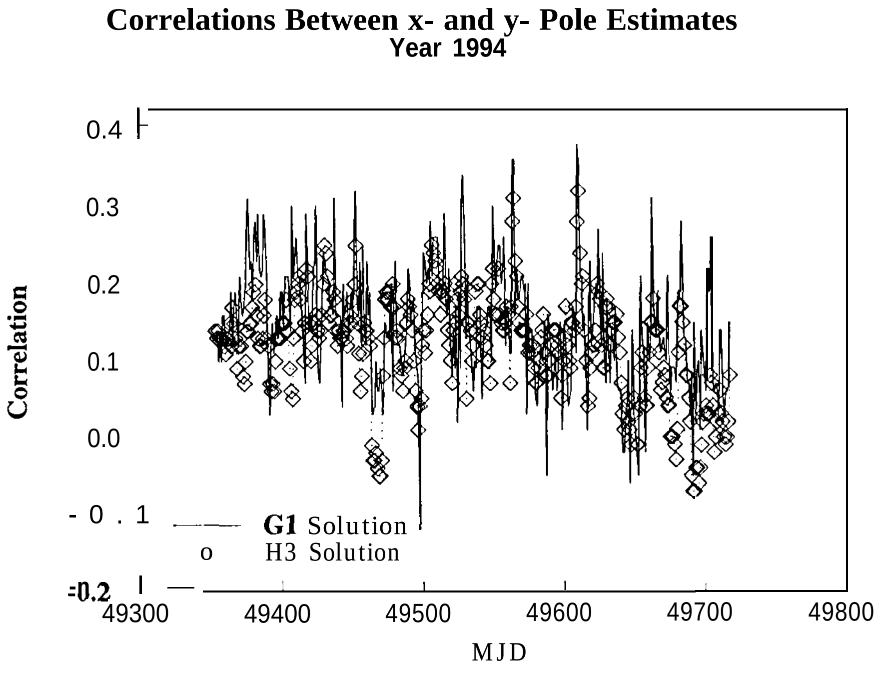


Figure 5. Correlations between x- and y- estimates of polar wobble for 1994.

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 February 1995). Although the 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.*

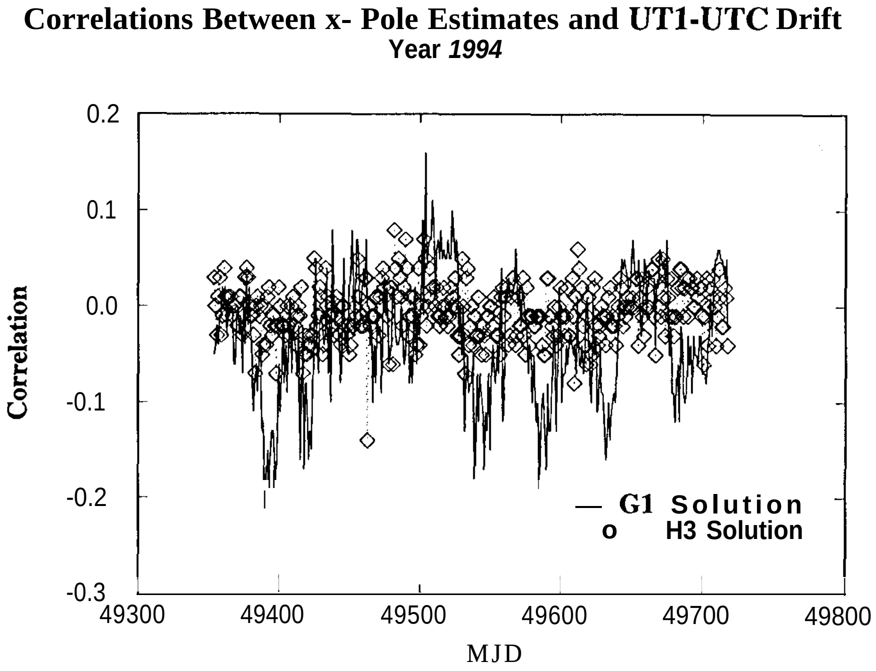
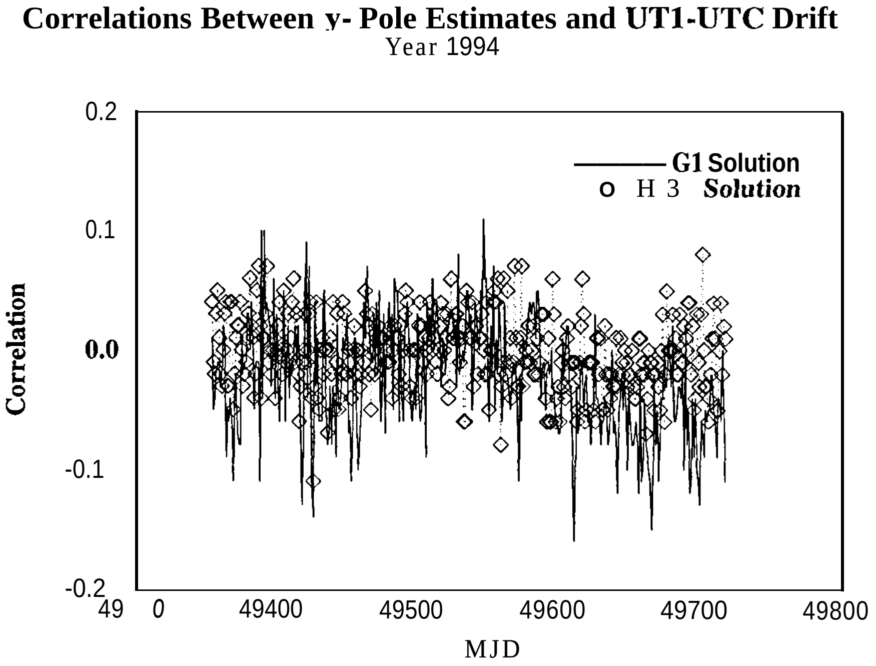


Figure 7. Correlations between y-estimate of polar wobble and ***UT1-UTC*** *drift for 1994.*



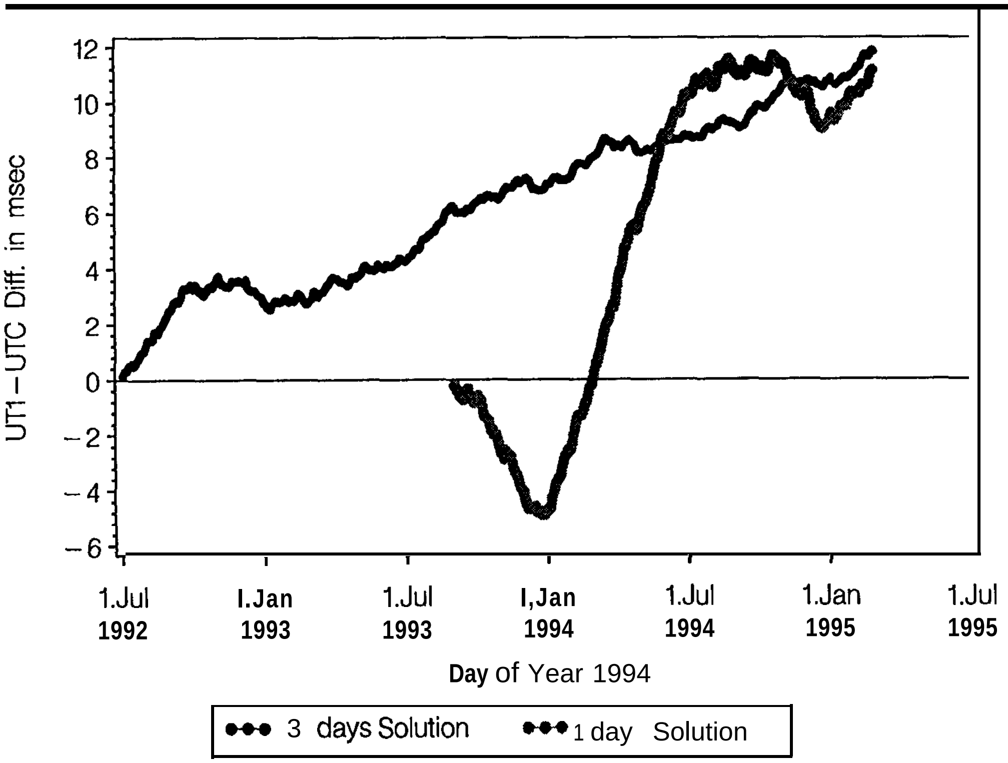


Figure 8. ***UT1-UTC estimates from one- vs. three-day solutions relative to VLBI estimates (from C04).***

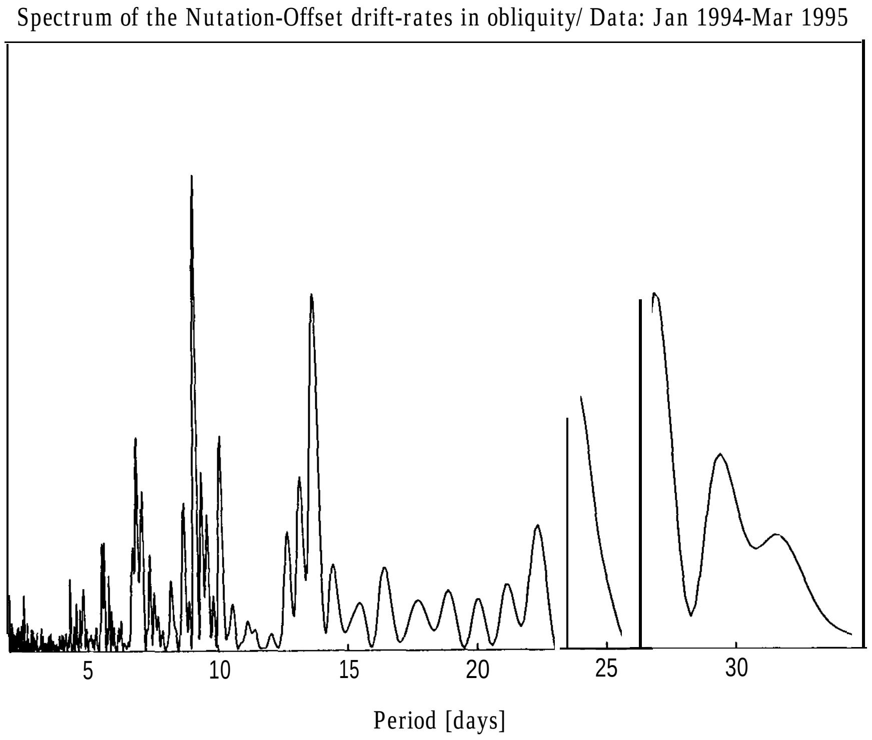
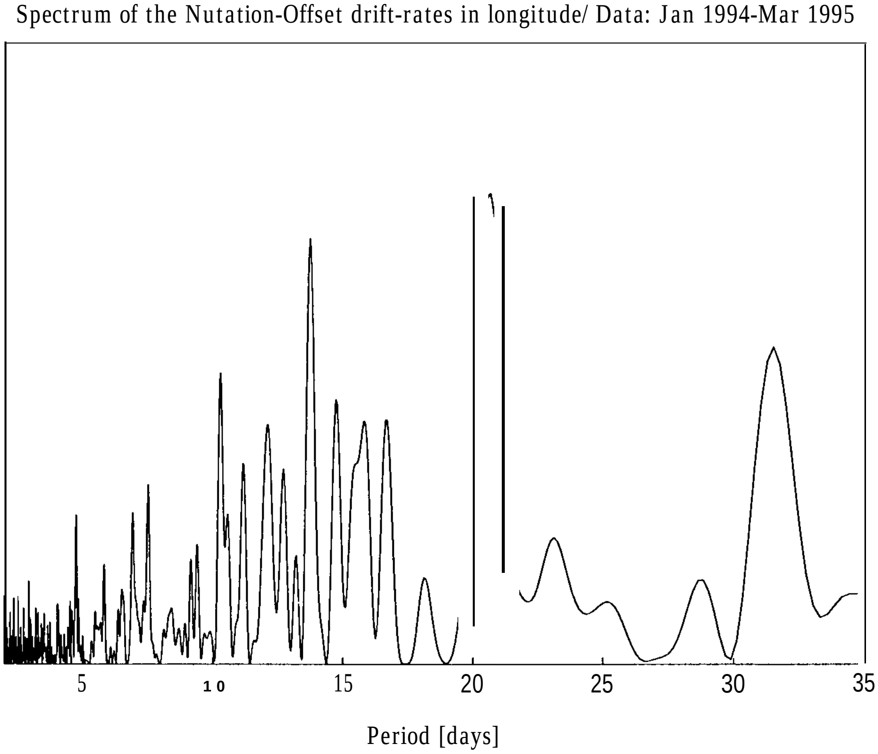


Figure 9. Frequency analysis of the drifts in $\Delta\varepsilon$ as estimated by the CODE ***processing center.***

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^{3}s^{-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 16–1 9 883.2 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		F	# Man	Epochs	da	da/dt
		since	until					
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	+	0			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	+	0			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).

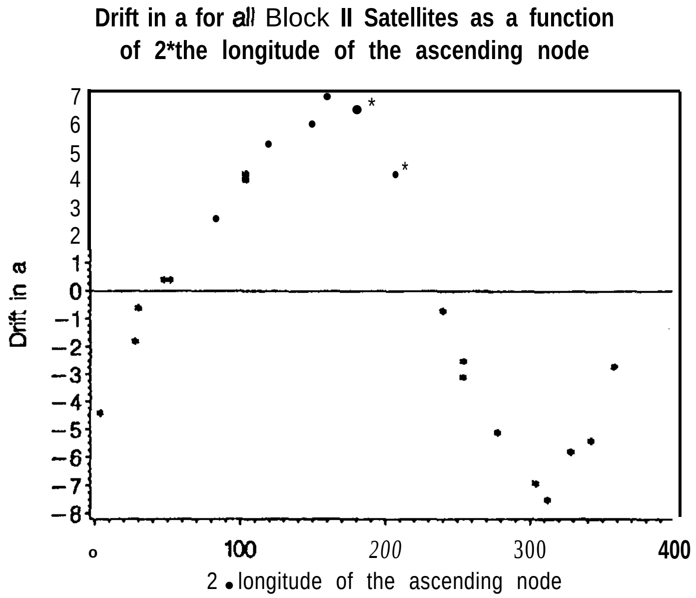


Figure 11. Drift in ***semimajor*** *axis a as a function of twice the geographic longitude of the ascending node.*

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 variation is roughly semiannual. The residuals are correlated with the angle 2γ, where y 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.

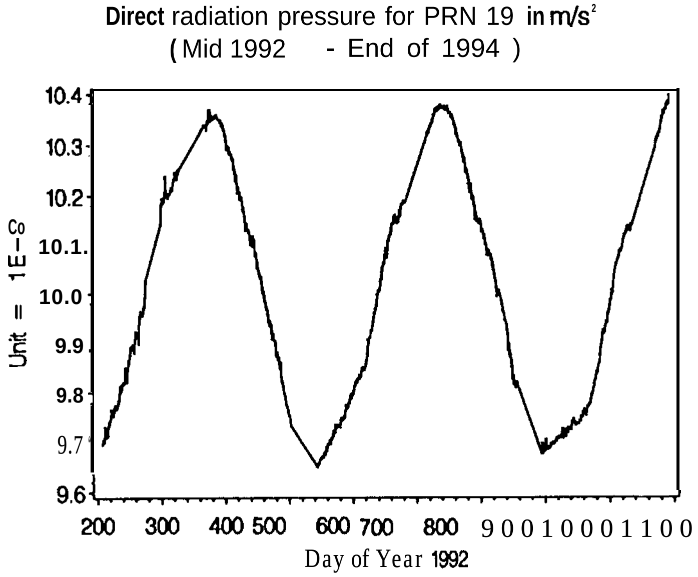


Figure 12. Direct radiation pressure for PRN 19 (June 1992-December 1994).

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.