International GPS Service for Geodynamics
1995 Annual Report

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IGS Central Bureau

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109-8099

Edited by:
J. F. Zumberge
M. P. Urban
R. Liu
R. E. Neilan

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Preface

Joe Popelar

Chief, Active Control Systems
Geodetic Survey Division
Natural Resources Canada

This 1995 Annual Report of the International GPS Service for Geodynamics (IGS) presents an overview of the second operational year of the service. It provides the many IGS contributing agencies and the rapidly growing user community with essential information on current organizational and technical matters promoting the IGS standards and products. But this report contains more than a description of the organizational framework, data processing strategies and statistics showing the remarkable expansion of the global GPS monitoring network, the improvement of IGS performance and product quality. It also introduces very important practical concepts for network densification by integration of regional stations and the combination of station coordinate solutions carried out by the newly incorporated IGS Associate Analysis Centers. This makes it possible to increase the accuracy of geodetic control and regional geodynamic monitoring networks which may contribute to further improvements of the International Terrestrial Reference Frame (ITRF) particularly in tectonically active areas.

There are many aspects of the IGS that have made it such a success and which hold a great promise for its future. It seems appropriate here to mention at least two of them which reflect on the inclusive nature of the IGS collaboration and its increasing practical importance:

- High demands on data quality, timely processing, intercomparison and combination of results into IGS products have challenged all participating organizations and have led to the establishment of efficient data processing and communication operations in support of the IGS. This truly distributed approach provides the necessary resources and capacity to manage the large volumes of data in a timely manner on a continuous basis producing consistently high quality results such as the IGS combined GPS satellite orbits, clocks, and the new polar motion series introduced in 1995.

- The global scope, continuous availability, and widespread use of GPS leads to rapid development of GPS applications for monitoring of ionospheric activity, measurements of precipitable water in the atmosphere, studies of sea level variations, and precise time and frequency distribution to name the most promising which dominated the IGS Workshop on "Special Topics and New Directions" organized in Potsdam in May of 1995. IGS support for these developments and for improvements of real-time positioning services is of major practical importance. This rare opportunity to demonstrate and benefit from a direct impact of scientific research initiatives on such wide-ranging practical applications is not to be missed.

From the point of view of the national geodetic agency our participation in the IGS has been most productive and rewarding. It has facilitated the development and introduction of the leading edge technology and modernization of the geodetic standards in Canada and provided us with access to the IGS data and products without which we could not have succeeded.

Introduction

J. F. Zumberge

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA

Now in its third year, the International GPS Service for Geodynamics continues to provide Global Positioning System data and products in support of geodetic and geophysical research activities. In this, its second annual report, I think you will find evidence that the IGS is not only achieving its objectives, but helping to foster the development of new GPS applications as well.

Although different in look, this year's report is organized like the 1994 Annual Report. The first group of articles describes general aspects of the IGS. Contributions from the Analysis Centers follow the general description, and next there are contributions from the Associate Analysis Centers (AACs). The AAC articles are a new feature, which we expect to continue in future volumes. Data Center contributions and IGS station contributions complete the report (please refer to last year's report for information on IGS stations not described in this volume).

This year's report is in part the result of an experiment with TEX. Our local Unix guru and TEX aficionado, Mike Urban, has done an admirable job in putting everything together. Overall I'm pleased with the results of the experiment.

I hope that we succeeded this year in producing a report that was at least a little more timely than last year's. However, there is still considerable room for improvement; at the Central Bureau we'll be considering how to handle this annual task more efficiently.

Finally, I would like to encourage readers to give us feedback. From your point of view, we need to know where improvements can be made. The best way to reach us is by e-mail to `igscb@igscb.jpl.nasa.gov`.

General Aspects of the IGS

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 it 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 1 January, 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
- tropospheric 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 Terrrestrial 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
- climatological research, eventually weather prediction.

The IGS accomplishes its mission through the following components:

- networks of tracking stations
- data centers
- Analysis and Associate Analysis Centers
- Analysis Coordinator
- Central Bureau
- Governing Board.

1 Networks of Tracking Stations

IGS Stations provide continuous tracking using high accuracy receivers and have data transmission facilities allowing for a rapid (at least daily) data transmission to the data centers (see below). The stations have to meet requirements which are specified in a separate document. The tracking data of IGS stations are regularly and continuously analyzed by at least one IGS Analysis Center or IGS Associate Analysis Center. These analyses must be available to, analyzed and published by the ITRF section of the IERS for at least two consecutive years. During this initial period the IGS Central Bureau can temporarily designate new tracking stations as IGS stations.

IGS Stations which are analyzed by at least three IGS Analysis Centers for the purpose of orbit generation, where at least one of the Analysis Centers lies on a different continent than the station considered, are in addition called IGS Global Stations.

All IGS stations are qualified as reference stations for regional GPS analyses. The ensemble of the IGS stations forms the IGS network (polyhedron).

2 Data Centers

The data centers required fall into three categories: Operational, Regional, and Global Data Centers.

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.

3 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.

4 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.

5 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.

Under the existing reciprocity agreement between IGS and IERS, the CB serves as the GPS Coordinating Center for IERS; 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.

6 Governing Board

The Governing Board (GB) consists of fifteen members. They are distributed as follows:

Elected by IGS Associates (see below):	
Analysis Centers' representatives	3
Data centers' representative	1
Networks' representatives	2
Elected by the Governing Board upon recommendations from the Central Bureau, for the next term:	
Representatives of Analysis, Data Centers or Networks	2
Members at large	2
Appointed members:	
Director of the Central Bureau	1
Representative of the IERS	1
IGS representative to the IERS	1
IAG/FAGS representative	1
President of IAG Sect. II or Com.VIII (CSTG)	1
Total	15

The appointed members are considered *ex officio* and are not subject to institutional restrictions. The other ten persons must be members of different organizations and are nominated for each position by the IGS components they represent as listed above (six persons) , or by the Central Bureau (four persons) for a staggered four year term renewable once. The GB membership should be properly balanced with regard to supporting organizations as well as to geography.

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 Global 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 election will be conducted by a nominating committee of three members, the chair of which will be appointed by the Chair of the IGS Governing Board.

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/she is the official representative of IGS to external organizations.

The IAG/FAGS representative is appointed by the IAG Bureau (or by FAGS) for a maximum of two four-year terms. Members of the GB become

IAG Fellows with the appropriate rights and privileges after an initial two-year period.

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 members present, provided that there is a quorum consisting of at least ten members of the GB. In case of lack of a quorum the voting is by mail. Changes in Terms of and Chairperson of the GB can be made by a 2/3 majority of the members of the GB, i.e., by ten 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 five members.

7 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.

8 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

The Year 1995 in Retrospective as seen from the IGS Governing Board

Gerhard Beutler
Astronomical Institute, University of Berne, Berne, Switzerland

1 IGS Events in 1995 in Overview

1995 was the second year of official IGS operations. Prior to the start of the official service we had the three months IGS test campaign from 21 June to 23 September 1992, which was followed by the IGS Pilot Service. It is worthwhile to point out that the IGS product quality, their reliability and timely availability significantly improved in this time period. These aspects will be dealt with in detail in the *IGS Analysis Center Coordinator's Report.*

The important events in the development of the IGS since January 1, 1994 are listed in Table 1. There were two Governing Board meetings in 1995, No. 4 in July in Boulder, No. 5 in December in San Francisco. Moreover we had the XXIst IUGG General Assembly in Boulder with the IAG Symposium No. 115 on *GPS Trends in Precise Terrestrial, Airborne, and Spaceborne Applications* [1]. Last, but not least, we had the IGS Workshop on Special Topics and New Directions May 15–18 in Potsdam, Germany.

Reports about some of the events in Table 1 were already delivered in electonic mail form:

- IGS-message No. 842 (dated January 17, 1995) contains a report about the 1994 Workshop in Pasadena (proceedings in [2]) and a summary of the third IGS Governing Board Meeting.
- IGS-message No. 961 (dated May 26, 1995) summarizes the Potsdam Workshop on Special Topics and New Developments.
- IGS message No. 1010 (dated July 17, 1995) announces the start of the IGS Pilot Project on Densification of the ITRF through Regional GPS Networks.
- IGS message No. 1080 (dated October 5, 1995) summarizes the fourth IGS Governing Board Meeting in Boulder and gives a general overview of IGS matters in October 1995.

- IGS message No. 1168 (dated December 22, 1995) summarizes the fifth IGS Governing Board Meeting in San Francisco in December 1995.
- IGS message No. 1266 (dated March 29, 1996) is devoted to the 1996 IGS Analysis Center Workshop in Silver Spring.

Table 1: Chronicle of IGS Events 1994–1996

Date	**Event**
15-May-95	IGS Workshop *Special Topics and New Directions* in Potsdam.
03-Jul-95	IAG Symposium No. 115 on *GPS Trends in Precise Terrestrial, Airborne, and Spaceborne Applications.* at the XXIst IUGG General Assembly.
06-Jul-95	Fourth IGS Governing Board Meeting in Boulder.
03-Sep-95	Start of IGS Pilot Project on the Densification of the ITRF using Regional GPS Networks
01-Dec-95	1994 IGS Annual Report available!
12-Dec-95	Fifth IGS Governing Board Meeting in San Francisco.
01-Jan-96	Production of IGS Preliminary Orbits with a delay of only 36 hours!
11-Jan-96	Call for Participation for future Regional Associate Analysis Centers(RNAACs) in the project 'Densification of the ITRF through Regional GPS Networks'.

The present report covering the year 1995 (extending somewhat into the year 1996) is based on these IGS mail messages, on the mentioned proceedings associated with the IGS workshops, on the proceedings of the IAG Symposium 115 [1], and on a paper [3] prepared for the U.S. National Research Council Workshop on improving the DGPS infrastructure for earth and atmospheric science applications, in Boulder, March 1996. Let us now look at the 1995 IGS Events in more detail.

2 The IGS Workshop on Special Topics and New Directions in Potsdam

The workshop was held in Potsdam at the beautiful Jagdschloss Glienicke. It was hosted by the GeoForschungsZentrum (GFZ), Potsdam, Germany.

The days in Potsdam will be remembered as the first IGS workshop where non-geodetic applications of the GPS and the involvement of the IGS in such developments were thoroughly discussed. Monitoring the atmosphere was the central issue.

In the opening review [4] the authors developed arguments to broaden the field of activities of the IGS, in particular into the direction of meteorology. It was also argued that there should be a broader sponsorship for the IGS.

At present the IGS is an IAG Service. Should other associations of the IUGG (like the IAMAP, the International Association of Meteorology and Atmospheric Physics) be asked become sponsors, too? The authors answered this question with a clear *yes*.

Troposphere aspects were discussed in detail in the presentation by Mike Bevis [5]. Obviously, with only a comparatively small additional effort — essentially the deployment of high precision barometers in the IGS network and the use of this information by the IGS Analysis Centers — the IGS would be capable of making remarkable contributions to climatology. Should rapid IGS products (delay of only hours rather than weeks) eventually become available the IGS contribution to weather prediction would become significant. In the discussion a two-step approach (deployment of barometers and treatment of climatologic aspects by IGS analysis centers as a first step, development of precise rapid products in a second step) seemed to find general approval.

It was understood that for meteorological applications the availability of really rapid IGS orbits with a delay of a few hours only is a central issue. This issue was brought up again and again, and eventually led to the production of so-called IGS Preliminary Orbits in 1996.

N. Jakowski's presentation [6] brought insight into the value of the IGS network from the point of view of ionosphere physics. High spatial resolution and the global station distribution make the IGS network very interesting for ionosphere physics. Jakowski stated that the production of ionosphere maps and the study of special phenomena might be very well supported by the IGS network.

Of course there were other very interesting topics discussed at the workshop. The proceedings are available [7] and the reader is referred to this very informative volume for more information. All workshop participants will remember the excellent organization of the workshop by the GFZ team and the generous and warm hospitality experienced.

3 IGS Events at the XXIst IUGG General Assembly

The first session of the IAG Symposium on GPS Trends in Precise Terrestrial, Airborne, and Spaceborne Applications was devoted to the International GPS Service for Geodynamics and other Permanent Networks. From the IGS presentations it became apparent how important for all kinds of high accuracy applications the IGS became in a relatively short time span. It became also clear that the IGS was (and is) setting the standard for other permanent GPS networks. Nobody would have the idea today to set up other procedures for data transmission, formats, etc. than those developed by the IGS. Together with the sessions Spaceborne Applications, Kinematic Applications, Atmosphere Applications, and GPS Theory, the symposium gave a broad overview of the state of the art in scientific applications of the GPS in 1995. A fair portion of this story was written or stimulated by the IGS. The proceedings of this symposium are available now [1].

The fourth IGS Governing Board Meeting took place on July 6, 1995 in Boulder during the IUGG general assembly. The meeting was of importance to define the action items emerging from the Potsdam workshop and to prepare delicate agenda items like elections into the Governing Board and change of the terms of reference for the fifth Governing Board meeting.

A highlight was the report given by the Analysis Center Coordinator who started producing an IGS combined pole in addition to the combined orbits. As could be seen in IGS mail messages 1068 and 1072, this combined IGS pole was carefully analyzed and the result had an important impact on the definition of the IERS Rapid Subbureau's Bulletin-A pole (IGSMail Message No. 1072). Both Bulletins A and B of the IERS changed their procedures to take into account variations of relatively short periods (3–10 days) as seen by the IGS Analysis Centers for the definition of their products.

Much time was devoted at the meeting for planning the Pilot Phase of the IGS Project on the Densification of the ITRF through Regional GPS Analyses. The following section of this report is devoted to that issue. For more information concerning the fourth Governing Board Meeting we refer to IGS-mail Message No. 1080.

4 IGS Pilot Project on the Densification of the ITRF through Regional GPS Networks

The theoretical foundations for this project were developed at the IGS Workshop in Pasadena, in December 1994 [2]. The project was also introduced in the 1994 IGS Annual Report [8]. It will again be addressed in this Annual Report. We may thus only briefly summarize the state of the project here:

- The project officially started on September 3, 1995, the first day of GPS week 817. The project was originally planned to last for one calendar year. Several delays demand a continuation at least till the end of 1996.

- In a first phase of the project (to last till mid 1996) the seven IGS Analysis Centers (COD, EMR, ESA, GFZ, JPL, NGS, and SIO) produce so-called 'free network solutions' which may subsequently be combined into a unified IGS coordinate solution. The AC contributions have to be in the SINEX format (a Software INdependent EXchange format). SINEX files should be delivered at weekly intervals (combining thus seven days of analysis).

- Three IGS Global Network Associate Analysis Centers (GNAACs) are combining these individual contributions every week. The three GNAACs are:
    - MIT (Massachussetts Institute of Technology) with Tom Herring,
    - NCL (University of Newcastle) with Phil Davies,
    - JPL (Jet Propulsion Laboratory) with Mike Heflin.

- On January 21, 1996 a Call for Participation was issued for so-called IGS Regional Associate Analysis Centers (RNAACs) which would perform regional analyses using IGS global products, and which would also produce weekly SINEX files to be combined by the GNAACs every week (IGS-mail message No. 1178).

- At present the Pilot Project is running smoothly: the three GNAAC centers, using rather different combination strategies come up with similar sets of coordinates. The consistency between AC solutions is of the order of 5 mm rms in the horizontal position of about 1 cm in height.

- The next essential step, the inclusion of the RNAAC solutions into the weekly GNAAC combinations will be an issue in the 1996 IGS Annual Report!

5 Elections into the Governing Board, Modified Terms of Reference

According to the terms of reference six members of the Governing Board are elected by the Associate Members, two (one each) are appointed by IAG and IERS, three are members *ex officio* — director of Central Bureau (Ruth Neilan); IGS representative to IERS (Bill Melbourne); and president Section II of IAG (or Commission VIII) — and four are appointed by the Governing Board upon recommendation of the Central Bureau.

According to the revised terms of reference (see below) the members (other than those *ex officio*) are elected/appointed for four years, one re-election/reappointment is possible. The terms were staggered initially to allow for continuity in the Governing Board. Three members had to be elected or confirmed by the IGS Associates by the end of 1995, and all four members appointed by the GB had to be re-evaluated this time because according to the "old" terms of reference there were only two-year terms for the appointed members.

Yehuda Bock, Jan Kouba, and John Dow were elected for a second period, Geoff Blewitt from University of Newcastle was elected for a two-year term as Analysis Center representative (filling the position originally taken by G. Beutler). Christoph Reigber (GFZ) and John Manning (AUSLIG) were appointed by the GB for four-year periods, Gerry Mader and Bob Schutz for two-year periods.

Table 2 gives an overview of the former and current IGS GB members. The chairman and the director of the Central Bureau expressed their thanks to those leaving the GB, namely Claude Boucher and Teruyuki Kato for their valuable contributions during the important initial development phase of the IGS. Claude Boucher and Teruyuki Kato were already members of the IGS Campaign Oversight Committee from 1991–1993.

The IGS Terms of Reference were modified to simplify the structure of the Governing Board. Originally the distinction was made between voting and

Table 2: The new and old IGS Governing Board (e: elected, a: appointed, x: *ex officio* members).

1994–1995		1996–...	
G. Beutler	(e,4y)	G. Blewitt	(e,2y)
Y. Bock	(e,2y)	Y. Bock	(e,4y)
C. Boucher	(a,2y)	Ch. Reigber	(a,4y,GB)
J. Dow	(e,2y)	J. Dow	(e,4y)
B. Engen	(e,4y)	B. Engen	(e,2y)
J. Kouba	(e,2y)	J. Kouba	(e,4y)
C. Noll	(e,4y)	C. Noll	(e,2y)
M. Feissel	(a,IERS)	M. Feissel	(a,IERS)
I. Mueller	(a,IAG)	I. Mueller	(a,IAG)
T. Kato	(a,2y,GB)	J. Manning	(a,4y,GB)
G. Mader	(a,2y,GB)	G. Mader	(a,2y,GB)
Ch. Reigber	(a,2y)	B. Schutz	(a,2y,GB)
B. Melbourne	(x)	B. Melbourne	(x)
R. Neilan	(x)	R. Neilan	(x)
B. Schutz	(x)	G. Beutler	(x)

non-voting members; also, the members appointed by the GB were given two-year terms only. Since the adoption of the modified terms of reference all GB members are voting members and all (except Bob Schutz and Gerald Mader, who were initially assigned to two-year terms) will have to serve (at least) one four-year period in the GB.

Modifications were made in the section *Network of Tracking Stations*. In the future only permanent tracking stations will be eligible as IGS stations. A permanent tracking station is called an *IGS station*, if its data are regularly analysed by at least one IGS (Associate) Analysis Center. If its data are analysed by at least three Analysis Centers (where at least one has to lie on a different continent from the tracking station) the IGS station is in addition called an *IGS Global Station*. The ensemble of the IGS stations forms the IGS network (polyhedron).

The modified terms of reference are included in this 1995 Annual Report.

6 Acknowledgements

The IGS Governing Board was extremely pleased by the progress made during the year 1995. This statement implies that in essence all components of our service are working well, today. Perhaps this is also due to many presentations given and meetings organized (Table 3) with the goal to make the scientific world aware of the existence and the achievements of the IGS.

Unanimously the IGS Central Bureau was congratulated for the preparation of the *IGS Annual Report 1994*. It was also noted that the IGS Analysis Centers made significant, in some cases even dramatic progress in 1995. The same conclusion could of course be drawn from reading the Analysis Center reports for 1994 (and for 1995). We are today approaching the 5–10 cm consistency level of orbits generated by the individual individual Analysis Centers. The permanent friendly competition between IGS Analysis Centers is one prerequisite for very successful work of the IGS Analysis Center Coordinator Jan Kouba and his team leading every week to the highly accurate and reliable official IGS products. The example of the IGS combined pole (see above) is a good example that this combination work is recognized also outside the IGS.

Last but not least the Governing Board wishes to express its gratitude to the operators of the IGS network and to the IGS data centers on all levels. It is the strength of the IGS that it may rely on the voluntary contributions of its member organizations and of many individuals devoting a good portion of their working power to IGS issues. Let us conclude by thanking all those contributing to the IGS and by expressing the hope that the same kind of support will be available in future, too.

Table 3: Presentations/Events in 1995 on behalf of the IGS Governing Board

Date	*Presentation/Event*	*Presented/organized by*
February	GLOSS Meeting	R. Neilan
May	ITRF Workshop	G. Beutler
May	IGS Contributions to Ionospheric Research (AGU Spring Meeting)	G. Beutler
July	IAG Symposium 115 (Session about IGS)	G. Beutler, B. Melbourne
August	Seminar in Ny Alesund	G. Beutler
August	1st Federal Civilian GPS-PPS Coordination Workshop	R. Neilan
September	ION95 Meeting	J. Dow *et al.*
October	Presentation at 46th International Astronautical Congress in Oslo	J. Dow *et al.*
October	Seminar at Technical University of Dresden	G. Beutler
October	Seminar at Technical University of Vienna	G. Beutler
October	Seminar at Technical University of Graz	G. Beutler
October	NASA Technology 2005	J. Zumberge
November	NASA-NSF Workshop on Sea Level	J. Zumberge
November	Mexican Geophysical Union Meeting	R. Neilan

References

[1] G. Beutler, G. W. Hein, W. Melbourne, and G. Seeber, editors, *GPS Trends*

in Precise Terrestrial, Airborne, and Spaceborne Applications, Number 115 in International Association of Geodesy Symposia, Springer-Verlag, 1996.

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The Organization of the IGS in 1995

Ruth E. Neilan

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California

1 Overview

This year marked the second fully operational year of the IGS, and the status of this evolving organization should be noted. The 1994 Annual Report [1], available from the Central Bureau, describes in greater detail the fundamental organization of the IGS. This report will provide an overview and summary of the organization and focus on the changes in 1995.

2 Brief Description of the IGS Organization

The organization of the IGS is depicted in Figure 1. The GPS stations shown below the GPS satellites are permanently installed and operate continuously receiving and recording the L-band, dual-frequency signals transmitted by the GPS satellites. The map of the network of tracking stations can be seen in this volume in [2]. The station data are accessed by Operational Data Centers through various communication schemes. The Operational Centers monitor and validate the data, format it according to standards and forward the data sets to the Regional (Table 1) or Global Data Centers (Table 2). The IGS Analysis Centers (Table 3) 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 [3] in this volume) to produce the official IGS orbit. The products are sent to the Global Data Centers and to the Central Bureau Information System for archival and access by users. The Central Bureau is responsible for the overall coordination and management of the service and is located at NASA's Jet Propulsion Laboratory, which is operated for NASA by the California Institute of Technology. The International Governing Board exercises general oversight and control over the IGS.

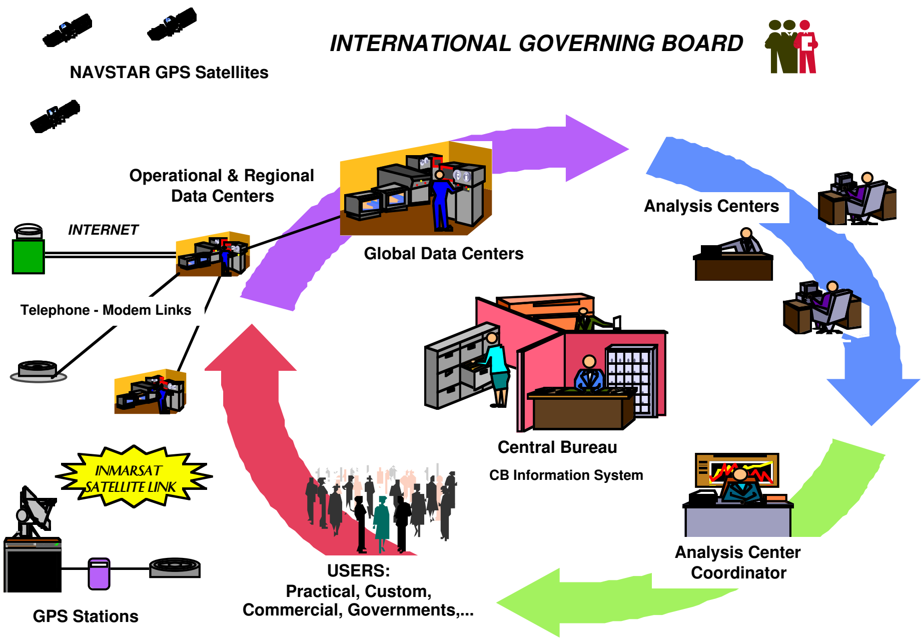

Figure 1: The Organization of the International GPS Service for Geodynamics

Table 1: IGS Regional Data Centers

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

Table 2: 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

Table 3: 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

3 Changes in the IGS Organization in 1995

3.1 Associate Membership

In 1995 two additions were made to the IGS Organization. The Associate members of the IGS are described in the Terms of Reference as

> ... 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.

The Associate Members along with the Governing Board Members are responsible for the nomination and election of the incoming Governing Board members every two years. The Associate Members also become IAG Affiliate Members. The list of Associate Members is shown in Table 4. More information on the formal relations can be found in [4], the IGS Terms of Reference, which was revised in December 1995.

3.2 Associate Analysis Centers — Pilot Project for the Densification of the ITRF

Associate Analysis Centers are organizations that produce unique products within the IGS. The Pilot Project for the densification of the ITRF reference frame using the IGS network officially began in September of 1995 (see [5] in this volume). This project is designed as a proof of concept for distributed processing of GPS data from many stations, and it relies on the Global Network Associate Analysis Centers (GNAACs) for a rigorous combination of results submitted by IGS Analysis Centers and the Regional Network Associate Analysis Centers (RNAACs) to produce precise station locations and velocities in a consistent reference frame (Zumberge and Liu; 1995). The Call for Participation at the regional level was announced in January 1996.

Other types of Associate Analysis Centers are being considered that would support the use of GPS data and products as required by other research areas, such as ionospheric and atmospheric applications.

Table 4: Associate Members of the IGS, 1995

Boudewijn Ambrosius	Ulf Lindqwister
Jeff Behr	Chi-cheng Liu
Loic Boloh	Thomas Martin-Mur
Claude Boucher	C. Garcia Martinez
Carine Bruyninx	Feng Meng-hua
Alessandro Caporali	Matti Paunonen
Miranda Chin	Peter Pesec
Loic Daniel	Markus Rothacher
Eduardo Diaz	Glen Rowe
Herb Dragert	Mark Schenewerk
Maurice Dube	Wolfgang Schlueter
Robert Duval	Mike Schmidt
Peng Fang	Andrew Sinclair
Joachim Feltens	Jim Slater
Luis Paulo Fortes	Janusz Sledzinski
Roman Galas	Keith Stark
Gerd Gendt	Suryia Tatevian
Werner Gurtner	Pierre Tetreault
Heinz Habrich	Hiromichi Tsuji
Martin Hendy	Francesco Vespe
Pierre Heroux	Michael Watkins
Waldemar Jaks	Zhu Wen-yao
Jan Johansson	Urs Wild
Teruyuki Kato	Pascal Willis
Izabella Kulhawczuk	James Zumberge

Table 5: Global Network Associate Analysis Centers for the Densification of the Global Reference Frame

University of Newcastle-upon-Tyne	UK
FLINN Analysis Center Jet Propulsion Laboratory	USA
Massachusetts Institute of Technology	USA

4 Governing Board

The Governing Board of the IGS is an international body which exercises general oversight and control over the activities of the Service. This year was the first election of new members to the Governing Board, see [6] in this volume. The members of the Governing Board are a combination of elected, appointed or *ex officio* positions. The Governing Board is intended to meet at least once annually, and in 1995 two Governing Board meetings were held, one at the XXI General Assembly of the IUGG in Boulder, and the other coinciding with the December AGU meeting in San Francisco.

Table 6: The IGS Governing Board Members, Current and Former

Name	*Country: Institution*	*Functions*	*Term**
Gerhard Beutler	Switzerland: University of Bern	Chair, Appointed (IAG)	4 years*
Geoff Blewitt	U.K.: University of NewCastle	Analysis Center Rep.	2 years†
Yehuda Bock	USA: Scripps Institution of Oceanography	Analysis Center Rep.	4 years†
John Dow	Germany: ESA/European Operations Center	Network Rep.	4 years†
Bjorn Engen	Norway: Statens Kartverk	Network Rep.	4 years*
Martine Feissel	France: International Earth Rotation Service	IERS Rep.	—
Jan Kouba	Canada: Natural Resources Canada	Analysis Coordinator	4 years†
Gerry Mader	USA: GRDL, National Oceanic and Atmospheric Administration	Appointed (IGS)	2 years†
John Manning	Australia: Australian Survey and Land Infomration Group	Appointed (IGS)	4 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 Noll	USA: Goddard Space Flight Center	Data Center Rep.	4 years*
Christoph Reigber	Germany: GeoForschungsZentrum	Appointed (IGS)	4 years†
Bob Schutz	USA: CSR, University of Texas-Austin	Appointed (IGS)	2 years†
Claude Boucher	France: Institut Geographique National	Former Member	'94–'95
Teruyuki Kato	Japan: ERI, University of Tokyo	Former Member	'94–'95

* Terms beginning January 1, 1994
† Terms beginning in January 1, 1996

5 Users

The consistent users of the IGS are mostly those participating agencies who gain so much from the cooperation of each component. In 1995 there was a significant increase in the requests for information and the access to information at the Central Bureau Information System. This increasing traffic and interest is no doubt a result of the increased visibility of Service through the efforts of all IGS components as well as the the outreach effort by the Central Bureau.

Table 7: Contributing Agencies of the International GPS Service for Geodynamics, 1995

Acronym	*Agency*
`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`	CSIR 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 Institute, 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, Greenbelt, MD, 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

Table 7: (continued)

Acronym	*Agency*
`IDA`	International Deployment of Accelerometers/IRIS, Scripps Institution of Oceanography, USA
`IESAS`	Academia Sinica, Institute of Earth Sciences, Taiwan
`IfAG`	Institut für Angewandte Geodasie, Frankfurt, Germany
`IGN`	Institut Geographique National, Paris, France
`IGNS`	Institute of Geological and Nuclear Sciences, New Zealand
`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 Nacional 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
`KAO`	Korean Astronomy Observatory, Taejon, Korea
`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
`ROA`	Real Instituto y Observatorio de la Armada, Spain
`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
`UNT`	University of Newcastle-upon-Tyne, United Kingdom
`UPAD`	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

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Contribution of the Central Bureau of IERS

C. Boucher, Z. Altamimi
Institut Géographique National, Paris, France

D. Gambis, E. Eisop, M. Feissel
Paris Observatory, Paris, France

Following its Terms of Reference, IGS works in close cooperation with the International Earth Rotation Service (IERS). The Central Bureau of IERS is operated jointly by Institut Géographique National (IGN), in charge of the International Terrestrial Reference Frame (ITRF), and Paris Observatory, in charge of the International Celestial Reference Frame (ICRF) and the Earth's rotation determination. The other techniques used by IERS are Very Long Baseline radio Interferometry (VLBI), Lunar and Satellite Laser Ranging (LLR, SLR), and Doppler Orbit determination and Radiopositioning Integrated on Satellite (DORIS).

The IGS has adopted the ITRF as the reference for the orbit computations. The GPS contribution is important for the maintenance and extension of the ITRF as well as for the global consistency of the IERS results through the permanent high resolution monitoring of polar motion. GPS also provides information on the high frequency variations in universal time. The general analyses of GPS results appear in the 1995 IERS Annual Report together with those of the other techniques. We present hereafter detailed analyses of interest to IGS.

1 Terrestrial Reference Frame

The ITRF Section of the IERS Central Bureau has issued the ITRF94 solution with a full description [1]. All information is also available on the World Wide Web at URL

`http://schubert.ign.fr/CIAG/index.CIAG.html`

The ITRF94 solution consists of two coordinate combinations at 1988.0 and 1993.0 epochs, as well as an associated velocity field derived from these two combinations. Class I solutions (see [1] for more details) have been selected for this realization: four VLBI, three GPS, two SLR, and three DORIS solutions.

For the improvement of the ITRF products, several new aspects were investigated and taken into account:

- full variance-covariance information between positions and velocities was used in the combination,
- specific quality analyses of the individual solutions were performed, based on combinations and comparisons per technique. These analyses also lead to the estimation of the Matrix Scaling Factor.
- The ITRF94 datum definition is based on:
  - the origin: weighted average of a selection of SLR and GPS solutions;
  - the scale: weighted average of a selection of VLBI, SLR and GPS solutions, modified in order to take into account the fact that the solutions use TAI (International Atomic Time) and not TCG (Geocentric Coordinate Time) as time scale;
  - the orientation: consistent with the ITRF92 (not the ITRF93) at 1988.0 epoch;
  - the time evolution: consistent with the geophysical model NNR-NUVEL1A.
- The ITRF94 stations were classified according to the quality of their positions and velocities.

For the purpose of the Annual Report for 1995, we will focus on the contribution of GPS/IGS solutions in the ITRF94 by noting the following issues:

- Only three GPS solutions were selected as class I;
- 41 GPS sites are collocated with VLBI, SLR, or DORIS sites for which local ties were used. Figure 1 shows the distribution of all the GPS sites, including the collocated ones.
- Table 1 shows the quality of the individual solutions in terms of weighted rms at both the 1988.0 and 1993.0 epochs. As far as the GPS solutions are concerned, we note that the weighted rms at epoch 1993.0 for JPL and CODE is at the level of 5 mm in the horizontal and 8 mm in the vertical components. The corresponding rms values at epoch 1988.0 could be estimated to be of the order of 15 mm in the horizontal and 35 mm in the vertical components (providing that the vertical velocities of the CODE solutions were constrained to the ITRF93 values).

In addition to the official ITRF94 solutions, three specific solutions were performed in order to help IGS Analysis Coordinator for more comparison and consistency check. These are :

- `ITRF94_P1` : Extract of GPS station coordinates from ITRF94 solution at 1993.0;
- `ITRF94_P2` : Combination of the three GPS solutions used in the ITRF94;

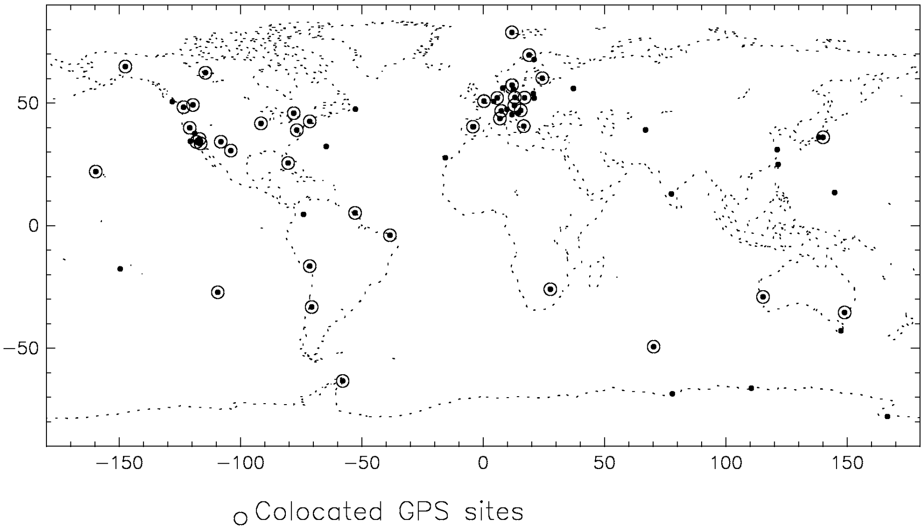

Figure 1: ITRF94 GPS Sites

- `ITRF94_P3` : Combination of VLBI, SLR, DORIS and local ties for GPS stations.

Comparisons between these three solutions were performed. The weighted rms of these comparisons are given in Table 2.

2 Earth Orientation

2.1 Polar motion

2.1.1 Individual GPS series

Seven analysis centers are deriving an operational daily solution of the coordinates of the pole: CODE, EMR, ESOC, GFZ, JPL, NOAA, and SIO. In 1995 the series were referred to ITRF93 (SSC(IERS) 94 C 02) and thus are expected to be consistent with the IERS EOP series. The level of agreement of the GPS polar motion with the IERS System is illustrated in Table 3, which gives for the six quarters from January-March 1995 through April–June 1996 the weighted mean bias with respect to the IERS EOP series. Table 3 also gives the weighted rms residual to the daily series IERS C 04 .

Analyses similar to those of Table 3 are provided monthly in the IERS Bulletin B, section 6, distributed in the IGS Reports.

Table 1: Global ITRF94 residuals per solution at epochs 1988.0 and 1993.0

SSC		*Label*	*Positions at 1988.0*				*Positions at 1993.0*			
			N(88)	*WSP* *cm*	*WSU* *cm*	*WSX* *cm*	*N(93)*	*WSP* *cm*	*WSU* *cm*	*WSX* *cm*
(GSFC)	95 R 01	RG	110	0.4	0.8	0.6	109	0.4	0.7	0.6
(JPL)	95 R 01	RJ	8	1.0	3.7	2.1	8	0.8	3.2	1.9
(NOAA)	95 R 01	RN	98	0.5	1.1	0.8	94	0.6	0.9	0.7
(USNO)	95 R 04	RO	68	0.9	1.1	0.7	72	0.3	0.6	0.4
(CODE)	95 P 02	PB	41	1.7	0.8	1.4	55	0.6	0.8	0.7
(EMR)	95 P 02	PE	11	5.3	14.5	8.0	25	2.0	4.7	2.0
(JPL)	95 P 02	PJ	44	1.4	3.5	2.3	45	0.3	0.8	0.5
(CSR)	95 L 01	LC	67	0.9	2.2	1.4	71	0.8	1.2	1.1
(DUT)	95 C 02	CU	78	0.8	1.4	1.0	85	1.0	1.8	1.3
(CSR)	95 D 01	DC	47	6.4	7.0	6.7	47	1.8	2.0	1.8
(GRGS)	95 D 01	DR	42	4.7	4.2	4.7	49	2.8	2.8	2.8
(IGN)	95 D 02	DH	52	7.0	7.3	7.1	52	1.9	2.0	1.9

N:	Number of common points	WSU:	Weighted rms residual
WSP:	2-D Weighted rms residual	WSX:	3-D Weighted rms residual

Table 2: Weighted rms residuals at epoch 1993.0 as result of the `ITRF94_P1`, `P2`, `P3` comparisons

Solution	*N*	*WSP* *cm*	*WSU* *cm*	*WSX* *cm*
Comparison `ITRF94_P1/P2`				
`ITRF94_P1`	80	0.2	0.4	0.3
`ITRF94_P2`	80	0.1	0.3	0.2
Comparison `ITRF94_P1/P3`				
`ITRF94_P1`	46	0.3	0.4	0.3
`ITRF94_P3`	46	0.6	0.8	0.6
Comparison `ITRF94_P2/P3`				
`ITRF94_P1`	46	0.2	0.4	0.3
`ITRF94_P2`	46	0.9	1.2	1.0

Table 3: Agreement of the GPS pole coordinates with the IERS System (dX, dY) and standard deviation (sdev) from EOP(IERS) C 04 over the quarters January – March 1995 (Qt=1) through April – June 1996 (Qt=6).

Analysis Center: CODE Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.20	0.02	0.21	-0.25	0.02	0.20	SSC(IERS) 94 C 02
2	95 P 01	-0.30	0.02	0.24	-0.37	0.02	0.23	SSC(IERS) 94 C 02
3	95 P 01	-0.53	0.02	0.22	-0.24	0.02	0.17	SSC(IERS) 94 C 02
4	95 P 01	-0.43	0.02	0.23	-0.09	0.03	0.25	SSC(IERS) 94 C 02
5	95 P 01	-0.23	0.02	0.17	-0.34	0.02	0.21	SSC(IERS) 94 C 02
6	95 P 01	-0.34	0.02	0.15	-0.45	0.03	0.22	SSC(IERS) 94 C 02

Analysis Center: EMR Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.44	0.03	0.26	0.21	0.04	0.34	SSC(IERS) 94 C 02
2	95 P 01	-0.34	0.03	0.26	-0.10	0.03	0.26	SSC(IERS) 94 C 02
3	95 P 01	-0.36	0.03	0.27	0.13	0.02	0.22	SSC(IERS) 94 C 02
4	95 P 01	-0.29	0.03	0.28	0.35	0.03	0.28	SSC(IERS) 94 C 02
5	95 P 01	-0.47	0.02	0.23	0.28	0.02	0.19	SSC(IERS) 94 C 02
6	95 P 01	-0.50	0.02	0.20	0.55	0.02	0.19	SSC(IERS) 94 C 02

Analysis Center: ESOC Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.04	0.04	0.38	0.41	0.04	0.37	SSC(IERS) 94 C 02
2	95 P 01	-0.10	0.03	0.30	0.73	0.03	0.27	SSC(IERS) 94 C 02
3	95 P 01	-0.15	0.03	0.29	0.58	0.03	0.28	SSC(IERS) 94 C 02
4	95 P 01	-0.05	0.03	0.30	0.52	0.03	0.33	SSC(IERS) 94 C 02
5	95 P 01	-0.08	0.02	0.23	0.04	0.03	0.29	SSC(IERS) 94 C 02
6	95 P 01	-0.31	0.02	0.20	-0.22	0.03	0.23	SSC(IERS) 94 C 02

Analysis Center: GFZ Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.08	0.02	0.24	-0.01	0.02	0.20	SSC(IERS) 94 C 02
2	95 P 01	-0.02	0.02	0.20	-0.05	0.01	0.14	SSC(IERS) 94 C 02
3	95 P 01	-0.12	0.02	0.21	-0.02	0.01	0.14	SSC(IERS) 94 C 02
4	95 P 01	-0.26	0.02	0.18	0.02	0.02	0.18	SSC(IERS) 94 C 02
5	95 P 01	-0.36	0.02	0.23	0.03	0.02	0.20	SSC(IERS) 94 C 02
6	95 P 01	-0.24	0.02	0.17	-0.04	0.02	0.15	SSC(IERS) 94 C 02

Analysis Center: JPL Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.04	0.04	0.32	0.01	0.05	0.47	SSC(IERS) 94 C 02
2	95 P 01	-0.24	0.06	0.50	-0.08	0.05	0.44	SSC(IERS) 94 C 02
3	95 P 01	-0.23	0.13	0.69	-0.09	0.07	0.37	SSC(IERS) 94 C 02
3	95 P 01	-0.17	0.06	0.57	-0.03	0.04	0.35	SSC(IERS) 94 C 02
4	95 P 01	0.17	0.06	0.62	-0.04	0.08	0.72	SSC(IERS) 94 C 02
5	95 P 01	0.01	0.04	0.37	0.13	0.04	0.36	SSC(IERS) 94 C 02
6	95 P 01	0.04	0.05	0.47	0.10	0.04	0.34	SSC(IERS) 94 C 02

Analysis Center: NOAA Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	0.23	0.04	0.35	-0.05	0.04	-0.39	SSC(IERS) 94 C 02
2	95 P 01	-0.13	0.04	0.34	0.02	0.04	-0.41	SSC(IERS) 94 C 02
3	95 P 01	0.00	0.07	0.39	-0.11	0.07	0.39	SSC(IERS) 94 C 02
4	95 P 02	-0.10	0.03	0.31	-0.09	0.04	0.39	SSC(IERS) 94 C 02
5	95 P 02	0.24	0.03	1.33	-0.09	0.04	0.36	SSC(IERS) 94 C 02
6	95 P 02	-0.47	0.04	0.33	-0.27	0.04	0.35	SSC(IERS) 94 C 02

Analysis Center: SIO Unit: 0.001″

Qt	*Series*	*dX*	±	*sdev*	*dY*	±	*sdev*	*Terr. reference*
1	95 P 01	-0.09	0.09	0.80	0.52	0.05	0.51	SSC(IERS) 94 C 02
2	95 P 01	-0.95	0.05	0.45	0.36	0.05	0.51	SSC(IERS) 94 C 02
3	95 P 01	-0.52	0.05	0.46	-0.20	0.05	0.47	SSC(IERS) 94 C 02
4	95 P 01	-0.19	0.08	-0.08	0.07	0.06	0.58	SSC(IERS) 94 C 02
5	95 P 01	-0.46	0.02	0.16	0.02	0.02	0.22	SSC(IERS) 94 C 02
6	95 P 01	-0.52	0.03	0.21	0.17	0.03	0.20	SSC(IERS) 94 C 02

The possibility of small systematic annual errors in the GPS polar motion series cannot be ruled out. Table 4 shows the sine and cosine components of the annual differences of the GPS series of polar motion over 1995 with an SLR solution (CSR) and two VLBI ones (IAA,USNO), described in IERS Technical Note 22 [2].

2.1.2 IERS GPS combined solution of the pole coordinates

Since 1994, a combined solution of the various GPS series referred to as IERS C 04 is performed and is used in our current analyses. Since all series are given at one-day intervals and for the same dates, the procedure of the combination is made by a weighted average of the various series. The weighting reflects the qualities of the series, long-term and short-term stability. Two different approaches are used for that purpose: a pair variance analysis based on the mutual comparisons of the series and secondly comparisons to other reference series. Both give similar results. The relative percentages of the series entering the combination for 1995 are listed in Table 5. Figures 2 and 3 show the plots of the differences of individuals series with IERS 95 P 01 for the two pole components. Table 6 shows the weighted rms agreement of the various series with this combined solution. We can notice that most of the values are smaller than 0.3 mas.

2.1.3 Comparisons between various series

Comparisons of this solution IERS 95 P 01 with various GPS, SLR and VLBI series are performed. Table 7 shows the mean differences and the rms agreements where biases have been removed, of the respective series with this combined GPS solution. USNO 1995 P 01 is the combined GPS solution performed by USNO for these comparisons. Note the fair rms agreement between the various combined GPS solutions (0.10 mas) and between different techniques (0.20 / 0.30 mas).

Table 4: Annual differences of GPS polar motion with VLBI and SLR over 1995, modelled as $a \sin(t - t_0) + b \cos(t - t_0)$, t in years, $t_0 = 1993.0$

Unit : $0.001''$

	X		*Y*		
	a	*b*	*a*	*b*	*Reference*
CODE 95 P 01	0.14	0.13	-0.15	0.25	CSR 95
	0.12	0.17	-0.16	0.21	IAA 95
	0.00	0.17	0.04	0.04	USNO 95
EMR 95 P 01	-0.03	-0.03	-0.22	0.33	CSR 95
	0.06	0.07	-0.20	0.34	IAA 95
	0.06	0.07	0.04	0.04	USNO 95
ESOC 95 P 01	0.01	0.04	-0.06	-0.08	CSR 95
	0.04	0.14	-0.03	-0.09	IAA 95
	0.07	0.08	-0.07	-0.17	USNO 95
GFZ 95 P 01	0.08	0.07	-0.05	0.17	CSR 95
	0.13	-0.14	-0.06	0.08	IAA 95
	0.06	0.06	0.04	0.04	USNO 95
JPL 95 P 01	0.01	-0.02	-0.05	0.12	CSR 95
	0.03	0.02	0.00	0.10	IAA 95
	0.06	0.07	-0.05	-0.01	USNO 95
NOAA 95 P 01	0.21	0.26	0.43	0.18	CSR 95
	0.09	0.21	0.01	0.05	IAA 95
	0.28	0.12	0.22	0.10	USNP 95
SIO 95 P 01	-0.19	0.38	0.33	0.14	CSR 95
	-0.24	0.48	0.28	0.04	IAA 95
	-0.35	0.07	0.26	0.05	USNO 95

Table 5: Percentage over 1995 of the various GPS series contributing to the EOP (IERS) P 01 pole solution

	X-pole	*Y-pole*
CODE	14	14
EMR	12	12
JPL	33	33
GFZ	33	33
ESOC	3	3
NOAA	3	3
SIO	2	3

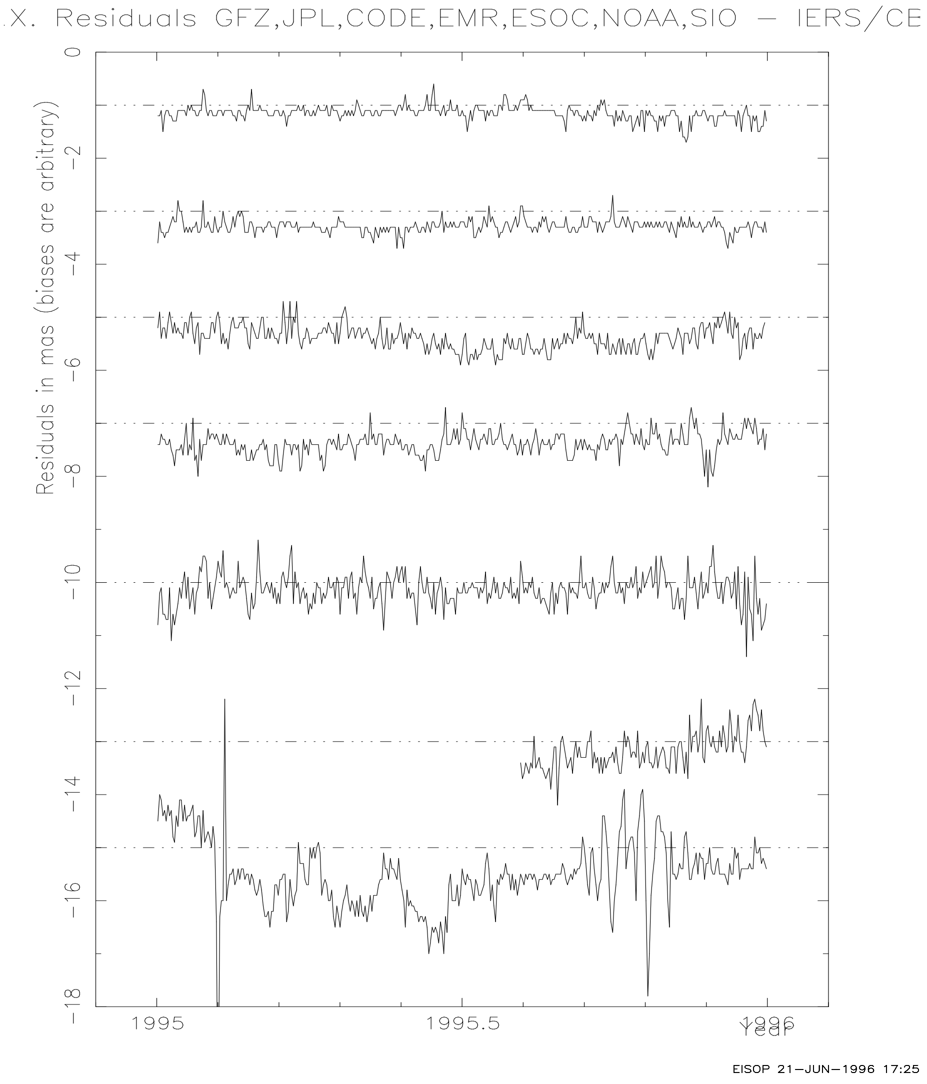

Figure 2: X pole coordinate in 1995. Daily differences of individual GPS series with IERS 95 P 01. Top to bottom: GFZ, JPL, CODE, EMR, ESOC, NOAA, SIO.

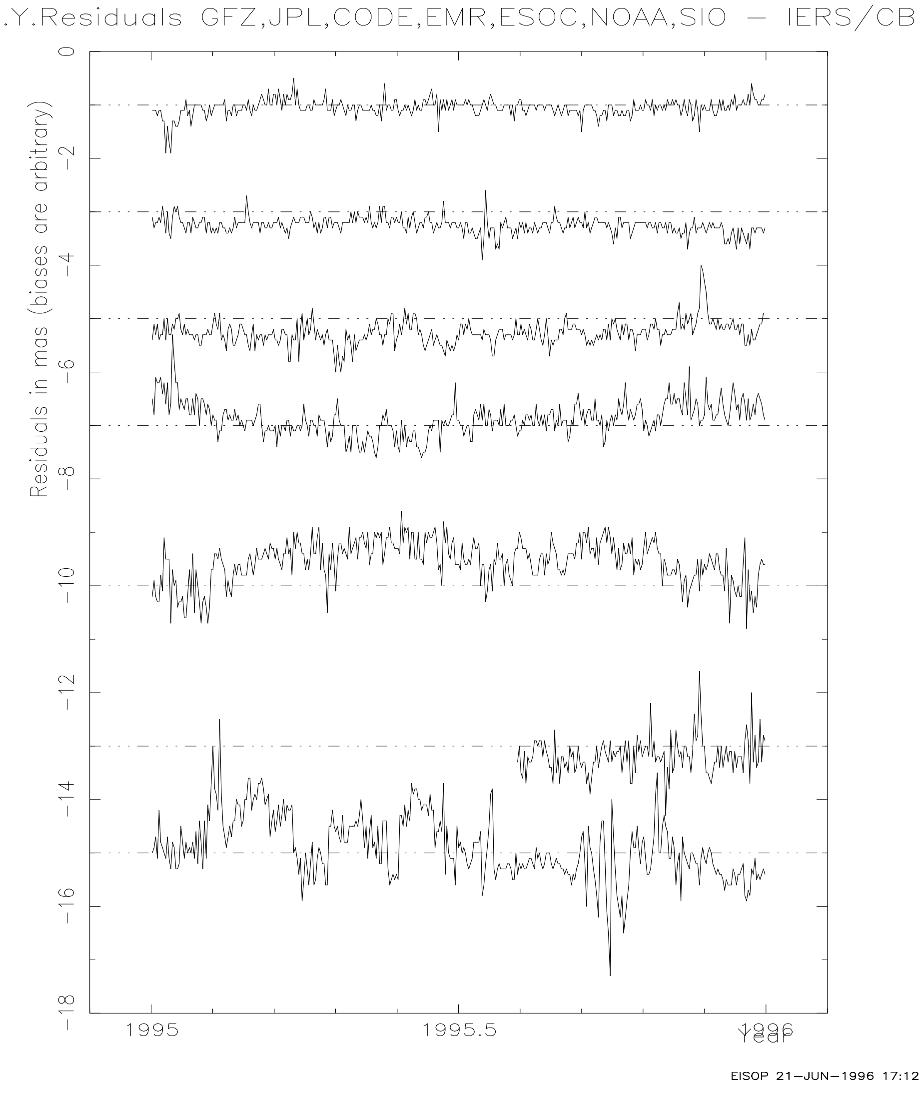

Figure 3: Y pole coordinate in 1995. Daily differences of individual GPS series with IERS 95 P 01. Top to bottom: GFZ, JPL, CODE, EMR, ESOC, NOAA, SIO.

Table 6: Weighted rms agreement of the GPS series to IERS 95 P 01

Center	*X-bias*	*rms*	*Y-bias*	*rms*
	mas	*mas*	*mas*	*mas*
CODE	-.40	.21	-.26	.21
EMR	-.38	.21	.13	.28
JPL	-.28	.12	-.25	.13
GFZ	-.15	.13	-.05	.13
ESOC	-.10	.27	.54	.32
NOAA	-.24	.28	-.20	.32
SIO	-.39	.67	.00	.58

Table 7: Mean differences and the rms agreement of the various solutions to a specified reference

Differences		*X-bias*	*rms*	*Y-bias*	*rms*
		mas	*mas*	*mas*	*mas*
Reference: IERS C 04					
IGS	95 P 01	-.27	.18	-.05	14
IERS	95 P 01	.02	.17	.00	.12
USNO	95 P 01	-.06	.20	-.02	.14
USNO	95 R 04	-.22	.17	-1.55	.13
CSR	95 L 01	-.27	.18	.04	.18
Reference: IERS 95 P 01					
IGS	95 P 01	-.28	.08	-.07	.08
USNO	95 P 01	-.09	.12	-.05	.09
USNO	95 R 04	-.31	.22	-1.60	.20
CSR	95 L 01	-.30	.34	.02	.31
Reference: IGS 95 P 01					
USNO	95 P 01	.21	.09	.02	.09
USNO	95 R 04	-.05	.23	-1.53	.18
CSR	95 L 01	-.02	.34	.08	.31
Reference: USNO 95 P 01					
USNO	95 R 04	-.26	.24	-1.55	.21
CSR	95 L 01	-.24	.35	.07	.31
Reference: CSR 95 L 01					
USNO	95 R 04	-.07	.32	-1.56	.38

2.2 Universal time based on both VLBI and GPS techniques

Due to the difficulty of determining the long-term behaviour of the non-rotating system realized through the orbit orientation, Universal Time UT1 cannot be accurately derived from GPS technique. Still, on time scales limited to a couple of months the high-frequency signal contained in the GPS UT determination can be used for densifying the series obtained by the VLBI technique and also for UT extension from the last available current VLBI estimate.

2.2.1 Combination

Long-term variations of the reference series are merged with the high-frequency signal of the GPS series. For a practical reason, IERS C 04 is here used for reference since it is given at one-day intervals. Three independent series based on CODE, EMR and JPL have been derived, mixed and calibrated to IERS C 04 to give a 'UT1 GPS combined solution', EOP(IERS) 95 P 01. In the processing, a variance analysis performed on the whole interval leads to the weighting of these three series in the combination. The weights take into account the formal uncertainties of the series scaled by an external factor.

The rms agreements between this series and the various series entering or not in the solution are given on Table 8. The uncertainty of the combined solution is about 0.03 ms for a single value which is a slight improvement compared to those of the independent series (about 0.04 ms). A signifiant correlation (about 0.6/0.7) appears between these three residuals series.

Table 8: rms agreement of EOP(IERS) 95 P01 with various UT1 solutions.

Series	*rms agreement (0.0001 s)*
VLBI (USNO) 24h	0.22
VLBI (USNO) 1h	0.28
VLBI (IAA) 24h	0.21
GPS(CODE)	0.23
GPS(EMR)	0.17
GPS((JPL)	0.24
SLR (CSR)	0.61
IERS C 04	0.23
NEOS	0.23
SPACE 95 (JPL)	0.21

2.3 Use of UT1 GPS estimates for near real time applications

Another application of LOD (or UT1 integrated series) derived by GPS is the estimation of Universal Time from the last VLBI estimation. Two questions arise:

1. How does the error of the UT extrapolation based on GPS estimates from the last current VLBI data compare to the usual prediction performed using VLBI data?
2. What is the evolution of the errors with respect to the horizon (1, 2 and 3 weeks in advance)?

A prediction model is used for the long term error of GPS UT1. It is based on a linear term, corrected locally by the re-adjustment of a bias performed over some time span ranging from 50 to 200 days preceeding the last VLBI solution. A series of simulations have been performed over the interval 1995.0–1996.3. Prediction errors are given on Table 9 for the three GPS solutions CODE, EMR and JPL. Comparison is also given in the last column with the performance reached when no adjustment of this model is made. (GPS UT1 estimates are in this case only put at the end of the VLBI UT1 solution).

We can notice that there is only a significant improvement in the case of CODE. A better knowledge is needed concerning the sources of long-term errors of the various GPS UT1 series.

Table 9: rms error out to 1, 2 and 3 weeks, with drift and bias estimated on time spans ranging from 50 to 200 days. The last column gives the rms error with no long-term prediction estimated.

Horizon: 1 week					Unit: 0.0001 s
Series	*50d*	*100d*	*150d*	*200d*	*No Model Estimated*
CODE	2.3	2.1	2.1	1.9	2.5
EMR	1.5	1.5	1.5	1.4	1.2
JPL	1.5	1.4	1.2	1.3	1.3

Horizon: 2 weeks					Unit: 0.0001 s
Series	*50d*	*100d*	*150d*	*200d*	*No Model Estimated*
CODE	3.4	2.9	2.9	2.8	2.5
EMR	2.2	2.2	2.2	2.0	1.7
JPL	3.6	2.8	2.5	2.7	2.6

Horizon: 3 weeks					Unit: 0.0001 s
Series	*50d*	*100d*	*150d*	*200d*	*No Model Estimated*
CODE	4.6	3.4	3.6	3.5	4.7
EMR	2.9	2.6	3.1	2.7	2.4
JPL	4.0	2.5	2.0	2.5	2.2

Note that the average uncertainty is about 0.2 ms over one week for a GPS solution. The degradation of the performance is small over time spans of 2 and 3 weeks (respectively 0.3 and 0.4 ms). These results can be compared to the UT1 predicted values based on VLBI data on the same analysis interval (Table 10).

Table 10: rms errors of the prediction of Universal Time and of GPS errors.

UNIT: 0.0001 s

	1 week	*2 weeks*	*3 weeks*
Pure Prediction	11.5	40.5	72.0
GPS estimates	1.5	2.5	3.0

3 Cross comparison of GPS EOP series and terrestrial frames with the IERS ones

Let us consider two series of EOP, each of which is referred to a terrestrial frame defined by the adopted Set of Station Coordinates (SSC). The expected systematic differences in the pole coordinates $(\Delta x, \Delta y)$ due to the rotations (R_1, R_2 around the G_x and G_y axes) between the two terrestrial frames are given by the relationships: $\Delta x = R_2; \Delta y = R_1$.

When considering two terrestrial frames, each one having its own velocity field, and the corresponding series of EOP, the relative drifts $\Delta x'$, $\Delta y'$ between the series of EOP can be predicted by: $\Delta x' = R_2'; \Delta y' = R_1'$, where R_1', R_2', are the rates of change of the rotation angles between the two terrestrial reference frames. These relationships are used to compare the biases and drifts of the GPS EOP series relative to EOP(IERS) C 01 with their predicted values derived from the rotation angles and their rates of change relative to ITRF94.

Table 11 gives the comparisons in biases, and Table 12 gives the comparisons in rates for data available for the 1994 IERS Annual Report (while section 2 used the 1995 operational series). The inconsistencies found in line 3 are partially due to the inconsistency that is known to exist between ITRF94 and the EOP(IERS) C 01. The closures given on lines 4 are corrected for this effect and therefore represent the part that can be atributed to the GPS results.

Table 11: Consistency of series of EOP and reference frames. The data span and the epoch are given. Unit : 0.001″

Series	1:	R_2	R_1
	2:	Δx	Δy
	3,4:	$C(x)$	$C(y)$
EOP(CODE) 95 P 02 1992–94 1993.00	1	-0.41 ±0.42	4.04 ±0.44
	2	-0.54 ±0.11	4.46 ±0.15
	3	-0.13 ±0.43	0.42 ±0.47
	4	-0.10 ±0.51	-0.40 ±0.55
EOP(EMR) 95 P 02 1994 1993.00	1	-0.23 ±0.23	-0.69 ±0.24
	2	-0.12 ±0.18	-0.87 ±0.22
	3	0.11 ±0.29	-0.18 ±0.33
	4	0.14 ±0.40	-1.00 ±0.44
EOP(GFZ) 95 P 02 1993–94 1994.00	1	-0.54 ±0.13	-0.92 ±0.13
	2	-0.28 ±0.05	0.07 ±0.05
	3	0.26 ±0.14	0.99 ±0.14
	4	0.29 ±0.32	0.17 ±0.32
EOP(JPL) 95 P 02 1993-94 1993.00	1	-0.12 ±0.20	-0.62 ±0.23
	2	0.15 ±0.04	0.19 ±0.04
	3	0.27 ±0.20	0.81 ±0.23
	4	0.30 ±0.35	-0.01 ±0.37

Note on the line contents:

1	R1, R2, R3 : terrestrial frames rotation angles wrt SSC(IERS) 95 C 01 (ITRF94)
2	Biases at epoch derived from the comparison of the series of EOP with EOP(IERS) C 01 over the listed data span.
3	Closure error : difference of line 2 with line 1.
4	Closure error corrected for an estimated inconsistency of the IERS results (1995 IERS Annual Report, Table II-2, p.II-17).

Table 12: Consistency of rates of change in series of EOP and in terrestrial reference frames. The data span of the EOP series is given. Unit : $0.001''/a$.

Series	1:	R'_2	R'_1
	2:	$\Delta x'$	$\Delta y'$
	3,4:	$C(x)$	$C(y)$
EOP(CODE) 95 P 02 1992-94	1	-0.22 ±0.12	-0.12 ±0.14
	2	0.05 ±0.09	0.16 ±0.12
	3	0.27 ±0.15	0.27 ±0.18
	4	0.17 ±0.17	0.17 ±0.19
EOP(EMR) 95 P 02 1994	1	-0.32 ±0.32	-0.05 ±0.38
	2	-0.03 ±0.12	0.46 ±0.15
	3	0.29 ±0.34	0.51 ±0.40
	4	0.19 ±0.34	0.41 ±0.40
EOP(JPL) 95 P 02 1993-94	1	-0.18 ±0.34	-0.08 ±0.34
	2	-0.04 ±0.04	0.23 ±0.04
	3	0.14 ±0.34	0.31 ±0.34
	4	0.04 ±0.34	0.21 ±0.34

Note on the line contents:

1 Terrestrial frames rotation rates wrt the SSC(IERS) 95C 01 (ITRF94) velocity field.

2 Rates of the series of EOP wrt EOP(IERS) C 01 over the data span listed.

3 Closure error: difference of line 2 with line 1.

4 Closure error corrected for an estimated inconsistency of the IERS results (1995 IERS Annual Report, Table II-2, p.II-17).

Electronic Access

IERS Central Bureau

E-mail address:	`iers@obspm.fr`
World Wide Web (via FTP):	`ftp://hpvlbi.obspm.fr/iers/ierscb.html`

Earth Rotation and Celestial Frame

Anonymous FTP:	`hpvlbi.obspm.fr` (145.238.100.7) directories `iers/eop` and `iers/icrf` respectively.
World Wide Web (via FTP):	`ftp://hpvlbi.obspm.fr/iers/ierscb.html`

Terrestrial Frame

E-mail address:	`boucher@ign.fr`
Anonymous FTP:	`schubert.ign.fr` (192.33.147.230), directory `/itrf`
World Wide Web:	`http://schubert.ign.fr/CIAG/index.CIAG.html`

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IGS Analysis Coordinator Report

J. Kouba and Y. Mireault

Geodetic Survey Division
Geomatics Canada, Natural Resources of Canada (NRCan, formerly EMR)
615 Booth Street, Ottawa, Canada, K1A OE9
e-mail: `kouba@geod.emr.ca`

1 Introduction

The 1995 IGS Analysis Center workshop held in Potsdam, May 15–18, 1995 [1], provided an opportunity for discussions amongst the IGS Analysis Centers (ACs). It also gave an opportunity to review IGS orbit clock combination/evaluation. Based on the workshop recommendations, starting on May 28, 1995, the IGS rapid orbit/clock combination has been produced directly in ITRF93 rather than adopting the *IERS Bulletin A* reference pole direction. Furthermore the production delay was reduced to 11 from 15 days. The new combination scheme has also produced an IGS Polar Motion (PM) series designated `EOP(IGS)95 P 01` which had a major impact on the IERS PM products. It has detected short period (2–10 days) atmospheric effects on PM which were smoothed out in both IERS EOP series (Bulletins A and B). Subsequently, both IERS EOP series adopted much weaker smoothing schemes to monitor this important atmospheric signal.

Starting January 1, 1996 a new IGS (preliminary) orbit/clock combination was initiated with the participation of six ACs and a much shorter production delay of less than 38 h. The preliminary combinations have provided good results despite initial difficulties, such as data delays and Internet problems. The second AC workshop held in Silver Spring MD, March 19–21, 1996, produced many recommendations for improving IGS product precision and reliability, and pointed out opportunities for new IGS products and applications [2].

This report is an attempt to summarize activities, cooperation and significant effort exerted by all ACs during 1995 and the beginning of 1996.

2 1995 IGS Operational Analyses

The improved set of the 13 station ITRF93 positions and velocities (Table 8 in [3]) has been fixed or tightly constrained in all AC solutions since January 1,

1995. During 1995 all ACs have continued to improve and enhance their analyses while maintaining timely processing and product generation. Significant precision improvements, realized by all ACs in 1995 are mainly due to processing improvements and establishment of IGS stations in remote areas. Some of the processing enhancements include: a new satellite yaw attitude model [4], an extended orbit modeling [5], [6], sub-daily tidal polar motion (PM) effects (e.g. [7]), ambiguity fixing for some parts of the networks.

The new satellite yaw attitude model developed by [4], together with the implicit right-hand-polarization phase correction and the new biased (0.5 deg/s) yaw rate scheme adopted by the GPS operational center on November 17, 1995, significantly improve observation modeling for the eclipsing satellites in particular. Most ACs adopted this model, at least for the observation modeling. The complete adaptation includes the observation model, yaw rate estimation and introduction of the yaw rates in orbit integrations. As a result of the new biased attitude rate scheme the yaw rates have become more stable and predictable than before. Since then, with some precaution, *a priori* rates, based on past estimation can be used [4]. *A priori* rates based on past estimates have been made available by JPL (node `sideshow.jpl.nasa.gov` in anonymous FTP directory `pub/GPS_yaw_attitude`) and used by some ACs (e.g., EMR).

The extended orbit modeling is designed to mitigate deficiencies specific to GPS, mainly related to the estimation of radiation pressure (Rp) and other parameters. It may include stochastic Rp modeling, once-per-revolution stochastic satellite velocity impulses and/or a periodic (with an orbit period) modeling of direct Rp scales and y biases. Since late 1994, JPL has implemented a new stochastic Rp modeling. CODE followed in July 1995 by extending a stochastic satellite velocity estimation from eclipsing to all satellites. In October 1995, SIO implemented a once-per-revolution Rp estimation. The main effect of these enhancements is the elimination of a small shift ($\approx$ 5 cm) in the y-coordinate of constrained orbits and even larger origin offsets for unconstrained station solutions. This is why one of the 1996 AC workshop recommendations asks the remaining ACs to make every effort to align their coordinate solution origin with the ITRF [8]. The improved orbit modeling also resulted in better statistics in the IGS long-arc analysis (Appendix A) and GPS-SLR comparisons [9].

Sub-daily tidal effects on EOP should average out provided that data spans used are multiples of 24 h, though as pointed out by Herring [10], biases at the 0.1-mas level may remain due to parameter aliasing in rather complex, global GPS analyses. However, the sub-daily tidal effects significantly degrade EOP rate estimation even for 24 h data spans. To achieve the highest EOP and solution precision, it was recommended by the 1996 AC workshop that all ACs implement sub-daily PM at all processing stages, including the orbit rotation, by July 1, 1996. Currently three ACs (JPL, NGS, SIO) already employ the sub-daily PM at the observation level, to maintain compatibility, submit orbit and EOP solutions corresponding to mean daily PM (i.e., tidal sub-daily effects excluded).

In the second half of 1995 both SIO and CODE have significantly increased the number of stations, and also started to resolve initial phase ambiguities further increasing precision. This is quite an achievement since ambiguity resolution in global, fully automated solutions adds additional complexity and risks the possibility of erroneous initial cycle resolutions, especially for very long baselines.

The significant precision improvements realized by all ACs during 1995 can be seen when comparing the summaries of the IGS Final combination for December 1994 and 1995 (see Tables 1 and 2). The significant increase in the number of stations used and the corresponding decrease of orbit RMS are seen in Table 2. Similar improvements can be observed for the rotation parameter (i.e., PM) rms. Also seen in Table 2 is the 5-cm *y*-coordinate origin shift, discussed above, when the properly aligned solutions (COD, JPL, SIO) are compared to the rest. For complete statistics and AC performance during 1995, see Appendix A.

Table 1: Statistics for IGS Final orbit/clock combination in December 1994. Start: 94 Dec 4 / wk778; end: 94 Dec 31 / wk781; WRMS, LaRMS, RMSc are the weighted orbit, long arc and clock rms, respectively.

CEN	STA	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	LaRMS	RMSc	Days
		m	m	m	mas	mas	ppb	cm	cm	cm	ns		
COD	47	0.00	0.01	0.01	-0.15	-0.03	0.03	0.0	11	10	12	3555.4	28
		0.01	0.01	0.01	0.47	0.34	0.28	0.1					
EMR	22	0.01	-0.01	-0.04	-0.09	0.11	0.13	-0.1	12	12	17	0.9	28
		0.01	0.01	0.01	0.33	0.36	0.14	0.1					
ESA	23	0.00	-0.01	-0.02	0.05	-0.18	-0.13	0.1	19	16	18	27.2	28
		0.01	0.01	0.02	0.68	0.51	0.34	0.2					
GFZ	38	-0.04	-0.01	0.00	-0.49	0.25	-0.41	-0.3	11	10	16	6.3	28
		0.01	0.01	0.01	0.26	0.23	0.18	0.1					
JPL	32	0.01	0.03	0.00	-0.31	-0.30	-0.02	0.1	10	10	13	0.8	28
		0.01	0.01	0.01	0.33	0.31	0.15	0.1					
NGS	33	0.03	-0.02	-0.02	-0.77	0.74	0.80	1.1	24	23	24	2730.7	28
		0.02	0.01	0.02	0.52	0.44	0.37	0.3					
SIO	32	0.01	-0.04	0.09	-0.81	0.69	0.14	-0.1	21	19	21	0.0	28
		0.02	0.01	0.05	0.53	0.50	0.19	0.2					

For more information on the individual AC processing approaches see the `*center*.acn` files available via anonymous FTP (`igscb.jpl.nasa.gov`) or WWW (`http://igscb.jpl.nasa.gov/`) from the IGS Central Bureau Information System (CBIS) [11] as `center/analysis/*center*.acn` .

All but one AC prepared and submitted a detailed analysis questionnaire summarizing in a standard form their processing strategy.

Although, as reported in the IGS 1994 Annual Report, most ACs were ready or were producing unconstrained station coordinate solutions, considerable effort was devoted to the development, testing and implementation of a common exchange format to facilitate efficient exchange of station solution exchange. A new, Solution INdependent EXchange (SINEX) format has been developed with the active participation of all ACs in preparation for the ITRF Densification Pilot Project which was launched on September 3, 1995 [12]. By the end of 1995 all ACs and three Global Network Associate Analysis Centers (GNAAC)

Table 2: Statistics for IGS Final orbit/clock combination in December 1995. Start: 95 Dec 03 / wk830; end: 95 Dec 30 / wk833; WRMS, LaRMS, RMSc are weighted orbit, the long arc and clock rms, respectively.

CEN	STA	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	LaRMS	RMSc	Days
		m	m	m	mas	mas	ppb	cm	cm	cm	ns		
COD	61	0.00	0.02	0.00	-0.19	0.05	-0.25	0.1	8	6	11	2.0	28
		0.01	0.01	0.01	0.13	0.20	0.21	0.1					
EMR	26	0.00	-0.03	-0.01	0.31	0.09	0.11	-0.1	11	11	15	1.0	28
		0.01	0.01	0.01	0.25	0.23	0.17	0.1					
ESA	44	0.01	-0.03	-0.04	0.13	0.03	0.17	0.1	16	14	18	5.0	28
		0.01	0.01	0.01	0.41	0.43	0.31	0.1					
GFZ	43	-0.03	-0.02	0.00	-0.03	0.11	-0.18	-0.4	13	12	17	5.6	28
		0.01	0.01	0.01	0.21	0.24	0.30	0.2					
JPL	37	0.01	0.03	0.00	-0.43	0.03	0.10	0.2	9	9	11	1.0	28
		0.01	0.01	0.01	0.19	0.26	0.15	0.1					
NGS	44	0.02	-0.03	0.02	-0.09	0.60	0.19	-0.1	14	14	18	3684.7	28
		0.01	0.01	0.01	0.30	0.32	0.22	0.1					
SIO	103	-0.01	0.03	0.02	-0.46	0.03	0.10	0.2	10	9	15	0.0	28
		0.01	0.01	0.01	0.23	0.26	0.24	0.1					

were submitting and producing weekly SINEX solutions. For more on the SINEX and the related developments see a separate report in this volume [13].

To supplement the winter tropospheric delay comparisons [14] ACs were asked to submit their total tropospheric delay solutions for three summer weeks (GPS weeks 812–814, July 30–August 19, 1995). All ACs submitted their tropospheric delay solutions to GFZ which agreed to complete the comparisons. The comparison results were reported at the 1996 AC workshop [1] showing rms agreement better than 5 mm.

3 1995 IGS Orbit/clock Combination

The 1995 IGS combined products are referred to ITRF93 as realized by the 13 ITRF93 station position and velocities (Table 8 in [3]). Complete summary of the IGS combination and evaluations is compiled in Appendix A. Three significant changes were introduced as a result of consultations and recommendations by all ACs. Namely, since May 28, 1995 (GPS week 0803), the IGS Rapid (IGR) orbits/clocks are no longer aligned to the IERS Bulletin A, but are directly combined in the ITRF93. Secondly, the IGR submission deadline of 14 days has been reduced to 10 days. The last addition includes a new orbit/clock evaluation by means of navigation position solutions which use precise orbits and corresponding clock solutions. The IGS combined and best individual AC orbit/clock solutions show navigation precision better than 0.5 m and 1 m for horizontal and vertical positions, respectively. The IGS combinations are consistently more reliable than the AC solutions with the most navigation position epochs as shown in the Appendix B.

The individual AC RY, RX rotations with respect to the IGS Final orbits, after accounting for the IERS(EOP)-ITRF93 alignment, should correspond to the PM differences with respect to the IERS Bulletin B, assuming error-free orbits, the same weighting and proper EOP and orbit correspondence. Table 3 lists statistics (means and sigmas of daily solutions) for the pole rotations based on the IGS Final orbits (Appendix A, Table 11) and the IERS EOP combinations during 1995. The differences for some ACs are likely due to a lack of consistency (at certain times) between the AC orbit and EOP solutions. Nevertheless the agreement in Table 3 is quite good and slightly better than in 1994 (see Table 7 in [3]).

Table 3: IGS Final Orbits and IERS (Bulletin B) pole differences for AC solutions during 1995. (corrected for the IERS-ITRF93 misalignment; units: mas)

Center	IGS Final Orbits				IERS (Bull. B)				Difference (IGS-IERS)			
	PMx	sig	PMy	sig	PMx	sig	PMy	sig	PMx	sig	PMy	sig
CODE	-.05	.29	-.39	.24	-.04	.31	-.35	.29	-.01		-.04	
EMR	-.06	.31	-.03	.38	-.04	.37	.04	.40	-.02		-.07	
ESA	.14	.41	.29	.42	.20	.43	.37	.42	-.06		-.08	
GFZ	.11	.25	-.21	.20	.18	.32	-.14	.26	-.07		-.07	
JPL	.04	.28	-.49	.25	.05	.31	-.34	.26	-.01		-.15	
NGS	.28	.41	-.31	.38	.25	.46	-.20	.43	.03		-.11	
SIO	-.15	.65	.04	.61	-.17	.70	.03	.63	.02		.01	
MEAN	.04	.05	-.16	.10	.06	.06	-.08	.10	-.02	.01	-.07	.02
IGR (EOP(IGS)95P01)					.05	.29	-.14	.22				

Since Jan 1, 1995 a new IGS EOP series (EOP(IGS)95 P 01), consistent with the new IGR orbits has been produced as a weighted average of AC PM solutions by applying the orbit weights while preserving the Bulletin A UT1-UTC values. For completeness the new IGR EOP series which is oriented to ITRF93 is also shown at the end of Table 3 to demonstrate that IGR and the IGS Final orbit combinations are consistent and compatible. Table 4 is a similar compilation of EOP/orbit orientation consistency for IGR orbits PM series. Table 3 could show an average bias between orbit and AC PM solutions whereas Table 4 can show only relative consistency with respect to the means.

In Table 3 the sigmas of about 0.2 to 0.3 mas for both orbit orientation and PM differences are mostly due to the Bulletin B smoothing of the short period atmospheric PM recently identified by Eubanks [15]. The Table 4 sigmas represents individual AC PM precision. The IGR PM accuracy is estimated to be about 0.1 mas (IGSMAIL #1072). For more details on IGR combined and individual AC PM solution comparisons see [16].

4 1996 IGS Products and Possible Future Improvements

The ITRF93 station coordinates still showed some inconsistencies of up to a few cm. The ITRF94 station coordinates and velocities have been improved and realigned with the NNR-NUVEL1A geophysical plate motion model which serves as a datum for ITRF time evolution [17]. This makes ITRF94 aligned

Table 4: IGS Rapid Orbits and IGR (EOP(IGS)P5P01) PM differences for AC solutions during 1995. (units: mas)

Center	IGS Rapid Orbits				IGR (IGS 95 P01)				Difference (IGS-IGR)			
	PMx	sig	PMy	sig	PMx	sig	PMy	sig	PMx	sig	PMy	sig
CODE	-.08	.17	-.17	.18	-.09	.18	-.20	.21	.01		.04	
EMR	-.09	.19	.19	.28	-.10	.21	.19	.30	.01		.00	
ESA	.11	.30	.50	.40	.14	.28	.52	.38	-.03		-.02	
GFZ	.08	.16	.01	.14	.13	.17	.01	.16	-.05		.00	
JPL	.01	.14	-.27	.14	.00	.14	-.19	.14	.01		-.08	
NGS	.24	.27	-.10	.31	.20	.33	-.05	.35	.04		-.05	
SIO	-.23	.82	.32	.67	-.22	.55	.17	.55	-.01		.15	
MEAN	.01	.05	.07	.10	.01	.06	.06	.10	.00	.01	.01	.02

closer to the old ITRF92 and slightly misaligned and drifting with respect to the IERS EOP series, requiring ITRF94-IERS alignment whenever ITRF94 and IERS EOP are used for high precision work. At the 1996 AC workshop it was recommended and agreed that the improved ITRF94 is to be adopted by IGS as of June 30, 1996 (Wk 860).

The introduction of ITRF94 will result in small discontinuities in all the IGS series on June 30, 1996, which will be insignificant for most applications. However, precise geodynamical studies require continuous and consistent series over many years. Since IGS is using the same 13 constraining sites, it is possible to determine the relationship between the 1994, 1995/6 and the future IGS products and the AC solutions more accurately than the nominal values given in the IERS 1994 Annual Report. The expected ITRF93-ITRF94 changes at 1996.5 are listed in Table 5. For the changes at 1995.0 see Table 9 in [3]. The ITRF93-ITRF94 changes in Table 5 are to a large extent the same as ITRF93-ITRF92 since ITRF94 realigns ITRF back to a NNR reference frame which is consistent with ITRF92 and the previous ITRF realizations. Table 5 values are based on a 7-parameter transformation using the 13 station position/velocity sets of ITRF93 and ITRF94, weighted according to respective ITRF sigmas.

Table 5: Expected discontinuities in IGS product series (orbits, EOP, station coordinates (SSC)) at 1996.50 (IGS(ITRF93)-IGS(ITRF94))

PRODUCTS	T1(cm)	T2(cm)	T3(cm)	D(ppb)	RX(mas) (PMy)	RY(mas) (PMx)	RZ(mas)
IGS & AC orb,							
EOP,SSC	-2.10	-.10	.10	-.20	-1.27	-.87	-.54
Sigma	.10	.10	.10	.20	.05	.04	.05
Rates per year	-.27	.00	.20	-.09	-.13	-.20	.04

Since individual ACs may be constraining more stations, using different station distribution, data weighting, etc., the actual changes will vary slightly from AC to AC. Some ACs may estimate better offsets for their solution after June 30, 1996. The rates for RX, RY, and RZ in Table 5 are consistent with the differences between NNR NUVEL1A and ITRF93 ([18], p. 17) and can be used to maintain the past and future time evolution of the IGS products, or to transform the 1995/6 ITRF93 based IGS products to the NNR reference frame.

In order to meet the demand for faster delivery of IGS combination products, a new IGS "Super Rapid" Preliminary combination with a delay of only 38 h was initiated. Since January 1, 1996, up to six ACs (COD, EMR, ESA, GFZ, JPL, SIO) have been providing input for the IGS Preliminary (IGP) orbit/clock computations. Despite the initial difficulties caused by delays and Internet problems, the IGP results have exceeded all expectations. For most ACs, delays in data availability from remote stations providing required station geometry determine solution precision. A new, less rigorous testing and evaluation had to be adopted to speed up processing. For example, ACs are required to deposit their solution directly into an IGS combination directory, and can resubmit, without any notice up to the delivery deadline (currently 36 h after the last observation). No IGP reprocessing, or long arc evaluation is performed. AC preliminary solutions differ significantly from the input into the IGS Rapid or Final orbit/clock combinations, mainly due to missing stations, and for some ACs also different processing. Typically individual AC preliminary solutions are submitted within 24 h and have rms orbit precision of about 10–20 cm. Nevertheless, the IGP combined orbit/clock and PM precision is approaching the IGS Rapid/Final product precision level. This is also apparent from Table 6 where IGP combination results are summarized for the first four months of 1996. Also included in Table 6 (as well as in all daily IGP combination summaries) are the broadcast (BRD) orbits in order to evaluate BRD orbit precision and consistency with respect to ITRF. As one can see, BRD reference frame (WGS84) is now compatible with ITRF. The BRD orbit rms, not shown in Table 6 but included in the daily IGP summaries, are typically at the 2- to 3 meter level.

The IGP combined orbits/clocks are also included, in the weekly statistics of the IGS Rapid combination summary reports in order to evaluate IGP precision and reliability. As seen in Appendix A, the IGP combined orbits/clocks typically show precision better than most ACs (at or below 10 cm/ 1 ns rms).

Based on this initial performance and as recommended by the 1996 AC workshop, on June 30, 1996, the IGP will be produced within 24 h and will replace the IGS Rapid (IGR) combination. The current IGR will become the IGS Final combination.

IGS orbit/clock combination precision and reliability is achieved most efficiently by improved AC orbit/clock solutions. The next significant impact on orbit/clock precision and reliability, yet to be fully realized, is likely to come from the ITRF Densification pilot project [19], [12], [13] which has been combining weekly station coordinate solutions from all ACs since Fall, 1995. Although 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. Future improvements may also be realized by including GPS data from low Earth orbit satellites with GPS receivers in IGS global solutions. For additional improvements suggestions and a complete set of recommendations see the 1996 AC workshop proceedings [2].

Table 6: IGS Preliminary Combination statistics. The broadcast orbits (BRD) are included for comparison. (Start: 96 Jan 7 / wk835; end: 96 Apr 27 / wk850

CEN	STA	DX m	DY m	DZ m	RX mas	RY mas	RZ mas	SCL ppb	Days
BRD	0	0.04	0.04	-0.02	0.93	0.87	7.43	5.8	112
		0.11	0.10	0.32	2.26	3.12	5.26	3.6	
COD	46	-0.01	0.01	-0.01	-0.15	0.17	-0.28	0.3	110
		0.02	0.02	0.02	0.57	0.58	0.44	0.9	
EMR	18	0.00	-0.02	0.00	0.21	-0.25	0.33	-0.2	107
		0.01	0.02	0.02	0.46	0.51	0.54	0.3	
ESA	46	0.02	0.00	-0.01	-0.11	0.20	-0.20	0.1	88
		0.02	0.01	0.02	0.48	0.51	0.38	0.4	
GFZ	35	0.00	-0.03	0.00	-0.04	0.23	-0.16	-0.3	87
		0.01	0.02	0.01	0.36	0.33	1.35	0.3	
JPL	18	0.00	0.03	0.00	0.02	0.12	0.31	0.1	96
		0.01	0.02	0.01	0.38	0.33	0.30	0.2	
SIO	25	-0.01	0.02	0.01	0.55	-0.16	-0.20	0.1	104
		0.01	0.02	0.02	1.63	2.35	0.59	0.4	

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A 1995 IGS Orbit, Clock and EOP Combinations and their Evaluation

A.1 Abstract

Seven IGS Analysis Centers (ACs) are currently contributing to the IGS official GPS satellite orbit and clock products. All AC orbit and clock solutions are evaluated and combined weekly within one day of the last AC submission but no later than 11 days after the last observation. This combination is referred to as the IGS Rapid orbit/clock combination. Before GPS week 803, the IGS Rapid orbit combination was based on the current IERS Rapid Service (Bulletin A) Earth Orientation Parameters (EOP). Starting with GPS week 803, the IGS Rapid orbit combination is performed directly in the ITRF reference frame. Since then the IGS mean EOP, obtained as a weighted average of all available AC EOPs, are also generated as part of the IGS Rapid combination. 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. Orbit, clock, and EOP products are summarized and made available through the IGS electronic data/mail distribution. Both satellite orbit and clock solutions are combined by means of a weighted average after proper alignments (when applicable). The best AC orbit solutions are consistent within 5–15 cm (coordinate RMS) as obtained from a week long-arc fit to daily

orbits for each AC. Combinations of best satellite clock solutions show sub-ns consistency even with Anti-Spoofing (AS). The IGS mean EOP series agrees very well with the Bulletin A. A new IGS 'super' rapid preliminary combination, designated as IGP and available within 38 hours after the last observation, has been generated since Jan. 1, 1996. Six ACs contribute regularly to IGP orbit and clock combination which show agreement with the IGS Rapid orbits and clocks at the 10-cm and 1-ns level, respectively.

A.2 Introduction

Since 1994, seven ACs contributed daily solutions to the IGS orbit/clock combination. The contributing ACs are listed in Table 7. Two IGS orbit/clock combinations are routinely produced: the IGS Rapid orbit/clock combination within one day after the last AC submission but no later than 11 days after the last observation, and the IGS Final orbit/clock combination produced about two months after the last observation. The IGS Rapid and Final orbit/clock combinations and their evaluation are performed on a weekly cycle.

Table 7: IGS Analysis Centers Contributing since 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 Spring MD, USA
sio	Scripps Institution of Oceanography La Jolla, USA

This Appendix will briefly review the combination/evaluation procedures. It will describe changes implemented during 1995 and will present the 1995 IGS Rapid and Final combination results. New IGS preliminary orbit, clock, and EOP combination products introduced in January 1996 are also discussed.

A.3 Orbit and Clock Evaluations

The long-arc orbit evaluation was implemented to detect problems that could affect the daily weighted average combinations and to assess the consistency of individual AC solutions including IGS combined orbits over a one-week period. Ephemerides are analyzed for individual ACs independently from the combination process. The long-arc orbit evaluation is described in the IGS 1994 Annual Report [3]. Long-arc RMS are presented in Figure 11.

Starting with GPS week 834 (Dec 31, 1995), the IGS combined Rapid orbits/clocks including all AC solutions which contain both the orbit and clock data are further evaluated by an independent single point positioning program (navigation mode) developed at NRCan. This is done to assess clock solution precision and orbit/clock consistency. Data from three stations are used daily, and the corresponding position RMS are summarized in Tables 4 and 5 of the weekly IGS Rapid combination summary file (`igs`*wwwwd*`.sum` where *wwww* is the GPS week number and *d* (0–6) is the day of the week). This evaluation is not performed for the IGS Final combination since the RMS values are virtually the same unless ACs submit new orbit/clock solutions which rarely happens. The three stations are Brussels in Belgium (BRUS), Usuda in Japan (USUD) and Williams Lake in Canada (WILL). Table 8 summarizes the point positioning results obtained from the IGS Rapid combination for GPS weeks 834 to 847 (Dec. 31, 1995 to Apr. 6, 1996). Figures 1 and 2 show the 1996 daily 3D point positioning RMS series for all ACs included in Table 8. For completeness, an example of Tables 4 and 5 of the IGS Rapid summary report is presented in Appendix B.

Table 8: 1996 IGS Rapid combination point positioning RMS (navigation mode) for ACs providing orbit/clock solutions.

AC	BRUS				USUD				WILL			
	Lat	*Lon*	*Ht*	*3D*	*Lat*	*Lon*	*Ht*	*3D*	*Lat*	*Lon*	*Ht*	*3D*
COD	57	38	95	68	52	37	101	69	46	33	78	56
EMR	43	31	75	53	35	27	71	48	35	19	52	38
ESA	211	118	381	261	181	113	332	228	188	107	236	185
GFZ	171	106	311	213	170	94	302	207	139	83	199	163
IGP	58	38	90	66	40	31	79	54	38	22	58	42
IGS	47	32	79	56	40	29	78	53	35	20	55	39
JPL	40	29	70	49	34	24	66	45	33	18	48	35

Period covered: GPS weeks 834-847 (Dec.31/1995-Apr.6/1996)
Units: centimeters (cm).
RMS > 999 cm were excluded from the RMS computations.

Figure 1: Rapid Combination—1996 Daily 3D Point Positioning RMS (navigation mode) for COD, EMR, ESA and GFZ.

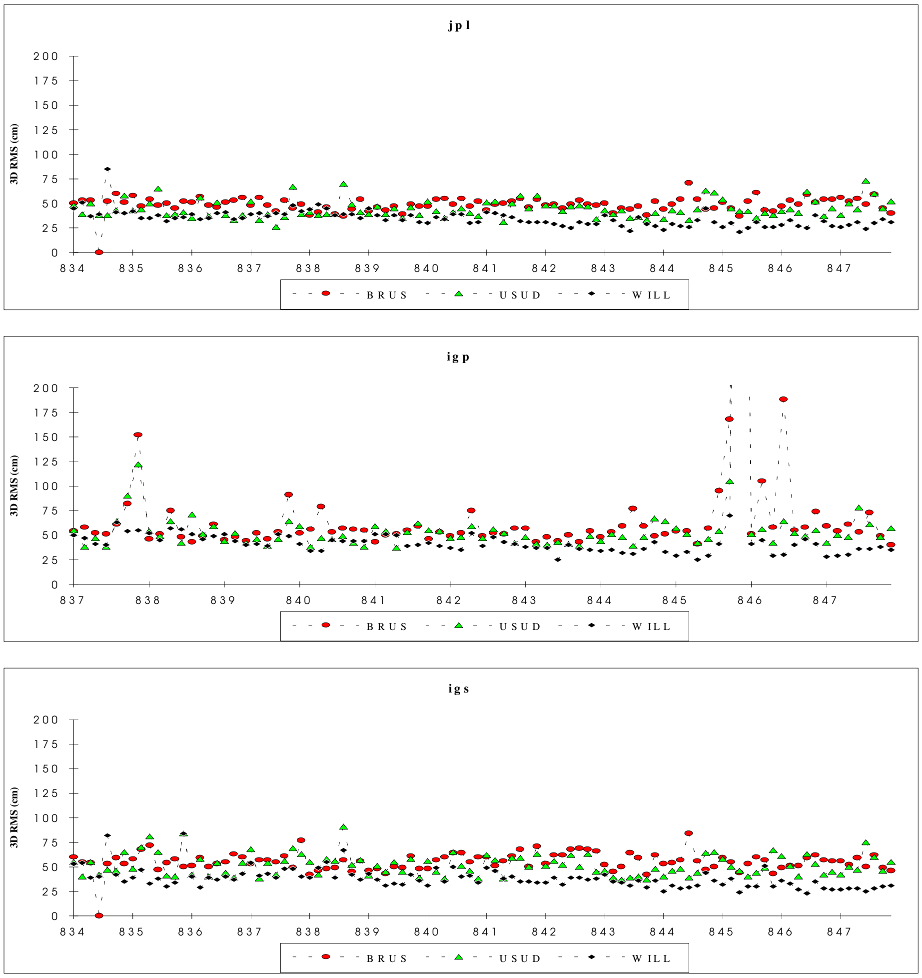


Figure 2: Rapid Combination—1996 Daily 3D Point Positioning RMS (navigation mode) for JPL, IGP and IGS.

A.4 IGS Orbit, Clock and EOP Combinations by Weighted Average

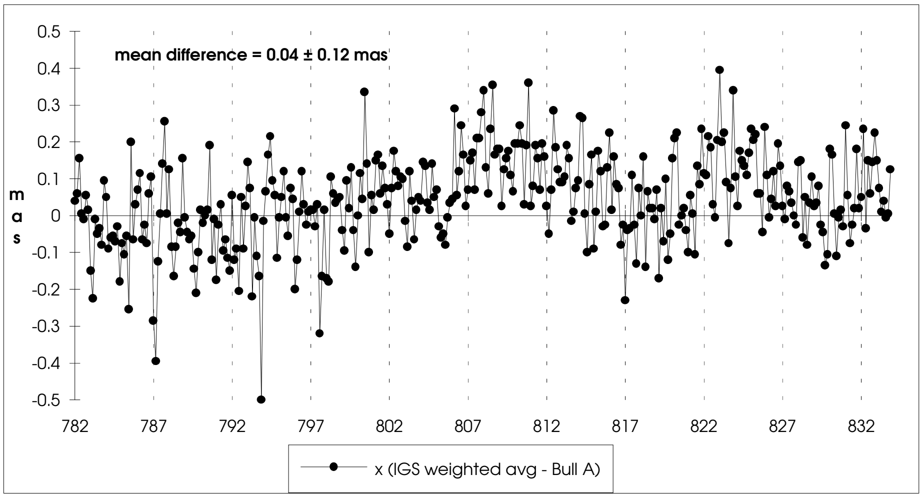
A.4.1 Method Description

The orbit combination is performed using all AC submissions for a given day. For the Final combination, each AC's ephemerides are first rotated to establish a common orientation by applying the difference between its associated x and y pole coordinate solutions and the reference Bulletin B EOP series. For the Rapid combination and prior to GPS week 803 (May 28, 1995), the same strategy was used but using the most recent IERS Bulletin A pole coordinates for the Pole reference. These small rotations are necessary to account for possible systematic pole offsets between individual AC solution and to make the IGS combined orbits compatible for the IERS EOP. Bulletin A and Bulletin B pole values are corrected with the ITRF93 inconsistency parameters [IERS 1993 Annual Report, Table II–3, page II–19].

Starting from GPS week 803, the Rapid combination is done directly in the ITRF reference frame without prior alignment to the Bulletin A EOP series, making available IGS mean x and y pole coordinates. These new IGS mean EOP series (IERS designation: EOP (IGS) 95 P 01), corresponding to the IGS Rapid ephemerides, are computed as weighted averages using all available AC results with weights from the orbit combination. The current IERS Bulletin A UT1-UTC values are provided with the IGS mean x and y pole parameters. The associated file is called `igs`*wwwwd*`.erp` where "`erp`" stands for "earth rotation parameters". This change of strategy was made possible since on the average, the mean GPS pole agrees to a fraction of a milliarc-second (mas) with the ITRF aligned Bulletin A series (Figure 3). Consequently, this strategy change in the IGS Rapid combination did not introduce any noticeable discontinuities in the IGS Rapid Orbits. The IGS mean EOP combination is performed only for the IGS Rapid combination and not for the IGS Final combination where the associated EOP file is still based on the IERS Bulletin B EOP series. The IGS Rapid (before GPS week 803) and IGS Final weekly EOP files contain nine daily EOP values at 0h UT to allow interpolation at the beginning and at the end of the week. The current IGS Rapid EOP files include only seven daily EOP values at the 12h UT epoch since all AC EOP solutions are at the 12h UT epoch.

The AC ephemerides (rotated ephemerides for the IGS Final combination and the IGS Rapid combination prior to GPS week 803) are finally weighted and combined to produce the IGS official orbits.

The satellite clock correction combination is similar to the orbit combination. Each AC clock corrections are first aligned to GPS time by L1-norm estimation of clock offset and drift using only non-SA satellite broadcast clock corrections (usually 2–3 satellites). AC clock weights are then 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



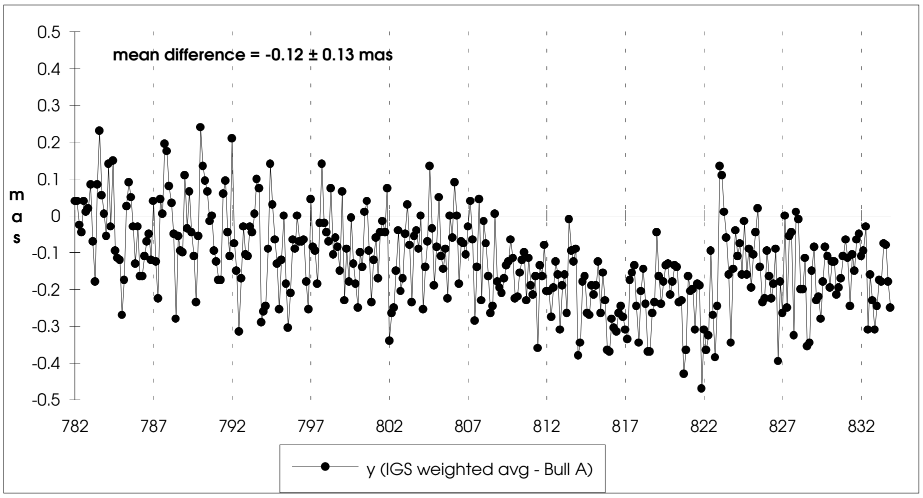


Figure 3: Difference between IGS mean and Bulletin A EOP values for 1995. (Bulletin A EOP were corrected with the ITRF93 inconsistency parameters)

satellites are representative of each AC clock solution quality. The transformed clock corrections are then combined as weighted averages of all submitted solutions. AC reference clock resets are accounted for by estimating additional clock offsets and drifts.

Table 9 summarizes step by step the Rapid and Final combination procedures for all three products: ephemerides, clocks, and EOP. A more detailed description including the formulas involved in the combination can be found in the IGS 1994 Annual Report [3].

A.5 IGS Rapid and Final Combination Results in 1995

In this section, results for the second year of IGS service, i.e., January 1 to December 30, 1995 (GPS weeks 782 to 833), are presented.

Tables 10 and 11 show each AC yearly means and standard deviations for the translation, the rotation and the scale parameters of the daily Helmert transformations with respect to the IGS Rapid and the IGS Final combinations respectively. Table 10 includes reprocessed GPS weeks 782 to 802 using the strategy currently used for the Rapid combination, i.e., no reference pole. Note, however, that the official IGS Rapid orbits for that period remained the original ones, i.e., the ones based on Bulletin A EOP series. In Table 10, the stability of each AC x and y pole series can be evaluated by looking at the RY and RX values respectively. On the average, RX and RY sigmas were below the 0.3- to 0.4-mas level. The total number of days for which a solution was submitted by each AC is also shown in the last column of Tables 10 and 11. Complete series have 364 days. All ACs submitted 364 solutions for the IGS Final combination (Table 11) which means that missing AC solutions from the IGS Rapid combination (Table 10) were submitted in time for the IGS Final combination. To complement Table 11, Figures 4 to 10 display the weekly averages and standard deviations of the translation, rotation and scale of the X, Y, Z satellite coordinates for each AC after the daily Helmert transformations with respect to the IGS Final orbits.

Sudden jumps in the weekly parameter averages may indicate a change in the processing strategy. For example, a Y-coordinate shift of about 4 to 5 cm was noticed in JPL solutions at the end of 1994 ([3] and [20]). A change in JPL's processing strategy was later confirmed and resulted in a closer alignment to the ITRF geocenter [8]. Subsequently, two ACs aligned their solutions to the geocenter: COD in June 1995 (June 6, GPS week 804, see Figure 4) and SIO in November 1995 (GPS week 826, see Figure 10). More details about the AC strategy changes can be found in [8].

Figure 11 shows coordinate RMS of all ACs with respect to the IGS Final orbit combinations. Three types of RMS are included in the figure: the weighted combination RMS (WRMS), the combination RMS, and the long arc evaluation RMS. Figure 12 summarizes the clock combination RMS. ACs used in the clock combination are EMR, ESA, GFZ, JPL and COD starting from GPS week 818 (Sep. 10, 1995). The other ACs are excluded because they either provide broadcast clocks (NGS and COD prior to GPS week 818) which are only used

Table 9: 1995 Orbit, Clock and EOP Combination/Evaluation Procedures

1. Long Arc Ephemerides Evaluation for each AC: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined.
2. Transformation to Common Reference:
    (a) Orbit

    Final Combination: the difference between each AC EOP solution and Bulletin B values are applied to the respective ephemerides;

    Rapid Combination: prior to GPS week 803, the difference between each AC EOP solution and Bulletin A values are applied to the respective ephemerides;

    Rapid Combination: from GPS week 803, the combination is performed directly in the ITRF reference frame without EOP alignment with Bulletin A.

    (b) Clock

    clock offset and drift with respect to broadcast GPS clock corrections are estimated for each AC using non-SA satellites and applied to the respective AC reference clocks.
3. Orbit and Clock Combinations:

    AC orbit weights are computed from absolute deviations with respect to unweighted mean orbits;

    AC clock weights are computed from absolute deviations from broadcast GPS clocks for non-SA satellites;

    satellite ephemerides and clock corrections are combined as weighted averages of AC solutions.
4. EOP Combination:

    Rapid IGS Combination (from GPS week 803) x and y EOP values are combined as weighted averages from available AC EOP values using orbit weights.
5. Long Arc Ephemerides Evaluation for the IGS Combined Orbits:

    Seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined.
6. Independent Point Positioning Evaluation (navigation mode):

    For Rapid IGS Combination all AC solutions which contain orbits and clocks (including IGS combinations) are evaluated using three IGS stations: BRUS, USUD and WILL.

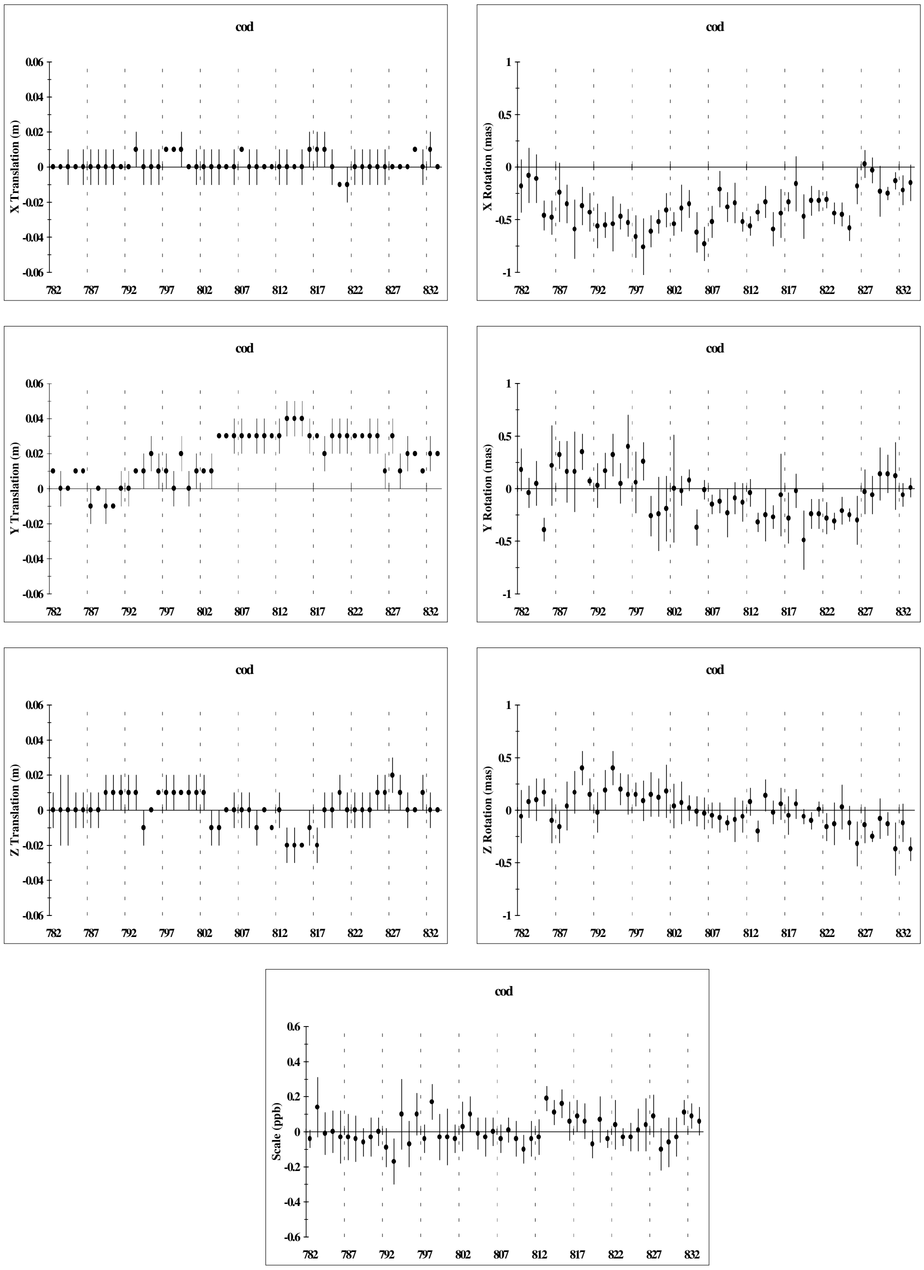


Figure 4: COD 1995: Final Weekly Mean 7-Parameter Helmert Transformations

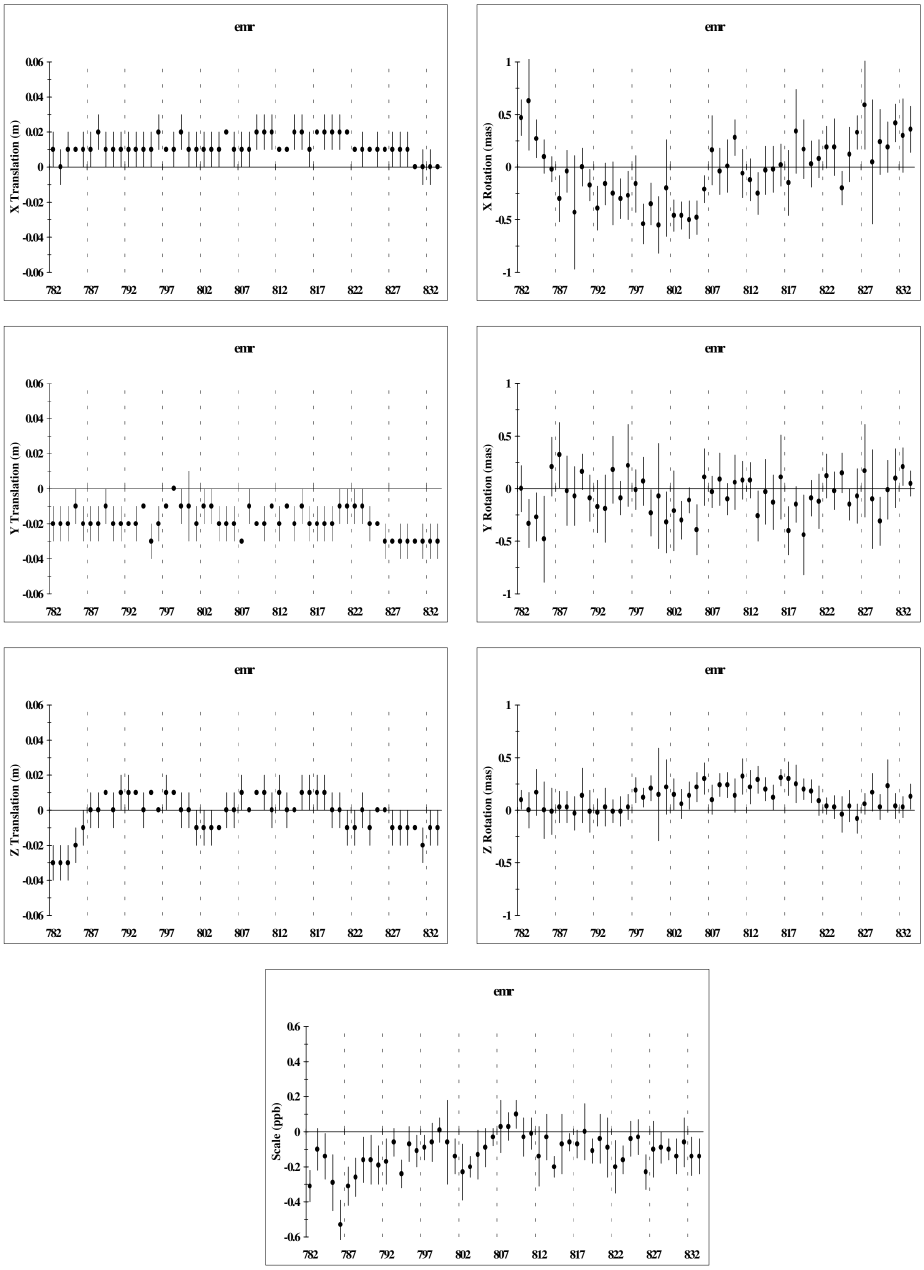


Figure 5: EMR 1995: Final Weekly Mean 7-Parameter Helmert Transformations

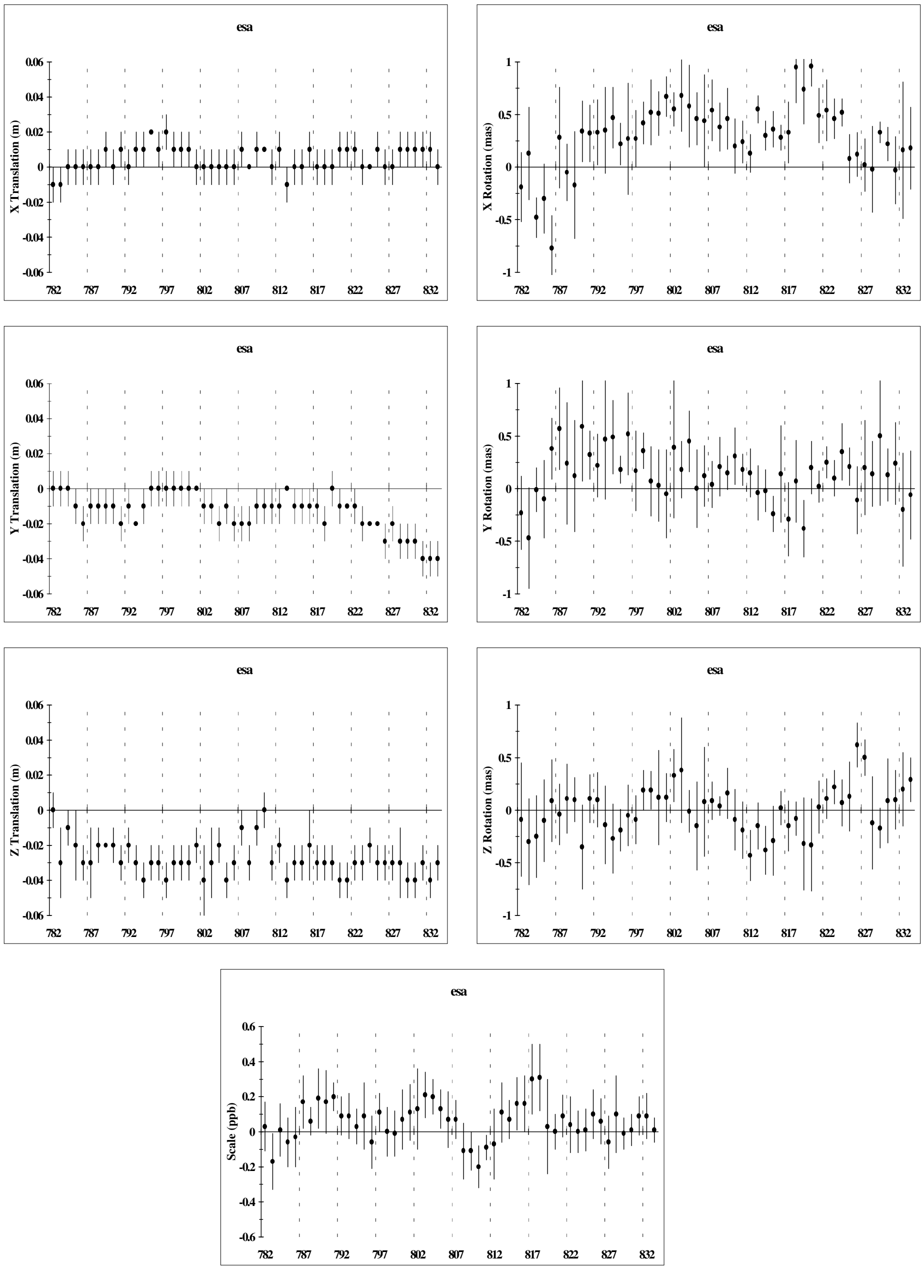


Figure 6: ESA 1995: Final Weekly Mean 7-Parameter Helmert Transformations

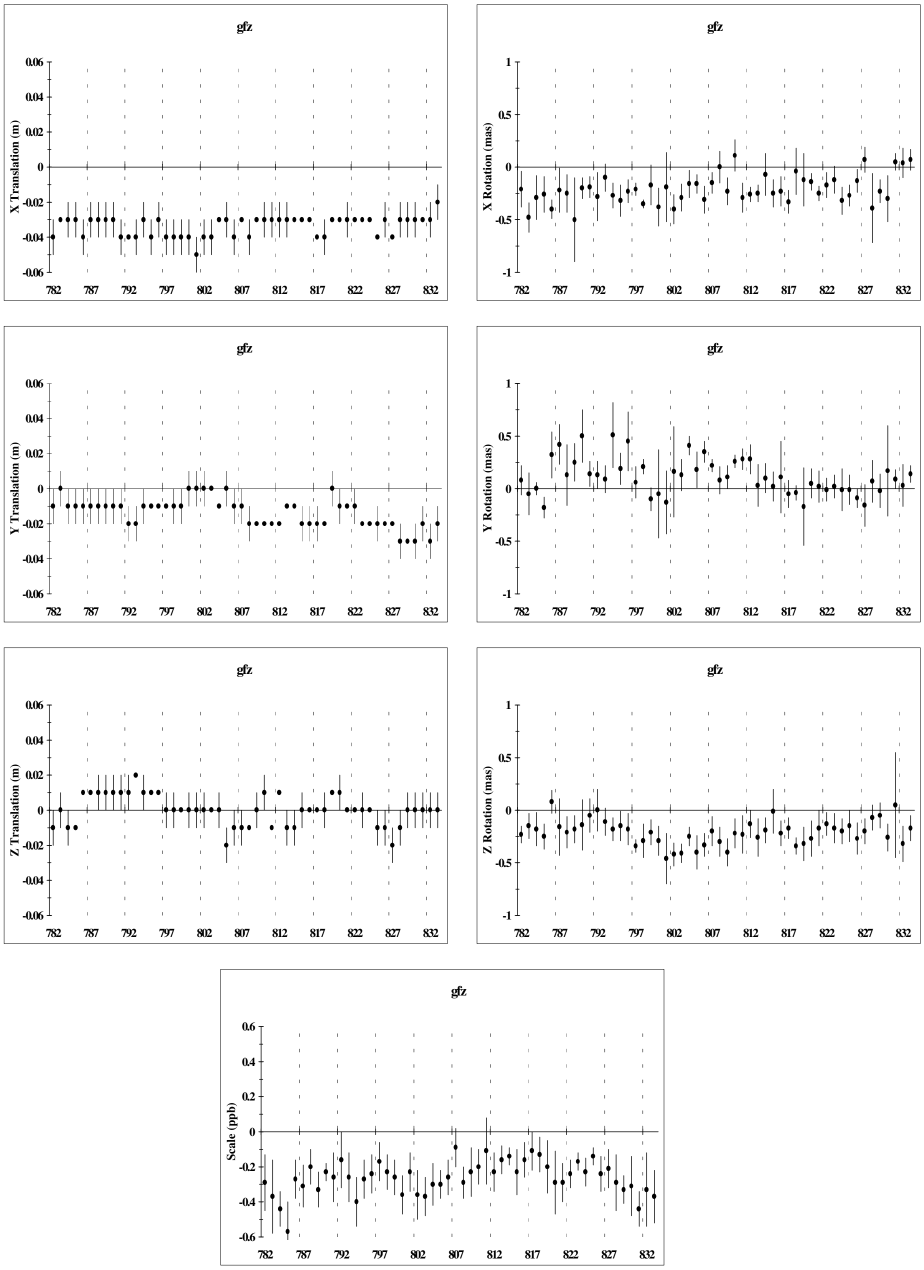


Figure 7: GFZ 1995: Final Weekly Mean 7-Parameter Helmert Transformations

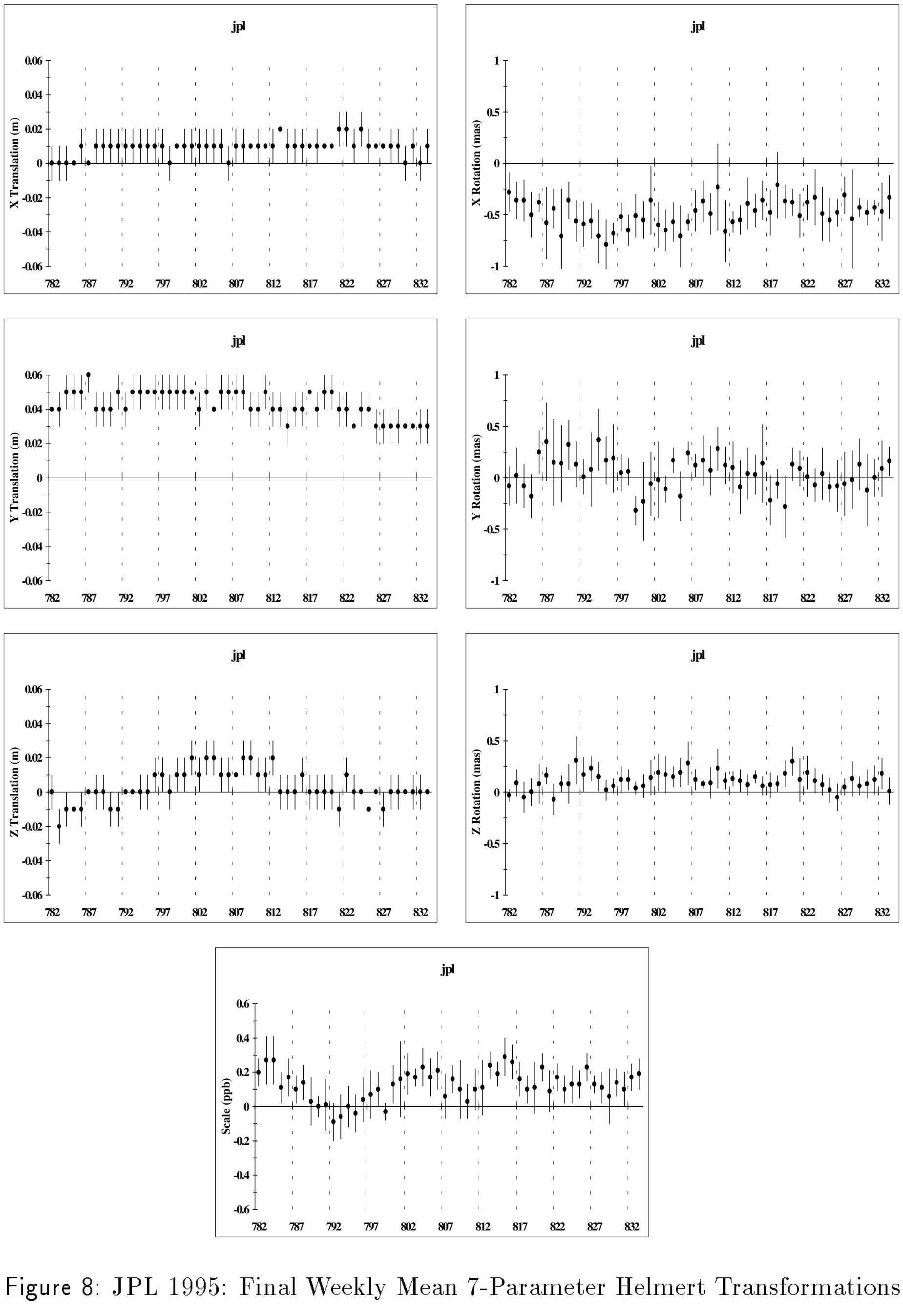


Figure 8: JPL 1995: Final Weekly Mean 7-Parameter Helmert Transformations

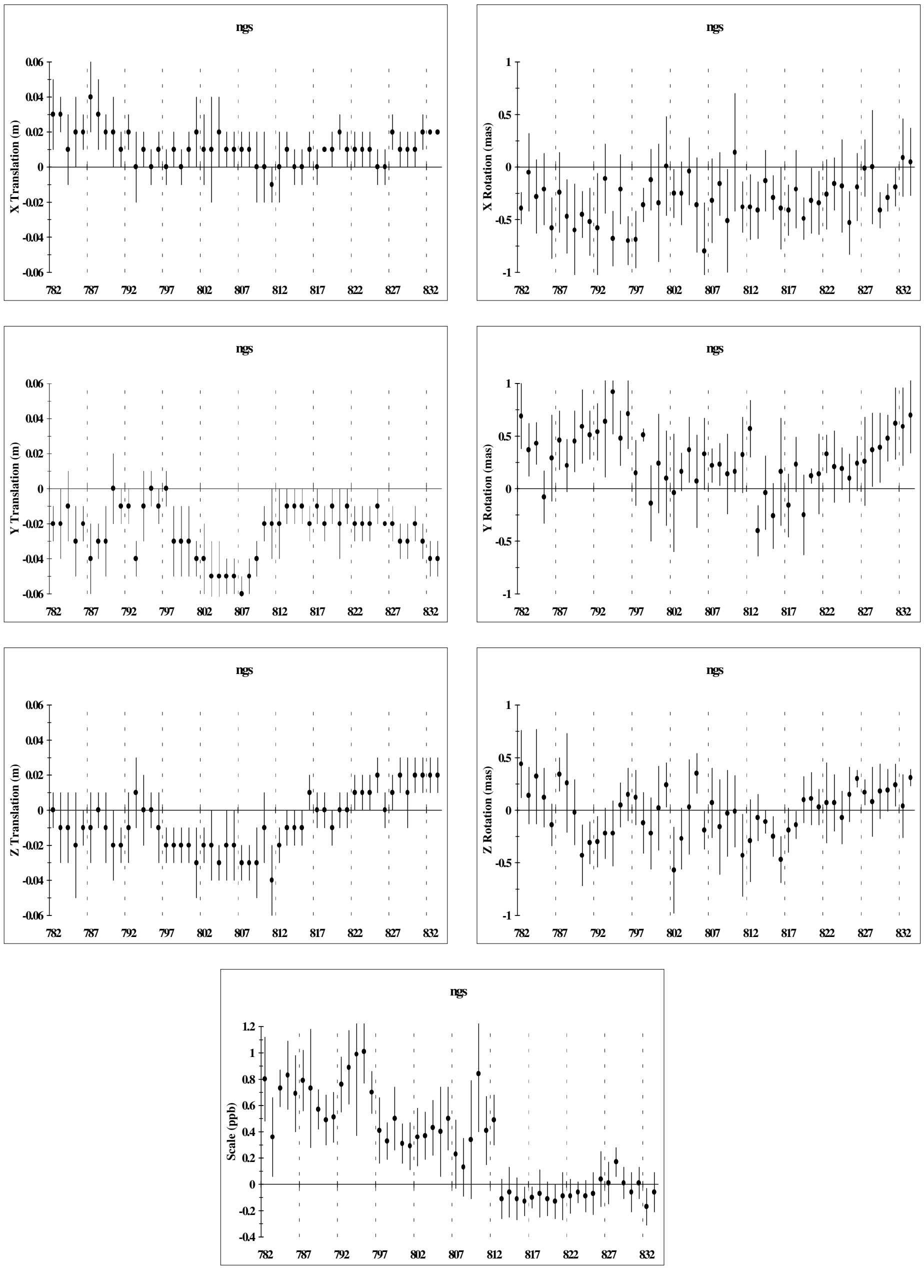


Figure 9: NGS 1995: Final Weekly Mean 7-Parameter Helmert Transformations

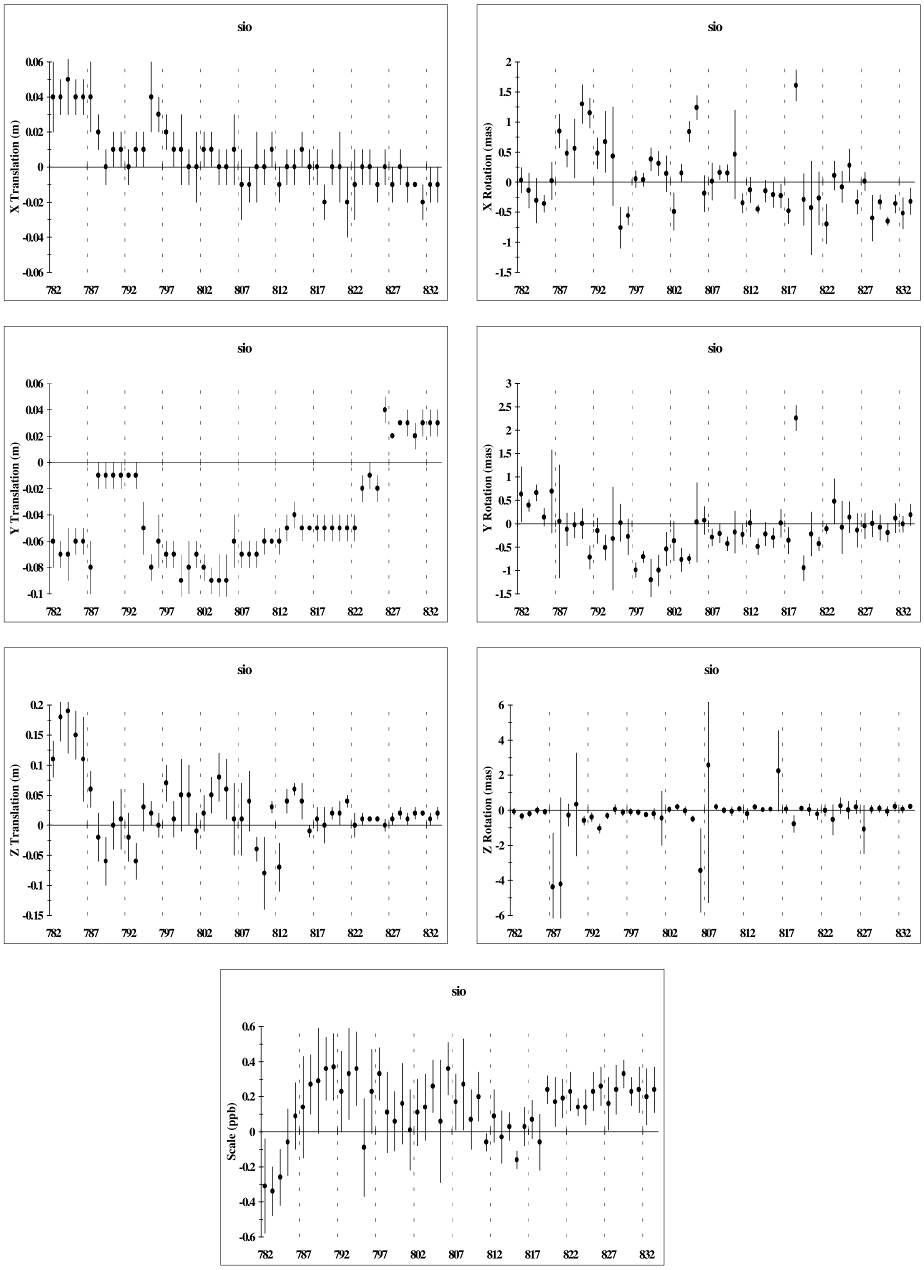


Figure 10: SIO 1995: Final Weekly Mean 7-Parameter Helmert Transformations

Table 10: IGS Rapid Combination - GPS weeks 782 to 833. (performed directly in the ITRF reference frame). Means and Standard Deviations of the Daily Helmert Transformation Parameters.

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(meters)			(mas)		(ppb)	
COD	mean	.00	.02	.00	-.17	-.08	.00	.0	364
	std	.01	.01	.01	.18	.17	.22	.1	
EMR	mean	.01	-.02	.00	.19	-.09	.12	-.1	364
	std	.01	.01	.01	.28	.19	.19	.2	
ESA	mean	.00	-.01	-.03	.50	.11	.00	.1	357
	std	.01	.01	.01	.40	.30	.36	.2	
GFZ	mean	-.03	-.01	.00	.01	.08	-.21	-.3	357
	std	.01	.01	.01	.14	.16	.20	.1	
JPL	mean	.01	.04	.00	-.27	.01	.12	.1	364
	std	.01	.01	.01	.14	.14	.16	.1	
NGS	mean	.01	-.02	-.01	-.10	.24	-.01	.3	352
	std	.01	.02	.02	.31	.27	.36	.4	
SIO	mean	.01	-.04	.03	.32	-.23	-.38	.1	336
	std	.02	.04	.06	.67	.82	1.69	.3	

Table 11: IGS Final Combination - GPS weeks 782 to 833. (referred to IERS Bulletin B EOP series). Means and Standard Deviations of the Daily Helmert Transformation Parameters.

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(meters)			(mas)		(ppb)	
COD	mean	.00	.02	.00	-.39	-.05	.00	.0	364
	std	.01	.01	.01	.24	.29	.22	.1	
EMR	mean	.01	-.02	.00	-.03	-.06	.12	-.1	364
	std	.01	.01	.01	.38	.31	.19	.2	
ESA	mean	.00	-.01	-.03	.29	.14	.00	.1	364
	std	.01	.01	.01	.42	.41	.36	.2	
GFZ	mean	-.03	-01	.00	-.21	.11	-.21	-.3	364
	std	.01	.01	.01	.20	.25	.19	.1	
JPL	mean	.01	.04	.00	-.49	.04	.11	.1	364
	std	.01	.01	.01	.25	.28	.15	.1	
NGS	mean	.01	-.02	-.01	-.31	.28	-.01	.3	364
	std	.01	.02	.02	.38	.41	.35	.4	
SIO	mean	.01	-.04	.03	.04	-.15	-.25	.1	364
	std	.02	.04	.06	.61	.65	1.80	.2	

in clock alignment and clock weight determination, or clock corrections are not provided (SIO). For completeness, the clock information not used in the combination is compared to the combined solution.

Bad satellite orbit or clock solutions are excluded from the combination (but kept in the RMS computations) if they bias the IGS combined solution. All exclusions are reported in the IGS weekly summary reports. High clock RMS for broadcast clocks (NGS and COD prior to GPS week 818) are generally due to broadcast clock resets for one or more satellites which are removed by ACs estimating clocks. Anti-Spoofing (AS) was deactivated for all Block II satellites three times during 1995.

Most AC processing strategies have become so robust that the AS on/off periods specified in Table 12 are hardly noticeable (see Figures 4–12). Examination of these figures shows that, as in 1994, a considerable effort was made throughout 1995 by all ACs to improve the quality of orbit and clock solutions. Towards the end of the year, the best clock RMS have reached sub ns levels and the best orbit position RMS have been approaching the 5 cm level, in spite of AS.

Table 12: Periods when AS was deactivated during 1995.

GPS Week Number			*Dates*		
From	–	*To*	*From*	–	*To*
797 day 3 (20:00)	–	800 day 3 (20:00)	Apr. 19	–	May 10
806 day 1 (00:00)	–	809 day 2 (00:00)	Jun. 19	–	Jul. 11
822 day 2 (00:00)	–	825 day 3 (00:00)	Oct. 10	–	Nov. 01

A.6 IGS Preliminary Orbit, Clock and EOP Combinations

In response to an increasing demand for a shorter delivery time of orbit and clock solutions, the IGS ACs initiated on Jan. 1, 1996 the 'super' rapid orbit, clock, and EOP combination. The AC participation in this pilot project requires submission of their solutions within 36 h after last observation. This 'super' rapid IGS combination of GPS orbits, clocks and x and y pole positions, designated as 'IGS Preliminary' combination (IGP), is then produced within 2 hours after the submission deadline, i.e., before 14:00h UT. As in the IGS Rapid combination, UT1-UTC values from the Bulletin A (prediction) are provided with the preliminary mean IGS EOP values. The IGS Preliminary combination products are available from CDDIS, the IGS Central Bureau, and at NRCan.

Some quality testing and evaluation is performed daily as part of the IGP combination. Starting with GPS week 837 (Jan. 21, 1996), quality evaluation of IGP orbits/clocks has been carried out by including them into the weekly IGS Rapid combination as another AC for statistical purposes. The AC average submission delay is generally less than 24 hours, which is well below the proposed 36 hours. The current IGP orbit and clock precision with respect to the IGS Rapid combination are at the 10-cm and 1-ns level respectively. Table 13 com-

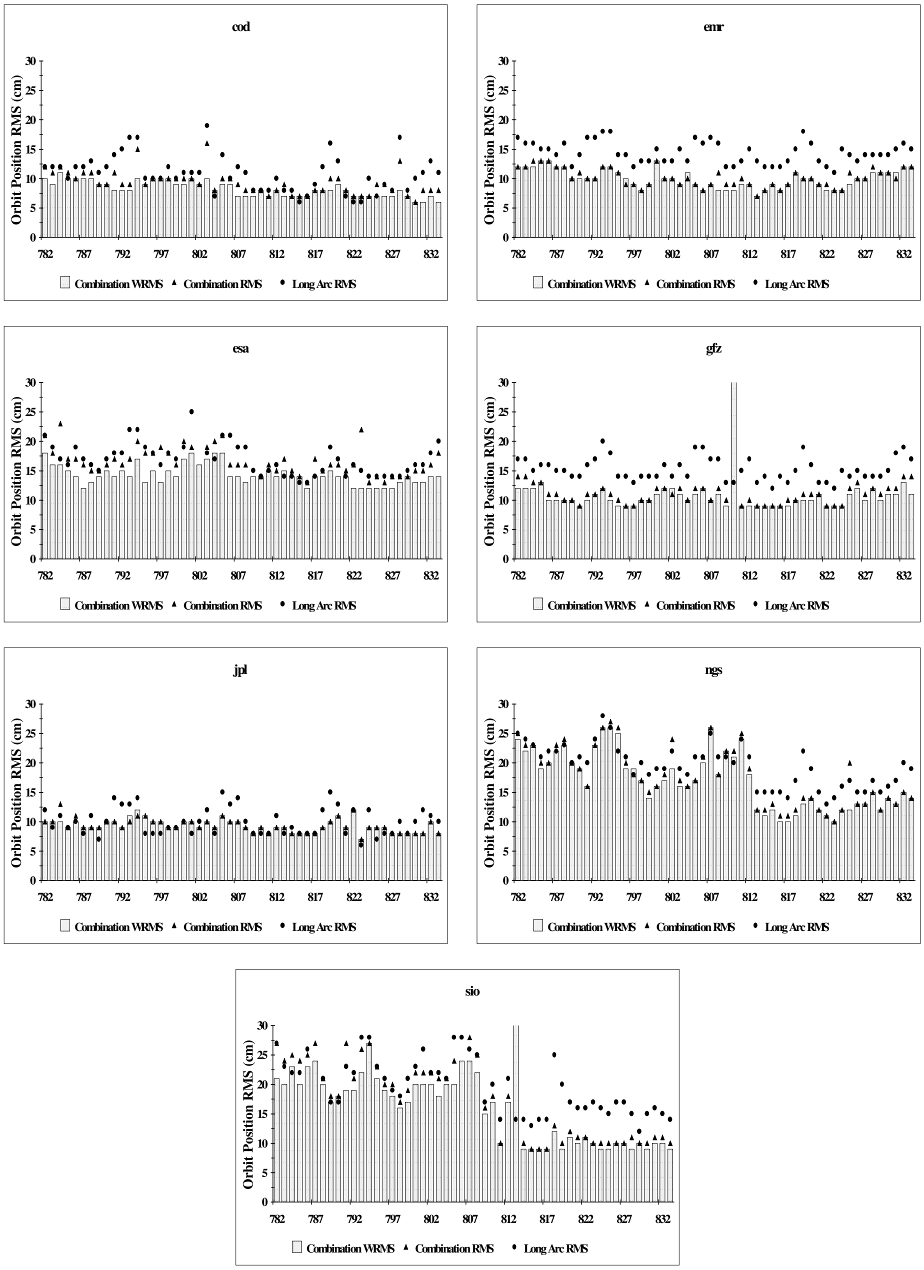


Figure 11: 1995 Final Weekly Mean Orbit Position RMS

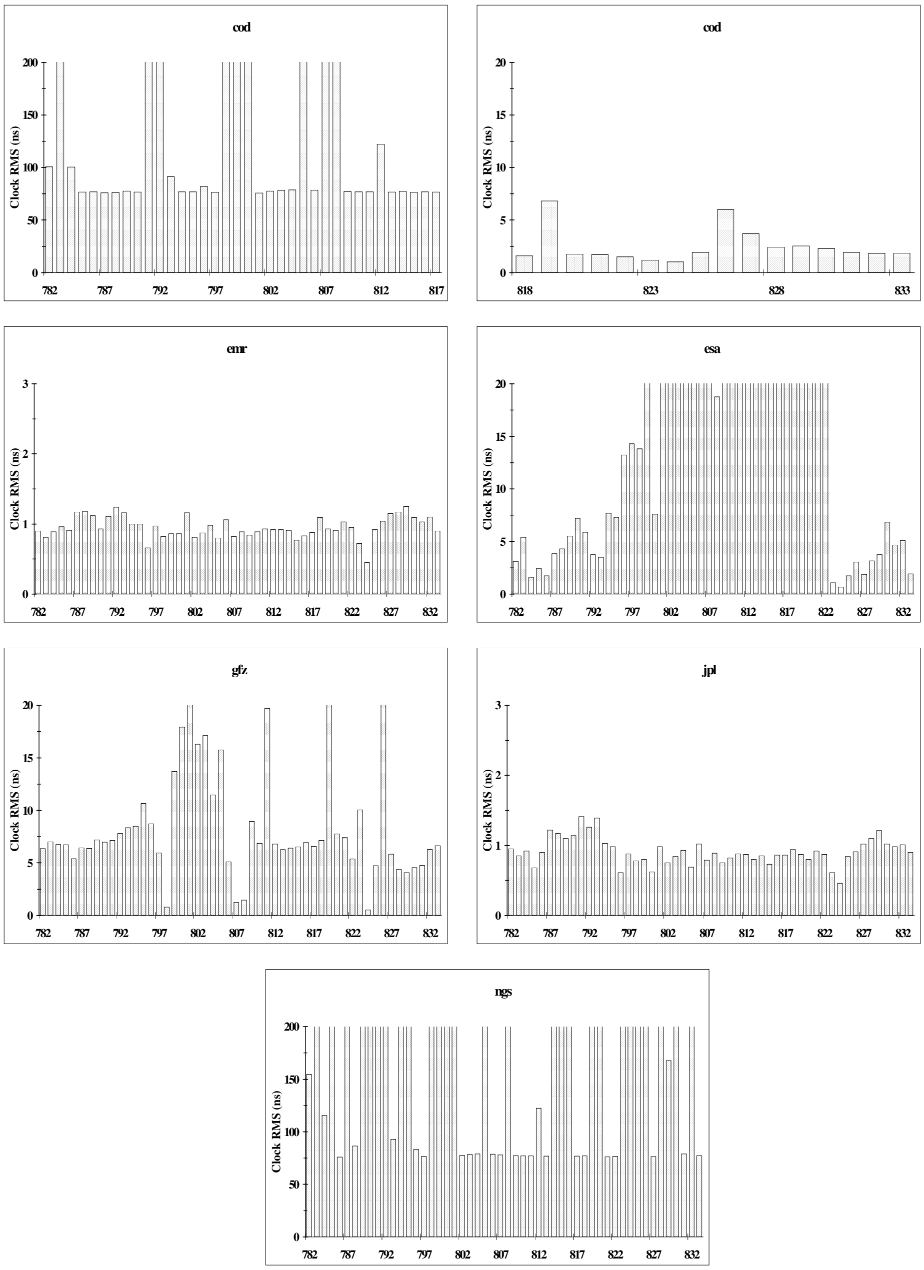


Figure 12: 1995 Final Weekly Mean Clock RMS (All ACs except SIO). Note the change of scale for ACs providing broadcast clock corrections, i.e. COD (top left corner) and NGS.

pares the IGP orbits and clocks to the IGS Rapid combination orbits and clocks. Statistics in Table 13 include results from GPS weeks 837 to 847 (Jan. 21, 1996 to Apr. 6, 1996) (week 837 being the first week of IGS quality evaluation). GPS week 845 days 5-6 (Mar. 22–23, 1996) statistics were purposely excluded from Table 13. Bad IGP results for these two days were due to lack of data caused by a shutdown at the JPL archive for maintenance.

Table 13: IGP Means and Standard Deviations of the Daily Helmert Transformation Parameters with respect to the IGS Rapid Combination. Orbit Position RMS, Weighted RMS (WRMS), and Clock RMS (RMSc) are also shown.

Period covered: GPS weeks 837 to 847 (Jan. 21 to Apr. 6, 1996).

AC	DX	DY	DZ	RX	RY	RZ	SCL	RMS	WRMS	RMSc
IGP mean	0.01	-0.01	-0.01	0.31	-0.11	0.19	-0.1	10	7	1.6
std	0.01	0.01	0.01	0.31	0.26	0.20	0.2			

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

For an overview of the IGP point positioning performance, the reader is referred to Table 8 and Figure 2.

A.7 Conclusion

AC orbit solutions have steadily improved, and by the end of 1995, the best AC orbit solutions were approaching the 5-cm level even under AS conditions. Satellite clock solution consistency is at the sub-ns level for the best ACs. Starting on May 22, 1995 (GPS week 803), the IGS Rapid combination has been done directly in the ITRF reference frame without any alignment to the Bulletin A EOP series. IGS mean x and y EOP have been introduced in 1995. It is computed as a weighted average of all available ACs data using orbit weights. Results have shown very good agreement between the Bulletin A and the IGS Mean EOP values.

On Jan. 1, 1996, a 'super' rapid orbit, clock and EOP IGP combination (IGS Preliminary) was initiated. The proposed AC submission deadline was 36 hours after the last observation, but most ACs have been submitting their solutions within about 24 hours. The IGP combination is produced within 2 hours after all submissions or within 38 hours after the last observation. Preliminary result are encouraging with orbit and clock RMS of about 10 cm and 1 ns respectively when compared to the IGS Rapid orbits and clocks.

The IGS combinations use and evaluate all available solutions, including days when satellites are being repositioned. The IGS combinations surpass individual

AC products in completeness, reliability and provide consistently data of the highest quality.

B IGS Rapid Combination: Point Positioning Summary Tables

Table 4 of the IGS Rapid combination is a weekly summary of the daily precise navigation summaries for centers providing both orbit and clock solutions. It contains weekly station RMS w.r.t. the initial coordinates for the latitude, longitude and height components for up to three IGS stations. It is labeled `Table 4.`*`gpsweek`*. Table 5 of the IGS Rapid combination is similar to Table 4 and contains daily precise navigation statistics. It is labeled `Table 5.`*`gpsweek.day`*. Only GFZ "exact" clock corrections are included in the combination, i.e., one clock correction out of two, which explains the small number of satellite clock epochs (EPO) for GFZ in Tables 4 and 5.

```
Table 4: Precise Navigation Summary.
         Weekly station RMS w.r.t. apriori station coordinates for
         Latitude, Longitude and Height.
         See Table 5 for the daily summary.

         CLK  - Satellite clocks used.
         EPO  - Mean number of satellite clock epochs available in the
                daily solutions.
         U    - Station included in AC's solution (at least one day).
         Units: centimeters.


Table 4.0847   GPS week: 0847   MJD: 50173.0-50179.0

CENT| CLK EPO  |      BRUS      |      USUD      |      WILL      |
----|----------|----------------|----------------|----------------|
cod | cod 2225 |U  58   38   96 |U  48   40  106 |   41   28   65 |
emr | emr 2288 |   41   29   76 |   36   31   80 |U  27   14   39 |
esa | esa 2011 |  265  153  475 |U 218  122  375 |  238  146  271 |
gfz | gfz 1145 |   42   29   80 |U  40   36   89 |   26   17   41 |
igp | igp 2280 |   43   31   82 |   37   34   83 |   28   18   47 |
igs | igs 2304 |   41   28   78 |   36   32   81 |   26   15   39 |
jpl | jpl 2300 |   39   28   75 |U  35   31   79 |   27   15   40 |
```

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Table 5: Daily Precise Navigation Summary using the corresponding Center
         orbit positions and satellite clock corrections at 15 min intervals.

         Each line gives the daily station RMS w.r.t. apriori station
         coordinates for Latitude, Longitude and Height.

         CLK  - Satellite clocks used.
         EPO  - Number of satellite clock epochs available
                for that day.
         Units: centimeters.


Table 5.0847.0   GPS week: 0847   Day: 0   MJD: 50173.0

CENT| CLK EPO  |      BRUS      |      USUD      |      WILL      |
----|----------|----------------|----------------|----------------|
cod | cod 2247 |   49   39  106 |   42   30   93 |   43   26   67 |
emr | emr 2301 |   39   27   85 |   32   19   56 |   31   14   34 |
esa | esa 1989 |  304  172  471 |  222  118  434 |  260  153  277 |
gfz | gfz 1104 |   47   30  100 |   36   22   67 |   27   17   35 |
igp | igp 2293 |   44   28   88 |   33   21   61 |   28   14   38 |
igs | igs 2304 |   38   27   85 |   31   20   62 |   28   13   36 |
jpl | jpl 2293 |   40   25   84 |   31   18   55 |   30   13   31 |


Table 5.0847.1   GPS week: 0847   Day: 1   MJD: 50174.0

CENT| CLK EPO  |      BRUS      |      USUD      |      WILL      |
----|----------|----------------|----------------|----------------|
cod | cod 2252 |   52   38   83 |   47   36   95 |   40   30   62 |
emr | emr 2299 |   39   26   81 |   34   22   77 |   27   14   39 |
esa | esa 2011 |  298  158  515 |  227  128  408 |  249  143  284 |
gfz | gfz 1152 |   41   26   84 |   41   24   95 |   26   17   41 |
igp | igp 2304 |   40   27   81 |   34   25   76 |   24   14   42 |
igs | igs 2304 |   37   28   77 |   34   24   75 |   26   14   39 |
jpl | jpl 2294 |   34   26   79 |   34   25   76 |   27   14   38 |
```

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Status of the IGS Initiative to Densify the ITRF

J. Kouba

Geodetic Survey Division, Geomatics Canada, National Resources of Canada
615 Booth Street,
Ottawa,Canada, K1A OE9
email: `kouba@geod.emr.ca`

1 Introduction

The importance of regional participation and efficient IERS Terrestrial Reference Frame (ITRF) delivery to users has been recognized by IGS since its beginning. ITRF densification has been the subject of numerous discussions both at the IGS Governing Board and the preceding IGS Oversight Committee meetings. Some of the problems discussed include distribution, density, and the benefits of periodic campaign-type or continuous operations. In principle, precise orbit/clock solutions contain all the necessary information for positioning within ITRF. However, to facilitate the highest precision with traditional relative positioning, to provide redundancy and to accommodate global geodynamic and reference studies (e.g., crustal plate motion), a concept of an IGS/ITRF station polyhedron was introduced (see, e.g., [1]). Such an IGS polyhedron or network should consist of about 200 points with spacing of about 1000 to 3000 km (see, e.g., [2]). After initial stages of IGS operations it became clear that permanent station deployment and continuous observations are most suitable for the establishment of such an IGS station polyhedron.

A continuous global GPS analysis of 200 or more stations is difficult, even with today's most powerful computers and state-of-the-art communication. So, efficient ITRF polyhedron processing and dissemination approaches have been sought by IGS since the fall of 1992. At the first Analysis Center workshop held in Ottawa in October 1993, an efficient and nearly optimal processing approach, based on addition of the reduced normal matrices (Helmert blocking), to be performed by Associate Analysis Centers (AACs), was identified and recommended for the IGS ITRF densification [3]. The proposed processing approach subdivides the GPS data analysis to manageable sizes determined by the participating agency needs and available resources. The global analyses are performed by a small number of agencies dedicated to providing the best possible orbit, clock, EOP, and station solutions. The Regional AAC will use a minimum of three stations also used by the global Analysis Centers.

The ITRF densification workshop held in Pasadena, in October 1994 [4] concentrated more on realization of the project, while following the processing principles established by the Ottawa AC workshop. In particular, Position Paper 2 [1] fully developed organization aspects, including a timetable for an ITRF densification pilot project. It also proposed the establishment of a new standard exchange format named SINEX (Software INedepenent EXchange format) and two types of AACs. The Regional Network AAC (RNAAC) (called Type 1 - AAC in the reference) which would analyze regional networks and contribute the results to the second type, the Global Network AAC (GNAAC) (called Type 2 - AAC) which would combine the regional solutions into an IGS polyhedron station network solution. In December 1994, the Pasadena workshop recommendations were approved by the IGS Governing Board meeting held in San Francisco; a SINEX working group was established and a GNAAC call for participation (CFP) was issued in early 1995, with the planned start of the ITRF Densification Pilot Project in April, 1995. Three GNAACs responded to the CFP and were accepted by IGS: MIT (Massachusetts Institute of Technology), NCL (University of Newcastle-upon-Tyne), and JPL. For more information and the chronological list of events, see [5] and [6].

By the end of 1995, despite initial difficulties such as late starts of AC submissions, SINEX format fine tuning and the problems associated with new GNAAC processing, the ITRF Pilot Project has been running smoothly. Since then, each week, the three GNAACs have been producing combined station solutions of six individual AC weekly SINEX solutions. In December 1995 the IGS GB decided to issue yet another CFP for the RNAACs in order to test and complete the regional level of the ITRF Pilot project in 1996.

1.1 SINEX (Software Independent Exchange) FORMAT

The SINEX acronym was suggested in [1], and the initial format versions (0.04, 0.05) evolved within the first six months of 1995 from the work and contributions of the SINEX Working Group (WG) chaired by Geoff Blewitt. The other SINEX WG members were Claude Boucher, Yehuda Bock, Jeff Freymueller, Gerd Gendt, Werner Gurtner, Mike Heflin and Jan Kouba. Also, contributions of Zuheir Altamimi, Tom Herring, Remi Ferland, Dave Hutchison and other IGS AC colleagues are noted and acknowledged here. In March 1996, after a six-month experience of the ITRF project, the new SINEX version 1.00 was finalized, presented, and adopted by the Silver Spring AC Workshop [7].

SINEX was designed to be modular and general enough to handle GPS as well as other techniques. In particular the information on hardware (receiver, antenna), occupancy/dates and various correspondence between hardware, solution and the input files can be preserved, which is essential for any serious analysis and interpretation of GPS results. It preserves input/output compatibility so that output SINEX files can be used (later on) as inputs into subsequent computation/solutions. In SINEX, *a priori* information along with solutions can be provided. With complete *a priori* information provided, one can change or remove constraints whenever necessary. This makes it unnecessary to submit or distribute multiple (SINEX) solution files, e.g., constrained and unconstrained (free) solution files. Furthermore SINEX allows flexible and precise epoch assignments to all relevant entries, including receiver/antenna occupancy, parameter solutions, etc.

The SINEX file is subdivided in groups of data called blocks. Each block is enclosed by a header and trailer line. Each block has a fixed format. The blocks contain information on the file, its input, the sites, and the solution. All elements within a line are defined. This lets the SINEX file be accessible "column-wise" as well as "line-wise". The first character of each line identifies the type of information that the line contains. Five special characters are reserved for this purpose. They have the designated meaning only when they are at the beginning of a line. The special characters are listed in Table 1. No other characters are allowed at the beginning of a line.

Table 1: Special characters of the SINEX format

Character	*Definition*
`%`	Header and trailer line,
`*`	Comment line within the header and trailer line,
`+`	Title at the start of a block
`-`	Title at the end of a block
(blank)	Data line within a block

A SINEX file must start with a header line and end with a trailer line. The currently defined blocks are listed in Table 2.

The most important blocks are `SITE/GPS_PHASE_CENTER`, `SITE/ECCENTRICITY` and `SOLUTION/ESTIMATE`. The first two blocks provide the necessary information on antenna phase center offsets from the monument, and thus validate the monument solutions in the `SOLUTION/ESTIMATE` block. The `SOLUTION/APRIORI` and `SOLUTION/MATRIX_APRIORI` blocks, when coded, provide the necessary information for the removal of *a priori* constraints if unconstrained solutions are required. Currently standardized parameter names have been defined for station coordinates, satellite initial state vectors, earth orientation parameters, radiation pressure parameters, and tropospheric delays. The SINEX block titles are immediately preceded by a "+" or a "-" as they mark the beginning or the end of a block. The schematic SINEX format structure is shown in Figure 1.

For the complete and up-to-date SINEX format description, see the IGS CB Archives at `ftp://igscb.jpl.nasa.gov/igscb/data/format/SINEX`

Table 2: Currently defined SINEX standard blocks

Standard SINEX *Block Label*	*Description/content*
`FILE/REFERENCE`	Organization/software/hard. information
`FILE/COMMENT`	General comments about the SINEX file
`INPUT/HISTORY`	Input files (SINEX headers)
`INPUT/FILES`	Inform./comments on the input files above
`INPUT/ACKNOWLEDGEMENTS`	Agency contributions/acknowledgements
`SITE/ID`	Inf. on each site (positions, monuments)
`SITE/DATA`	Relates stations & the input SINEX files
`SITE/RECEIVER`	Receivers/epochs used at each site
`SITE/ANTENNA`	Antennas/epochs used at each site
`SITE/GPS_PHASE_CENTER`	Phase centers of all antennas used (above)
`SITE/ECCENTRICITY`	Antenna offsets/epochs used at each site
`SOLUTION/EPOCH`	Solution start/end/middle epochs
`SOLUTION/STATISTICS`	Solution statistics, sampling rate, etc.
`SOLUTION/ESTIMATE`	Estimated (total) parameter values
`SOLUTION/APRIORI`	*A priori* parameter values
`SOLUTION/MATRIX_ESTIMATE` *p type*	Solution matrix
`SOLUTION/MATRIX_APRIORI` *p type*	*A priori* matrix
Where: *p* is `L` or `U`	Lower or upper triangular matrix
type is `CORR` or `COVA`	Correlation or var. covariance matrix
or `INFO` or `SRIF`	The matrix of normals or SRIF matrix

```
%=SNX........... (Header line)----------|
.............                           |
+(BLOCK TITLE)-------------|            |
 ............              |            |
 ............              |            |
 ............              |            |
-(BLOCK TITLE)-------------|            |
.............                           |
+(BLOCK TITLE)-------------|            |
 ............              |            |
 ............              |            |
 ............              |            |
-(BLOCK TITLE)------------ |            |
.............                           |
%ENDSNX          (Trailer line)---------|
```

Figure 1: Structure of a SINEX file

2 ITRF Densification Pilot Project

Although the framework for the IGS ITRF pilot project was well laid down by the Pasadena workshop and most ACs were capable and ready to produce unconstrained solutions for station positions in 1995, the launching of the ITRF project proved to be more difficult and took longer than originally anticipated. This was mainly due to the enormous workload which is experienced by all ACs while maintaining continuous (albeit fully automated) processing, as well as the initial growing pains and delays of the SINEX format development and GNAAC combination processing. In particular proper *a priori* information removal/testing likely caused a delay of up to several months. However, in the end, fine tuning this important feature of SINEX has significantly enhanced the economy and usefulness of the ITRF project as only constrained solutions are sufficient to satisfy all the levels of IGS users and applications, i.e., constrained station solutions in ITRF93 as well as unconstrained station solutions. Testing of this feature revealed insufficient numerical precision of standard deviations in the `SOLUTION` blocks for the SINEX version 0.05, which lead to the increased numerical field of the `SOLUTION/MATRIX` blocks in the SINEX Version 1.00. This new version allows 15- or 16-digit numerical precision for the matrix block, which is sufficient for rigorous constraint removal in all but extreme cases.

The ITRF Pilot project officially started on September 3, 1995, five months later than originally planned. Since January 1996, all seven ACs have been contributing their weekly solutions. Four ACs submit constrained station solutions while three ACs opted for unconstrained solutions. Although it was recommended at the Pasadena workshop, only one AC includes daily EOPs in addition to the usual station solutions. Currently, all three GNAACs produce and submit combined SINEX files to the IGS Global Data center. Both individual and combined SINEX solution files follow the usual IGS naming convention, i.e., `cccwwwwd.snx`, where *ccc* is the IGS assigned AC or GNAAC code, *wwww* is the GPS week number, and *d* is day number (a '7' for a weekly solution) in the case of ACs, and should be '`G`' for GNAAC combined solutions. All GNAACs also submit the corresponding summary files (`cccwwwwd.sum`) which contain evaluation reports, brief descriptions and remarks related to the combined and input SINEX solutions.

All the three GNAACs, in principle, use an equivalent combination approach, i.e., addition of the reduced normal matrices which are approximated by the submitted or reconstructed unconstrained solutions. In fact, the unconstrained solutions, for better numerical stability and to allow matrix inversions, as suggested in [1] still do have very weak constraints corresponding to station position sigmas of 10 to 100 m. There are significant differences in numerical implementations, solution alignments, and variance matrix scales. Some of the important differences between the GNAAC SINEX combinations are shown in Table 3.

Unconstrained SINEX station solutions are nearly singular in orientation, unless EOP solution parameters have been fixed or included in the SINEX solutions. The coordinate origin (geocenter) and scale are well defined in global GPS analyses; this is the consequence of the orbital dynamics when the three first-degree

Table 3: Summary of SINEX combinations by Global Network AACs (GNAAC)

GNACC	*Variance Factor*	*Reference Frame Alignment*
JPL	Assigned, based on relative 7-parameter transformations between unconstrained AC solutions using sol. matrices	Unconstrained AC solutions aligned; prior combination; free combined solutions
MIT	Computed from chi-square var. equivalent to adjustment of unconstrained AC solutions with no coord. transformation, solution matrices used	No translation transformation of individual unconstrained AC solutions (the AC solutions are rotated during combination). Combined solutions constrained to 13 ITRF93 positions.
NCL	Computed from chi-square var. of transformation w.r.t. the 13 ITRF94 stations (unconstr. AC solutions and matrices used)	No alignment or transformation of individual unconstrained AC solutions. Combined solution constrained to 13 ITRF94 positions.

coefficients of the Earth gravity model are set to zero. AC SINEX solutions should not need any translation or scale transformation. In fact, both scale and geocenter solutions can contribute to ITRF origin and scale. In reality some AC solutions may be misaligned in origin due to deficiency of orbit modeling, station distribution, and the peculiarities of GPS satellites.

For some ACs the geocenter and scale biases can reach more than 100 mm or 10 ppb, respectively, as can be seen in Table 4, where sample geocenter shift and scale solutions are shown for all ACs in the recent GPS week 848. Most ACs are already well aligned at least in the x- and y-coordinate origin. The larger variation in the z-coordinate origin is typical for GPS global analysis, and it is related to solving for (rather than fixing) initial phase ambiguities and a lack of stations in the Southern Hemisphere (e.g., [8]). The large 11-ppb scale bias for NGS SINEX solutions is caused by an antenna chamber calibration used in NGS processing and which causes a scale bias of about 15 ppb (see [9]; [10]; [11]). Origin or scale offsets, if not properly accounted for, can bias the combined solutions. The biasing of combined solutions can be prevented or mitigated by using transformation or large variance factors (caused by the origin/scale offsets) for the misaligned solutions prior the SINEX combinations. Both approaches are employed by GNAACs as seen in Table 3. It is preferable to have all AC solutions aligned (by improving orbit modeling at the AC processing level) rather than to include shift transformations; this way the implied geocenter and scale information is preserved. This is why it was recommended by the 1996 AC workshop that all ACs make every effort to align the origin of their solutions. The small coordinate shifts have also significant effects (about 5 cm) on the origin of constrained AC orbit solutions [12]. Also shown in Table 4 are horizontal coordinate rms and the number of the ITRF93 positions used for the coordinate transformations. Note that the station HART was down for that week.

Table 4: Apparent geocenter and scale variations in AC unconstrained SINEX solutions. Compiled from MIT summary file for Wk 0848.

CEN	Tx	sig	Ty	sig	Tz	sig	Scal	sig	rms(2D)	ITRF93
	(mm)		(mm)		(mm)		(ppb)		(mm)	stat.
COD	-7.2	2.8	1.9	2.7	-27.6	2.8	-1.4	0.9	5.8	12
EMR	4.2	4.0	154.5	4.0	-122.1	4.2	-2.3	1.3	8.2	11
ESA	17.6	5.6	7.6	5.6	-70.2	5.9	-3.0	1.8	11.2	10
GFZ	104.6	3.2	49.5	3.1	-103.7	3.3	-1.4	1.0	6.7	12
JPL	22.0	3.2	3.9	3.1	-83.0	3.3	-1.9	1.0	6.4	11
NGS	-3.1	4.6	210.3	4.5	-8.1	4.7	11.5	1.4	9.6	12
SIO	2.3	3.2	22.6	3.1	-100.5	3.3	-1.2	1.0	6.5	11

In Table 5, the combined SINEX solutions produced by JPL, MIT, and NCL are compared after 7-parameter transformations. Shown are average coordinate rms (this time, unlike in Table 4, the height component is included). The agreement is very good, approaching 5-mm coordinate rms for the 12 ITRF stations.

Table 5: RMS coordinate differences of the combined SINEX solutions by JPL, MIT, and NCL GNAACs, after a 7-parameter transformation for Wk 0848.

	All stations		*13 ITRF stations (HART down)*	
	RMS(mm)	*#*	*RMS(mm)*	*#*
JPL- MIT	84.1	84	4.9	12
MIT- NCL	12.3	83	4.3	12
NCL- JPL	13.7	85	7.9	12

The large rms obtained for all stations in the JPL-MIT comparison is likely due to incompatible antenna heights rather than wrong solutions. This demonstrates an important point that despite the SINEX design, not all ACs take the care to code antenna information correctly or even to include the mandatory `SITE/ECCENTRICITY` blocks. There are also some persistent confusions about correct antenna heights for some stations. As already pointed out in [1], it is desirable that IGS CB take on the responsibility for keeping an official, electronically readable, antenna offset file. The most convenient and logical format would be the corresponding SINEX (SITE) blocks. Relying on the RINEX file headers of individual stations is not practical for SINEX (GNAAC) processing since RINEX files are no longer used and available at this processing level. Besides, the IGS ITRF realization is defined by the set of the (13) ITRF station coordinates along with the corresponding antenna heights, and it would be more convenient when this defining (antenna height) set is in one file, maintained by one organization rather than relying on a number of organizations responsible for the 13 ITRF stations.

3 Conclusions

Despite the initial difficulties, the ITRF densification pilot project has been in operation since September 1995, thanks to collaboration and support of ACs and new GNAACs. A new challenge will be to incorporate the regional high precision networks and the coordination of the new RNAAC processing, which is scheduled for July 1, 1996. The ITRF densification project already has started to provide useful feedback to IGS processing centers, which will further improve accuracy of IGS solutions.

IGS will continue to face new challenges as a result of many new applications of the GPS technology leading to AAC specialization and generation of a variety of different products such as precise station coordinates, atmospheric and ionospheric modeling, LEO orbit determination, time synchronization, etc. The task of maintaining the compatibility and consistency of future IGS products will have to be shared by specialized AAC coordinators as it is beyond the capability of a single person.

4 Acknowledgements

The author would like to express appreciation to all AC and GNAAC colleagues for their effort and help with this project. In particular the support and help of Elmar Brockmann of CODE and Remi Ferland of EMR are greatly appreciated. They provided support at the initial sometimes difficult stages of the project.

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Status and Activities of the Central Bureau

Ruth E. Neilan
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California

1 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.

2 Activities in 1995

This was the second fully operational year for the IGS, and it was quite a busy time for the Central Bureau as well as all aspects of the Service. The Central Bureau was involved in a number of activities, some of which are highlighted below:

GLOSS Meeting: The first meeting was held with the Global Sea Level Observing System, affiliated with International Associations for the Physical Sciences of the Ocean (IAPSO). The IGS was invited by the GLOSS Group and the Permanent Service for Mean Sea Level (PSMSL), to plan a joint activity aimed at using GPS to monitor tide gauge benchmarks. At the meeting held in Bordeaux, France, February 1995, the IGS was represented by R. Neilan and J. Zumberge. The goal is to develop a methodology where GPS can be used to monitor the motion of the tide gauge and the surrounding area to decouple ground signals from the tide gauge record, i.e., so that crustal motion measurements are accounted for and are removed from the long term tide gauge measurement record of the changes in sea level.

Proceedings from 1994 Workshop: The Proceedings from the December 1994 Workshop entitled *Densification of the IERS Terrestrial Reference Frame through Regional GPS Networks* was completed, published, and distributed.

Special Topics and New Directions Workshop: The Central Bureau provided some assistance to GeoForschungZentrum for the IGS Workshop hosted in Potsdam, May 1995. One result of this workshop, and the 'Densification' workshop of December 1994 was the establishment of IGS paper and publication formats for all IGS documents and proceedings.

IGS Brochure: The Central Bureau began working on a brochure for the IGS in March of 1995. The intent was to have a well designed and informative brochure that could be distributed to describe the IGS, its purpose, and its applications. The target completion date was mid-June so that the brochures could be widely distributed at the XXI General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Boulder, Colorado.

Application to FAGS: The CB prepared an IGS membership letter application to the Federation of Astronomical and Geophysical Data Analysis Services (FAGS), part of the International Council of Scientific Unions (ICSU). The IGS letter was presented and approved at the IUGG Council Meeting, and therefore, would be forwarded to the FAGS Council for consideration. The FAGS Council Meeting was scheduled for April, 1996.

IGS Exhibit: In order to promote further information on the IGS and achieve widespread public outreach, the Central Bureau designed a traveling display that could be set up in the exhibit area of various conferences or workshops. The display includes a computer with a link to demonstrate the Central Bureau Information System (CBIS) and other aspects of the World Wide Web (www). Exhibits were set up at:

- Geological Society of America, New Orleans, November 1995
- Fall AGU, San Francisco, December 1995.

P. Van Scoy and R. Liu did a great job in getting this effort started.

First IGS Annual Report: The 1994 Annual Report was prepared, published, and widely distributed. The process of obtaining contributions from everyone was lengthy. We felt that this first Annual Report should be a very fundamental document which would include the historical development of the IGS and details about the organization and the contributing agencies. Since its distribution, numerous additional requests have been responded to for people from all over the world who have seen a copy or heard about the publication. Over 1300 copies have been distributed to date. J. Zumberge is recognized for his exceptional organization and compilation of the report, as well as the very valuable assistance from R. Liu.

IGS Presentations: The IGS CB prepared presentations to brief various groups on all aspects of the IGS. Presentations were given to:

- U.S. GPS Users Council, videoconference July 1995

- 1st Federal Civilian GPS-PPS Coordination and Users Workshop, Fort Worth Texas, August 1995.
- Mexican Geophysical Union Meeting, Puerto Vallarta, November, 1995

3 Central Bureau Information System (CBIS)

The CBIS continues to serve as the key repository of information related to the IGS. The CBIS was established in 1993 and is available via anonymous FTP or through the World Wide Web on a UNIX-based server. The CBIS provides necessary information to both IGS contributors, the public organizations and individuals who use IGS data and products. Summarized global data holdings are updated daily in the information system, indicating the source and dates of observations and how to access them. RINEXed station data are held at Data Centers, and not at the CBIS. IGS products are all accessible on the CBIS, including accurate and highly reliable IGS GPS orbits, earth rotation parameters, tracking station coordinates and velocities, and satellite and receiver clock information, etc. The directory tree showing all files available is located on the inside back cover of this report.

Anonymous FTP access is available through

`igscb.jpl.nasa.gov` (Internet address 128.149.70.171)

in the directory `/igscb`. The files `README.TXT`, `TREE.TXT` and `IGSCB.DIR` in the main directory provide on-line help and current directory and file information.

For World Wide Web users, the required URL is

`http://igscb.jpl.nasa.gov/`

The CBIS is also mirrored at the IGN in Paris, also a Global Data Center, to facilitate the access of information by the Eastern Hemisphere. All directories under `/igscb` at `igscb.jpl.nasa.gov` excepted the products subdirectory (which is already available at IGN through the data center structure) are mirrored in the directory `/pub/igscb` on the anonymous FTP server `schubert.ign.fr`. This access is currently available only by FTP, and WWW access is planned for 1996.

Requests to be included in the IGS Mail service, or questions regarding IGS Mail, the CBIS or any aspect of the IGS can also be directed to a group mail box of the Central Bureau:

`igscb@igscb.jpl.nasa.gov`

The plot of Figure 1 shows the access statistics for the CBIS during 1995. The CBIS is primarily maintained on a daily basis by Rob Liu and Mike Urban.

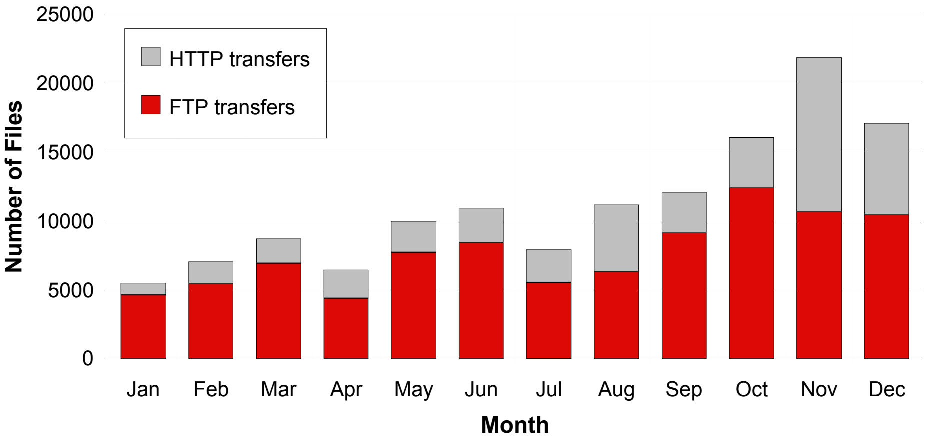

Figure 1: CBIS Access Statistics for 1995

4 Future Activities

The Central Bureau has a number of activities to focus on in 1996 that include:

- redesign and reconstruct the web page of the CBIS to make it more user friendly and easier to navigate,
- automate the generation of access statistics for the various data centers and the CBIS to log the connections and files transferred,
- support the Pilot Project for the densification
- implement a system for network and station monitoring,
- work with Operational Centers for improving data communications and data flow,
- continue to promote the extension of the network into remote areas lacking continuous GPS coverage,
- continue to investigate options for proposing the commercial data use policy for the IGS,
- update the IGS Brochure

5 IGS Publications Available at the Central Bureau

Any of the publications listed below are available through the IGS Central Bureau at Jet Propulsion Laboratory; simply contact `igscb@igscb.jpl.nasa.gov` with your request.

Special Topics and New Directions May 15–18, 1995, edited by G. Gendt and G. Dick, GeoForschungsZentrum, Potsdam, Germany. Also available from GFZ.

1994 Annual Report International GPS Service for Geodynamics, September 1995, edited by J. Zumberge, R. Liu, and R. Neilan. IGS Central Bureau, JPL Publication 95-18, Pasadena, CA.

Densification of the ITRF through Regional GPS Networks, workshop proceedings, November 30 – December 2, 1994, edited by J. Zumberge and R. Liu, IGS Central Bureau, JPL Publication 95-11, Pasadena, CA.

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

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

IGS — Monitoring Global Change by Satellite Tracking, brochure describing the IGS, June 1995, IGS Central Bureau, JPL Publication 400-552, Jet Propulsion Laboratory, Pasadena, CA.

IGS Directory, addresses and contact information for approximately 1000 people worldwide participating with or interested in the IGS. Updated annually.

IGS Resource Information, Network information, station location, specific contact information, and synopsis of IGS. Updated every six months.

IGS Network Status 1995

Ruth E. Neilan
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California

1 Current Network Configuration

The configuration of the IGS network as shown in Figure 1 demonstrates significant expansion again in 1995, incorporating eighteen new stations that fill in some of the geographically sparse areas. The agencies implementing these stations are to be congratulated and thanked for their efforts in contributing to the GPS global network, the backbone of the IGS. It is not solely the implementation of the station, which can be time consuming and logistically challenging, but the continued commitment to provide for communication costs, operations and maintenance, daily health monitoring, and on-going assurance of delivering quality data. More in-depth information on the evolution of the GPS global tracking network is discussed in [1].

In 1995, network stations have been further categorized and defined based on their use. At the end of 1995, there were over 110 stations in the network, however few agencies are actually interested in analyzing every station's data. With the increasing pressure for rapid turn around products, most of the IGS Analysis Centers rely on a subset of the stations that are optimally distributed to produce the global rapid orbits. Some of the centers then use another method to further analyze additional stations for regional or scientific applications. Based on discussions within the IGS during 1994 and 1995, any station whose data is used by three or more Analysis Centers for the purpose of orbit determination will be designated an IGS Global Station. This is reflected in the revised Terms of Reference (see IGS Organization, this volume). The Central Bureau began recording the use of all IGS stations by noting which Analysis Centers access what stations. The map of these Global Stations is shown in Figure 2. Of the eighteen stations implemented in 1995, six are already designated as Global. These six stations are: Ankara, Turkey; Chatham Island, New Zealand; Irkutsk, Russia; Kellyville, Greenland; La Plata, Argentina; Malindi, Kenya; and the Seychelles Island. A bullet after the station name in Table 1 designates each Global Station.

Table 1: Permanently Operating Stations of the IGS Network (Stations implemented in 1995 are highlighted in **bold**, all locations in decimal degrees)

	Station	*Country*	*GPS Receiver*	*Lon (E)*	*Lat (N)*	*Agency*
1	Albert Head ♦	Canada	R SNR-8000	- 123.48	48.38	NRCan/GSC
2	Algonquin ♦	Canada	R SNR-8000	- 78.07	45.95	NRCan/GSD
3	**Ankara** ♦	**Turkey**	R SNR-8000	32.83	39.92	IfAG
4	AOA Westlake†	USA	R SNR-8000	- 118.83	34.16	NASA/JPL
5	Arequipa ♦	Peru	R SNR-8000	- 71.48	- 16.45	NASA/JPL-GSFC
6	**Auckland**	**New Zealand**	R SNR-8000	174.19	- 35.43	IGNS/DOSLI/JPL
7	Bangalore ♦	India	R SNR-8000	77.57	13.02	CMMACS/JPL/CU
8	Bermuda ♦	United Kingdom (Is.)	R SNR-8000	- 64.65	32.35	NOAA
9	Bishkek	Kyrghyzstan	R SNR-8000	74.69	42.68	UNAVCO
10	Blythe†	USA	A ZX-II3	- 114.71	33.43	PGGA
11	Bogotá	Colombia	R SNR-8000	- 74.08	4.64	NASA/JPL
12	Bommer Canyon†	USA	A ZX-II3	- 117.80	33.44	PGGA
13	Borowiec ♦	Poland	R SNR-8000	17.07	52.09	ALO
14	Brand†	USA	R SNR-8000	- 118.28	34.19	PGGA
15	Brasília	Brazil	R SNR-8000	- 47.88	- 15.94	IBGE/NASA/JPL
16	Brussels ♦	Belgium	R SNR-8000	4.36	50.80	ROB
17	Caltech Pasadena†	USA	R SNR-8000	- 118.13	34.14	NASA/JPL
18	Carrhill†	USA	R SNR-8000	- 120.43	35.71	NASA/JPL
19	Casey ♦	Antarctica	R SNR-8100	110.53	- 66.27	AUSLIG
20	**Catalina Island**†	**USA**	R SNR-8000	- 118.24	33.23	NASA/JPL
21	Catalonia	Spain	T 4000 SST	2.00	42.00	ICC
22	**Chatham Island** ♦	**New Zealand**	R SNR-8000	- 176.70	- 44.00	IGNS/DOSLI/JPL
23	Chilao Flats†	USA	A ZX-II3	- 118.03	34.33	PGGA
24	**China Lake**†	**USA**	A ZX-II3	- 117.81	35.98	PGGA
25	Davis	Antarctica	R SNR-8100	77.97	- 68.57	AUSLIG
26	Easter Island	Chile	R SNR-8000	- 109.38	- 26.99	NASA/JPL
27	Fairbanks ♦	USA	R SNR-8	- 147.48	64.97	NASA/JPL-GSFC
28	Fortaleza ♦	Brazil	R SNR-8000	- 38.58	- 3.75	NOAA
29	Goldstone† ♦	USA	R SNR-8	- 116.78	35.23	NASA/JPL
30	Grasse	France	R SNR-8100	6.85	43.73	CNES
31	Graz	Austria	R SNR-8C	15.48	47.07	ISRO
32	Greenbelt	USA	R SNR-8000	- 76.82	39.02	NASA/JPL-GSFC
33	Guam ♦	USA (Mariana Is.)	R SNR-8000	144.87	13.59	NASA/JPL/IRIS
34	Hartebeesthoek ♦	South Africa	R SNR-8	27.70	- 25.88	CNES
35	Harvest†	USA	R SNR-8000	- 120.68	34.29	NASA/JPL
36	Herstmonceux	United Kingdom	R SNR-8C	0.33	50.87	RGO
37	Hobart ♦	Australia	R SNR-8100	147.43	- 42.80	AUSLIG
38	Holcomb Ridge†	USA	A ZX-II3	- 117.85	34.46	PGGA
39	**Irkutsk** ♦	**Russia**	R SNR-8000	104.00	52.16	DUT
40	Jozefoslaw	Poland	T 4000 SSE	21.03	52.08	WUT
41	JPL Mesa Pasadena†	USA	R SNR-8100	- 118.17	34.20	NASA/JPL
42	**Kellyville** ♦	**Greenland**	R SNR-8000	- 50.94	66.99	NOAA
43	Kerguélen ♦	France (Is.)	R SNR-8C	70.26	- 49.35	CNES
44	Kiruna ♦	Sweden	R SNR-8100	20.25	67.88	ESA/ESOC
45	Kitab ♦	Uzbekistan	R SNR-8000	66.89	39.13	GFZ
46	Kokee Park ♦	USA (Hawaiian Is.)	R SNR-8	- 159.67	22.17	NASA/JPL
47	Kootwijk ♦	Netherlands	R SNR-8	5.80	52.17	DUT
48	Kourou ♦	French Guiana	R SNR-8C	- 52.62	5.13	ESA/ESOC
49	Lake Matthews†	USA	T 4000 SSE	- 117.44	33.68	PGGA
50	Lamkowko	Poland	R SNR-8000	20.67	53.89	OUAT
51	**La Plata** ♦	**Argentina**	R SNR-8000	- 57.95	- 34.90	GFZ
52	Lhasa	China	R SNR-8000	91.12	29.41	IfAG
53	Long Beach†	USA	R SNR-8100	- 118.20	33.79	NASA/JPL
54	Longdon Yard†	USA	A ZX-II3	- 118.00	34.02	PGGA
55	Macquarie Island ♦	Australia	R SNR-8100	158.94	- 54.50	AUSLIG
56	Madrid ♦	Spain	R SNR-8	- 4.25	40.42	NASA/JPL
57	**Malindi** ♦	**Kenya**	R SNR-8C	40.13	- 3.23	ESA/ESOC
58	Mammoth Lakes	USA	R SNR-8000	- 118.95	37.64	NASA/JPL
59	Maspalomas ♦	Canary Islands	R SNR-8100	- 15.63	27.77	ESA/ESOC
60	Matera ♦	Italy	R SNR-8	16.70	40.63	ASI
61	McDonald ♦	USA	R SNR-8000	- 104.02	30.67	NASA/JPL

Table 1: (continued)

	Station	*Country*	*GPS Receiver*	*Lon (E)*	*Lat (N)*	*Agency*
62	McMurdo ♦	Antarctica	R SNR-8000	166.67	- 77.85	NASA/JPL
63	Mendeleevo ♦	Russia	T 4000 SSE	37.22	56.03	IMVP/DUT
64	Metsahovi ♦	Finland	R SNR-8C	24.38	60.22	FGI
65	Monument Peak†	USA	A ZX-II3	- 116.42	32.72	PGGA
66	Mount Wilson†	USA	R SNR-8100	- 118.06	34.23	NASA/JPL
67	North Liberty ♦	USA	R SNR-8000	- 91.50	41.80	NASA/JPL-GSFC
68	**Noto**	**Italy**	R SNR-8100	14.99	36.88	ASI
69	Ny Ålesund	Norway	R SNR-8	11.85	78.92	SK
70	Oat Mountain†	USA	R SNR-8100	- 118.60	34.33	NASA/JPL
71	O' Higgins ♦	Antarctica	R SNR-8000	- 59.90	- 63.32	IfAG
72	Onsala ♦	Sweden	R SNR-8000	11.92	57.38	OSO
73	Padova	Italy	T 4000 SSE	11.88	45.41	UPAD
74	Palos Verdes†	USA	T 4000 SSE	- 118.40	33.57	PGGA
75	Pamatai ♦	Tahiti	R SNR-800	- 149.57	- 17.57	CNES
76	Pecny	Czech Republic	T 4000 SST	14.79	49.91	GOPE
77	Penticton ♦	Canada	R SNR-8000	- 119.62	49.32	NRCan/GSC
78	Perth ♦	Australia	R SNR-8100	115.82	- 31.97	ESA/ESOC
79	Pie Town ♦	USA	R SNR-8000	- 108.12	34.30	NASA/JPL-GSFC
80	Pinemeadow†	USA	T 4000 SST	- 116.61	33.61	PGGA
81	Pinyon Flat†	USA	A ZX-II3	- 116.45	33.60	PGGA
82	Potsdam ♦	Germany	R SNR-8000	13.07	52.38	GFZ
83	Quincy	USA	R SNR-8000	- 120.93	39.97	NASA/JPL
84	**Reykjavík**	**Iceland**	R SNR-8000	- 21.51	64.09	IfAG
85	Richmond ♦	USA	R SNR-8000	- 80.38	25.60	NOAA
86	**Saddle Peak†**	**USA**	R SNR-8000	- 118.65	34.06	NASA/JPL
87	**Saint Croix**	**USA (Virgin Is.)**	R SNR-8000	- 64.43	17.40	NASA/JPL
88	Saint John's ♦	Canada	R SNR-8000	- 52.68	47.60	NRCan/GSD
89	**San Fernando**	**Spain**	T 4000 SSE	- 6.21	36.46	ROA
90	Santiago ♦	Chile	R SNR-8	- 70.67	- 33.15	NASA/JPL/CEE
91	Scripps†	USA	A ZX-II3	- 117.25	32.87	PGGA
92	**Seychelles** ♦	**Seychelles**	R SNR-8000	55.50	- 4.68	NASA/JPL/IDA
93	Shanghai ♦	China	R SNR-8100	121.20	31.10	SAO/NASA/JPL
94	**Taejon**	**South Korea**	T 4000 SSE	127.26	36.20	KAO
95	Taipei ♦	Taiwan	R SNR-800	121.63	25.03	IESAS
96	Thule ♦	Greenland	R SNR-8000	- 68.73	76.56	NASA/GSFC-JPL
97	Tidbinbilla ♦	Australia	R SNR-8	148.97	- 35.38	NASA/JPL
98	Tromsø ♦	Norway	R SNR-8	18.93	69.67	SK
99	Tsukuba ♦	Japan	R SNR-8100	140.08	36.10	GSI
100	UCLA Los Angeles†	USA	R SNR-8000	- 118.44	34.07	NASA/JPL
101	USC Los Angeles†	USA	R SNR-8000	- 118.29	34.02	NASA/JPL
102	Usuda ♦	Japan	R SNR-8000	138.37	36.13	ISAS
103	Vandenberg†	USA	A ZX-II3	- 120.48	34.55	PGGA
104	Villafranca ♦	Spain	R SNR-8100	- 3.95	40.44	ESA/ESOC
105	Westford ♦	USA	R SNR-8000	- 71.48	42.62	NOAA
106	Wettzell ♦	Germany	R SNR-800	12.87	49.13	IfAG
107	**Whittier College†**	**USA**	R SNR-8000	- 118.04	33.97	NASA/JPL
108	Yaragadee ♦	Australia	R SNR-8	115.33	- 29.03	NASA/JPL
109	Yellowknife ♦	Canada	R SNR-8000	- 114.47	62.47	NRCan/GSD
110	Yucaipa†	USA	A ZX-II3	- 117.10	34.04	PGGA
111	Zimmerwald	Switzerland	T 4000 SSE	7.45	46.87	BfL
112	Zwenigorod ♦	Russia	R SNR-8000	36.54	55.46	GFZ

♦ Global site: processed by three or more IGS Analysis enters, one of which is on another continent

† SCIGN site (Southern California Integrated GPS Network)

R: Rogue, A: Ashtech, T: Trimble

It should be noted that there are currently more high-precision GPS stations operating than those listed by the IGS. There are a number of dense GPS arrays being implemented, such as the 600-station Japanese Geographical Survey Institute (GSI) Array and the proposed 250 station Southern California Integrated GPS Network (SCIGN). Other countries are also implementing networks

Table 2: Future or Proposed IGS Stations

	Station	*Country*	*GPS Receiver*	*Lon (E)*	*Lat (N)*	*Agency*
1	Alma-Ata	Kazakhstan		77.08	43.19	UNAVCO
2	Ascension	United Kingdom (Is.)		-14.22	-7.57	NASA/JPL/IDA
3	Bandung	Indonesia		107.22	-7.00	DUT
4	Bar Giyyora	Israel	R SNR-8000	35.08	31.72	NASA/JPL-GSFC
5	Changchun	China		125.42	43.92	SAO/NASA/JPL
6	Cocos Island	Australia		96.83	-12.20	AUSLIG
7	Darwin	Australia		131.13	-12.85	AUSLIG
8	Darmstadt	Germany		8.67	49.85	ESA/ESOC
9	Diego Garcia	Island		72.25	-7.20	NASA/JPL/IDA
10	Dudinka	Russia	R SNR-8000	85.42	69.15	GFZ
11	Ensenada *	Mexico		-116.30	32.00	NASA/JPL-UNAVCO
12	Galapagos Islands *	Ecuador	R SNR-8000	-89.62	0.90	NASA/JPL
13	Höfn	Iceland		-15.00	64.50	SK
14	Hyderabad	India		79.28	17.29	UB
15	Ishigaki	Japan		125.00	24.25	WING
16	Kunming	China		102.83	25.17	CAS/NASA/JPL
17	Krasnoyarsk *	Russia	R SNR-8000	93.12	56.13	GFZ
18	Kwajalein	USA (Marshall Is.)		167.47	9.38	NASA/JPL
19	La Paz	Bolivia		-68.50	-17.00	NASA/JPL
20	Libreville	Gabon		9.27	0.23	CNES
21	Limón	Costa Rica		-83.02	10.00	NASA/JPL-UNAVCO
22	Manila	Philippines		121.00	14.37	WING
23	Marcus	Japan		155.00	24.00	WING
24	Mauna Kea	USA (Hawaiian Is.)		-155.30	19.52	NASA/JPL
25	Mbarara	Uganda		30.70	-0.60	IDA/NASA-JPL
26	Petropavlosk-Kam.	Russia	R SNR-8000	158.65	53.13	GFZ
27	Simeiz	Ukraine		34.00	44.40	IAA
28	Tristan da Cunha	United Kingdom (Is.)		-12.50	-35.50	NASA/JPL/POL
29	Urumqi *	China	R SNR-8000	87.72	43.82	GFZ/NBSM
30	Villafranca	Spain		2.67	42.25	ESA/ESOC
31	Vladivostok	Russia		131.47	43.06	WING
32	Wellington	New Zealand		174.78	-41.27	DOSLI/AUSLIG
33	Wuhan *	China		114.25	30.50	WTU/NGS
34	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.

for their national mapping, land information and civil aviation purposes, such as the Continuously Operating Reference Stations (CORS) and Federal Aviation Administration (FAA) networks in the US, the Canadian Active Control System (CACS), and networks in Australia, Sweden, Norway, Central Europe, etc., to name a few. The goal of the IGS is to develop accessibility to information concerning any continuously operating GPS station and to make this information available to the IGS community. This would entail a meta-data type catalog or cross referencing that would log in a simple but complete manner all of the high-precision GPS stations.

2 Monitoring Network Performance

With the increasing need for timely data delivery from the IGS network there comes the need to improve the performance monitoring of the network, so that problems at the stations can be detected and resolved quickly. The Central Bureau has been urged to implement a system of monitoring the health of the IGS network, including advisory notification and assistance in resolving performance problems. It is important that users have information on how stations perform so that they can adjust their processing as needed, for example if one of the constrained stations is inoperable. By categorizing the Global Stations, the IGS CB plans to implement improved monitoring over the next year which is a key step to achieving a healthy and robust tracking network.

3 Space Flight Support

Four stations of the IGS network were configured to provide required high-precision, high-rate GPS ground tracking support for the GPSMET space flight mission. This mission, GPS METeorology, utilizes the GPS data to estimate the delays through the Earth's atmosphere as the GPS satellite 'sets', i.e., as the GPS signals received by GPSMET from the GPS satellites pass through the limb of the Earth's atmosphere. These data have been successfully used to recover pressure and temperature profiles that compare very favorably with the ground-based radiosonde data. With the potential of future global coverage from additional GPSMET-type satellites, this GPS radio occultation technique can positively impact weather and climate applications. The ground stations directly involved in the experiment are Fairbanks, Alaska; Potsdam, Germany; Tidbinbilla, Australia; and Kokee Park, Hawaii. They were configured to return 1-second data over standard Internet lines using a unique method to reduce the data volume. Additional stations will be configured as needed to support GPSMET or other similar missions and will not impact the standard data flow to the IGS. Other IGS stations were used for the GPSMET satellite precise orbit determination process.

4 Meteorological Equipment at IGS Stations

Discussions at the Special Topics Workshop in Potsdam pointed to augmenting a number of the IGS stations with high quality meteorological sensors providing information useful for atmospheric applications, both weather forecasting and climate change monitoring. It seems timely for the IGS to begin planning such additional ancillary equipment and support the retrieval of the ancillary data files. Continued development in this area is seen for 1996.

References

[1] J. F. Zumberge, R. Liu, and R. E. Neilan, *International GPS Service for Geodynamics 1994 Annual Report*, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena CA, 1995, JPL Publication 95–18.

Figure 1: Operational Stations of the IGS GPS Tracking Network at the end of 1995

Figure 2: Global Stations of the IGS Tracking Network, 1995. These stations are processed by three or more IGS Analysis Centers, one of which is on another continent.

Analysis Center Reports

Scripps Orbit and Permanent Array Center 1995 Report to IGS

Peng Fang and Yehuda Bock
Scripps Institution of Oceanography
University of California San Diego
La Jolla, California, USA

1 Introduction

In the past year, the Scripps Orbit and Permanent Array Center [1] (SOPAC) has continued with its best effort to participate in IGS activities as a Global Analysis Center (AC), Global Data Center (GDC), as well as Regional Data Center (RDC). This report will cover most functions of these centers. However, we will omit the descriptions of our processing procedures. The general strategy can be found in our previous report to IGS [1]. Only the changes or additions will be given in this report.

SOPAC maintains a strong tie with the MIT group (R.W. King, T.A. Herring, S. McClusky) and Australian National University (P. Tregoning) who made significant contributions to our activities reported here.

In this report, we would like to share some of our findings in three particular areas of relevance to the IGS: (1) predicted orbits, (2) GPS-SAR integration, and (3) site stability studies.

2 Routine Processing

From August of 1995 (GPS week 0814), we added an extra step in our regular weekly data analysis to produce, in software-independent exchange (SINEX) format, a global solution (with selected European sites included due to their long and stable history of observations) with extremely loose constraints. Independent analysis [2] shows that our solutions are of very high quality, at the 5 mm rms level with respect to ITRF93 and at the 3 mm level with respect to the 7 AC combined solution (Figure 1).

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[1] SOPAC permanent staff includes Yehuda Bock, Director; Jeff Behr, Staff Research Associate; Jeff Dean, Programmer Analyst; Peng Fang, Specialist; and, Rosemary Leigh, Research Project Assistant. Scripps researchers affiliated with SOPAC in 1995 are Jie Zhang, a graduate student, Jeff Genrich a postgraduate researcher, and Paul Tregoning a postgraduate researcher (now at Australian National University).

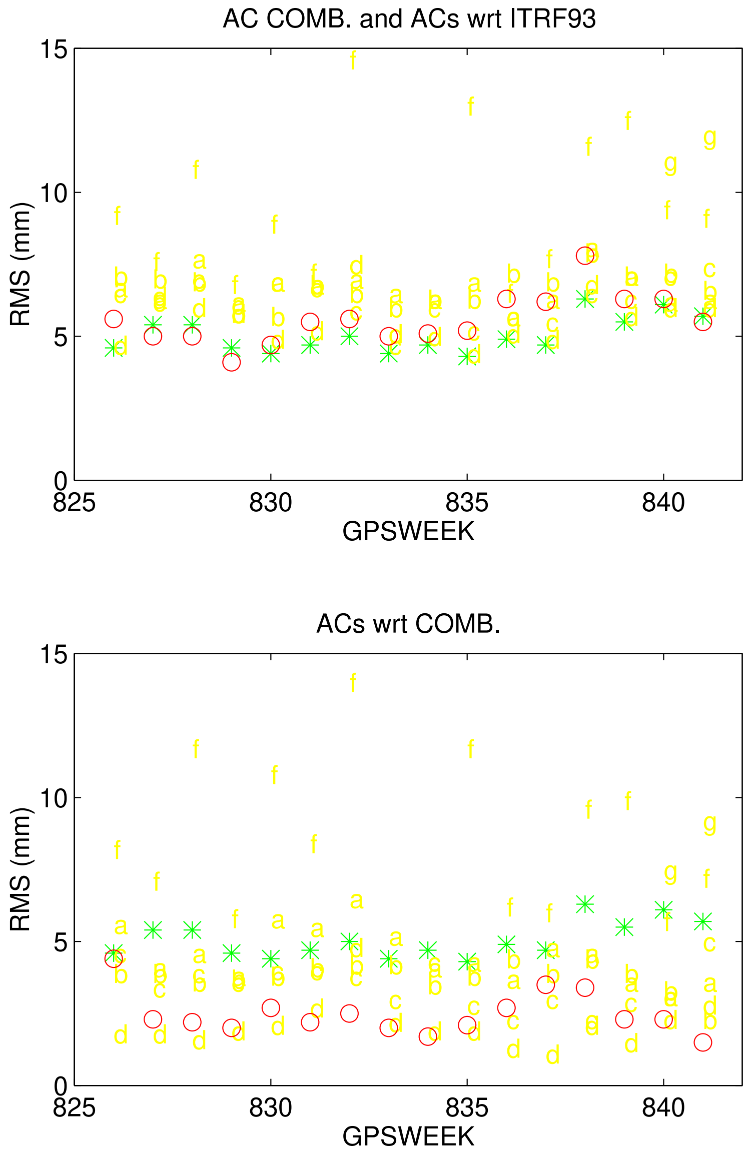

Figure 1: Comparison of SIO weekly SINEX with respect to ITRF93 and AC combined. The symbol '*' denotes the rms series of AC combined, symbol 'o' denotes that of SIO. Letters are used for other centers.

Owing to the improvements in the global network configuration, data quality, our processing software GAMIT [3]/GLOBK [4], the processing strategy, and many other factors, SOPAC products have steadily improved over the last year. The current regular[2] orbit precision is at 10-cm level compared to the IGS final orbit; rapid[3] orbit precision is at 15 cm. The daily EOP estimates are stabilized with an rms of 0.55 cm for pole-x and 0.51 cm for pole-y with respect to IERS-B.

3 Processing strategy modifications

Along with the increased global network coverage, we started, from the middle of May 1995, using a distributed processing strategy in our regular daily global processing, of which the efficiency has been greatly improved and the overall quality of the solutions is somewhat improved. The global network is divided into two subnets (Figure 2), roughly north-west sites in one and south-east sites in the other. Each subnet consists of up to 32 stations including 4–5 common ones with a set of substitutes in case that any of the first choices are not available. Another change is the number of iterations required per solution. Two iterations were required for convergence when single-network strategy was used while the new scheme requires only one iteration. It should be noted here that even this iteration is redundant more than 90% of the time due to the fact that all *a priori* information as well as data editing procedures have been considerably improved along the way. Currently this strategy is applied to reprocessing the data before May 1995 in order to provide a uniform solution series for numerous investigations. One of the changes in our rapid processing is the site selection scheme. Along with the improved global data availability, an optimized site selection scheme is designed to ensure the best global coverage within a network size limited by processing speed. In this site selection scheme, a site list is constructed in such a way that higher priority is given first to the upper sites in any column, and then to the leftmost in any row. A shell script descends through the rows, picking up only the first available site in any row. This scheme is illustrated in Table 1.

Location importance and data quality should be considered regardless of data availability in each row. Data availability should be considered column-wise in addtion to location importance and data quality. The site list needs to be updated from time to time when new sites are included in the network.

Currently, we set our network size between 18 to 26 sites. The automatic procedure will therefore delay the start of rapid processing until 18 sites or more are available, or initiate the processing as soon as 26 sites are available. It should be noted that (1) the upper limit (26) is set according to our hardware limitation; (2) the lower limit (18) is set according to the current availability of good quality data (relatively well distributed). According to our experience, 12–14 well distributed sites is the absolute minimum.

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[2] The regular solution is generated with a 4- to 7-day delay for IGS rapid (final) combination solution with 10- to 14-day (28-day) delay.

[3] SIO rapid [5] solution is generated with a 14- to 16-hour delay for IGS super rapid combination solution with 24- to 36-hour delay.

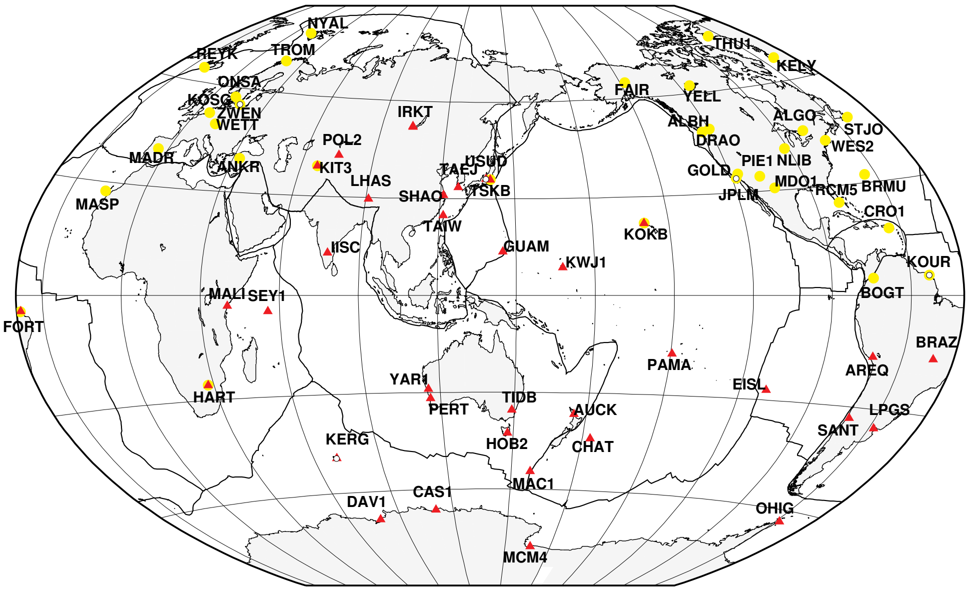

Figure 2: Subnetworks of SIO global daily solution in distributed processing mode. Open circles belong to subnet 1 and triangles belong to subnet 2 with 5 first-choice common sites which have a set of backup sites denoted with small circles.

Table 1: Site selection scheme for distributed processing

Site list	Availability 1	Resulting selection 1	Availability 2	Resulting selection 2
aaa0 aaa1	aaa0 aaa1	aaa0	aaa1	aaa1
bbb0				
ccc0 ccc1 ccc2	ccc1 ccc2	ccc1	ccc2	ccc2
ddd0 ddd1	ddd1	ddd1	ddd0	ddd0
eee0 eee1	eee0 eee1	eee0	eee0 eee1	eee0
fff0 fff1				
......				
......				

Another change in the rapid processing is again the reduced number of iterations which saves more than 2 hours of processing time.

4 Other related efforts

As part of our support of world-wide geodynamic programs, we (including Bob King and Tom Herring of MIT) participated in the super high density array (600 sites) processing strategy planning and software integration at GSI in Japan. We have also provided GPS processing setup/training at University of Hawaii, and at CRI in New Zealand. In addition, numerous in-house training and consultations were provided to many outside scientists.

Since the beginning of 1995, we began estimating precipitable water vapor (PW) at a select group of NOAA Continuously Operating Reference Stations (CORS). After initial successes [6] with our approach described in [7], we began to to estimate PW on a regular basis in July 1995 as part of our rapid daily processing. Figure 3 shows a 3-month time series of PW as a result of using SOPAC rapid products in near real time. This completely hands-off automatic system will be transferred to the Forecasting Systems Laboratory (FSL) facility in 1996 as an absolute surface GPS meteorological package for the US National Weather Prediction System.

5 Data Archive

5.1 Data content

SOPAC maintains data in basically three categories: observations, products/solutions, and related information. The daily volume of observations is about 180 Mb (160 for RINEX and meteorological data, 20 for raw data); the volume is 50 Mb per day for solutions (6 subnets) and 27 Mb per week for global products. The current online capacity for archive use is about 80 Gb including 60 Gb of optical jukebox storage. This capacity enables us to hold the last 120 days of data online. The most recent 10 days of data are stored on magnetic disk media in order to provide faster and more reliable access.

The directory structure is as follows:

`raw/`*`yy`*`data/`*`ddd`* (*yy* denotes year, *ddd* denotes day of year) receiver raw image files (binary format)

`RINEX/`*`yy`*`data/`*`ddd`* global and regional RINEX files, met files, broadcast ephemerides (ASCII)

`global/`*`yy`*`data/`*`ddd`*`[m]/[rapid]` regular global solutions; rapid global solutions under rapid subdirectory. regular met solutions; rapid met solutions under rapid subdirectory.

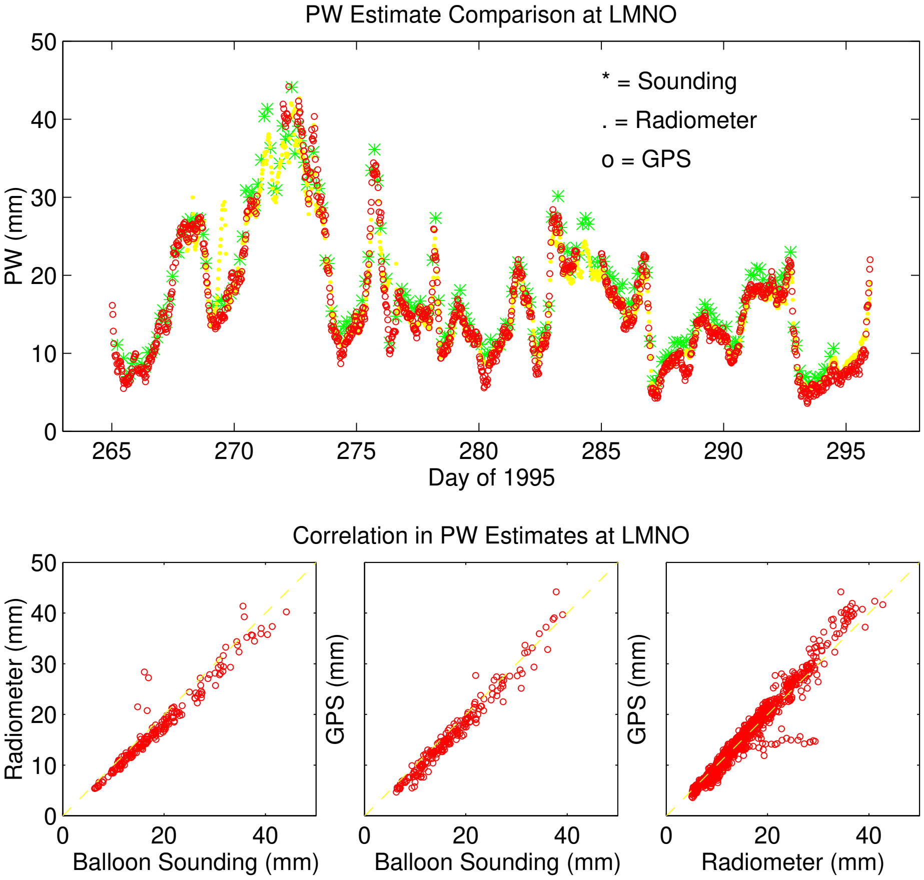

Figure 3: Comparison of near real time GPS absolute precipitable water vapor (PWV) estimation with balloon sounding and water vapor radiometer (ground based). Correlations between the GPS, sounding, and water vapor radiometer.

`regional/`*`yy`*`data/`*`ddd`*[d|e|p] regular DGGA[4](d), EURA[5].(e), PGGA4 (p) solutions

`products/`*`wwww`* (*wwww* denotes GPS week, e.g., `0800`) precise ephemerides, EOP, and SINEX solutions of IGS and ACs

`combination/`*`wwww`* SIO weekly combination solutions

The server address is `toba.ucsd.edu` (132.239.152.80). Due to limited online storage capacity, some older data may be off line. These can be loaded upon electronic request via our WWW home page (`http://toba.ucsd.edu`) or email (`pgga@pgga.ucsd.edu`). The response time is normally within one working day. Jeff Behr and Jeff Dean maintain the SOPAC data archive [8].

5.2 Data flow

Figure 4 depicts the SOPAC data collection, archive, and information service system. Automatic data collection, retrieval, and internal reporting are scheduled at 2-hour intervals for any data unarchived or with size less than 50% for files up to 2 days old. A special data retrieval procedure for the past 30 days is scheduled once per day in order to catch any missed or re-posted data. The weekly data holding and weekly processing reports are posted once per week. The rapid products are posted daily.

5.3 Usage statistics

Figure 5 shows the external usage statistics of the SOPAC server system.

6 Predicted Orbits and Applications

We experimented with various prediction schemes before and after we started with our rapid orbit service in Jan 1995 [5]. The simplest one is to extrapolate orbits 24 hours ahead using the previous day's solution. Here we name this procedure pred-A. The precision of pred-A orbits is not adequate for some very demanding applications though they had been used quite successfully by several researchers as well as by local surveyors. Furthermore, they can be obtained with little added effort and can be used for the next day's *a priori* orbits (much better than broadcast orbits). The major drawback is that extrapolation is based on a rapid solution which is less precise than the regular orbits because of poorer global tracking coverage. In addition, once-per-rev orbital parameters can not be well solved for with only 24 hours of data. It should be pointed out that in the majority of cases the extrapolated orbits are at the 50- to 90-cm level for most satellites, with the exception of a few problematic and/or

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[4] The Southern California Integrated GPS Network (SCIGN) is composed of the Dense GPS Geodetic Array (DGGA) in the Los Angeles Basin and the more regionally based Permanent GPS Geodetic Array (PGGA).

[5] Most of the Euopean sites are processed in a regional subnetwork (EURA)

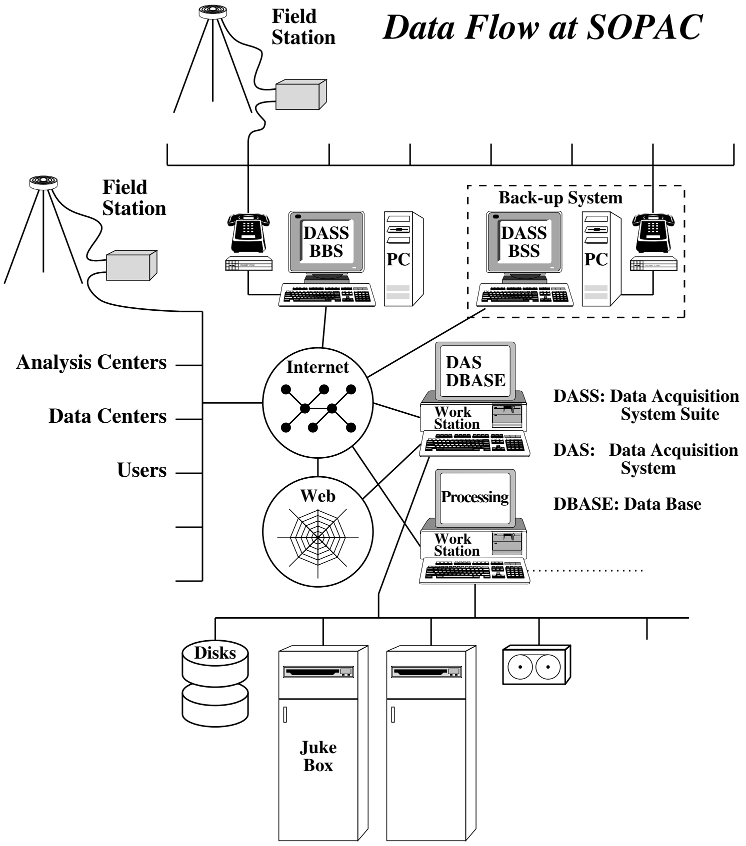

Figure 4: Data flow chart of SOPAC data collection and server system.

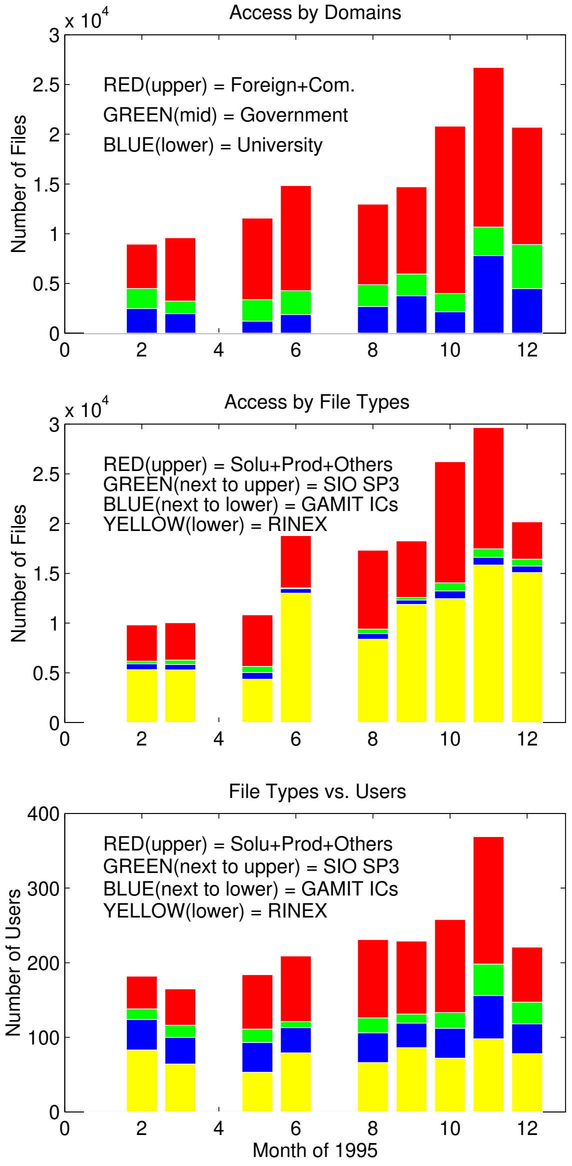

Figure 5: External usage statistics of SOPAC data archive system. Note the number of files served in the top figure (sorted by domains) is actually less than the real number since there are many unsolvable IP addresses.

eclipsing satellites, for which the mismodeling can cause extrapolated orbital errors as large as a few meters.

Orbits estimated from longer arcs (24 + 24 and later 24 + 12) were also tried, referred to here as pred-B. But the improvement was negated by stressing severely our computational resources at that time which caused delays in delivery of both rapid and predicted orbits.

P. Tregoning while visiting SIO implemented a scheme that combines the orbits from the rapid solutions of the previous two days to estimate initial conditions for the predicted time range. Here we call it pred-C. This scheme has the advantage of optimizing computer resources and gaining some precision in the prediction. The shortcoming of this scheme is that the strength of the observations is not fully utilized in the orbital parameter estimation process, and therefore it is still subject to the 'run-away' error due to mismodeling. Pred-C has been in use since August 1995. To provide some redundancy, pred-A orbits are always generated, which are then replaced by pred-C orbits as they become available.

Tregoning devised a second scheme described in [9] which uses the full previous two days of data, plus data available up to about about 21 hours of the current day. A long arc solution is generated from which the orbits are extrapolated to the next day. Here we call it pred-D. Of the 4 schemes that we experimented with, it is the only one that that achieves a fully real-time orbital prediction. Figure 6 illustrates the differences among these schemes.

Since the details of the pred-D scheme are described in [9], we would like to examine only three aspects of the prediction here.

6.1 The impact of network coverage on the quality of orbital predictions

When we began experimenting with pred-D there were only two organizations (U.S. CORS and Canadian EMR) collecting observations at subdaily intervals (as is well known, the IGS provides data in full 24-hour blocks — 0000 to 2400 UTC). However, the U.S. CORS and Canadian sites are all located in North America which is not ideal for global orbit determination. Therefore, as a first step, we studied how much improvement could be expected by including observations from other parts of the world. The sites managed by AUSLIG were identified as a potential source of data. Two sets of predictions for six consecutive days (called pred-1 and pred-2 here) were computed (simulating real time conditions, after-the-fact), one with AUSLIG data and one without.

Figure 7 shows the orbit overlap comparison with respect to IGS final orbits. On day 308, the satellite PRN09 was problematic and not included in the IGS combined orbit. From this comparison, it is clear that (a) by only using North American data, it is possible to achieve 50-cm accuracy for real-time orbital predictions, and (b) by including observations from the Southern Hemisphere, the predicted real time orbit may achieve 20- to 30-cm accuracy.

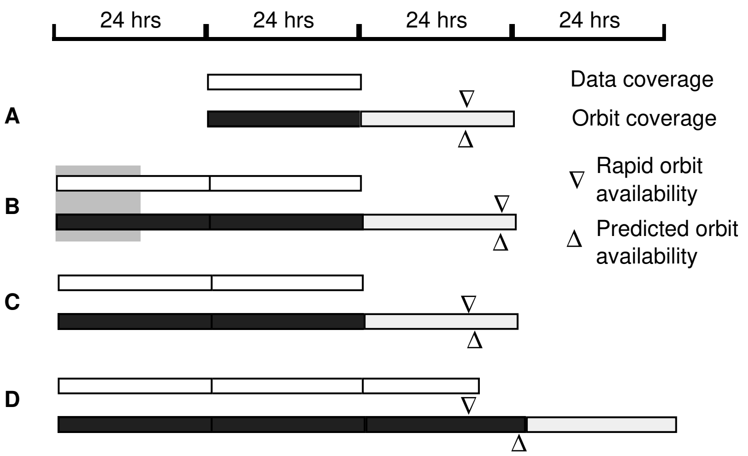

Figure 6: Orbital Prediction Schemes. Pred-A/B/C can only provide a few hours of real time orbit with sufficient precision while Pred-D can provide a full 24 hours of real time orbit coverage.

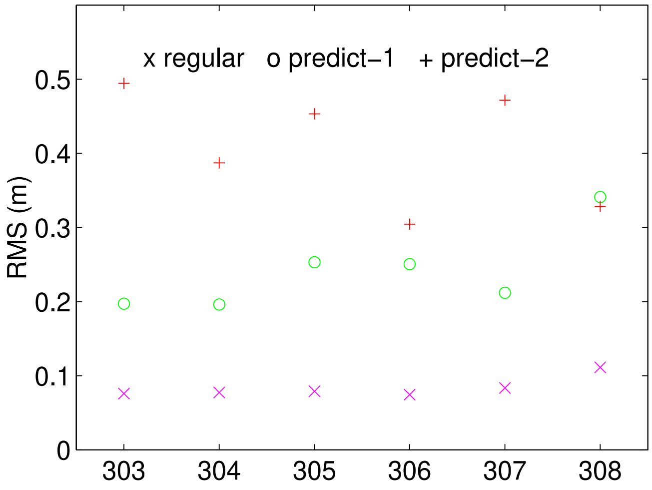

Figure 7: Orbit overlap comparison of prediction with/without AUSLIG data included, regular with respect to IGS final.

6.2 The impact of orbit quality on absolute positioning and baseline length determination

Two regional networks, DGGA and EURA were chosen to test orbit quality. Baseline lengths range between 10 and 130 km for the former and 50 and 3400 km for the latter. The time series we show below are average cases.

Figure 8 shows the effect of orbit prediction error on the absolute position time series for sites AOA1 and CLAR (in the small-scale DGGA), and for sites BRUS and METS (in the large-scale EURA network). From these cases, we see (a) pred-1 and pred-2 data sets give basically identical results, and (b) both pred-1 and pred-2 are only slightly poorer in the vertical component, compared to positions computed with regular orbits.

Figure 9 shows the effect of orbit prediction error on baseline lengths compared to the regular solution for DGGA and EURA. We conclude that (a) both pred-1 and pred-2 data sets give basically identical results for small-scale regional networks. Differences with respect to the regular solutions are less than 1 mm, (b) the baseline precision for both pred-1 and pred-2 is at the 1.5-ppb level for baseline lengths are up to 3500 km (the scatters of pred-1 come from day 308 due to cleaning problem, which should be treated as an exception), (c) there is a noticeable scaling error for both pred-1 and pred-2, which can be seen from day 307 (Figure 10). The scaling error has not yet been fully investigated.

6.3 The impact of orbit quality on tropospheric delay estimation

Since the impact of orbit quality on tropospheric delay estimates for small networks is small, here we will only look at the differences for larger networks, the EURA for example. Figure 11 shows the zenith neutral delay (ZND) differences using pred-1 and pred-2 orbits compared to the regular orbits. From this figure, of which the first three sites are chosen to represent typical cases, it is clearly shown that (a) the ZND estimates from both pred-1 and pred-2 differ from the ones using regular orbits by only few mm (or sub-mm for PW), (b) there are no biases in the ZND estimates compared to the regular orbits, at the sub-mm level. These results indicate that the predicted orbits can be safely used to estimate real time precipitable water for weather forecasting.

7 Site Stability

Site stability directly concerns the IGS's ability to achieve its long-term goals in establishing a global reference frame and estimating site velocities at major plate boundaries. J. Zhang was given the task to investigate the site stability problem using continuous data from 10 PGGA sites for the period between the 28 June 1992 Landers earthquake and the 17 January 1994 Northridge earthquakes. We would like to highlight the relevent findings of this work [10].

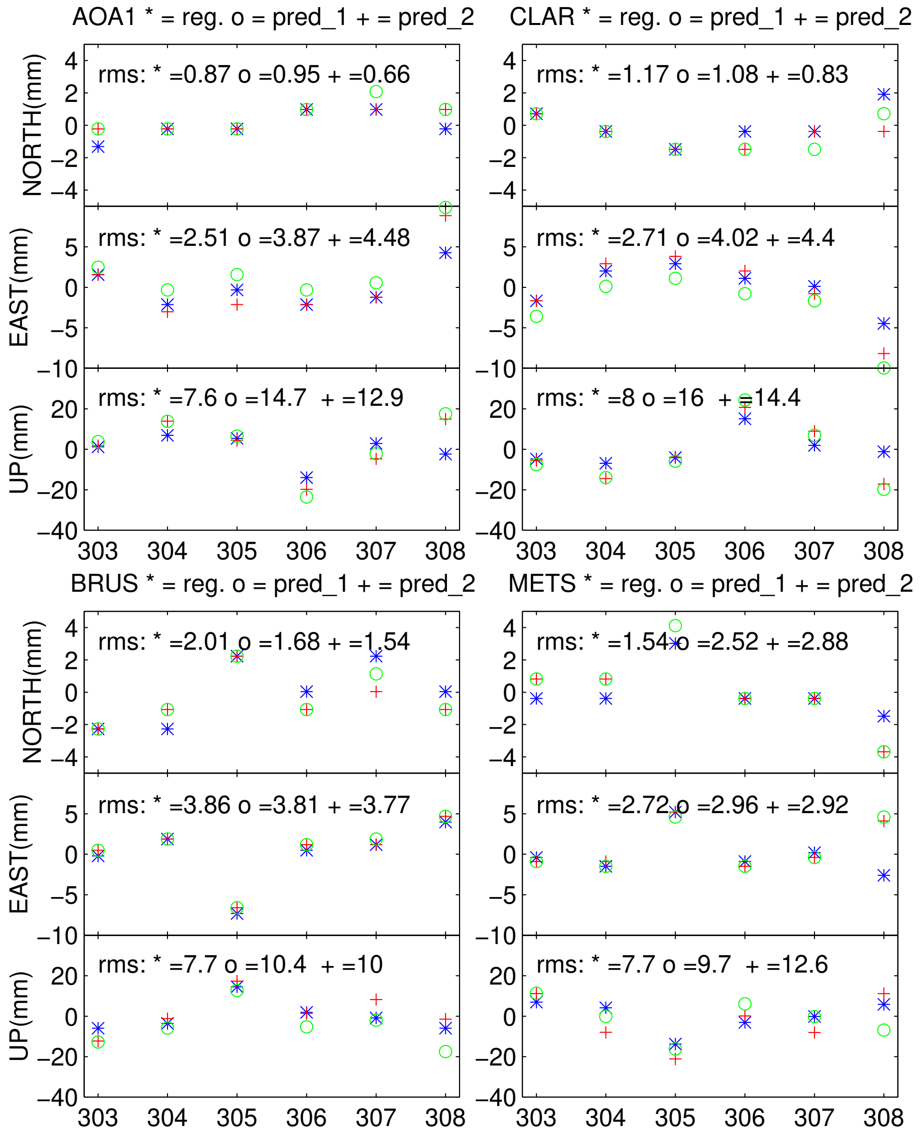

Figure 8: Position repeatability comparison of using prediction 1, prediction 2, and regular orbits, for AOA1 and CLAR, and for BRUS and METS.

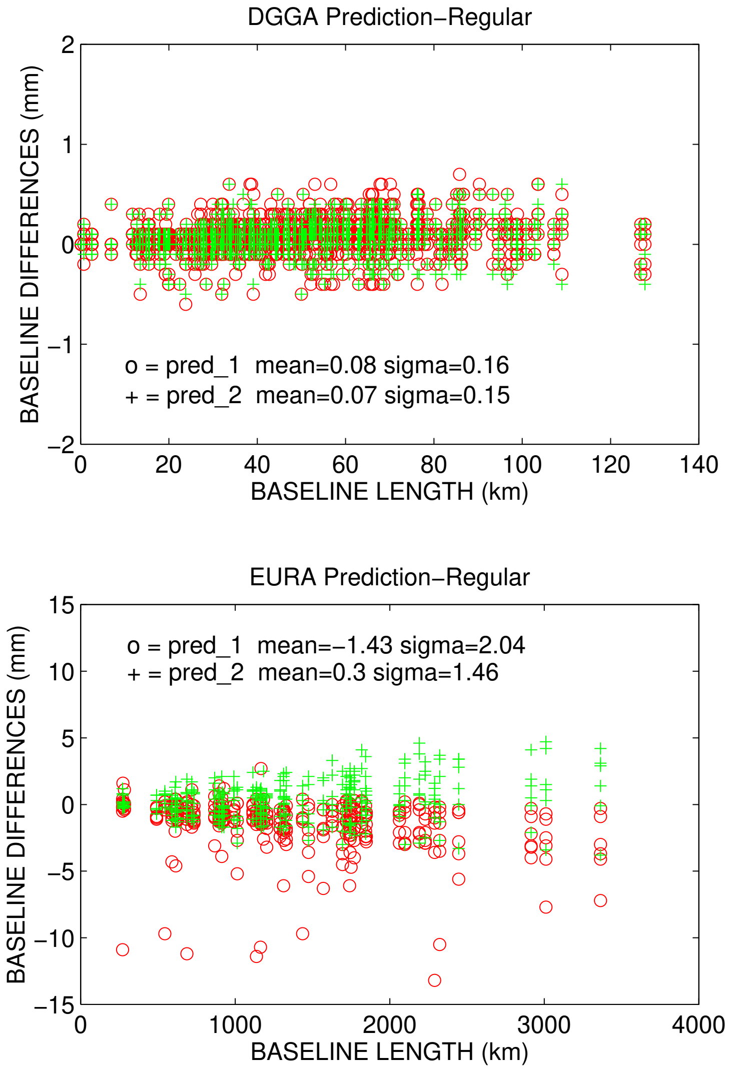

Figure 9: Baseline length determination comparison of using prediction 1 and prediction 2 with respect to regular solutions. It should be noted that there are some scatters in the EURA network due to just one day (308) of poor prediction-1 solution.

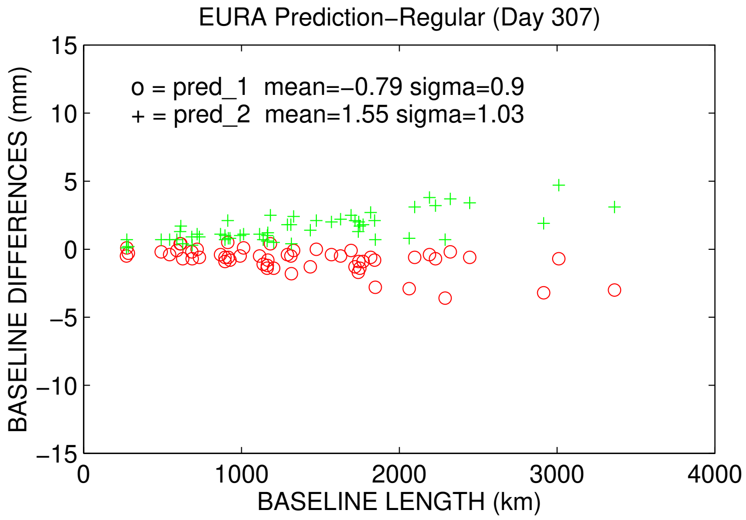

Figure 10: Baseline length determination comparison of using prediction 1 and prediction 2. The scatters show noticeable scaling errors in both cases.

A weighted autocorrelation analysis of the daily position time series revealed that several sites have significant temporal correlations (Figure 12); of particular interest is the IGS 'core station' at Goldstone (GOLD). This logically leads to further analysis of the stochastic properties of the temporal correlations. There is evidence from other longer and more precise continuous geodetic data sets in southern California that geodetic monuments exhibit spectra with $1/f^2$ behavior, i.e, Brownian motion (random walk error). Maximum likelihood estimation was used to estimate the degree of uncorrelated measurement error (white noise) and random walk error in the data [11] as applied by Johnson and Agnew [12] on synthetic data. The results indicate that all position time series exhibit a non-white noise component, with magnitude of 1–3 mm/yr$^{1/2}$ and a random walk to white noise ratio of at least 1–2/yr$^{1/2}$. A few sites show much higher magnitude, as much as 10–14 mm/yr$^{1/2}$ and a ratio 3–5/yr$^{1/2}$ (Table 2).

This study indicates that there may be a 1-mm/yr$^{1/2}$ position uncertainty in horizontal components, and as high as 5–10 mm/yr$^{1/2}$ in the vertical, even at sites with very stable monumentation (many IGS sites do not meet this criterion, including GOLD). The size of the random walk error will affect the velocity uncertainties of IGS sites by at least 1 mm/yr for data collected over a 5-year period. Site stability may limit continued improvement in the terrestrial reference frame.

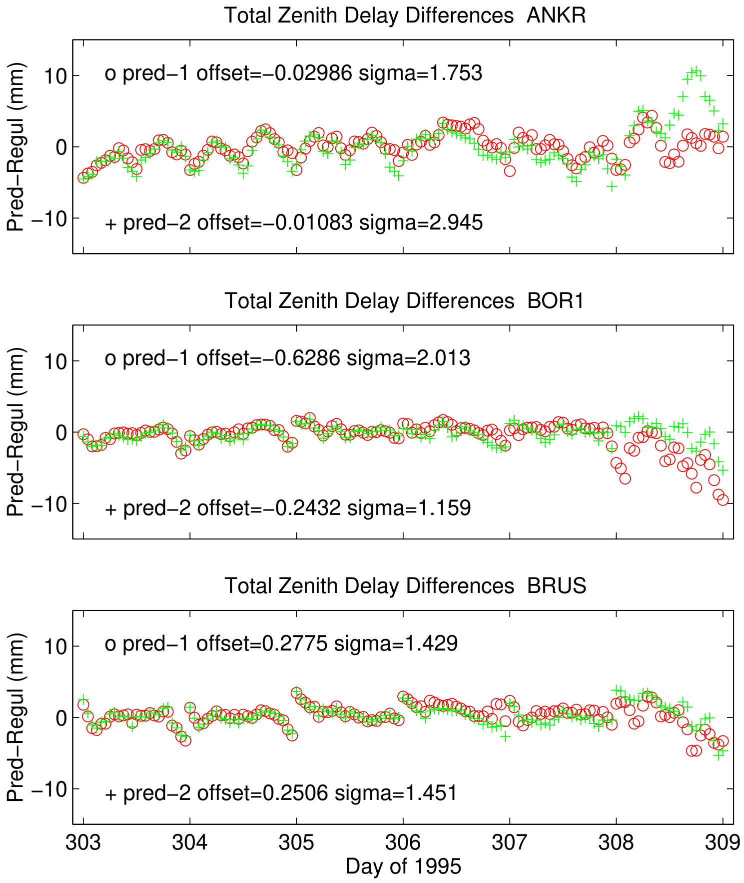

Figure 11: Neutral zenith delay comparison of using prediction 1 and prediction 2 with respect to regular solutions at ANKR, BOR1, BRUS.

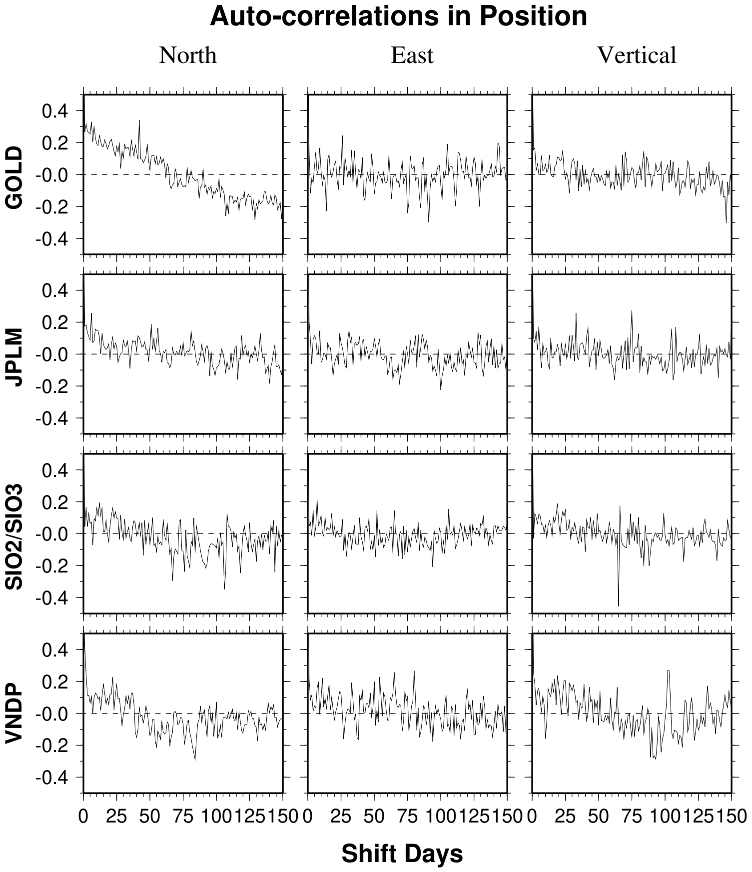

Figure 12: Autocorrelation in position for GOLD, JPLM, SIO2/3 and VNDP.

Table 2: Random Walk Analysis of PGGA Time Series

Site Description		$\hat{b}$ (mm/yr$^{\frac{1}{2}}$)	$\hat{a}$ (mm)	rms (mm)	$\hat{b}/\hat{a}$ (1/yr$^{\frac{1}{2}}$)
GOLD	N	8.8 ± 1.4	2.9 ± 0.1	4.1	**3.0**
No Changes	E	4.6 ± 1.9	5.9 ± 0.2	6.3	**0.8**
Tall Tower	U	20.7 ± 5.7	11.0 ± 0.4	11.7	**1.9**
HARV	N	4.4 ± 2.0	2.1 ± 0.1	2.2	2.1
No Hardware Change/	E	7.4 ± 2.5	4.4 ± 0.2	4.7	1.7
Oil Platform	U	6.5 ± 3.9	6.0 ± 0.3	6.1	1.1
JPLM	N	4.1 ± 1.2	2.2 ± 0.1	2.7	1.9
No Hardware Change/	E	5.9 ± 1.9	3.7 ± 0.1	4.2	1.6
Shallow geodetic mark	U	8.7 ± 3.0	7.2 ± 0.3	7.9	1.2
MATH	N	1.3 ± 0.5	1.3 ± 0.1	1.3	**1.0**
No Changes	E	3.7 ± 1.6	2.4 ± 0.1	2.9	**1.5**
Bedrock	U	3.7 ± 2.2	4.5 ± 0.2	4.6	**0.8**
PIN1	N	4.1 ± 1.1	1.9 ± 0.1	2.1	2.2
Hardware Swap	E	7.9 ± 2.2	3.8 ± 0.2	4.0	2.1
Deeply Anchored	U	9.1 ± 3.7	8.4 ± 0.3	9.1	1.1
PIN2	N	2.4 ± 0.8	1.7 ± 0.1	1.9	1.4
No Hardware Change	E	2.9 ± 1.7	3.5 ± 0.1	3.6	0.8
Deeply Anchored	U	6.8 ± 2.3	7.0 ± 0.3	7.4	1.0
PVEP	N	3.8 ± 1.0	1.7 ± 0.1	2.1	2.2
No Hardware Change	E	14.2 ± 2.9	3.1 ± 0.2	4.4	4.6
/Cliff/Massive concrete	U	24.3 ± 7.0	7.3 ± 0.4	8.1	3.3
SIO3	N	3.4 ± 0.8	2.2 ± 0.1	2.3	1.6
Hardware Swap/SIO2	E	5.0 ± 1.5	3.3 ± 0.1	4.1	1.5
Survey/Deeply Anchored	U	5.4 ± 3.1	7.5 ± 0.3	8.5	2.1
VNDP	N	5.4 ± 1.6	3.0 ± 0.1	3.3	1.8
Hardware Swap/	E	10.1 ± 2.7	5.6 ± 0.2	5.9	1.8
Deeply Anchored	U	14.2 ± 3.4	9.9 ± 0.4	10.6	1.4

8 GPS-INSAR Integration

SOPAC staff along with other investigators at Scripps are working on integration of GPS and spaceborne interferometric synthetic aperture radar (INSAR) [13, 14] integration for determining interseismic deformation in southern California. GPS can make a contribution in two primary ways: (a) to provide a regional reference frame to help in calibrating SAR orbital errors; we are installing radar reflectors at several SCIGN sites to locate the site in the radar image, and installing new sites in sidelapping SAR images; (b) to provide regional tropospheric delay information for INSAR corrections. Tropospheric delay errors are considered the major source of error in limiting displacement uncertainties, at perhaps the several-cm level. Due to the fact that the sensing signals of SAR travel twice through the atmosphere, its effect is doubled. Spatial variability of signal delays can amount to a few cm over a satellite pass. Figures 13–14 show the spatial distribution of bi-hourly averaged variations of a typical 24-hr period. The interpolation error follows the inverse distance rule, and should be below 50% in the area we are interested in.

9 Outlook

SOPAC is currently working in the following areas: improved and more efficient processing strategies, online GPS positioning service, infinite online data archive with distributed data base system, GPS-INSAR integration, precise real-time positioning applications, atmospheric monitoring, and site stability investigations.

10 Acknowledgment

Material for this report was garnered from important contributions by Paul Tregoning Jie Zhang, Jeff Behr, Jeff Dean and Simon Williams at Scripps; Tom Herring, Bob King, and Simon McCluskey at MIT; Mike Bevis at the University of Hawaii; and Seth Gutman and Dan Wolfe at NOAA. We would like to thank all our colleagues at the IGS for keeping our feet to the fire. Funding for SOPAC participation in the IGS is provided by NSF EAR 94 05934.

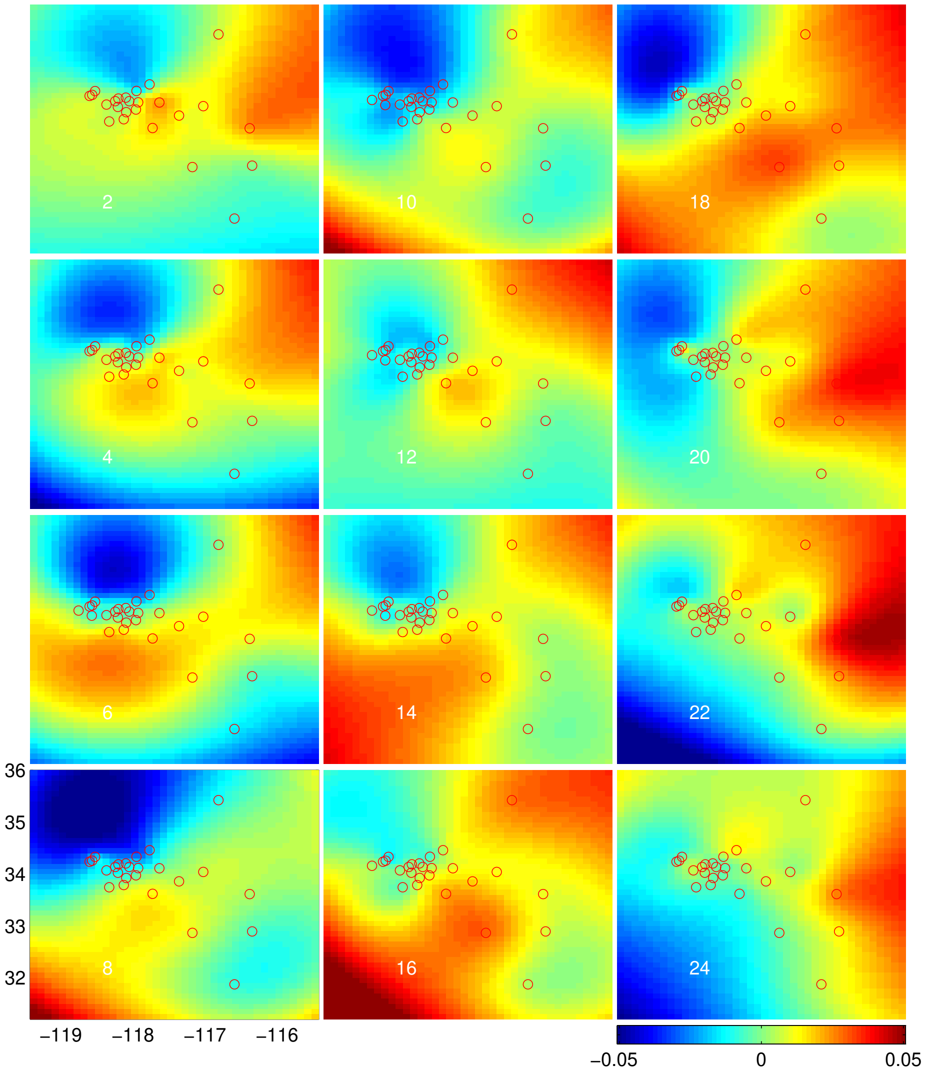

Figure 13: Residual tropospheric delays over southern California for day 155, 1995, interpolated from every-30-minute estimates. The residuals are defined as the variations with respect to one month average, implying most of the hydrostatic portion of the delay is removed. Each of the 12 plates represents 2-hour average residual distribution in meters.

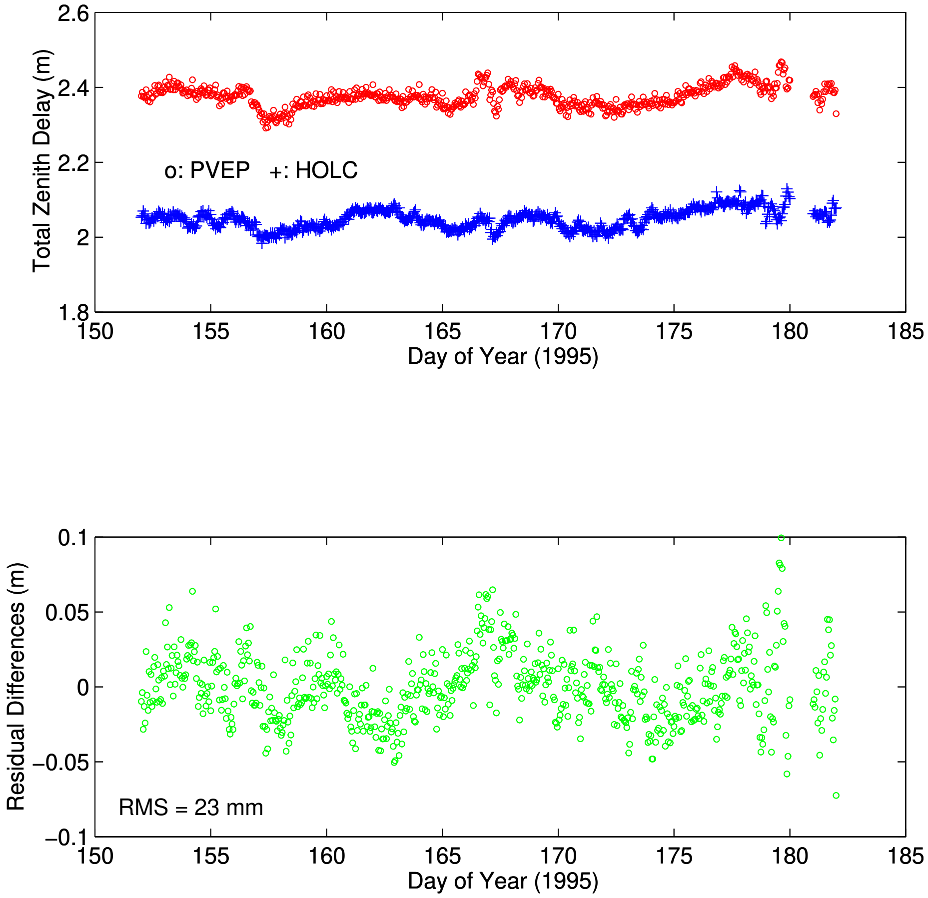

Figure 14: Neutral zenith delay time series of PVEP and HOLC and demeaned differences between these two sites. These differences indicate the magnitude of spatial variation.

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IGS Annual Report of GFZ for 1995

Gerd Gendt, Galina Dick, and Christoph Reigber
GeoForschungsZentrum Potsdam, Division 1,
Telegrafenberg A17, D-14473 Potsdam., Germany

1 Introduction

The daily analysis of the global IGS data carried out since the beginning of the IGS has been continued with an enlarged set of stations (see Figure 1). In 1995 emphasis was put on the development of the software, especially to meet the demands from the introduction of the SINEX format. Further on, in preparation of super fast orbit products with one- or two-day delay (including weekends), the software and technology were improved.

2 Developments of Software

For the introduction of the new product, i.e., the weekly solutions of all station coordinates in a free network in the SINEX format, a couple of software changes were necessary. This was the motivation to perform basic changes in our software — to introduce a new parameter controlling system:

- The description of all parameters is done by 8-character names together with a time interval. All software components, starting from the ORBIT part, including the SOLVE part up to the accumulation part SUMP for SINEX format, are controlled by these names.
- Most of the files are arranged according to the SINEX principle.

The main advantage of the new parameter controlling system is the possibility to introduce a new parameter in a simple way. There are also no longer any restrictions for the number of parameters. Two parts of the the software package were especially affected by this basic change — the adjustment part SOLVE and the combination part SUMP. Both programs were recoded nearly completely.

SOLVE: In this part the parameters selected by the user are estimated by a HELMERT blocking method, e.g., each parameter can be eliminated for a chosen time interval and then estimated by backward substitution. The new features of the program are:

- high flexibility due to parameter controlling with name and time interval

- instead of elimination of parameters in given steps, the parameters can be put parallel and constrained (random walk) — e.g., highly resolved ERP, tropospheric zenith path delay (TROP)
- output of normal equation matrix with all possible parameters (e.g., ERP and TROP parameters in steps of one hour).

SUMP: In this part the normal equations (NEQs), stored in SOLVE part during the last iteration, can be accumulated over longer time intervals in different variants. The new program allows:

- combination of archived NEQs applying rules given by the user for parameter elimination, combining and constraining, e.g., concatenated 1-hour parameters to 4-hour ones, put random-walk constraints to intervals
- homogenization of different parameter initials
- fill in velocity for chosen parameters (used for station coordinates, ERP)

In addition to these fundamental changes the new yaw model [1] was implemented. Instead of using a separate parameter for each shadow and noon event only one parameter per day was introduced. The yaw model results in a much better fit to the data in the shadow. The 20-minute intervals after the shadow were deleted from the data. This may cause some minor problems in defining the multiple of a revolution in phase rotation for the phase wind-up modeling. Here one has to introduce an additional ambiguity. The daily yaw results for some selected interval compared to the results of JPL can be seen in Figure 2.

3 Operational IGS Data Processing

The main strategy for the analysis (e.g., 32-hour arc length, solve-for parameters) was not changed in 1995 and has been already described in [2]. The analysis is based on 30-sec RINEX data which are sampled to 60 sec for the double-difference data cleaning in the preprocessing part and to 360 sec for the analysis itself. Since the beginning of 1995, altogether 10 new stations have been added to the analysis, resulting in 53 stations in total (see Figure 1).

3.1 Reference Frame

The terrestrial reference frame, for the orbit and the ERP products, is defined by 17 sites, the coordinates and velocities of which are strongly constrained in the analysis. The initial values for these sites are taken from ITRF'93 (SSC(IERS)94C01) for epoch 1995.0, except for three sites (Maspalomas (MAS1), Richmond (RCM5), Taiwan (TAIW)) where GFZ coordinates best aligned to the ITRF'93 are used (see Figure 1). It should be mentioned that no antenna-phase center corrections are performed, and the JGM2 geopotential with GM=398600.4418 $\mathrm{km}^3/\mathrm{s}^2$ is used (most other Analysis Centers use 398600.4415 $\mathrm{km}^3/\mathrm{s}^2$).

The initial values for the pole parameters and UT1 are taken from the daily analysis itself by prediction from the day before. The UT1 values are aligned from time to time to the Bulletin A if the difference is larger than 5 ms.

3.2 Weekly SINEX products

In the daily analysis the normal equations for station coordinates and ERP are archived without any constraints, before fixing the coordinates of the fiducial sites to about 1 mm to produce the products for orbits and ERP. This archive is the basis for the computation of the weekly SINEX file, which enables the rapid densification of the global network by distributed processing. Besides the parameters for the stations coordinates, the SINEX file also contains parameters for daily pole position and LOD. The last parameters were put into the SINEX to allow for the combination of SINEX with the same ERPs for all individual SINEX inputs.

3.3 Satellite Clocks

Whereas in the past the P-code measurements were used to predefine the ambiguities only, they are now introduced into the adjustment with a weight of L3 to P3 as 300 to 1. Thus, by using the P-codes from the 'nearly' bias-free new Rogue receivers, the clocks can be estimated with an accuracy of 0.5 to 1 ns. Since the 'old' Rogues with large P-code biases under Anti Spoofing are being steadily replaced, we do not intend to determine and correct for their biases at the moment.

3.4 Super Rapid Orbits

Since the beginning of 1996 a new product, super-rapid orbits with 36-hour delay, is offered by the IGS. In order to contribute to this product, a more sophisticated technology had to be introduced at GFZ. Because every day (also on weekends) an AC's orbit product has to be delivered for the orbit combination, the demands for an automated analysis is much more stringent than it is for the weekly product. This means that, e.g., exclusion of maneuvers and bad station data had to be handled fully automatically. Before sending the product to the combination center, the quality of the satellite orbits has to be checked and problematic satellites should be marked or excluded. The rapid analysis is split into two parts. With a delay of about 12 hours, a first analysis is performed to check the data and to look for possible maneuvers. The second part — the proper analysis — starts with 30-hour delay and has normally a significant higher number of sites. In the case of serious problems the 12-hour orbits are taken instead of the 30-hour one. The quality of the fast products is about 10 cm (Figure 3).

4 Results

4.1 Determination of Global Reference Frame

A fiducial free global set of coordinates for 50 IGS stations has been determined [3]. The stability and accuracy of the determined reference frame can be demonstrated from the results of 7-parameter similarity (HELMERT) transformations. Transformations between three adjacent annual solutions and between our global solution and ITRF93 (label SSC(IERS)94C01) have been performed (Table 1). The three annual solutions of 1993 to 1995 coincide within 3 to 5 mm in horizontal and 5 to 6 mm in the height component. If the simultaneously adjusted GFZ velocities are used, the agreement is even better. A comparison with ITRF93 yields a high accuracy of 5 mm in the east, 7 mm in the north and 10 mm in the height component. For dense parts of the network (Europe, North America) repeatablility of 2 mm in horizontal position is reached.

Table 1: Helmert transformations of global coordinate solutions (unit: mm)

Variant	Number of sites	ITRF93 velocities			GFZ velocities		
		N	E	H	N	E	H
GFZ93–GFZ94	23	4.4	5.6	5.4	3.0	3.7	4.9
GFZ94–GFZ95	30	2.8	3.1	6.0	2.5	2.5	4.4
dto.,only Euro&NoAm	16	1.8	1.6	4.7	1.4	1.1	3.0
dto., only Europe	9	1.5	1.9	4.0	0.5	0.6	2.8
GFZ93_95–ITRF93	23	6.7	5.4	10.1			

4.2 Determination of Plate Kinematics

For the investigation of recent global crustal kinematics the IGS data of 3 years have been used. The daily, fiducial-free and unconstrained normal equations for station coordinates and ERP, which are stored in the routine IGS, were combined into weekly normal equations [2]. The parameters of no interest (e.g., ERP) have been eliminated during the combination. The combined normal equations can be extended by parameters for site velocities. From the theoretical point of view the best way to determine the site velocities is to adjust them simultaneously with the determination of station coordinates. In this way the correct weighting according to the data distribution and the correlations between all parameters are considered automatically. To have another insight into the stability and accuracy of the solution and to check the data quality, baseline rates as well as station position time series have been computed from weekly station coordinate solutions.

The results for site velocities as determined from the global simultaneous adjustment over the 3 years are shown in Figures 4 and 5. The agreement with

NUVEL-1 and ITRF93 velocities, given for comparison, is obvious for Europe, North America, and the Pacific. Due to densification of the IGS core network in the last year a large number of new sites of special interest for global applications became available. The comparison indicates some significant differences for these stations (e.g., Casey (CAS1) and Davis (DAV1) in Antarctica; Kerguelen Island (KERG); and MacQuarie Island (MAC1)), that can be explained with a short time span of observations. The remaining discrepancies for other sites with near complete observation span of 3 years (e.g., Usuda (USUD); Tsukuba (TSKB); McMurdo (MCMU)) should be further investigated. For some stations the reason could be a bad data quality. Other sites are located near the plate boundaries (e.g., TSKB, USUD). Figure 5 gives the comparison of GPS results with the results from the other techniques (SLR and VLBI). Here again, the results agree for most of the sites.

The baseline rates from Kokee (KOKB) and Wettzell (WETB) to their neighbouring sites, as obtained from the weekly coordinate solutions, are shown in Figure 6. The rate values from NUVEL-1 and ITRF93 are given for comparison. The accuracies of most baselines in Europe and North America are ±1 mm/yr (except for new sites, e.g., Zwenigorod (ZWEN), Russia, and Kitab (KIT3), Uzbekistan). The agreement with the rates from NUVEL-1 and ITRF93 is also in the range of few mm/yr. Only for some stations (e.g., USUD, Taiwan (TAIW), and Easter Island (EISL)) the differences are slightly larger.

Additionally, time series for position of all IGS sites have been computed from weekly unconstrained solutions. In order to remove small net rotations from week to week, the reference frame was defined by the transformation of weekly solutions into the global 3-year solution. Figure 7 shows the results for latitude, longitude, and height of selected sites. A linear trend is easily visible on the given plots. The derived rate from the weekly solutions, given on each plot, is represented by solid line; corresponding rates from NUVEL-1 and ITRF93 as well as weekly repeatability of each component are also printed.

4.3 Determination of ERP

To evaluate the accuracy of the GFZ polar motion for 1995, the IGS mean was taken. The rms-differences show an accuracy of 0.15 mas for X-pole and of 0.13 mas for Y-pole (Figure 8, the second half of 1995). The daily estimates of length of day (LODR) from 32-h arcs compared with the IERS Bulletin B solution are also given in Figure 8. The comparison yields an accuracy of 0.06 ms.

5 Conclusions

The results of the year 1995 confirm the major role of IGS for realization and maintainence of the global reference frame, as well as for investigation of present day tectonics and for determination of the Earth rotation with the highest level of accuracy. The future products of IGS will provide the opportunity to cover such non-geodetic applications as the monitoring of ionosphere and troposphere, weather and climate research. These applications demand not only new products but also quality improvements, targets which will be driving issues in the next years.

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[3] G. Gendt et al., Earth Rotation Parameters, Station Coordinates and Velocities from GFZ using GPS data, IERS technical note, Observatoire de Paris, Paris, 1996, in press.

Figures

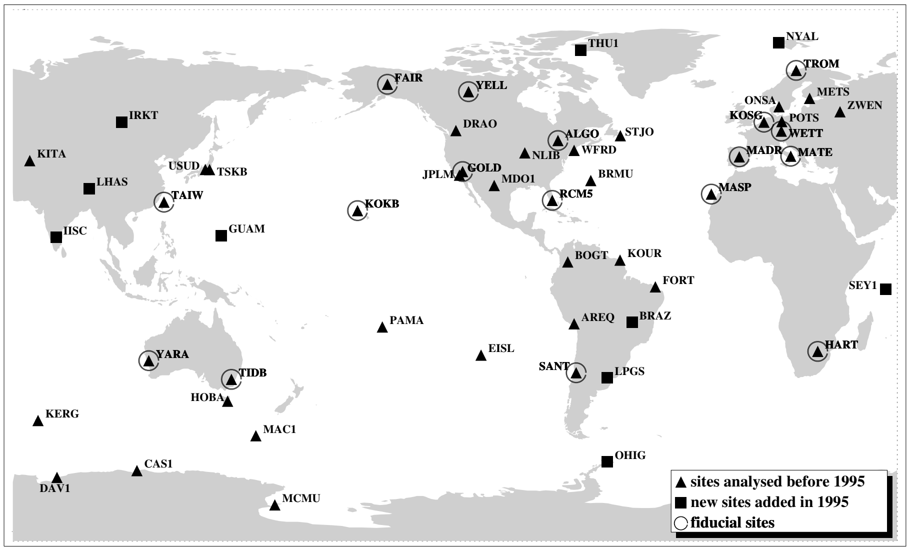

Figure 1: IGS Sites Analysed at GFZ (Sites added to the analysis in 1995 and fiducial sites are marked).

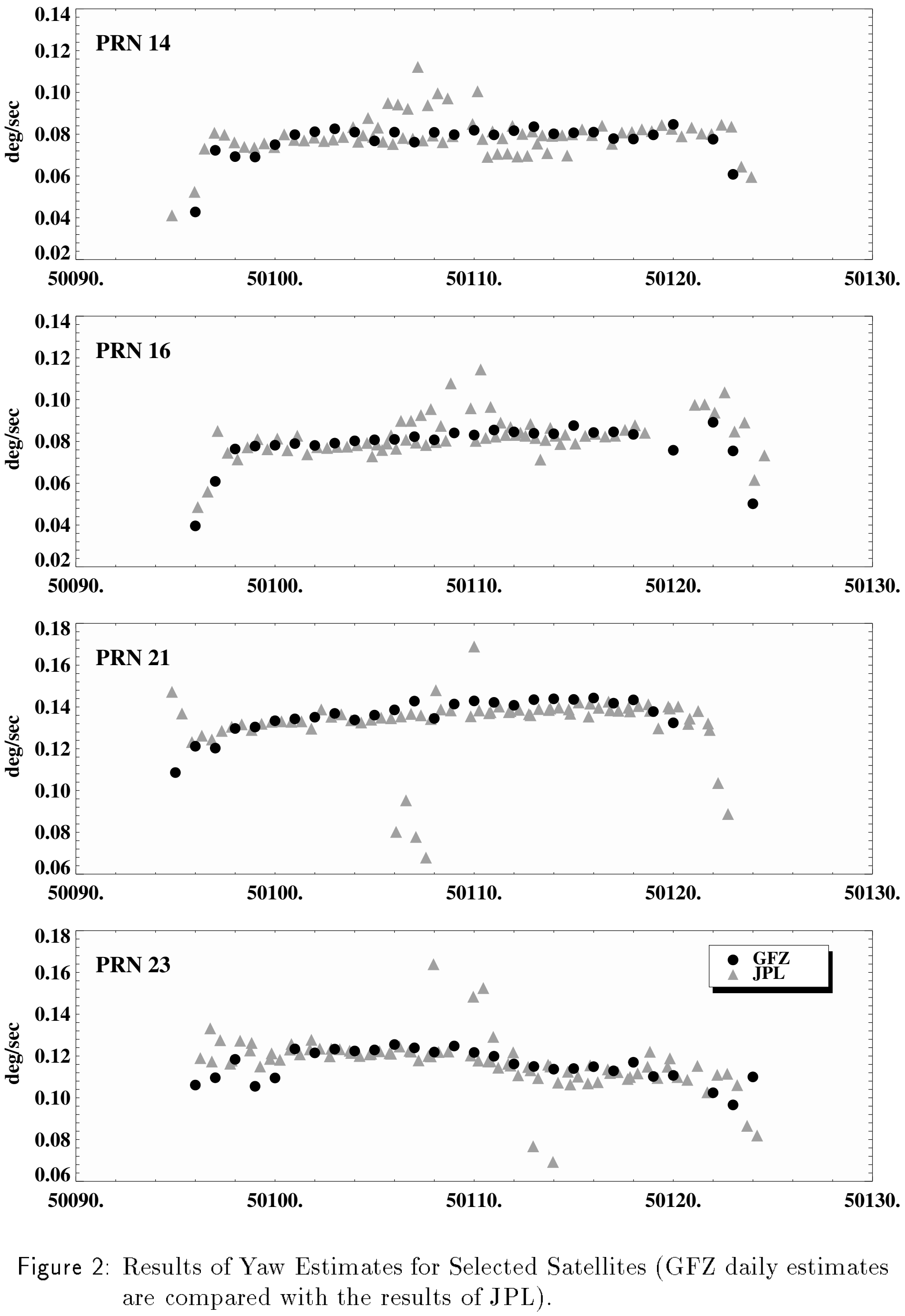

Figure 2: Results of Yaw Estimates for Selected Satellites (GFZ daily estimates are compared with the results of JPL).

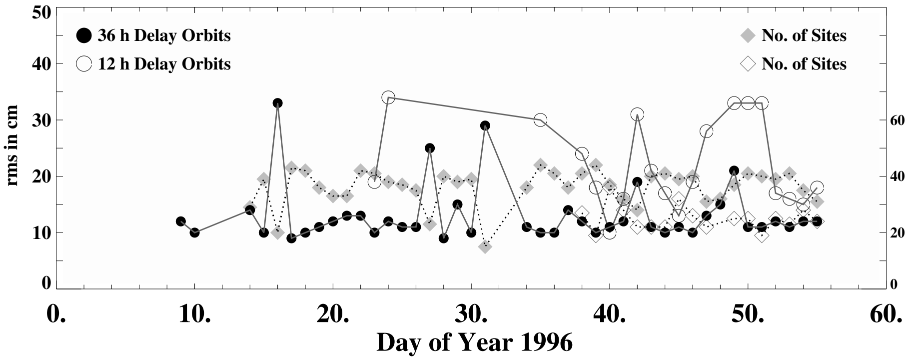

Figure 3: Quality of the GFZ Rapid Orbits with 12- and 36-hour Delay. Difference to IGS final orbit combination.

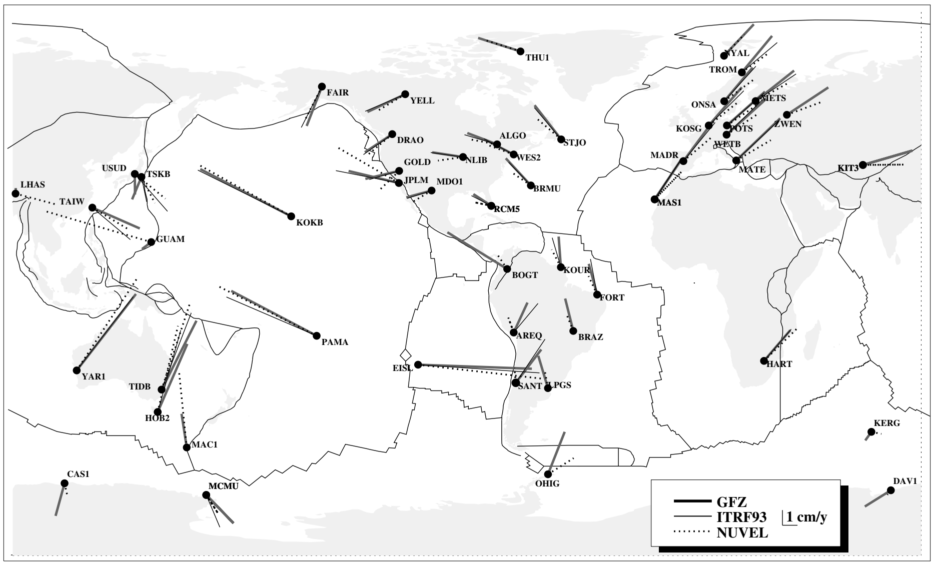

Figure 4: Site Velocities From 3 Years of IGS Data (NUVEL-1 and ITRF93 values are given for comparison).

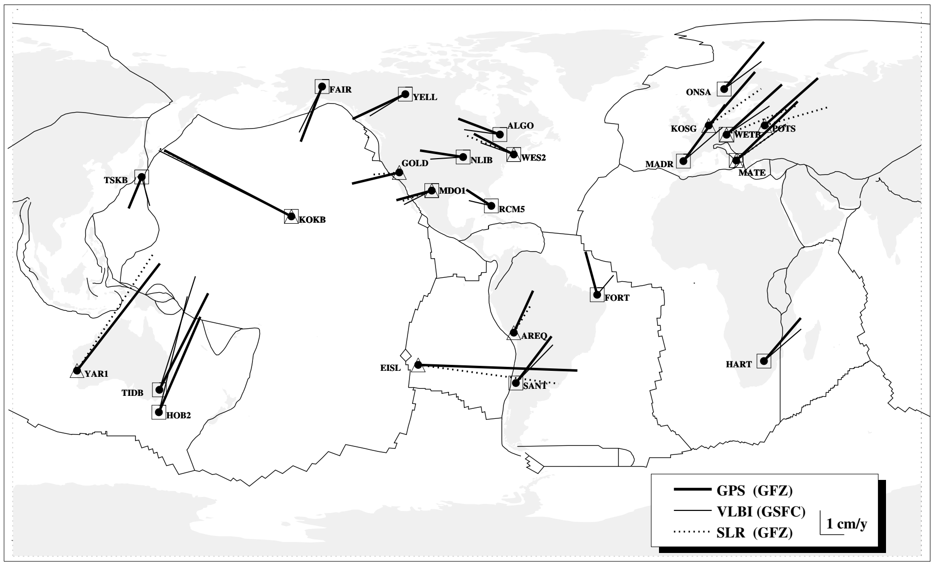

Figure 5: Site Velocities as Determined from Different Techniques:
GPS: GFZ Solution from 3 Years of IGS data SSC(GFZ)96P01
SLR: GFZ Solution SSC(GFZ)95L01
VLBI: GSFC Solution GLB1014

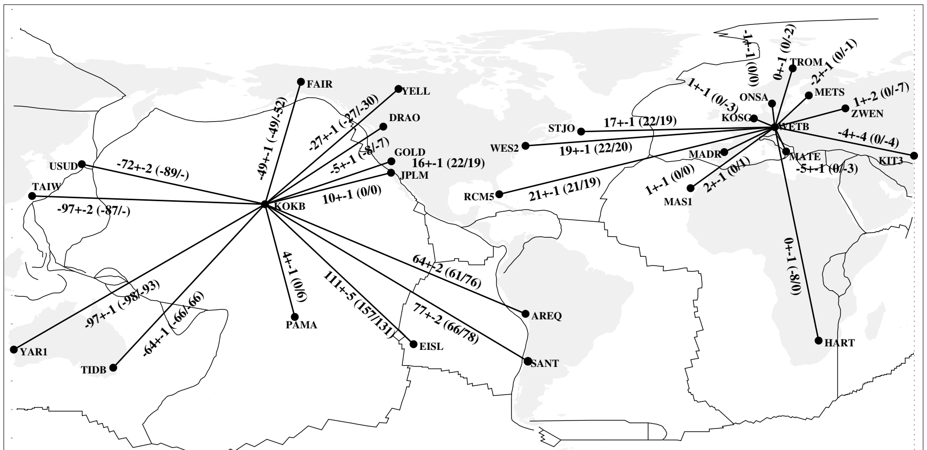

Figure 6: Baseline Rates of KOKB and WETB to Neighbouring Sites Derived from Weekly Coordinate Solutions (NUVEL-1 and ITRF93 values are given in parantheses).

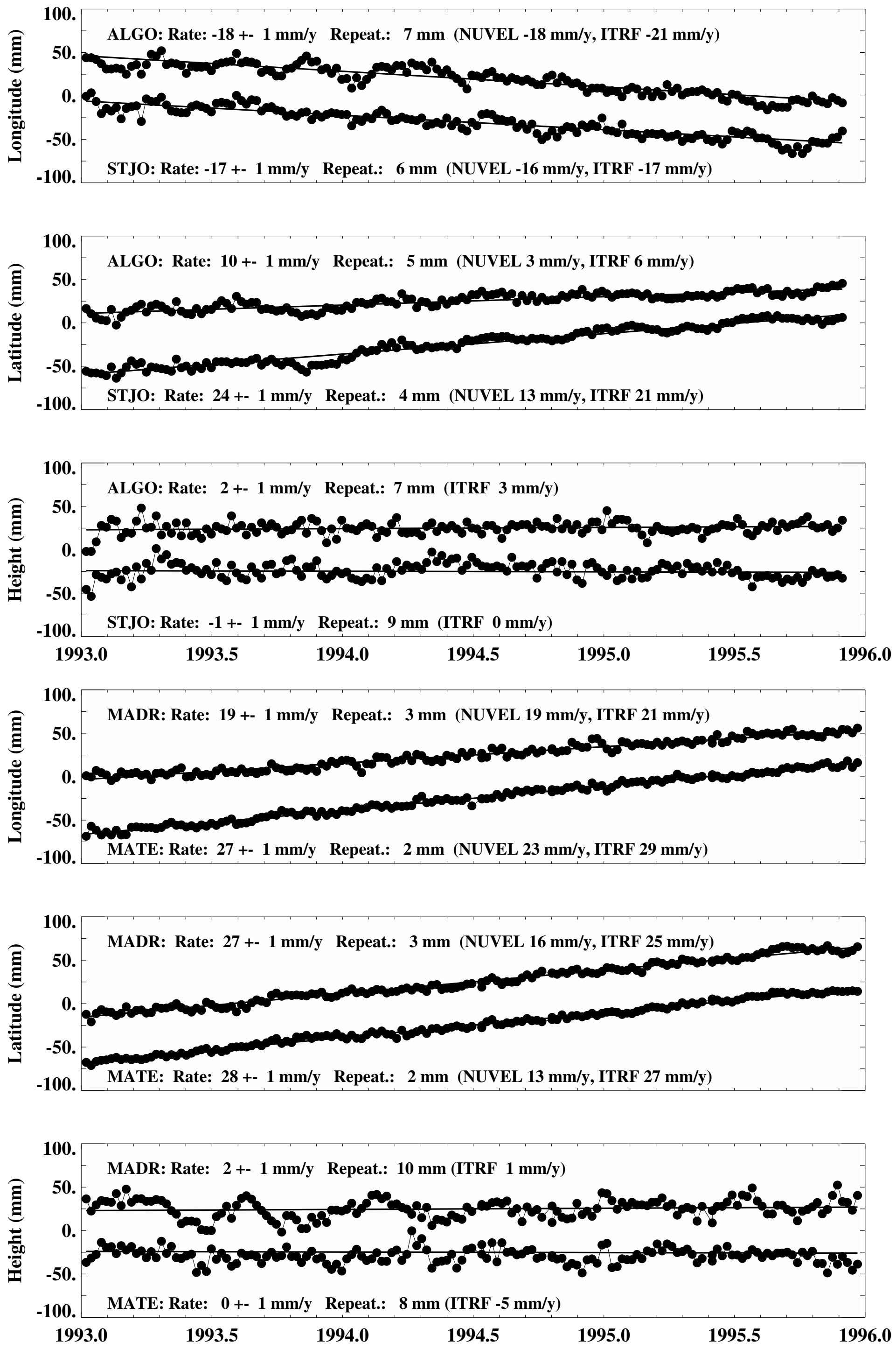

Figure 7: Time Series of Station Coordinates in Longitude, Latitude and Height for MADR and MATE (top), ALGO and STJO (bottom). NUVEL-1 and ITRF93 rates are given for comparison.

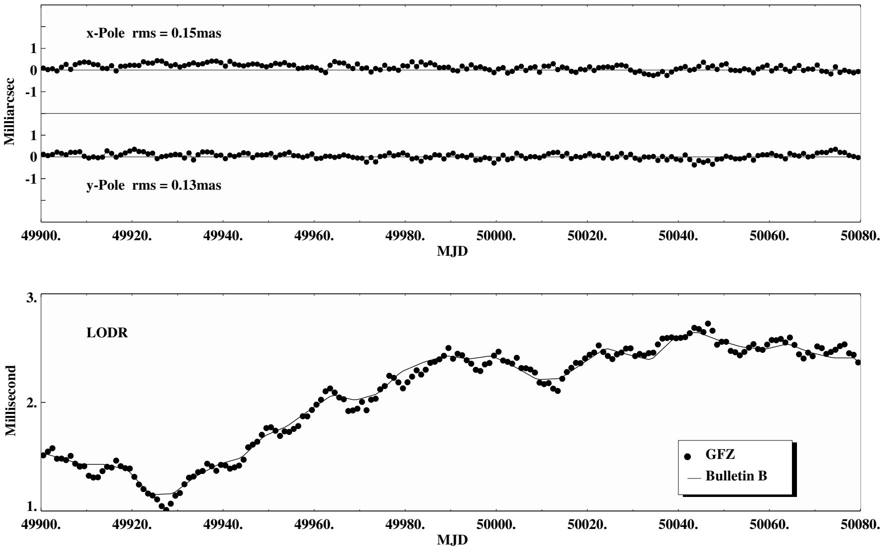

Figure 8: GFZ Results for Daily Polar Motion (top; differences to IGS mean) and Daily LODR (bottom; difference to IERS Bulletin B) for the Second Half of 1995.

GPS Orbit and Earth Orientation Parameter Production at NOAA for the International GPS Service for Geodynamics for 1995

Gerald L. Mader, Mark S. Schenewerk, James R. Ray
Geosciences Laboratory, Office of Ocean and Earth Sciences
National Ocean Service, National Oceanic and Atmospheric Administration,
Silver Spring, MD USA

William G. Kass, Paul R. Spofford, Robert L. Dulaney, Dale G. Pursell
National Geodetic Survey
National Ocean Service, National Oceanic and Atmospheric Administration,
Silver Spring, MD USA

1 Introduction

The GPS orbit and EOP solutions submitted to the IGS by the National Geodetic Survey (NGS) are a joint effort between NGS and the Geosciences Laboratory (GL). The Geosciences Laboratory is responsible for the development of the processing software and techniques while NGS is responsible for the operational production. NGS and GL are both activities within the National Ocean Service (NOS) of NOAA (National Oceanic and Atmospheric Administration) which ensures a close working relationship between the two groups.

2 Station Network

NGS used an average of about 40 tracking stations for the GPS orbit and earth orientation solutions that have been submitted to the IGS. This list of included stations is not static but changes occasionally to include new stations that offer a more favorable geometry or new geographical coverage and to drop stations in regions where the tracking density is greater or redundant. Generally, the number of included stations will probably be maintained at about 40. Additional stations do not appear to noticably improve the orbit solutions. This number also appears adequate to provide overall tracking network stability that is relatively insensitive to daily tracking irregularities within the total global tracking network.

Table 1 summarizes the tracking stations used during 1995. All stations that were used are listed along with the date at which their use began in order to highlight those new stations that were added during the year.

Table 1 also shows which station positions were held fixed for the orbit and EOP solutions. NGS began 1995 fixing the positions of about 25 reference sites to their ITRF92 positions. All other sites were unconstrained. The effect of daily tracking dynamics on these reference stations was mitigated by the larger number of constrained sites. However, during 1995 several significant upgrades were made to our software. It was then found that restoring the constrained sites to the original list of 13 plus two additional sites — Matera and McDonald — produced better agreement with the combined IGS orbit.

Table 1: 1995 Selected NGS fiducial sites for precise GPS orbit computations

Abbrev	*Ref Frame*	*Station*	*Active*
algo	ITRF93	Algonquin, Canada	01JAN94
areq	UNCONSTR	Arequipa, Peru	16AUG94
auck	UNCONSTR	Auckland, New Zealand	24OCT95
bogt	UNCONSTR	Bogota, Columbia	01JAN95
braz	UNCONSTR	Brazilia, Brazil	01APR95
brmu	UNCONSTR	Bermuda	01JAN94
cas1	UNCONSTR	Casey Station, Antarctica	02AUG94
chat	UNCONSTR	Chatham, New Zealand	29OCT95
cro1	UNCONSTR	St Croix, Virgin Islands	29OCT95
dav1	UNCONSTR	Davis, Anarctica	14JUL94
drao	UNCONSTR	Penticton, Canada	01JAN94
eisl	UNCONSTR	Easter Island, Chile	15AUG94
fair	ITRF93	Fairbanks, USA (Alaska)	01JAN94
fort	UNCONSTR	Fortaleza, Brazil	01JAN94
gold	ITRF93	Goldstone, USA (California)	01JAN94
guam	UNCONSTR	USGS Guam Obs, Dededo	21JAN95
hart	ITRF93	Hartebeesthoek, S Africa	01JAN94
hob2	UNCONSTR	Hobart, Australia	16JUL94
iisc	UNCONSTR	Bangalore, India	07JUL95
irkt	UNCONSTR	Irkutsk, Russia	13OCT95
kely	UNCONSTR	Kellyville, Greenland	24SEP95
kerg	UNCONSTR	Kerguelen, Indian Ocean	10DEC94
kit3	UNCONSTR	Kitab, Uzbekistan	21OCT94
kokb	ITRF93	Kokee Park, USA (Hawaii)	01JAN94
kosg	ITRF93	Kootwijk, Netherlands	01JAN94
kour	UNCONSTR	Kourou, French Guyana	01JAN94
lhas	UNCONSTR	Lhasa, Tibet	11JUL95
lpgs	UNCONSTR	La Plata, Argentina	15JUL95

Table 1: (continued)

Abbrev	*Ref Frame*	*Station*	*Active*
mac1	UNCONSTR	McQuarrie Is, Anarctica	02AUG94
madr	ITRF93	Madrid, Spain	01JAN94
mali	UNCONSTR	Malindi, Kenya	05DEC95
mas1	UNCONSTR	Maspalomas, Canary Islands	16JUL94
mate	ITRF93	Matera, Italy	01JAN94
mcm4	UNCONSTR	McMurdo, Anarctica	15JAN94
mdo1	ITRF93	McDonald, USA (Texas)	01JAN94
mdvo	UNCONSTR	Mendeleevo, Russia	20MAR95
mets	UNCONSTR	Metsahovi, Finland	01JAN94
nlib	UNCONSTR	N Liberty, USA (Iowa)	23SEP95
nyal	UNCONSTR	Ny-Alesund, Norway	01JAN94
ohig	UNCONSTR	O'Higgins, Antarctica	06MAY95
onsa	UNCONSTR	Onsala, Sweden	01JAN94
pama	UNCONSTR	Pamatai, Tahiti	01JAN94
rcm5	UNCONSTR	Richmond, USA (Florida)	01JAN94
sant	ITRF93	Santiago, Chile	01JAN94
sey1	UNCONSTR	Seychelles, Africa	15OCT95
shao	UNCONSTR	Shanghai Obs, China	21JAN95
stjo	UNCONSTR	St Johns, Canada	01JAN94
taej	UNCONSTR	Taejon, Korea	05DEC95
taiw	UNCONSTR	Taipei, Taiwan	01JAN94
tidb	ITRF93	Tidbinbilla, Australia	01JAN94
trom	ITRF93	Tromsoe, Norway	01JAN94
tskb	UNCONSTR	Tsukuba, Japan	01JAN95
wes2	UNCONSTR	Westford, USA (Massachusetts)	01JAN94
wett	ITRF93	Wettzell, Germany	01JAN94
yar1	ITRF93	Yarragadee, Australia	01JAN94
yell	ITRF93	Yellowknife, Canada	01JAN94

3 Software Changes

During 1995, several significant improvements were made to our processing programs resulting in a new version of our orbit software, designated PAGE4. Some additional changes were also made to selected input parameters. These changes are summarized below. The first use of PAGE4 in ephemeris production was August 6, 1995.

1. Elevation angle cutoff lowered from 20 degrees to 15 degrees.
2. Corrections were applied for the double-difference effect of RHC polarization, according to the model of [1].
3. The default tropospheric mapping functions were changed to the NMF dry and wet. The station met data were changed from a single set of global

values to site-dependent as a function of latitude, ellipsoidal height, and day-of-year. The troposphere parameter partial was changed to correspond to adjustment of the wet zenith delay, rather than the total, and the parametrization interval was decreased from 6 hours to 2 hours.

4. The solid Earth tide model (of [2]) was updated to fix bugs in the old routine, use modern estimates for the Love and Shida numbers, and add vertical corrections due to resonances of six diurnal tides near the free-core nutation frequency.
5. The effect of sub-daily Earth orientation variations was accounted for in modeling the observables (but not in reporting the adjusted Earth-fixed satellite ephemerides) using the model of [3].
6. The orbit integration program ("arc") was modified in a number of ways including simplification of the coding and to include individual satellite masses and solid Earth tidal variations of the geopotential field.
7. The terrestrial frame realization was changed from fixing the coordinates of 25 sites to fixing 15 sites (the standard IGS 13 plus MATE and MDO1).
8. Adjustment of a daily LOD offset was added.
9. The calculation of observed satellite elevation was modified to account for the oblateness of the Earth.

The effect of these changes may be seen in Figure 1. This Figure shows the rms deviation between the NGS orbits and the IGS combined orbits for the entire year along with the parameters of the seven-parameter transformation. The large variations in rms between 10 and 30 cm prior to these modifications have settled down to reasonably steady values between 10 and 15 cm. At the same time the scale factor which had been unusually large, moved to a level near 0.1–0.2 ppb.

The x and y components of the pole position with respect to the IERS Bulletin A is shown for 1995 in Figure 2. A decrease in the noise in the x component is visible beginning with the introduction of the new software around day 218. The rms agreement of both components is now in the 0.3- to 0.4-mas range.

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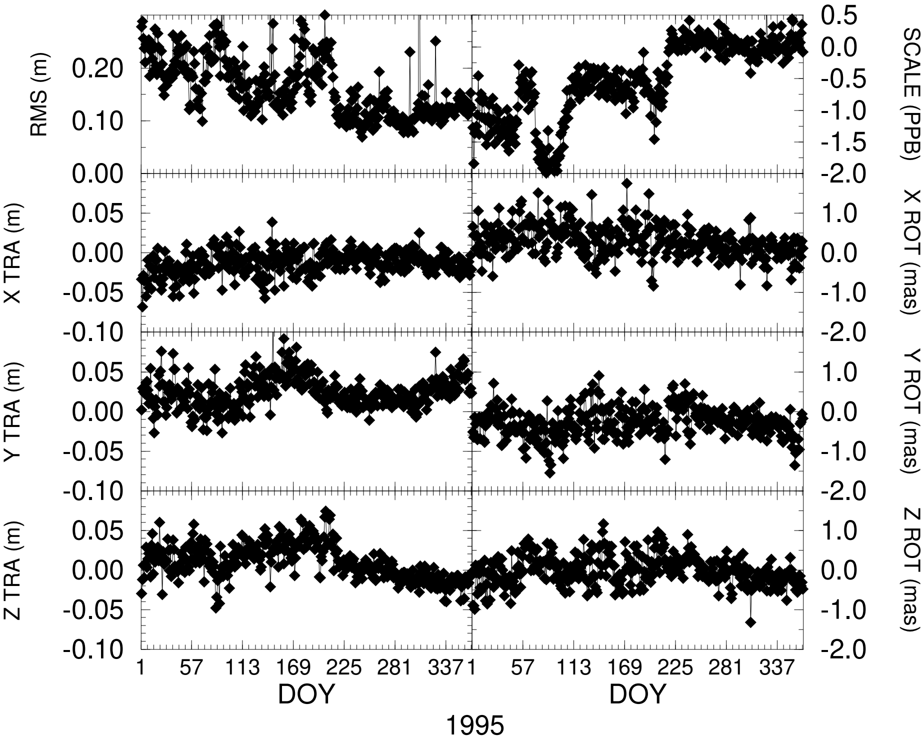

Figure 1: NOAA-IGS Seven Parameter Transformation

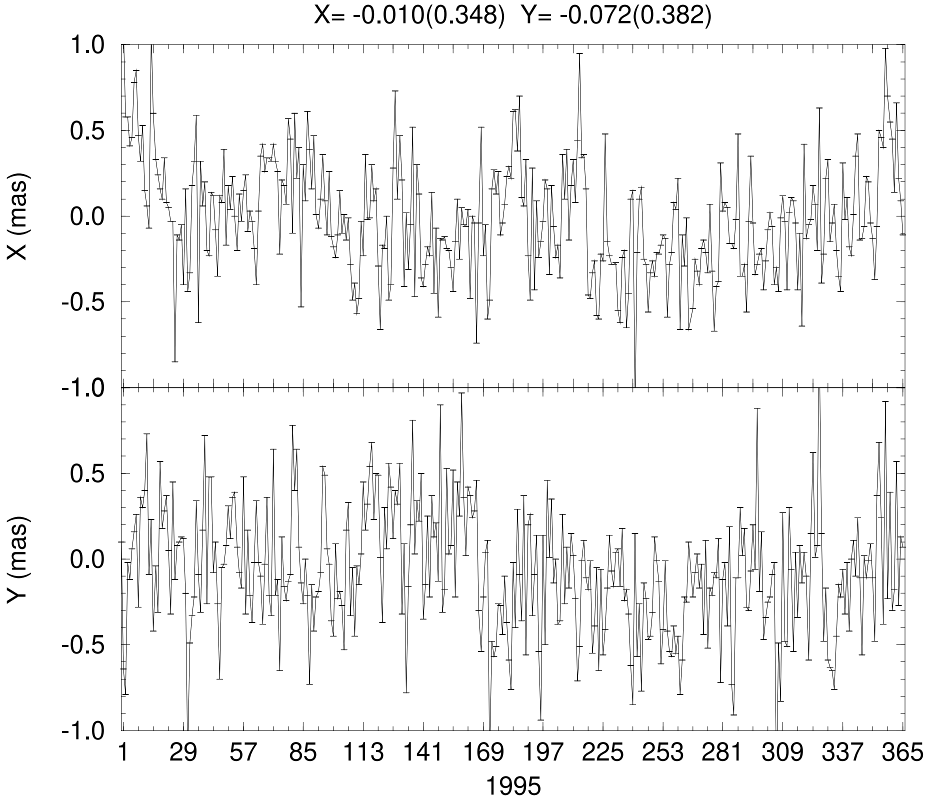

Figure 2: NOAA-IERS Bulletin A

The ESA/ESOC IGS Analysis Centre

T. J. Martin-Mur, J. M. Dow, C. Garcia Martinez, and J. Feltens

ESA/European Space Operations Centre
Darmstadt, Germany

1 Introduction

The European Space Operations Center (ESOC) is the satellite control center of the European Space Agency (ESA). It is responsible for the operations of the ESA satellites, its ground stations, and its communications network. In order to operate the satellites that are under control of ESA, ESOC has to be able to precisely determine their orbits, the position of the possible tracking stations, and other geodetic parameters. A state of the art software package has been developed over a number of years at ESOC and before the IGS campaign started it was already well proven through extensive processing of data from many satellites, including satellite laser ranging (SLR) from Lageos and Starlette. Although not able to handle GPS data types (pseudo-range and phase) at that time, a multi-satellite solution capability was already implemented. After submitting the proposal for ESOC participation as an IGS Analysis Centre a major effort was undertaken to develop GPS capabilities in our software. Important aspects of the use of the ESOC orbit and geodetic parameter estimation software are that this software is independent from other packages in use for GPS analysis, and there is the possibility of consistent processing of other geodetic satellite data with a single package (SLR, Doris, GPS, altimetry, PRARE,...).

ESOC is preparing for the use of GPS or other Global Navigation Satellite System (GNSS) in operational and precise orbit determination. Some European spacecraft have already been equipped with GPS receivers and it is foreseen that some ESA spacecraft will also use GPS. An additional application of GPS of interest for ESOC is the use of GPS receivers located in our ground stations to obtain ionospheric corrections for single-frequency ranging.

We have been participating as an IGS Analysis Centre from the beginning of the IGS. Our first solutions for orbital and polar motion parameters were transmitted to the CDDIS on 24 July 1992, about one month after the start of the Epoch 92 campaign. By early August the delay with respect to real time was reduced to about 10 days. Along with several other centers, ESOC continued to process IGS data after the decision of the IGS Campaign Committee in October 1992 to continue the IGS activity in the form of an 'IGS Pilot Service' and then in January 1994 as the IGS Operational Service. These series have guaranteed continuity of the IGS activities after the success of the first campaign.

2 ESOC IGS Analysis

ESOC is using the observation of most of the Rogue and TurboRogue receivers in the IGS network. Those that are always used are the 13 fixed stations and our own stations. Additional receivers up to a total of about forty are added to improve the global distribution of observations. We use phase double differences as our basic observable, because they are especially well-suited for batch estimation. With double differences the satellite and clock biases for every epoch do not need to be estimated with the same accuracy as that of the measurement, so the total number of parameters to be estimated is greatly reduced. Precise clock biases are produced in post-processing, after the orbits have been determined.

3 Preprocessing

Preprocessing is done with the program GPSOBS. GPSOBS reads RINEX observation files and obtains independent ionospheric-free double-difference phase combinations. An elevation cut-off angle of 20 degrees is used. Cycle slip detection is performed using two-integer, almost-ionospheric-free combinations, the 4L1 - 3L2 and the 5L1 - 4L2. Satellite center of mass and phase wind-up corrections are performed at this step. For the satellite center-of-mass correction the following values are used:

- Block I: 0.210, 0.000, 0.854m in satellite x, y, z.
- Block II/IIA: 0.279, 0.000, 1.026m in satellite x, y, z.

GPSOBS also estimates the station clock biases to correct the time tags of the measurements. Double-difference phase measurements are output every six minutes. Observations of eclipsing satellites are excluded during eclipse and 30 minutes after it. We are not modeling the biased-satellite yaw model because it does not fully predict the attitude of the satellite.

4 Orbit and Geodetic Parameter Estimation

Orbit and geodetic parameter estimation is performed using the program BAHN. BAHN is a batch least-squares estimator for dynamic orbit determination. We use a 48-hour arc in order to obtain the precise orbit and erps for each day, with 12 hours before and after the central day.

Starting in February 96 we are taking into account the correlations of the double-difference observables in our estimation process.

5 Measurement Models

Velocity of light: 299 792.458 km/s

Troposphere: Willmann model.

Ionosphere: first-order term removed by using the so-called ionospheric-free combination.

Plate motions: ITRF values used when available, if not Nuvel-NNR.

Tidal displacements: Wahr model used for solid earth tidal displacement. Pole tide and ocean and atmospheric loading are not modeled.

Ground antenna phase center calibration: not used. Only Rogue and Turbo-Rogue receivers with Dorne-Margolin choke-ring antennas used.

6 Dynamic Models

Geopotential: GEM-T3 up to degree and order 8 with the GM (398 600.4415 km^3/s^2), C21 and S21 from the IERS standards.

Third-body forces: Sun, Moon and four planets regarded as point masses. Ephemeris form JPL DE200, GM of Sun 132 712 440 000.0 km^3/s^2, GM of Moon 4902.7991 km^3/s^2

Solar radiation pressure: ROCK4 and ROCK42 approximations denoted as T10 and T20 used for Block I and Block II satellites. One scale factor and one Y-bias estimated per arc.

Tidal forces: Wahr model for solid earth tides, Schwiderski for ocean tides.

7 Reference Frames

Inertial: Geocentric, mean equator and equinox of 2000 Jan. 1 at 12:00 (J2000.0).

Terrestrial: ITRF reference frame realized through a set of 13 station coordinates and site velocities.

Interconnection: Precession, IAU 1976 Precession Theory; Nutation, IAU 1980 Nutation Theory; Celestial pole offsets from IERS Bulletin B; relation between UT1 and GMST, Aoki 1982; Pole and LODR estimated as constants for 24-hour intervals; Tidal variations in UT1, Yoder model.

8 Numerical Integration

Adams-Bashforth/Adams-Moulton predictor-corrector of order 8 started with a Runge-Kutta/Shanks of order 8. Integration step of 6 minutes.

9 Estimated Parameters

Station coordinates: 13 stations fixed to the agreed ITRF positions. Remaining station positions estimated.

Orbital parameters: Initial position and velocity, solar radiation pressure scale factor and y-bias estimated as constant through the 48-hour orbital arc.

Double-difference phases ambiguities estimated as real values.

Earth rotation parameters: x and y pole and LODR estimated as constants for 24-hour intervals. LODR is the excess of the length of the day regularized as described in the IERS standards.

Receiver clock biases and drifts estimated as constant parameters between clock resets.

Maneuvers estimated as instantaneous velocity changes.

Tropospheric zenith delay and shape parameter estimated linear in 6-hour intervals.

Velocity discontinuities for eclipsing satellites at the times of the eclipse exits. Newly implemented in February 1996.

Allow for small velocity discontinuities for non-eclipsing satellites every 12 hours. Newly implemented in February 1996.

10 Precise Clock Bias Estimation

The Rogue and TurboRogue receivers used for our IGS Analysis can track the P code pseudorange when Anti-Spoofing (AS) is not activated. When AS is activated they track the CA code and the cross-correlation between the codes in L1 and L2. With these two measurements a code in L1 is directly obtained (CA code) and a code in L2 can be reconstituted by adding the cross-correlation delay to the CA code. We have observed that these receivers have a bias between the P and the CA code. This bias can be clearly observed when the receiver is tracking simultaneously P and CA code (e.g., for a satellite that is not performing AS). The value of the bias depends on the particular receiver and its software and can be as big as 60 meters. In order to calculate the clock biases the values of the CA pseudo-range biases have to be estimated. This has to be done every day because of unannounced receiver changes.

We are using the daily average of double differenced pseudo-range residuals as the basic observable to estimate the CA biases. For most of the receivers these biases do not depend on the PRN number, but for others we have to calculate a bias for every satellite.

The precise clock bias values are estimated from pseudo-ranges and carrier phase by using the CA pseudorange biases and the parameters estimated in BAHN to correct the measurements.

The clock bias estimation is separated into a clock drift estimation using carrier phase and a clock bias estimation that uses the estimated clock drifts and pseudoranges. Satellite clock bias values are constrained to the Navigation Message values to produce values aligned with the GPS system time. The evolutions of the drift of receivers connected to hydrogen masers is also constrained to stabilize the drift and clock estimates.

Precise values are obtained every 60 seconds and can be used to interpolate the satellite clock value at any time.

In 1995 we replaced the Kalman filter used for the clock bias estimation by a square root information filter.

11 Post-Processing and Quality Control

The orbits obtained with BAHN are combined with the precise clocks and output every 15 minutes in a file with the sp3 format. The erps are output to a file with the IERS format.

Quality control is performed by checking the following:

- Post-fit double-difference phase measurement residuals per station and satellite.
- Orbit overlaps between consecutive days.
- Pseudorange residuals after calculating the clock biases.
- Agreement of the estimated clocks with the values contained in the Navigation Message.

12 BATUSI

At the end of 1995 and the beginning of 1996 our orbit determination package BAHN has been modified to output in a more suitable way the normal equations.

Using the new software BATUSI (BAHN to SINEX) the results of different BAHN estimations can be combined to provide a free network solution for the unconstrained normal equations in the new established SINEX format.

Every week a SINEX (see [5]) file is generated using the normal equations from each of the seven days.

13 'Rapid' Orbits

At the beginning of 1996 we have started to produce orbits that are available with a delay of maximum 36 hours since the last observations were collected.

The strategy is basically the same that is used for the 11-day-delay orbits but the observation period is only 36 hours instead of 48. The last 12 hours overlapping cannot be used because the processing is started before these data are available.

It is foreseen that in July 1996 the current 36 hours will be shortened to only 23 hours.

14 Products

Our routine products are the following:

- Daily orbits and clocks in the SP3 file: `esa`*wwwwd*`.sp3`, *wwww* being the gps week and *d* the day of the week (0-6). These are values at 15 minute intervals and include the accuracy codes. There are two sets, the rapid (23 hours delay after July 1996), distributed via EMR, and the final (11 days delay), distributed via CDDIS. Both have the same name but are delivered to different data centres as remarked.
- daily rapid EOP (pole, LODR) solutions in IERS format: `esa`*wwwwd*`.erp`.
- weekly final EOP (pole, LODR) solutions in IERS format: `esa`*wwww*`7.erp`.
- weekly summaries: `esa`*wwww*`7.sum`.
- weekly free network station coordinate solution in the SINEX format: `esa`*wwww*`7.snx`

We are also producing and archiving satellite clock bias files at 60-minute intervals. For these we are using our own internal format. They are available on request.

We have provided the IERS with several solutions, including more recently the following:

EOP (ESOC) 94 P 01: an EOP solution, including the integration of the LODR values to obtain a continuous UT1 series.

SSC (ESOC) 95 P 01: a free network station coordinate and velocity solution based in 274 days of observations in 1994. It is referred to the IERS terrestrial reference frame by fixing the EOP at their Bulletin B values and by loose constraints on the positions and velocities to the ITRF92 values.

15 Outlook

Several developments of interest for the IGS that we are planning to implement in the future are the routine generation of ionospheric TEC models and a review of our current tropospheric and clock estimation algorithms.

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Annual Report 1995 of the CODE Analysis Center of the IGS

M. Rothacher, G. Beutler, E. Brockmann, L. Mervart,
S. Schaer, T. A. Springer
Astronomical Institute, University of Bern

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

C. Boucher
Institut Géographique National, Paris

H. Seeger
Institut für Angewandte Geodäsie, Frankfurt

1 Introduction and Overview

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

- the Federal Office of Topography (L+T), Wabern, Switzerland
- the Institut Géographique National (IGN), Paris, France
- the Institute for Applied Geodesy (IfAG), Frankfurt, Germany
- the Astronomical Institute of the University of Berne (AIUB), Berne, Switzerland

The CODE Analysis Center, according to its name and the participating institutions, lays special emphasis on Europe in two respects:

- The European region is clearly over-represented in the global CODE solutions (about one third of the 75 sites used in the global solutions are European sites). This should guarantee that the CODE orbits are of as good a quality as possible over Europe.

- A special solution for approximately 30 European sites is routinely computed with a delay of about 14 days using the final CODE orbits to monitor the European sites and reference frame.

The CODE is located at the AIUB and uses a cluster of DEC Alpha processors for the daily IGS processing. The data are analyzed with the Bernese GPS Software Version 4.0.

This report covers the time period from January 1995 to April 1996. During this period the number of sites in "our" global network — and therefore also the number of observations and parameters — again grew considerably. Table 1 gives an overview of the daily workload at CODE since the beginning of the IGS (test campaign) in June 1992.

Table 1: Workload of the Routine 3-Day Solutions at CODE from 1992 to 1996.

Solution Characteristic	Number Used in Daily CODE Processing				
	June 1992	Jan. 1993	Jan. 1994	Jan. 1995	Jan. 1996
Number of Satellites	19	21	26	25	25
Number of Stations	25	28	38	49	72
Number of Observations	50,000	60,000	140,000	210,000	250,000
Total Number of Param.	2,000	2,300	6,000	9,000	12,000
Ambiguity Parameters	1,500	1,800	5,300	8,000	10,500

Figure 1 shows the number of global sites processed by CODE and the number of parameters in the ambiguity-free and ambiguity-fixed 3-day solutions during the time interval discussed in this report.

Whereas the number of parameters in the ambiguity-free case is increasing in a similar way as the number of sites, there is no such increase visible in the ambiguity-fixed solutions due to a shortening of the average baseline length in the global network and due to improvements in the ambiguity resolution strategy. On day 084, 1996, the ambiguity-free 3-day solution was discontinued.

Not only did the size of the solutions increase over time but also the number of different solutions produced at CODE: in addition to the solutions already computed day-by-day in January 1995, CODE is now running the ambiguity resolution step and the ambiguity-fixed 1- and 3-day solutions, satellite and receiver clock estimation, a special European solution, ionosphere model computations, rapid orbit solutions, and last but not least an orbit prediction procedure was implemented. The daily processing as it is implemented at CODE at present (April 1996) is outlined in Section 2.

During the last year many new developments took place at the CODE Analysis Center. They are described in more detail in the following sections. Table 2 summarizes major changes during the time period covered by this report.

Table 2: Changes/Modifications of Processing at the CODE Analysis Center of the IGS During 1995 and the Beginning of 1996

Date	doy/Year	Description of Change at CODE	Section
01-JAN-95	001/95	Change from the ITRF92 to the ITRF93 coordinate and velocity set for the 13 fixed sites.	3
19-MAR-95	078/95	Pseudo-stochastic pulses set up for the eclipsing satellites at 45 minutes after the exit from the shadow.	4
04-JUN-95	155/95	Estimation of pseudo-stochastic pulses for *all* satellites at 12:00 UT and 24:00 UT (once per revolution).	4
04-JUN-95	155/95	Submission of the first weekly coordinate solution in the SINEX format.	3
25-JUN-95	176/95	Ambiguity-fixed solutions submitted as the official solution.	8
10-SEP-95	253/95	Precise satellite clocks are estimated using code observations and submitted together with the precise orbit files.	5
03-NOV-95	307/95	Station GOLD (Goldstone) not fixed any longer on ITRF coordinates (unknown antenna change).	3
01-JAN-96	001/96	Routine computation of global ionosphere models to support the ambiguity resolution algorithm. Daily global ionosphere models are available starting January 1, 1995 (reprocessing of 1995).	7
01-JAN-96	001/96	Computation of the first rapid orbits with a delay of 12 hours after the observations. These orbits are predicted for two days to obtain real-time orbits.	4
12-JAN-96	012/96	Terrible disk crash.	–
22-JAN-96	022/96	The new radiation pressure model with 9 parameters per satellite implemented in processing, but all parameters constrained to zero with the exception of the conventional ones (direct rad. pressure coeff. and y-bias). Switch from the Rock4/42 S-model to the T-model.	4
24-MAR-96	084/96	Ambiguity-free 3-day solution discontinued.	–
24-MAR-96	084/96	Set-up of subdaily pole and UT1-UTC estimates (offsets and drifts in 2 hour intervals) in the routine solutions for internal purposes.	6
07-APR-96	098/96	A routine test solution making use of the fully new radiation pressure model (except that no x-comp. is estimated).	4
07-APR-96	098/96	A special pole file is created using the rapid pole results to omit large jumps when passing from one Bulletin A file to the next updated version.	–
08-APR-96	099/96	Pseudo-stochastic pulses are set up for all satellites at 12:00 UT for the 1-day solutions to improve the orbit quality. These 1-day orbits are used for ambiguity fixing.	4
09-APR-96	100/96	Rapid orbits are computed with fixed ambiguities.	4

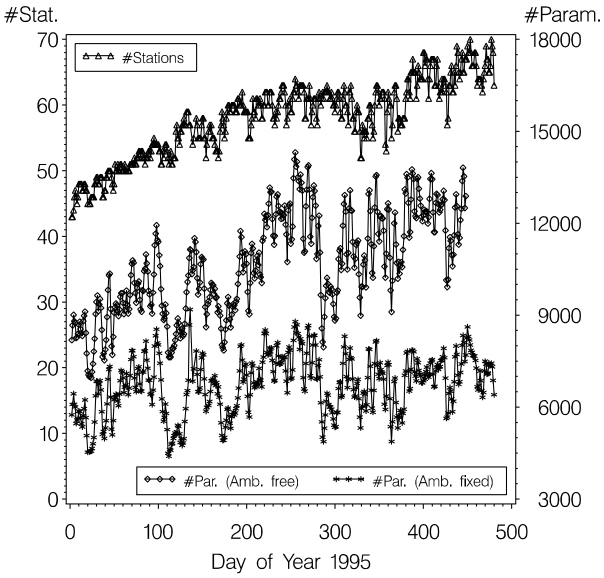

Figure 1: Statistics of Global 3-Day Solutions Computed at CODE

2 Daily Routine Processing at CODE

Since January 1, 1996, there are three major processing procedures running at CODE every day: the normal IGS processing (producing the final CODE orbits), the generation of a rapid orbit solution, and the computation of a European solution. A flow chart of the normal IGS routine at CODE is shown in Figure 2 and discussed in detail below. For the rapid IGS procedure only the differences with respect to the normal IGS routine will be discussed.

Figure 3 gives a map of the complete network of 75 stations used for the normal IGS routine analysis at CODE (April 1996).

The routine analysis currently starts at 21:45 local time with the processing of the data that were gathered three days before. The routine processing first checks what data are available — the IGN Global Data Center provides us with the data of the stations we want to process — and tries to download any data, that might still be missing, from CDDIS or SIO, the two other global data centers. Under normal circumstances only a few stations (on average about 4) have to be downloaded in this step.

After the download step all RINEX data (observation and navigation data) are transformed into the Bernese format, the code observations are checked for outliers, and code single point positioning solutions are computed for each station. This single point positioning is used to synchronize the receiver clocks with respect to GPS time. Broadcast ephemerides and clocks are used in this step. This procedure, called “IGSA”, takes about 30 minutes of CPU time.

The next part of the routine procedure, called "IGSG", is dedicated to the generation of a global 1-day solution of good quality. In a first step the phase data must be cleaned. For this step the orbit quality used is essential. Before we started the routine computation of rapid orbits in January 1996, we had to use either orbits predicted from the solutions of previous days or, in case of maneuvers or modeling problems, the broadcast orbits.

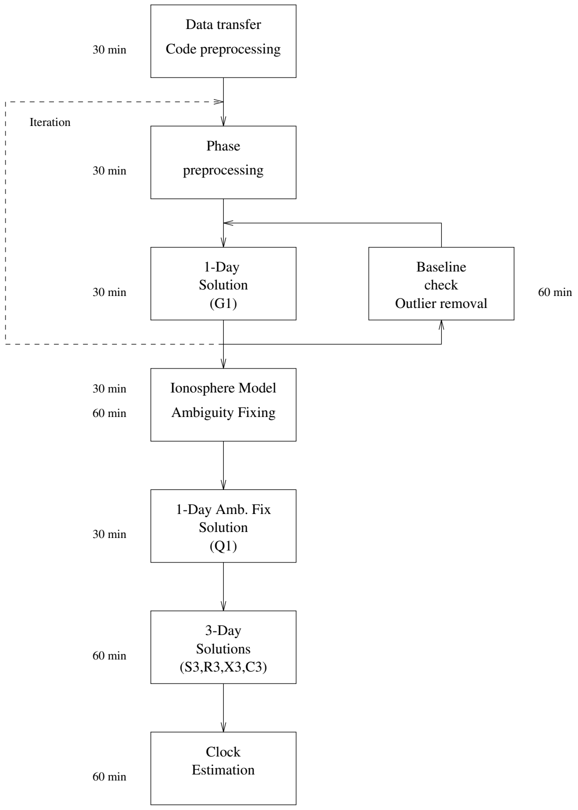

Figure 2: IGS Data Processing Flow at CODE (April 1996).

In both cases it was necessary to perform an iteration to improve the orbit quality (producing a first 1-day solution and then cleaning the phase data a second time with these improved 1-day orbits). Nowadays such an iterative procedure is obsolete because of the high quality of the rapid orbits (maneuvers have to be dealt with now at the rapid orbit stage). In the 1-day solution (computed after the phase cleaning) we estimate orbit parameters, ERPs (including ERP drifts), station coordinates, and troposphere zenith delays.

Because under AS (anti-spoofing) some receivers (mainly Rogues and some Turborogues) sometimes produce data with strange systematic biases that are difficult to detect with our conventional pre-processing algorithms, an extra step was added to screen the post-fit residuals of all baselines for outliers. The full 1-day solution is then repeated producing the final 1-day results, labeled G1 (see "Global Solution Types" below). The final 1-day orbits have a quality already comparable to the orbits of the best IGS AC centers, but an improvement is still possible when going to longer arcs, i.e., to 3-day solutions.

The G1-products are made available on our anonymous ftp account as soon as they have been computed (see "Daily Products" below). The complete "IGSG" routine requires about 2.5 hours of CPU time.

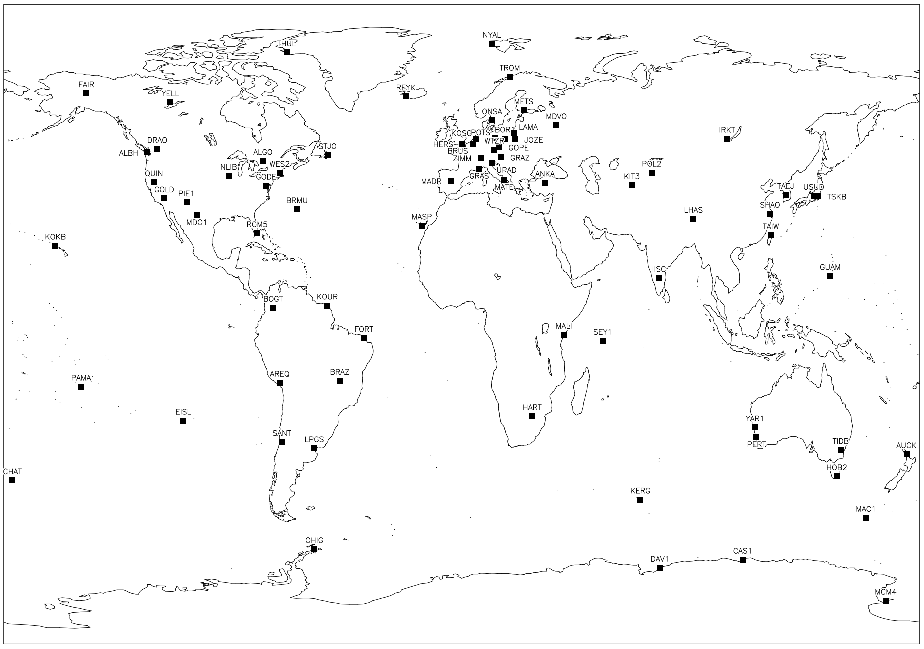

Figure 3: The Global Network of 75 Stations Used in the CODE Routine Analyses.

The procedure for the 3-day solutions starts with the computation of a global ionosphere model used for the ambiguity resolution step to follow (see Sections 7 and 8). After ambiguity fixing (on the single baseline level) a new, complete 1-day solution is generated saving the normal equation information for *all* parameters that might be of interest later on (as, e.g., the parameters of the extended orbit model, subdaily ERPs, nutation drifts, center of mass coordinates, satellite antenna offsets, ...). A 3-day solution is then produced combining the normal equations of this last day with the normal equations of the previous two 1-day solutions (see [1] for the algorithms used to combine 1-day arcs into 3-day arcs). Four different 3-day solutions are currently created in this way, labeled S3, R3, X3, and C3 (see "Global Solution Types" below). Our official IGS products stem from the middle day of the R3-solution. The 3-day solution procedure takes about 3 hours CPU time.

Finally a clock solution is computed where the satellite and station clocks are solved for simultaneously using code observations only. This clock solution is described in detail in Section 5 and takes about 1 hour of CPU time including one iteration and several steps for quality checks.

The complete IGS routine needs about 7 hours of CPU time per day, which means about 10 hours turn-around time.

The Rapid Orbit Computation

Since January 1, 1996, CODE is making available rapid orbits with a delay of only 12 hours! The estimation scheme for the rapid orbits is very similar to the normal routine processing up to the 1-day ambiguity-fixed solution. The basic differences are that (a) an iteration is necessary for the orbit improvement, since there is no good *a priori* orbit information available, and that (b) at present no ionosphere model is estimated and used in the ambiguity resolution step. The final rapid orbit solution is a 5-day solution with 5-day satellite arcs in contrast to the 3-day arcs in the normal procedure. For these 5-day solutions the 9 radiation pressure parameters of the extended orbit model are set up and solved for.

The most important difference from the operational point of view is, however, that the rapid orbits are generated using the Bernese Processing Engine (BPE), a tool for the fully automated processing of permanent networks, which allows a parallel processing on many CPUs. The ambiguity resolution step e.g., which is done baseline by baseline, is run on 6 different machines simultaneously. This reduces the processing time considerably because it makes optimal use of the 6 DEC Alpha stations available at our university. Instead of 10 hours (normal IGS procedure) the generation of the rapid orbits takes about 3 hours turn-around time. With such a strategy the processing time only grows linearly with the number of stations, i.e., a network of about 100 stations might be processed in 4 hours.

The European Solution

Apart from the normal and the rapid IGS procedures CODE also generates a European solution. This solution — Figure 4 shows a map of the network — is computed with a delay of about 2 weeks making use of the official CODE products (orbits and ERPs). It was mainly set up for test purposes. With this regional network we can in a first step check the quality of our orbits, then use it to test new processing strategies, and finally gain experiences in how a typical IGS "customer" should make use of the IGS products to achieve the highest possible precision and how the regional solutions may be combined with the global solutions (densification issues).

The stations `CAGL`, `EBRE`, `HFLK`, `PENC`, `KELY`, `KIRU`, `MEDI`, `NOTO`, `SFER`, `VILL`, and `ZWEN` are included *only* in this European solution providing

Figure 4: European Network of 35 Stations Processed at CODE with a Delay of two Weeks.

an independent check of our orbit quality, whereas all other sites are also part of the global CODE solution.

The series of European solutions is combined with the series of global solutions for the annual submission to the ITRF Sub-bureau of the IERS.

Global Solution Types

Several different solution series are routinely generated at the CODE Analysis Center (see also Figure 2), although only one official series is submitted to the global data centers:

G1-Series: Since June 21, 1992, our final 1-day solution. Precise ephemerides files, earth rotation parameters, and station coordinates are saved. The orbits and ERPs are available on our anonymous ftp account until we have completed our official 3-day solution. Older results are available on request.

Q1-Series: Q1 designates the ambiguity-fixed 1-day solution series. Although the computation of Q1-solution started on June 25, 1995, we began only recently to save the results of this solution type.

R3-Series: Starting June 25, 1995 (GPS week 807), this is the official CODE solution delivered to the global data centers. The satellites are modeled using our conventional 8-parameter orbit model. In addition, five small velocity changes (pseudo-stochastic pulses) per satellite are estimated over the 3-day arc in the radial and along-track directions. The earth orientation parameters are estimated as a first-degree polynomial over the three days. Four troposphere zenith delays are determined per station and day.

S3-Series: The S3-series only started on April 7, 1996. But due to the reprocessing of 1995 (including S3-solutions) almost a full year of S3-solutions is available. The S3-series is identical to the R3-series with the exception of the ERP estimation: instead of one first-degree polynomial over three days we estimate subdaily pole and UT1-UTC values in 2-hour intervals (see Section 6).

X3-Series: This solution type was started together with the S3-series on April 7, 1996, and was also included in the reprocessing of 1995. This solution determines a subset of the parameters of the extended orbit model (the "X"-terms are heavily constrained, see Section 4). Apart from this the X3-series is identical to the R3-series.

C3-Series: This series is produced since January 1, 1994. It includes the estimation of the nutation drift corrections in longitude $\Delta\psi$ and obliquity $\Delta\varepsilon$ (in addition to the other ERPs). All other characteristics are identical to the R3-Series (except that before April 7, 1996, the C3-series was based on ambiguity-free solutions).

Daily Products

On the anonymous ftp account CODE makes available several of its (IGS) products (*ftp ubeclu.unibe.ch -or- 130.92.6.11, after login: cd aiub$ftp*).

The anonymous ftp area is divided into two product directories: the directory `CODE` containing our official IGS products and the Bernese Software user directory `BSWUSER` with Bernese-specific information like daily coordinates and troposphere estimates.

```
BSWUSER --- ATM       CODE --- 1992
        |-- DATPAN         |-- 1993
        |-- GEN            |-- 1994
        |-- OUT            |-- 1995
        |-- STA
```

The subdirectories of the `CODE` directory contain the products of the past years. Some of the products in these annual directories have been compressed using the standard compression algorithms used by the IGS (e.g., for RINEX file compression). The data of the current year are located (in uncompressed form) directly in the `CODE` directory. A summary of the products available on our anonymous ftp is given in Table 3.

Table 3: CODE Products Available Through Anonymous FTP.

Daily Products	
CODwwwwd.EP1	CODE 1-day orbits (G1-series). Available with a 3-day delay
CODwwwwd.ER1	CODE 1-day ERPs (G1-series) belonging to the 1-day orbits
CODwwwwd.ERH_R	CODE rapid orbits. Available with a 12-hour delay
CODwwwwd.ERP_R	CODE rapid ERPs belonging to the rapid orbits
CODwwwwd.EPH_P	CODE 24-hour orbit predictions
CODwwwwd.ERH_P2	CODE 48-hour orbit predictions
Weekly Products	
CODwwwwd.EPH	CODE final orbits (R3-series). This is our official orbit product!
CODwwwwd.ERP	CODE final ERPs (R3-series) belonging to the final orbits
CODwwww7.SUM	CODE weekly summary file
CODwwww7.SNX	CODE weekly SINEX file
CODwwwwd.ION	CODE daily global ionosphere model, Bernese format
CODwwwwd.CLK	CODE satellite clock estimates (5 min. sampl.), Bernese format
B1_yyddd.CLK	Broadcast satellite clock information, Bernese format
BSWUSER Subdirectories	
ATM	Contains the troposphere estimates of the R3-series
DATPAN	Contains some files specific to the Bernese software
GEN	Official IERS poles (C04 and Bulletin A) in the Bernese format and some additional files for the Bernese software
OUT	Contains the ERP estimates of the R3-series
STA	Contains the coordinate estimates of the R3- and the European series

3 Coordinates and Velocities

With the beginning of the year 1995 the CODE Analysis Center introduced, in agreement with all other Analysis Centers of the IGS, the ITRF93 (IERS Terrestrial Reference Frame) as the new reference for the computation of the daily products (orbits and ERPs). The system is realized by tightly constraining the coordinate and velocity values of the 13 IGS core sites to the ITRF93 values in the daily solutions.

A consequence of the change from ITRF92 to ITRF93 is a discontinuity in the x and y coordinates of the pole; the LOD estimates are not affected. Based on normal equations we reprocessed all the solutions back to September 1993 to determine the impact of the system change [2]. A comparison of the two series (ITRF92 and ITRF93 as reference frame) over a time interval of about 1.5 years gives the following results:

At epoch 1993.0 we see an offset in the x and y pole of about -0.15 ± 0.06 mas and -0.85 ± 0.08 mas respectively. The drift difference of -0.45 ± 0.06 mas/yr in the x pole and -0.40 ± 0.05 mas/yr in the y pole can be attributed to the differences between the two velocity fields (alignment with NNR-NUVEL1 for ITRF92 versus alignment with the C04 pole drift for ITRF93).

In Table 4 we compared the IGS core sites of a CODE 2.75-year solution with ITRF92 and ITRF93 using a 7-parameter Helmert transformation. The epoch of comparison is August 1994. The improvement in the consistency between the GPS solution of CODE and the ITRF is mainly a consequence of the fact that GPS contributed considerably to the ITRF93 solution.

Table 4: RMS of a 7-Parameter Helmert Transformation Comparing the 13 IGS Core Sites of the CODE 2.75-Year Solution with the Values of ITRF92 and ITRF93.

ITRF92			ITRF93		
North	East	Up	North	East	Up
12.1 mm	12.0 mm	23.9 mm	4.7 mm	4.3 mm	11.7 mm

The 2.75-year solution, mentioned above, was submitted to the IERS in April 1996 in the SINEX format (Software Independent Exchange Format) as the CODE 1995 contribution to the ITRF. A total of 102 sites are included in this solution. Site velocities were estimated for 58 sites (using the information of 69 site occupations).

As a new product (starting with GPS week 804) weekly site coordinate solutions are computed at CODE from 3-day solutions (combination of three non-overlapping 3-day solutions). The weekly results are reported to the global data centers in the SINEX format. Such weekly solutions of all the IGS Analysis Centers are then combined and compared by the Global Network Associated Analysis Centers (GNAAC) as part of the IGS Densification Pilot Project.

To study the quality of our weekly coordinate estimates we analyzed the repeatabilities in baseline length of weekly solutions in 1993, 1994, and 1995. The quantity "baseline length" is well-suited for this purpose because of its invariance with respect to the reference frame definition. The velocities estimated from 2.75 years of GPS observations were used to take into account the linear motion of the sites within the time period analyzed.

Assuming that the baseline length repeatability σ_L may be written as a linear function of the baseline length L:

$$\sigma_L\ [mm] = a\ [mm] + b\ [ppb] \cdot L\ [1000\ km]. \tag{1}$$

we obtain the values listed in Table 5 for the three years. Substitution of these values into formula (1) shows that a mean precision of 3 mm in baseline length may be expected for, e.g., typical baselines in Europe of 1000 km using one week of continuous GPS observations. A considerable improvement from

Table 5: Repeatability for the Baseline Length Determined from Weekly Free GPS Solutions.

Year	# Baselines	Repeatability	
(Interval)	(# Stations)	a [mm]	b [ppb]
1993	383	0.09	2.96
(0.75 yrs)	33		
1994	520	1.07	2.00
(1.0 yrs)	44		
1995	765	1.77	1.41
(1.0 yrs)	65		

1993 to 1995 can be seen for long baselines. A 6000-km baseline (e.g., between Europe and North America) was determined with a precision of approximately 18 mm in 1993 and with about 10 mm in 1995. The improvement in the results is mainly a consequence of the increasing number of global IGS sites, the better geographical distribution, and the improvements in the processing strategies at the CODE Analysis Center.

The excellent agreement between the weekly results of different Analysis Centers is demonstrated by the IGS reports of the three Global Network Associated Analysis Centers and is not discussed here.

In Figure 5 we would like to address the problem of the station height estimation in the case of a mixture of different antenna types. Depending on how elevation-dependent antenna phase center variations are modeled, large differences may be seen between the height estimates of the individual IGS Analysis Centers (see Section 9). The reason for the discrepancy between the CODE heights on one hand and the SIO heights on the other hand resides in the fact that SIO does *not* apply elevation-dependent phase center variations for the Trimble antennas (relative to the Dorne Margolin antennas).

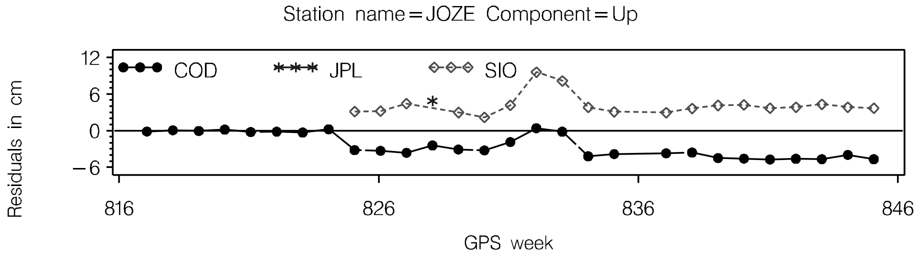

Figure 5: Comparison of Station Height Estimates for the Site `JOZE` Derived from the Weekly SINEX Contributions of the IGS Analysis Centers.

4 Orbit Modeling Improvements

During the first months of 1995 it became more and more evident that the orbit model used at CODE was not sufficient to represent the satellite trajectories over a 3-day period, even for satellites not passing through the Earth shadow. Figure 6 compares five different orbit estimation strategies:

1. 1-day arcs without the estimation of pseudo-stochastic pulses
2. 1-day arcs with 2 stochastic pulse per revolution (one in radial "R", the other in along-track direction "S")
3. 3-day arcs without pseudo-stochastic pulses
4. 3-day arcs with 2 stochastic pulses per revolution
5. 3-day arcs with 3 stochastic pulses per revolution (including an additional pulse per revolution in the out-of-plane direction "W")

by fitting a 7-day arc through 7 individual 1-day or 3-day solutions (middle days only) using the CODE Extended Orbit Model (9 radiation pressure parameters instead of 2, see [3]). The improvement due to the estimation of pseudo-stochastic pulses is pronounced in the case of 3-day solutions.

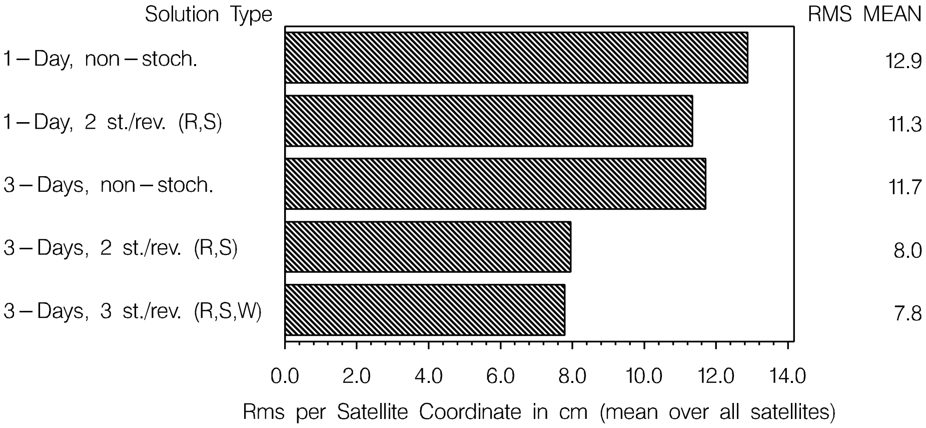

Figure 6: Comparison of orbit estimation strategies by fitting a 7-day arc through the 7 individual 1- or 3-day solutions of GPS Week 765 using the extended CODE orbit model.

Seeing this, the estimation strategy for pseudo-stochastic pulses was changed on June 4, 1995 (see also Table 2): whereas up to this date pseudo-stochastic pulses were only set up for the eclipsing satellites, such pulses were now estimated for *all* satellites. This new strategy considerably improved the CODE orbit quality.

In January 1996 the Extended CODE Orbit Model with a maximum of 9 radiation pressure parameters per satellite and arc — only used so far with satellite positions as pseudo-observations (e.g., in the long arc comparisons done by the Analysis Center Coordinator) — was fully implemented into the parameter estimation and normal equation stacking programs [4]. The full radiation pressure model may now be estimated using the phase (and code) observations directly. The final CODE products are still based on the conventional radiation pressure model, although all 9 radiation pressure parameters are set up for later use.

Reprocessing about 8 months of the year 1995 with the Extended CODE Orbit Model gave us a sufficiently long series of solutions to obtain more information on how this new model may be optimally tuned for the routine CODE processing. The new model is already in daily use for two other IGS applications at CODE that started in January 1996: the rapid orbit determination and the orbit predictions.

The rapid orbit procedure used at CODE has already been described in Section 2 and the quality of this new product — available 12 hours after the observations — may be seen in the weekly IGS reports of the rapid orbit combination. In the orbit prediction scheme the rapid orbit results from the last three days are fitted using 3-day arcs. These arcs are then extrapolated for two days thus making predicted orbits available for real-time applications. The quality presently achieved is about 30 cm for 1-day predictions and about 80 cm for 2-day predictions (needed for real-time applications). Both products (the CODE rapid orbits and the orbit predictions) have been available at CODE since January 1, 1996 (see Table 3).

During the last year some research was performed at CODE concerning the correlations between ERPs and orbital parameters with the goal to improve the quality and stability of the UT1-UTC and nutation drifts determined from global GPS data. First results concerning the correlation between UT1-UTC, the pseudo-stochastic pulses, and the conventional two radiation pressure parameters (direct coefficient and y-bias) were presented in [5]. A more general approach (including also nutation parameters) may be found in [6].

5 Satellite Clock Estimation

Since September 10, 1995 (GPS week 818) precise satellite clocks have been routinely determined at CODE and reported to the IGS global data centers in the precise orbit format. The procedure to estimate the satellite and station clocks is the last part of our IGS routine processing. It consists of five steps.

First a reference clock has to be selected because not all (receiver and satellite) clocks can be estimated. We normally use the receiver clock at Algonquin as time reference. If the Algonquin data are not available another station connected to a hydrogen maser frequency standard is automatically selected. This reference clock is then aligned to GPS time by estimating offset and drift with respect to the broadcast satellite clock values.

In the second step, the actual clock estimation, all good code observations are processed simultaneously to estimate all satellite and station clocks except the clock of the selected reference station. We currently use code measurements only (no phase observations) and only from receivers which are not affected by AS-related biases in the code observations. No Rogue receivers, but most of the Turborogue and all Trimble receivers are included. For the clock estimation we use our "final" orbits, ERPs and coordinate results to guarantee that the clock estimates are consistent with the other final CODE products.

The estimated satellite clocks are then used in the third step to compute a code single point positioning solution for each station contributing to the clock estimation. This alows us to detect and remove outliers and, if necessary, to repeat the actual clock estimation.

A similar single point positioning solution (step 4) — estimating only offset and drift for each receiver clock instead of epoch-wise clock corrections — allows us to check whether the reference clock had a jump sometime during the day and shows us which stations have good external oscillators connected to the GPS receivers.

In the fifth and last step a code single point positioning, but now using *all* available code data (including the data from stations with code biases), is done to verify the code quality of *all* receivers. In this last step we use a cutoff angle of 20 degrees. In all other steps the cutoff angle is set to 30 degrees to avoid the effects of code multipath.

The quality of the CODE satellite clock estimates is of the order of 1-2 nsec (according to the weekly reports on IGS orbit combination, where the satellite clock results are combined and compared, too).

6 Earth Rotation Parameters and Nutation

The quality of the daily ERP values obtained from the CODE 3-day solutions is now of the order 0.1–0.2 mas for the x- and y-pole components and about 0.02 msec for LOD. This can be seen from the monthly and weekly IGS reports of the IERS Central Bureau and IERS Rapid Service Sub-bureau.

At CODE we are also routinely estimating — in the special solution series C3 (see Section 2) — the drifts of the nutation in longitude $\Delta\psi$ and obliquity $\Delta\varepsilon$. The *a priori* nutation model introduced for all the global CODE solutions is the IAU 1980 model, i.e., no correction terms as e.g., given in [7] are taken into account. The estimated nutation drifts are therefore corrections with respect to the IAU 1980 model. A series of such nutation drifts is available from April 22, 1994, up to now, covering a time interval of almost two years. It is clear that GPS cannot contribute to the long-periodic nutation terms, but it might give contributions to a future nutation model in the high frequency domain. As examples the spectra obtained from the daily estimated nutation drifts in obliquity and in longitude are shown here in Figure 7 covering periods from 3 to 12 days.

The dotted vertical lines mark the known nutation periods (e.g., given in the

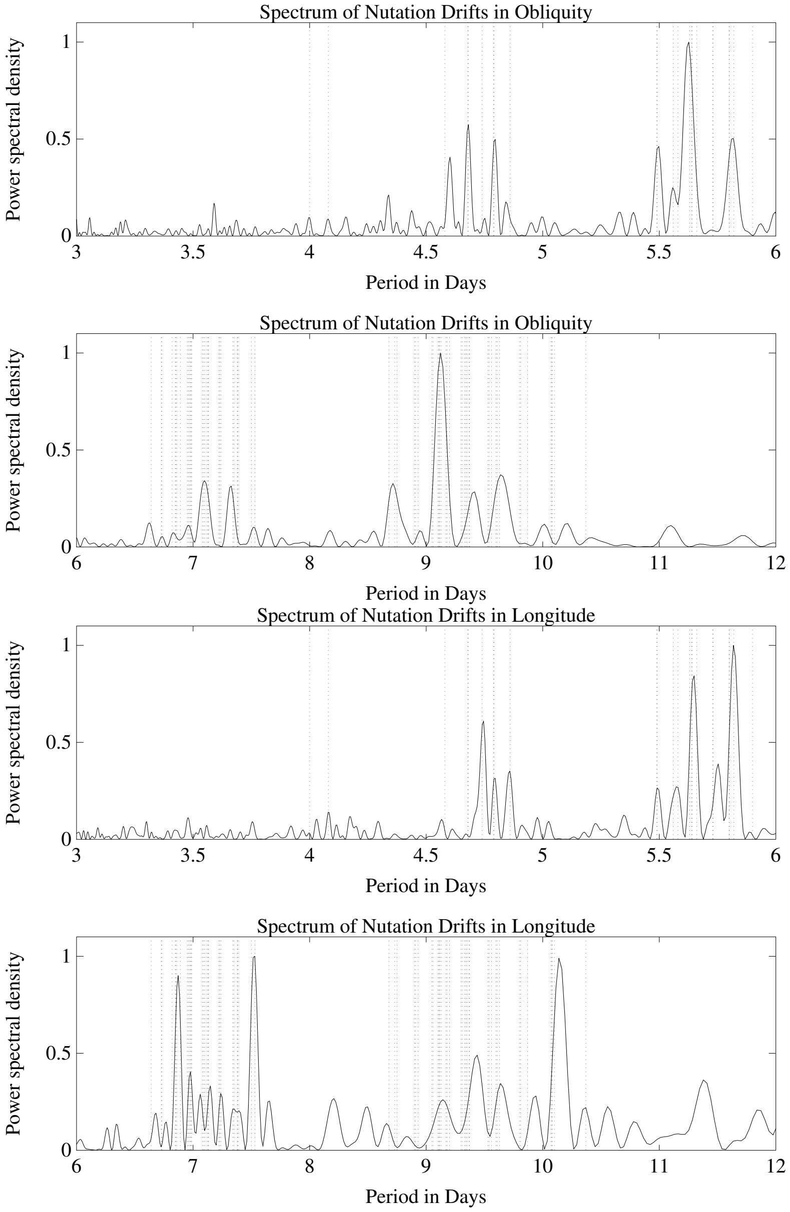

Figure 7: Spectrum of Nutation Corrections in Obliquity and Longitude Derived From the CODE Results in the Time Interval from April 1994 to January 1996.

IERS Standards [8]). In a next step the nutation drift series will be analyzed to obtain the amplitudes of the most important correction terms that may then be compared to theoretical and VLBI-derived models. A first GPS nutation model was presented at the XXI General Assembly of the IUGG in Boulder [9].

After having processed several time periods (CONT'94 and CONT'95 campaigns, and a 3-month period in fall 1995) with the estimation of subdaily ERPs for test purposes, we are now routinely setting up ERPs (pole x- and y-coordinates, and UT1-UTC) in 2-hour bins, i.e., as a linear function over 2 hours, enforcing continuity at the interval boundaries. For the official CODE results, these 2-hourly parameter sets are reduced to just one set over the three days of a 3-day solution. At present no *a priori* model for the subdaily ERP variations is included in the CODE solutions and the results reported to the IERS and IERS Sub-bureau do not contain any subdaily corrections . (The values reported for noon each day are the mean values over one day, averaging the subdaily variations).

Based on the saved daily normal equation systems a special solution — called S3 in Figure 2 — is produced to estimate the subdaily variations. This S3-series was started on March 22, 1996. Thanks to the reprocessing effort the same solution type (S3) is available for all days since day of year 127 in 1995. This time series should allow a detailed study of the subdaily ERP variations that can be obtained from a global GPS network. First results were presented by [9] and [10].

7 Global Ionosphere Mapping

As shown in [11] it is possible to produce reasonable Global Ionosphere Maps (GIMs) by analysis of the geometry-free linear combination of double-difference phase observations. We are fully aware of the fact that by using *double* instead of *zero* differences we lose part of the ionospheric signal, but we have the advantage of *clean* observations (no code biases). In addition we are *not* affected by Anti-Spoofing (AS).

Since January 1, 1996 (see Table 2 and Figure 2), the GIM estimation procedure has been running in an operational mode. Several GIM products are computed every day:

- Ambiguity-free 1-day GIMs are estimated right prior to the ambiguity resolution step. These GIMs are subsequently used to improve the resolution of the initial carrier phase ambiguities on baselines up to 2000 kilometers.
- Improved GIMs (ambiguity-fixed, with single-layer heights estimated) are derived after the ambiguity resolution step.

At present, the GIM files containing the total electron content (TEC) coefficients for one day are available with a delay of 4 days. These files are copied weekly to our anonymous ftp server.

The global TEC distribution is represented over 24 hours by spherical harmonics up to degree 8 in a geographical reference frame which is co-rotating with the *mean* Sun. A single-layer model is adopted in this approach assuming a spherical ionospheric shell in a height of 400 kilometers above the Earth's mean surface. To extract the global TEC information a separate least-squares adjustment of the observations of the complete IGS network is performed using an elevation cutoff angle of at present 20 degrees. Note that — even under AS — *no* restrictions concerning receiver types or satellites have to be made in our approach. An example of a 1-day GIM representing an average TEC distribution is shown in Figure 8.

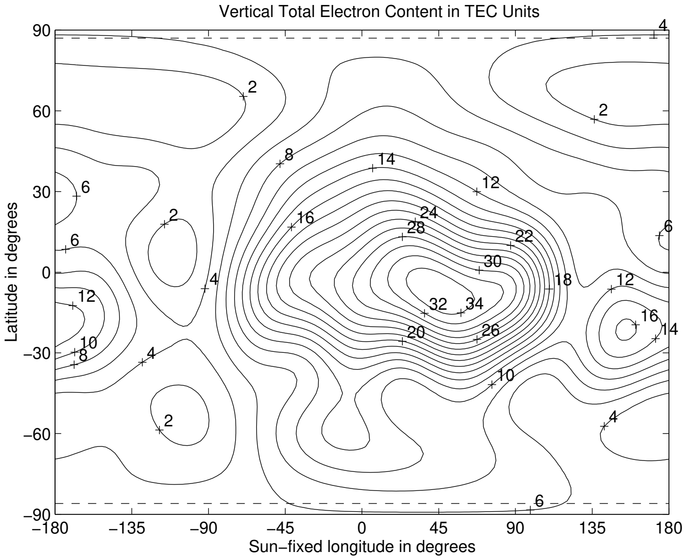

Figure 8: Global Ionosphere Map (GIM) for Day 073, 1996, Plotted in a Sun-Fixed Coordinate System.

After reprocessing all IGS data of the year 1995 and gathering all GIMs already produced in 1996, we may present a long-time series of global TEC parameters [12]. Two special TEC parameters, namely the maximum and the mean TEC, roughly characterizing the deterministic part of the ionosphere, are shown in Figure 9.

The three non-AS periods in 1995 are marked by dashed lines.

Let us mention that we also generate *regional* ionosphere maps for Europe based on about 30 European IGS stations in a fully automatic mode since December 1995. These ionosphere maps are used in the processing scheme of the European cluster to support the ambiguity resolution there. The European TEC maps are available on special request.

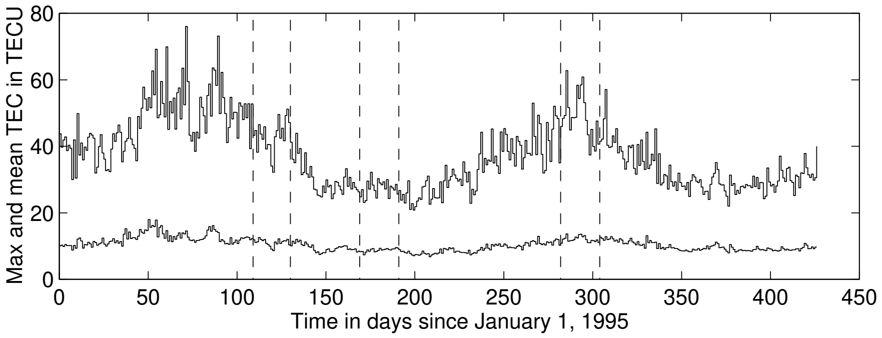

Figure 9: *Maximum* and *Mean* TEC Values Extracted from the Daily CODE GIMs. Shown in TEC units

8 Global Ambiguity Resolution

Since June 25, 1995 (GPS week 807) — after an experimental phase of several months — the *ambiguity-fixed* 3-day solutions are submitted to the IGS as official CODE contribution. We perform ambiguity resolution on baselines up to 2000 kilometers using the so-called Quasi-Ionosphere-Free (QIF) ambiguity resolution strategy [13], which allows ambiguity resolution on long baselines without using code measurements. Since January 1, 1996, the QIF strategy is supported by GPS-derived global ionosphere models [12]. At present we resolve about 85 % of the ambiguities referring to baselines below 2000 kilometers, that means that on average about 50 % of *all* ambiguities can be fixed to their integer values (see also Figure 1). Figure 10 shows the percentage of resolved ambiguity parameters on baselines shorter than 2000 kilometers. We may recognize (a) three significant peaks caused by AS-free periods and (b) on January 1, 1996, a jump of about 10 % when we started to use our 1-day GIMs.

The effect of resolving ambiguities in a global network has been discussed in [14].

9 Antenna Phase Center Calibrations

The importance of the antenna phase center calibrations for the IGS network can be seen from the example given in Section 3, Figure 5.

During the last year two GPS antenna calibration campaigns were processed at the AIUB to compute elevation-dependent phase center variations:

- The *THUN-94 Campaign*
- The *WETTZELL-95 Campaign*

The antenna types calibrated during these campaigns were `DORNE MARGOLIN T` and `B` (Turborogue, Rogue), `4000ST L1/L2 GEOD` (SN14532, Trimble), `TR`

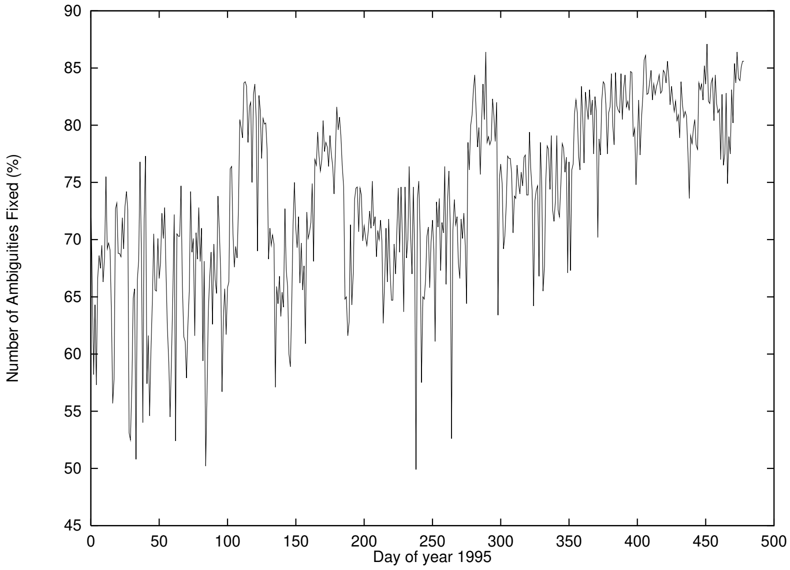

Figure 10: Percentage of Ambiguities Fixed on Baselines Below 2000 km.

`GEOD L1/L2` (SN22020, Trimble), `SR299E EXTERNAL` and `SR299 INTERNAL` (Leica), and `GEOD L1/L2 P` (SN700228, Ashtech).

The results show that the phase center variations estimated from GPS data are very consistent, even between different campaigns with different local environments (multipath).

For the L1 frequency the agreement between the GPS results and the results of recent UNAVCO chamber tests [15] is very promising, not so, however, for the L2 results, where some problems still wait for a solution.

The estimation strategy, the models used, and results have been published in [16], [17], and [18].

The elevation-dependent phase center corrections used in the CODE processing are listed in Table 6.

The offsets are given relative to the "Antenna Reference Point" as defined by the IGS (for antenna names and antenna sketches see the files `ANTENNA.GRA` and `RCVR_ANT.TAB` at the IGS Central Bureau Information System described in [19]). The elevation-dependent corrections for the Trimble antennas (relative to the Allen Osborne Rogue antennas!) were introduced into the routine processing on July 20, 1993, and are stemming from old chamber measurements by [20], the values for the Trimble micropulse antenna were introduced in April 1996 (for the EBRE site) and were computed at the AIUB from GPS calibration measurements.

A new and improved set of consistent calibration values are currently being put together from various sources by a small group and should be implemented by the IGS Analysis Centers by June 30, 1996.

Table 6: Antenna Phase Center Corrections Used at the CODE Analysis Center Since 1993

```
PHASE CENTER OFFSETS INCLUDING ELEVATION DEPENDENCE USED AT CODE
---------------------------------------------------------------------------------------------------

RECEIVER TYPE      FREQ  PHASE CENTER OFFSETS (M)       ELEVATION DEPENDENCE OF PHASE CENTER (MM)
ANTENNA  TYPE       L*    NORTH    EAST      UP   90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10
*****************    *   **.**** **.**** **.****  ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** ** **

ROGUE SNR-8          1     0.0     0.0    0.0779   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
DORNE MARGOLIN B     2     0.0     0.0    0.0964   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

ROGUE SNR-8          1     0.0     0.0    0.0779   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
DORNE MARGOLIN R     2     0.0     0.0    0.0964   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

ROGUE SNR-8100       1     0.0     0.0    0.1100   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
DORNE MARGOLIN T     2     0.0     0.0    0.1280   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

TRIMBLE 4000SSE      1     0.0     0.0    0.0692   0  1  3  7 10 13 15 16 18 17 16 15 12 11 10  9  8
4000ST L1/L2 GEOD    2     0.0     0.0    0.0677   0  0  2  3  3  4  5  5  7  7  6  7  7  6  7  7  6

TRIMBLE 4000SSE      1     0.0     0.0    0.0625   0  1  3  7 10 13 15 16 18 17 16 15 12 11 10  9  8
TR GEOD L1/L2 GP     2     0.0     0.0    0.0625   0  0  2  3  3  4  5  5  7  7  6  7  7  6  7  7  6

TRIMBLE 4000SSE      1     0.0     0.0    0.0700  -4 -4 -4 -3 -2 -2 -1  0  1  1  1  0 -1 -1 -1  0  8
M-PULSE L1/L2 SUR    2     0.0     0.0    0.0900  -3 -2  0  0 -1  0  0  0  1  1  1  0  1  1  1  1 -5
```

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NRCan (EMR) Analysis Centre
1995 Annual Report to the IGS

P. Tétreault, R. Ferland, J. Kouba, J. Popelar
Geodetic Survey Division
Geomatics Canada
Natural Resources Canada
Ottawa, Ontario

1 Introduction

During 1995, particular attention has been given to station coordinate solutions including the development of the Software Independent Exchange format (SINEX) by an IGS working group to facilitate combination of Analysis Centres (ACs) weekly station coordinate solutions. In 1995, IGS has also incorporated several important stations to improve global network geometry. The NRCan Analysis Centre (EMR), for its part, contributed to the SINEX format development and also benefited from the additional stations. NRCan analysis centre activities during 1995 and early 1996 are described in the following report.

2 IGS ITRF Densification Project

The ITRF densification project, with the main objective to make the ITRF more accessible [1], was initiated as a pilot project in 1995. The development of the SINEX format (in [2]) was required to exchange information from individual AC solutions in order to produce combined solution for Earth Orientation Parameters (EOP) and station parameters. NRCan has played an active role in the development and application of the SINEX format. SINEX has been used since April 1995 to submit NRCan's weekly combination of daily solutions to the IGS and it has also been adopted for the annual NRCan submission of station coordinates to the IERS.

3 NRCan Combination of Station Coordinates and EOP for 1995

The annual combination of daily solutions has been carried out using the newly developed SINEX format and combination software [3]. As in 1994, all daily solutions were retrieved and subjected to additional statistical testing and editing to improve the station coordinate solutions. The *a priori* (ITRF93) constraints on the 13 fiducial station coordinates were removed and 10 metre sigma constraints were applied. All the other parameters estimated in the daily solutions were eliminated from the solutions. The variance-covariance matrices and the solutions for station coordinates and EOP were then combined to produce a consistent set of station coordinates and velocities and daily EOPs for the epoch 1995.0. The new solution is based on the 1995 GPS data only. The daily EOPs were modeled as a white noise process in the combined solution. Station coordinates were modeled as an initial position state vector with a constant velocity. This approach produces a solution which is practically unconstrained and which approximates addition of reduced normal matrices. The solution for mean 1995 station positions and EOP was obtained by constraining the 13 fiducial station positions and velocities using the ITRF94 values and sigmas.

The weekly and annual station coordinates and EOP combinations reduce the effect of reference frame inconsistencies which affect the daily solutions. NRCan processing strategy is based on 24-hour data sets without observation overlaps and is, therefore, subject to daily variations in data quality and availability which may change network geometry. Figure 1 shows differences between the IGS 95P01 solution and two NRCan EOP solutions — the original daily series (EMR 95P01) and the annual combination solution (EMR 96P02). Although the EMR 95P01 EOP solution was used in the IGS 95P01 EOP combination, the annual combination solution agrees better with the IGS 95P01 series as shown by the rms given in Table 1.

Table 1: Differences between the IGS 95P01 EOP solution and two NRCan EOP solutions for 1995

Solution	x-pole mean/sigma (mas)	y-pole mean/sigma (mas)
original daily solution (EMR95P01)	-0.09/0.21	0.19/0.30
1995 combination solution (EMR96P02)	0.43/0.20	1.04/0.23

4 Processing Strategy in 1995

Few modifications were made in 1995 to the NRCan processing strategy based on the JPL's GIPSY II software. Its main characteristics are: the use of undifferenced, elevation-weighted phase and smoothed pseudo-range observations with a 7.5 minute sampling for 24-hour data sets without observation overlap, and the use of *a priori* estimates from the previous day solution for most parameters

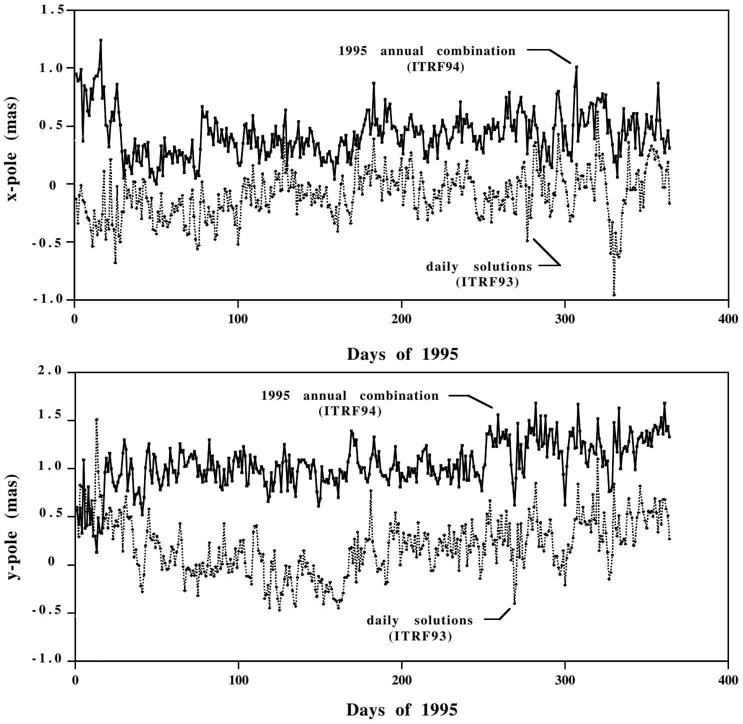

Figure 1: Differences between the EMR 95P01 and 96P02 EOP solutions and the IGS 95P01 EOP solution; (a) pole x-coordinate difference and (b) pole y-coordinate difference.

including corresponding variance-covariance satellite state vector information. More details on the NRCan processing strategy can be found in the IGS 1994 Annual Report [4]. The stochastic orbit modeling used by NRCan makes it possible to directly estimate UT1-UTC. The NRCan UT1-UTC series was initialized on January 2, 1994 and has not been reset since. Although systematic trends are seen in Figure 2, the series has a short term stability with an rms of about 30 μsec [5]. The Bulletin A pole and UT1-UTC values have been used as *a priori* values until July 9, 1995 (Wk 809). Since then, the NRCan EOP solutions for the preceding 3 days are extrapolated for one day and used as *a priori* information. No significant effects on the NRCan EOP solution were noticed when the new scheme was introduced.

Stations IRKT (Irkutsk, Russia), and LHAS (Lhasa, Tibet), have been introduced in early 1996 to improve the geometry of the IGS global network used by NRCan for its daily processing. PAMA (Pamatai, Tahiti), was reinstated after its hardware had been upgraded in late December 1995. Since April 1995, NRCan includes either CHUR (Churchill, Manitoba), or SCHE (Schefferville, Quebec), as a weekly alternative station in the daily processing.

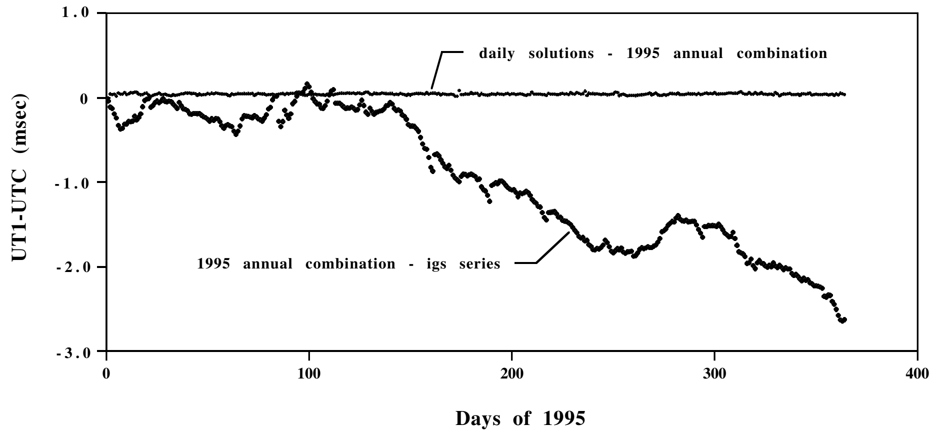

Figure 2: NRCan UT1-UTC Series for 1995

In early 1996 (GPS Week 840), NRCan started to use TurboRogue data from the alternate stations at Wettzell and Goldstone, WTZR and GOL2, replacing SNR-8 Rogue data sets for stations WETT and GOLD. The published station tie for WTZR [6], verified by simultaneously processing the WTZR and WETT data and in consultation with other ACs, was used to obtain ITRF93 coordinates for WTZR. The GOLD ITRF93 position has not been changed because the same antenna is used for GOL2 [7]

In January 1996, NRCan discontinued use of pseudo-range observations for satellites with AS at stations equipped with receivers other than TurboRogues. This was done to improve the quality of NRCan satellite clock corrections. A degradation in solution precision had been noticed when using Rogue C/A pseudo-range observations due to changing C/A pseudo-range observation biases.

Satellites being re-positioned were not included in NRCan's processing for the whole maneuver, usually one day. In 1995 NRCan started to use the 'zero position' option of the SP3 format [8] and now provides ephemerides for such satellites until a few minutes before the scheduled time of repositioning. This feature is especially useful when maneuvers occur during the last hours of a day since this makes an almost complete arc available to IGS users. During 1995, satellites were excluded totally or partially from NRCan daily solutions on 13 occasions due to repositioning, on 8 occasions due to modeling problems and on 4 occasions due to lack of data.

5 Preliminary Orbits

A need for producing orbits with faster turnaround time was discussed amongst the Analysis Centres, and NRCan has contributed to a preliminary orbit pilot project which was initiated in January of 1996. The strategy used for NR-

Can preliminary orbits is similar to that used for regular orbit computations. Minor modifications to the processing scripts have been made to improve robustness and process automation. Given a smaller number of stations available for preliminary orbit computations NRCan constrains more stations than the 13 required.

Figure 3 shows the number of stations used for the NRCan preliminary orbit computations and corresponding rms of the differences between the NRCan preliminary orbits and the IGS combined preliminary orbits (IGP) since the beginning of 1996. A 'weekend' effect with more stations available on weekdays and less on weekends can be seen. The correlation between the number of available stations and satellite orbit rms can also be seen. More details on NRCan orbit processing and result quality can be found in [9] and [10].

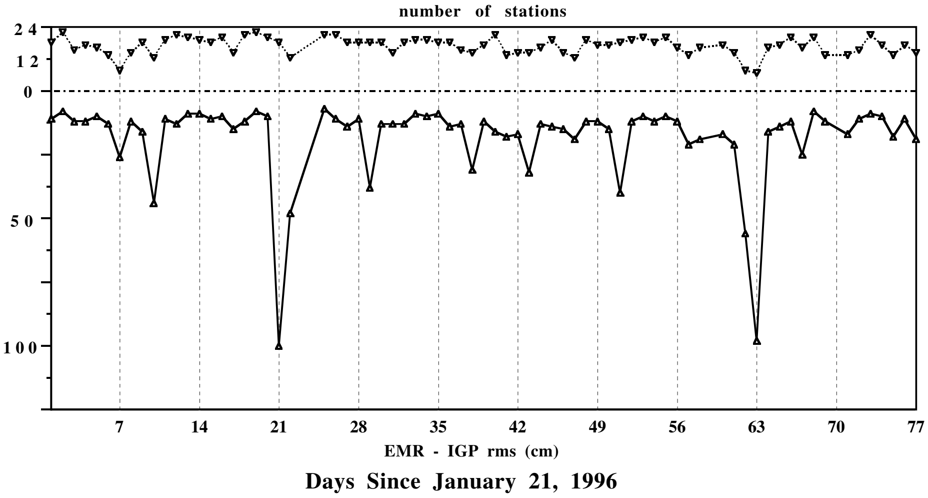

Figure 3: Number of stations (upper part) used for NRCan preliminary orbit computations and corresponding rms (lower part) of the differences between the NRCan preliminary orbits and the IGS combined preliminary orbits (IGP).

6 Conclusion

NRCan participation in IGS activities in 1995 included development of new products such as SINEX, but the computations of precise and reliable GPS orbits and clock corrections have been maintained. Improvements in precision and reduction of processing time have been the main objectives in 1995. IGS preliminary orbit and clock correction processing has a potential for achieving the reliability and precision of regular AC solutions.

7 Acknowledgment

We wish to acknowledge the contribution of C. Huot and D. Hutchison to the precise orbit computations and the support of the Canadian Active Control System (CACS) Data Acquisition and Validation Team.

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Jet Propulsion Laboratory IGS Analysis Center Report, 1995

J. F. Zumberge, M. B. Heflin, D. C. Jefferson,
M. M. Watkins, F. H. Webb
Jet Propulsion Laboratory/California Institute of Technology
Pasadena, California

1 Summary

Regular analysis of GPS data from the global network of precision GPS receivers continued at the Jet Propulsion Laboratory throughout 1995. In addition to precise GPS orbits and clocks, Earth orientation, and site coordinates, new products in 1995 include rapid (1-day) precise orbits and clocks, and predicted orbits. Precise point positioning based on the rapid products allows improved selection of stations for the regular solution. Sub-daily modeling of Earth orientation has been implemented. Free-network GPS parameters are regularly saved. Automation of the processing has reduced costs.

2 Evolution in 1995

Material relating to JPL (Jet Propulsion Laboratory) participation as an IGS analysis center, beginning in 1992, can be found in [1] and references therein. [2] describe JPL activities as a GNACC (Global Network Associate Analysis Center).

Table 1 indicates the evolution of our activities during 1995. A major event was the regular estimation of free-network parameters. That is, a solution with only weak (1-m) constraints on locations of the 13 IGS fiducial sites avoids the consequences of erroneous fixed coordinates, which are not easily undone. Although the weak constraints leave each day's solution in an uncertain reference frame, that uncertainty can be eliminated by a Helmert transformation into the ITRF.

3 Product Summary

Tables 2 and 3 summarize the regular products that result from JPL IGS AC activities. New for 1995 and especially notable are the rapid turn-around GPS

Table 1: Evolution in 1995.

Action	*Date*
inadvertent use of 0° elevation cutoff	Jan 18
incorporated GPS yaw-attitude solutions into precise point-positioning analyses	Jan 28
global network consists of 32 sites (29 well-distributed, 3 chosen randomly)	Feb 18
elevation cutoff reset to desired value of 15°	Feb 28
global network consists of 34 sites, TurboRogue subset chosen first	Mar 26
point-positioning analyses based on 24 (not 30) hours of data	Mar 26
acceptable GPS clock formal error cutoff lowered to 0.3 ns	Mar 26
extended UTPM model correctly reflected in Earth-fixed orbit solutions	Mar 26
made free-network orbits and clocks, used in precise point-positioning	Apr 2
used solutions from rapid-service point-positioning for data validation	Jun 12
all 34 global network sites chosen based on distribution (no random sites selected)	Jun 18
discontinued pre-editing of RINEX files with broadcast orbits and clocks	Jul 22
precise point-positioning performed separately from orbit determination analyses	Sep 3
a priori error on yaw-rate parameters reduced to 0.01°/sec	Oct 6
processing uses built-in lag of 3 days	Dec 10

clocks and orbits [3]. Table 4 indicates addresses of World Wide Web pages with related information.

4 Automation

The automation of daily precise orbit determination at JPL has been greatly improved. A parent UNIX 'cron' process is used to monitor activity on each of three HP 735 workstations, and determines which computer should be used for the analysis of any given day, and when the analysis should start.

In general, we use a 4-day lag (that is, processing for day N does not occur before 00:00 local time on day N+4). As a 30-hour data arc is used, this allows enough time for data for day N+1 to arrive at our database, especially from isolated key sites. The lag time may be manually modified at any time if necessary, and the change will affect the next day to be processed.

Once the specified delay has elapsed, processing starts on any of the designated workstations, provided that there isn't an analysis in progress on the chosen machine already. When the analysis is done, daily products are moved to a predetermined location, and held until weekly quality statistics are gathered.

Table 2: Regular products from the JPL IGS Analysis Center, available with anonymous ftp to `sideshow.jpl.nasa.gov`, directory `/pub/jpligsac`.

Example File	*Contents*
`0850/jpl08500.sp3.Z`	precise orbits for day 0 (Sun) of GPS week 0850
`0850/jpl08507.sum.Z`	narrative summary for GPS week 0850
`0850/jpl08507.erp.Z`	fixed-network Earth orientation parameters for GPS week 0850
`0850/jpl08507.snx.Z`	free-network station coordinates for GPS week 0850
`0850/jpl08506.yaw.Z`	yaw-rate information for eclipsing satellites, week 0850 day 6 (Sat)
`1995.eng.Z`	engineering data for 1995, sites in global solution
`1995_p.eng.Z`	engineering data for 1995, point-positioned sites
`ytd.eng`	year-to-date engineering data, sites in global solution
`ytd_p.eng`	year-to-date engineering data, point-positioned sites

Table 3: Other products available with anonymous ftp to `sideshow.jpl.nasa.gov`, directory `/pub/gipsy_products`.

Example file(s)	*Contents*
`RapidService/orbits/jpl08520.sp3.Z`	quick-look precise orbits, day 0 week 852 (May 5, 1996)
`RapidService/orbits/jpl08520_pred.sp3.Z`	quick-look 3-day predicted orbit (May 6-8, 1996)
`1995/clocks/orbits/1995-04-27.*`	1995 precise clock files for use in Gipsy
`1995/orbits/orbits/1995-04-27.*`	1995 precise orbit files for use in Gipsy
`RapidService/orbits/1995-05-05.*`	quick-look and predicted files for use in Gipsy
`IERSB/*`	IERS Bulletin-B information

Table 4: Addresses of relevant web pages (all begin with `http://`).

Address	*Contents*
`sideshow.jpl.nasa.gov/mbh/series.html`	graphical time-series of site coordinates
`sideshow.jpl.nasa.gov/mbh/global/table.html`	table of site coordinates and velocities
`milhouse.jpl.nasa.gov/eng/eng.html`	graphical displays of engineering data by site

The master process then waits or processes the next day as governed by the set delay value.

By far, the most frequent source of processing mishaps in 1994 was anomalous ground receiver data. Towards the end of that year, loop baseline processing was implemented as a way to predetermine which stations were not to be used. Although this process drastically reduced the number of incomplete analyses due to bad data, it was fairly time-consuming computationally, and grew more so as the global network expanded. In mid-1995, individual receiver performance statistics from rapid-service point-positioning offered an alternative means of observation data validation. These have been used since then to determine station usage in a much more time-efficient manner.

In 1995, the main problems were software related. Many of these were simply due to the growth of the global network; program dimensioning limits were reached and exceeded, and modifications were necessary to accommodate the increase in the number (and even types) of stations. Today, problems tend to be more hardware oriented (for example, failure of disks), and should be alleviated with more efficient use of computer resources.

5 Results

Figure 1 shows the improvement in orbit quality that began in late 1995. As measured by internal consistency — the degree to which estimates from adjacent days agree near the midnight boundaries — our 3-dimensional orbit quality is currently at the 15-cm level.

Shown in Figure 2 are our daily measurements of excess length of day (LODR) superimposed on estimates from the time derivative of UTR1 as given in the IERS Bulletin B Final values. An improvement that began in the last quarter of 1994 has continued throughout 1995, with a bias in LODR of only 2 μsec/day. Table 5 summarizes the performance in Earth orientation measurements.

Table 5: Earth orientation statistics — average difference and standard deviation of the differences — for daily results; comparison with respect to IERS Bulletin B Final values.

Quantity	*Bias*	*Sigma*
lodr (μs/day)	-2	46
x (mas)	-0.20	0.49
y (mas)	-0.31	0.32

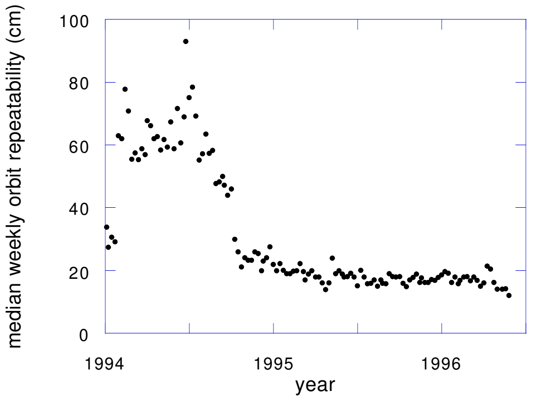

Figure 1: JPL orbit repeatability (3drms) since the official start of the IGS in 1994. Each weekly number indicates the median over all satellites and days during that week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Beginning in late 1994, the typical weekly value is about 20 cm or less.

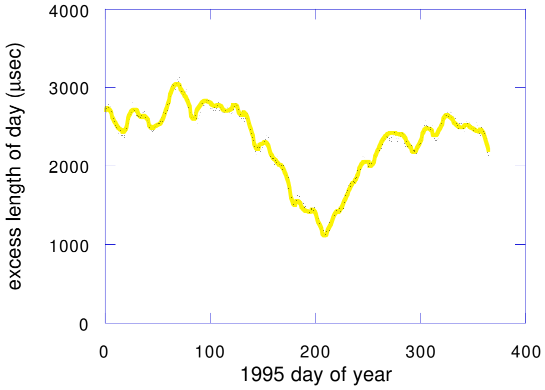

Figure 2: Length of day performance in 1995. Each dot corresponds to a daily estimate from the JPL AC; the shaded background indicates the IERSB Final value (from the time derivative of UTR1). The average difference of 2 μsec/day is insignificant. The low scatter of 46 μsec/day demonstrates the value of GPS estimates.

References

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Associate Analysis Center Reports

Newcastle-upon-Tyne IGS Global Network Associate Analysis Centre Annual Report 1995

P. B. H. Davies and G. Blewitt
Department of Surveying
University of Newcastle-upon-Tyne, UK

1 Introduction

The Global Network Associate Analysis Centre (GNAAC, previously known as a Type Two AAC) at the University of Newcastle (NCL) was established during 1995 in response to the call for participation in the pilot project of the IGS distributed processing scheme for densification of the ITRF, which is running for a year from September 1995. The background to this project, the definitions of Analysis Centre types and the weekly data transfer scheme are described by the papers collected in [1]. SINEX format is detailed by [2]. Figure 1 is a simple diagram of the densification project.

NCL's feedback on weekly SINEX coordinate solutions (A-SINEX) provided by Analysis Centres (ACs) began with the submission of the first A-SINEX networks (A-networks) in May '95 (GPS week 0798) — format and discrepancy reports were e-mailed directly to ACs. These were discontinued as formatting problems became less common. Our submission of weekly G-SINEX combined solutions commenced with the start of the pilot project in September (week 0817). A weekly summary report comparing G-SINEXes was begun in October (week 0823). Since December (week 0834) this has included station discrepancy information for each Analysis Centre. The other component of the scheme for which GNAACs are responsible, the integration of regional networks and submission of P-SINEX, remains for 1996.

Figure 2 shows the number of stations positioned by 1–7 A-Networks in a typical week. There are approximately equal numbers of stations (10-12) positioned by 1, 2, 3, 4, 5 and 6 ACs, with a higher number of 18 in the 'processed by all ACs' category. The reliability of the combined G-network is based on these redundancies.

NCL's G-SINEX analysis method and the comparison report format have

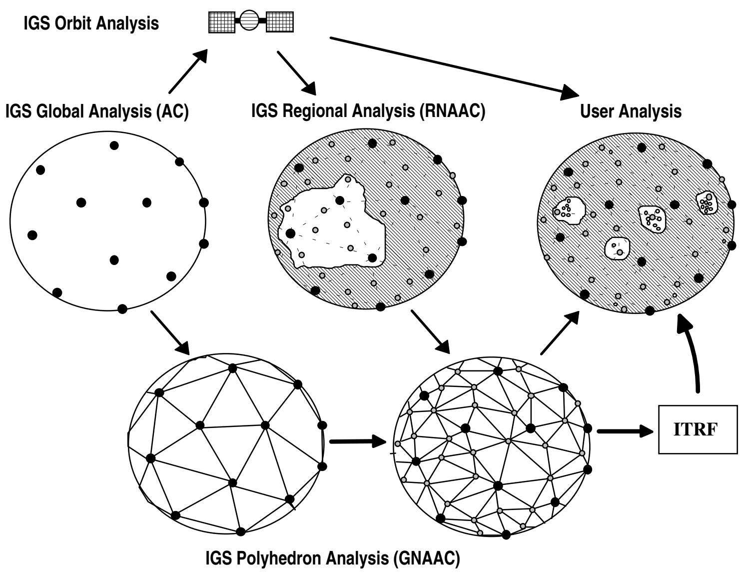

Figure 1: IGS Network densification by distributed processing

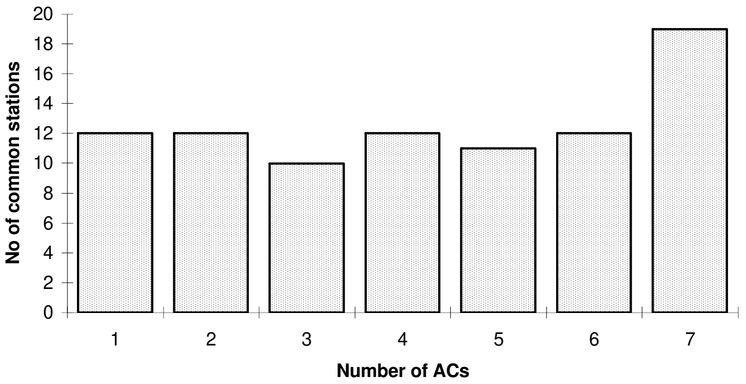

Figure 2: Station redundancy in A-Networks

been modified several times as the project has progressed, and at the half-way stage of the pilot year NCL is under daily development. This status report summarises our analysis method as of April '96 (the time of writing). At the current rate of development, it is likely to be out of date by the time of publication! No time-series analysis is attempted at this stage.

The GNAAC weekly comparison and G-SINEX combination for a GPS week i take place in week $i+2$ following A-SINEX production by ACs in week $i+1$. A-SINEX files are currently collected from CDDIS on Wednesday of week $i+2$, deliberately allowing several days after the A-SINEX due time during the pilot period. This is four days before the G-SINEX deadline — usually the analysis results are delivered to CDDIS on the same day. These results consist of the G-SINEX file and the comparison summary file, which is also copied to the IGSREPORT service.

This analysis is carried out using a new set of programs known as TANYA developed in C during 1995 and running on HP workstations. The processing steps which lead to the weekly data products are summarised in Figure 3. Apart from the input A-SINEXes and output G-SINEX, various types of specialised SINEX file are employed, as described in the following sections.

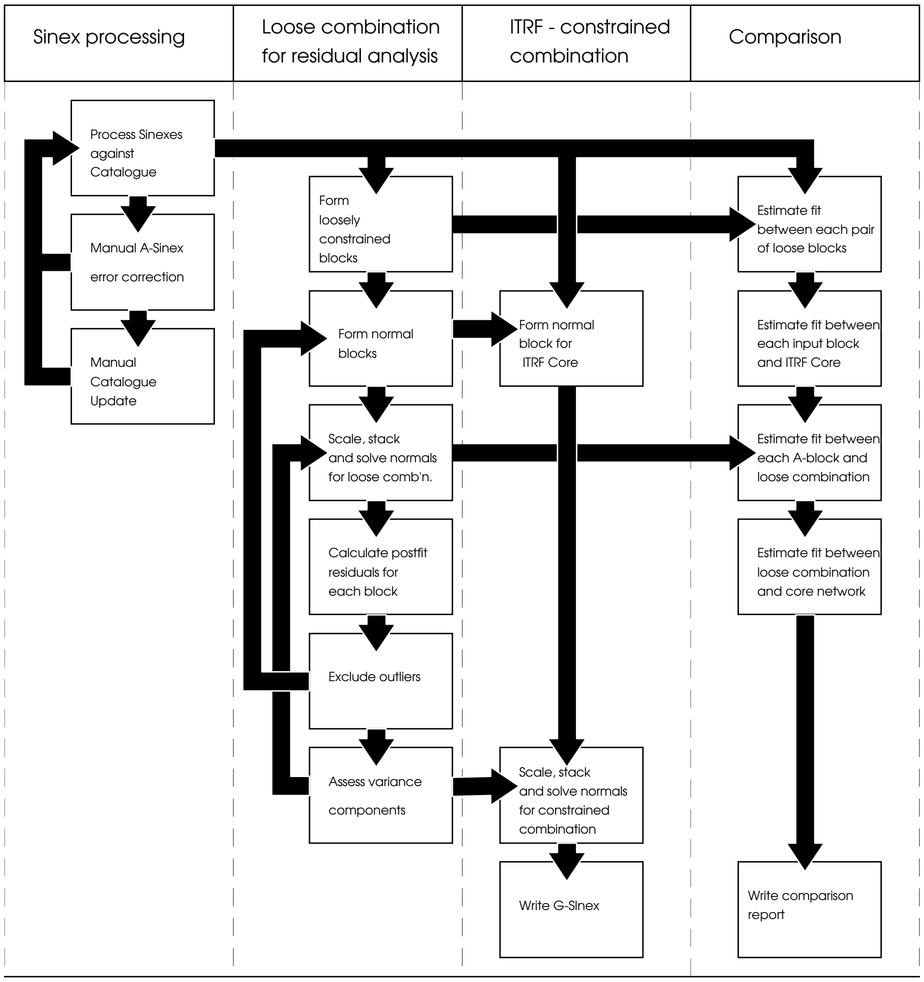

Figure 3: NCL G-Network analysis overview

2 A-SINEX Processing

Those A-SINEX files which contain known format errors are manually edited before processing. A software module then reads and checks the syntax of each A-SINEX file, ensuring that the contents of each field and block are appropriate and also sanity-checking the relations between records in the various blocks. To do this it reads a Formatting SINEX file specific to each AC, containing header lines only for each data block which define the record field widths used by that AC (this idea was suggested by Gerd Gendt of GFZ). Variable field widths have been abandoned in SINEX v1.00, so a new simplified version of this program does not require the formatting files.

A Catalogue SINEX file is manually maintained, containing the reference information for each station encountered in A-SINEXes. Specifically, the Catalogue file contains the `FILE/...` and `SITE/...` SINEX block sets and a `SOLUTION/EPOCHS` block. This is not compiled from station log information but from previous A-SINEXes. Where discrepancies exist between ACs, the catalogue contains the most popular value for each data item. The Catalogue SINEX serves four purposes:

1. Provides the overall reference parameter list for the analysis;
2. Governs common parameter selection in A-SINEX processing by controlling the epoch and attribute criteria for station matching;
3. Enables station information discrepancies in A-SINEXes to be reported on without having to compare each A-SINEX to each other.
4. Provides the station information written into the NCL G-SINEX.

For each A-SINEX successfully read, the program compares each station to the Catalogue SINEX by a series of criteria in the following way. (Note: A station is to be distinguished from a monument, in that multiple stations may be estimated at a monument in SINEX, each with its own epoch and station records.)

1. For each station invoked by `SOLUTION/EPOCHS` in the A-SINEX, the corresponding monument given in SITE/ID is compared to that of each station in the Catalogue. The DOMES code is matched when present - otherwise the SITE code is matched. Multiple matches are permissible at this stage.
2. For each catalogue match to the station by monument, the epoch range given in the A-SINEX `SOLUTION/EPOCHS` is compared to that of the catalogue stations, to create a reduced list of possible matches. The program allows various epoch criteria to be applied in this comparison, e.g., to force separate parametrization of estimates of a monument in two epoch ranges (in such cases the two stations must exist independently in the Catalogue). For routine weekly processing, the catalogue epoch ranges are set so as to admit all the A-SINEX monument matches, because multiple epoch estimates are not expected in weekly A-SINEX. This may change in the future in more complex processing situations.

3. For each station match by monument and epoch, the receiver, antenna (including phase centre information) and local eccentricity is compared. Stations matched by monument and epoch may optionally be rejected when a discrepancy is detected in one of these data items. At present, such discrepancies do not cause rejection because they may be due to non-standardised description strings, or to typographic errors in the file. It is more useful to match the stations then provide feedback on possible errors. Station attribute discrepancies are recorded to be used later in writing the comparison report.
4. For each A-SINEX station uniquely matched to a catalogue station by the steps 1 to 3, the estimate and *a priori* vector and matrix elements are read, and the matrices are converted to covariance form if they have been given in one of the other allowed forms. Unstated off-diagonal elements are set to zero. The SINEX-processing module then writes textual reports on SINEX syntax and integrity and Catalogue referencing and discrepancies for each A-SINEX, and produces internal files containing the numerical data and parameter lists.

Table 1 lists a few facts about the A-SINEXes being submitted by ACs at the time of writing (from the week 0847 files). The NGS one-day SINEX is not included in the NCL processing. As a result of feedback from the GNAACs, almost all station vector discrepancies have now disappeared from A-SINEXes.

Table 1: Some A-SINEX file comparisons

agency	# stations	station info?	format errors?	matrix type	stated constraint type	EOP given?	# DOMES not stated
COD	68	yes	no	L COVA	block diag, some stns	no	0
EMR	31	yes	no	L COVA	diagonal, some stns	yes	0
ESA	55	yes	no	L COVA	diagonal, some stns	yes	2
GFZ	52	yes	no	L CORR	diagonal, all stns	yes	0
JPL	50	no	yes	L COVA	none stated	no	13
SIO	69	yes	no	L COVA	diagonal, all stns	yes	3

3 Formation of Loose Solutions

The distributed processing project is based on the exchange of coordinate solutions, rather than normal equations. A coordinate solution and its covariance matrix is dependent for reference frame constraint on *a priori* information — this may be minimal (not affecting estimable quantities, e.g., constraint of orientation) or non-minimal (network-distorting, e.g., constraint of several station positions). SINEX allows non-minimal constraints to be stated by an *a priori* parameter vector and covariance matrix, and hence to be removed, which should lead to the singular normal equations. In SINEX, then, the correctness (and completeness) of the *a priori* information is just as important as that of the estimate information.

ACs have chosen a wide variety of stated constraints in their A-SINEXes. Some A-SINEXes also include unstated constraints, which are apparent for instance as finite standard deviations of rotation parameters after removal of all stated constraints. If non-minimal, unstated constraints may also cause network distortion. These errors cannot be detected by GNAAC analysis, so it is essential that non-minimal unstated constraints in A-SINEXes be loose enough to be negligible.

Due to unstated constraints, the singular free normal equations of an A-SINEX network may not be obtainable. Free-network theory, which depends on applying constraints which are orthogonal to the observation space and hence minimal, therefore offers no advantage in this situation over the 'loose non-minimal constraints' approach, where reference frame definition is provided with negligible bias of estimable quantities by weak non-orthogonal constraint. Frame definition is monitored by calculating the standard deviations of the seven frame parameters. All inversions are carried out by singular value decomposition which provides the range of eigenvalues indicating the inversion stability.

A loose solution is obtained from each A-network in the following way:

1. A fraction of the inverse *a priori* covariance is subtracted from the inverse estimate covariance (reordering the *a priori* vector and matrix appropriately). This fraction varies from 0 to 1 depending on the constraint characteristics of the network.

2. For some A-SINEXes, the normal equation component due to three pseudo-observations of orientation is then formed, with previously chosen loose standard deviations of these observations, and added to the deconstrained inverse covariance.

3. This is re-inverted to give a covariance matrix which is used to compute the loosely constrained parameters, and the standard deviations of the seven frame parameters.

Tables 2–4 show the effects of this procedure on frame definition for a typical week's data. Tables 2 and 4 show the SDs of the seven frame parameters in constrained and loose A-networks respectively. The variety of variance scaling and constraint types is apparent. Table 3 summarises the deconstraint procedure currently used for each A-network (i.e., the parameters of steps 1 and 2 above), and includes the relative variance components currently applied to each AC (see Section 5 below).

4 Free and Constrained Network Combination

Network combination takes place in two steps:

Table 2: Frame parameter SDs of constrained A-networks (mm) using all stations

agency	Tx (mm)	Ty (mm)	Tz (mm)	Sc (mm)	Rx (mm)	Ry (mm)	Rz (mm)
COD	0.041	0.041	0.040	0.037	0.048	0.043	0.051
EMR	1.2	1.3	1.04	0.57	1.6	1.2	1.5
ESA	2.8	2.7	11	0.94	97	97	21000
GFZ	0.048	0.047	0.031	0.038	0.038	0.044	0.064
JPL	2.3	2.4	7.0	0.37	1000	1000	1000
SIO	4.7	4.7	15	0.82	1200	1200	240

Table 3: Deconstraint of A-networks

agency	fraction of stated constraint remaining	SDs of 3 added orient. obs. (all stns)			relative scale factor
		X	Y	Z	
COD	1.0E-5	none	none	none	5.80
EMR	1.0E-4	none	none	none	0.22
ESA	1	large	large	3 m	2.50
GFZ	0	none	none	none	2.19
JPL	N/A	none	none	none	1.00
SIO	0	13 m	13 m	large	0.22

- formation of reduced normal equation blocks with a common parameter list

- summation of the blocks and solution of the normal equations

These tasks are implemented in separate software modules for maximum flexibility. Module (a) makes use of the following parameter lists in order to write a combination common parameter list:

- the parameter list (referenced to the NCL Catalogue) of each A-network,

- an excluded-station list for each A-network, from the Catalogue-matching stage (see Section 2), the outlier-detection stage (see Section 5) or manual input,

- an optional list of stations to be entirely excluded from (or included in) the combination.

Table 4: Frame parameter SDs of loose A-networks (mm) using all stations after relative scaling

agency	Tx(mm)	Ty(mm)	Tz(mm)	Sc(mm)	Rx(mm)	Ry(mm)	Rz(mm)
COD	1.9	2.0	3.0	0.50	32	30	39
EMR	1.5	1.8	4.9	0.31	60	51	69
ESA	2.1	2.0	7.2	0.62	66	66	69
GFZ	1.5	1.5	7.8	0.50	33	27	6.0
JPL	2.3	2.4	6.9	0.37	1000	1000	1100
SIO	2.1	2.1	6.9	0.38	114	110	112

In general, these lead to the intersection of an A-network station set with the combination station set being smaller than either. 'Reduced' normal equation components are therefore formed for each input solution (see e.g., [3]), a technique that reduces the A-SINEX parameter list to a subset of the combination list with minimum computational effort.

The second 'stacking' module (b) adds together and solves the normals after dividing each block by a variance component to provide statistically reasonable scaling between the input networks. (Applying the variance component at this stage allows iterative variance component estimation when required (see Section 5) without re-forming the normal blocks at each iteration — only the stacking module is run repeatedly.)

Two types of G-network (combined network) are formed:

- A 'free' combination, which is possible because the loose constraints of the A-networks contribute the reference frame definition. This gives a loose combination which is considered an adequate approximation of a free network and is used for residual analysis, most importantly for outlier detection. This solution can be iterated if necessary to trap successive outlying observations. At present, outlier detection is still under development and is manually controlled (see Section 5). Outlying observations are flagged in each A-network and removed from the corresponding normal equations block in an iteration of module (a).

- A constrained combination, including an additional normal equations block due to the ITRF94 positions of the 13-station IGS Core network. This is obtained by processing a Core SINEX file against the NCL catalogue exactly as described for A-SINEXes in Section 2, then applying the velocity field appropriately. The Core SINEX file is an extract from the ISEF file published by IGN.

The constrained combination is the solution written into the NCL G-SINEX. Note that this solution has its own loose unstated constraints, which are a combination of the loose known constraints and the unstated constraints of each input solution. These make the G-network coordinates estimable with all stated constraints removed. This is not the ideal situation, but is unavoidable since A-SINEX unstated constraints exist. Table 5 shows the frame parameter standard deviations of the loose and constrained A-SINEX. It is intended shortly to introduce realistic overall variance scaling to the loose G-network (see note in Section 5 below) which will change these values.

Table 5: Frame parameter SDs of loose and constrained G-network (mm)

G-net	Tx (mm)	Ty (mm)	Tz (mm)	Sc (mm)	Rx (mm)	Ry (mm)	Rz (mm)
loose	0.74	0.79	2.0	0.17	20	18	5.8
constr.	0.72	0.77	1.5	0.17	2.9	2.6	3.2

5 Residual Analysis

The two residual analysis tasks of outlier detection and variance component estimation are mutually dependent since each requires the fulfilment of the other. A circular problem is avoided by assuming the scaling factors (variance components) for the ACs to have continuity from week to week, while outliers, being random, do not. Variance component estimation (VCE) is therefore a medium-term study rather than a weekly task, although the components may be tested against each week's residuals using empirically-determined confidence intervals. It follows from this that ACs and RNAACs should inform GNAACs of any change in their analysis causing a significant change in variance scaling (this is allowed for in SINEX v1.00).

A simple approach to relative variance scaling has been used for the NCL combination during 1995 (giving the factors listed in Table 3). We assume that the common stations of the A-networks estimate network origin and scale equally well in each A-network, and scale their matrices to equalise the standard deviations of these estimable quantities. This method has been useful in establishing the analysis because it is not dependent on the dispersion of residuals in individual solutions. An overall chi-square scaling will be introduced soon in order to give correct weighting between the loose solution and the ITRF Core in the constrained solution — this has not been applied up to now.

Outlier detection is carried out using the free combination as described above. Various statistics are drawn from the residuals and manually examined after the removal of a weighted seven-parameter transformation (and the accompanying covariance matrix) between each A-network and the free G-network. Particularly, we are using the full-matrix form of the Baarda outlier test ([3]) to detect outlying stations. The significance levels chosen by GNAACs for outlier removal depend on their approach to Polyhedron building. Our current policy is to remove only grossly-outlying observations, because the primary aim is to compare A-networks by their residual SDs, not to 'artificially' minimise these SDs.

A slow-converging iterated MINQE variance-component estimation method ([4], algorithm similar to [5]) has been implemented. Such methods are highly sensitive to outliers in the A-Networks, so much testing is necessary, but we have seen that this approach applied to multiple weeks' data gives results not entirely dissimilar to those of the frame-scaling method already described. However, individual ACs scale factors will change significantly when partitioned-residuals VCE is introduced. It should be noted that considerable changes in AC scale factors often have only minor effects on the combined solution — of greater importance is their influence on outlier-detection methods which depend on residual covariances.

6 Writing G-SINEX

The output G-SINEX is assembled by another software module from four sources including three internal SINEX files:

- Process SINEX (see below)
- Catalogue SINEX
- The ITRF-constrained combined solution
- Core SINEX

The first of these is present because SINEX allows a solution history to be described in the three `INPUT/...` blocks. A Process SINEX file contains only these blocks (and the `FILE/...` header blocks), the idea being that this file may be written by UNIX shell scripts as the process steps occur. Each software module is called by a shell script which also writes appropriate lines into the Process SINEX file. Calling these module scripts from an overall process script causes a SINEX-format process history to be written automatically.

For brevity of the G-SINEX history only the SINEX processor and normal block stacker modules currently write to the Process SINEX. The Catalogue SINEX contributes the `SITE/...` blocks (station attribute information) to the G-SINEX. The `SOLUTION/...` blocks are compiled from the constrained and constraining solutions. The completed G-SINEX file is processed by the SINEX v0.05 (from April '96, SINEX v1.00) processor to check for errors.

7 Comparing Solutions and Writing the Summary Report

The contents of the weekly comparison report are also under development. At present it consists of five substantive sections:

- A triangular table of common station set sizes between the loose A-networks, the NCL loose G-network and the Core network.
- A triangular table of postfit residual standard deviations (the fit being a diagonally-weighted seven-parameter frame transformation between all common stations after removal of far-outliers) between the networks just mentioned,
- The seven parameters, and their standard deviations, estimated between the loose A-networks and the loose G-network, again with a diagonal weighting of parameters.
- The seven parameters, and their standard deviations, estimated between the loose A-networks and the Core network, and between the loose G-network and the Core.
- A table of discrepancy reports, also showing the station sets of each AC and stations excluded from the combination.

Each station appearing in the week's A-SINEXes is listed, and for each AC including each station, a six-character report on the match to the NCL Catalogue is given. This includes codes for antenna, receiver and eccentricity discrepancies, distinguishing between textual and vector discrepancies, a code to indicate inclusion/exclusion in the combination, and a code to indicate the combination residual size (not yet implemented). This approach to discrepancy reporting depends of course on the Catalogue SINEX being up-to-date, but a Catalogue error can be clearly seen by the majority of ACs being flagged as discrepant on the same data item.

8 Residual Series

Shown here are series of postfit residual SDs between A-Networks and the NCL G-Network (Figure 4) and between A-Networks and the ITRF Core network (Figure 5), for GPS weeks 0823–0848. These are of historical rather than scientific interest, i.e., they show improvement since early in the pilot Programme, but are not consistent series because our analysis method has developed throughout the period shown.

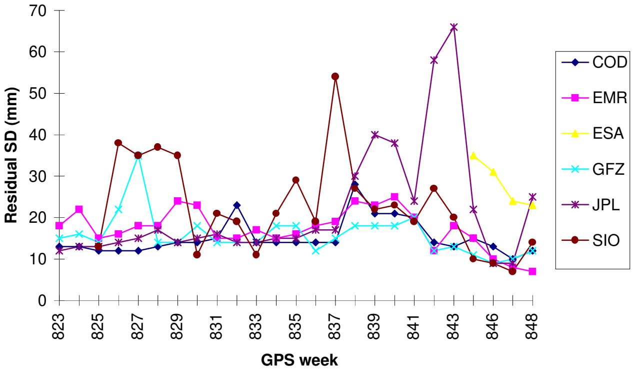

Figure 4: Loose A-Nets to G-Net postfit residuals SDs

9 Outlook for 1996

The NCL G-network task has become steadily more automated and the most arduous software development is behind us, allowing more time for testing and improving the procedure. The residual analysis has been rather crude, but we expect to refine this rapidly during 1996, leading to an increasingly consistent time series. The adoption of SINEX v1.00 by all agencies should give us a more uniform and well-defined transfer format.

We are now looking forward to the introduction of Regional Network Associate Analysis Centres (RNAACs, previous known as Type One AACs) to the

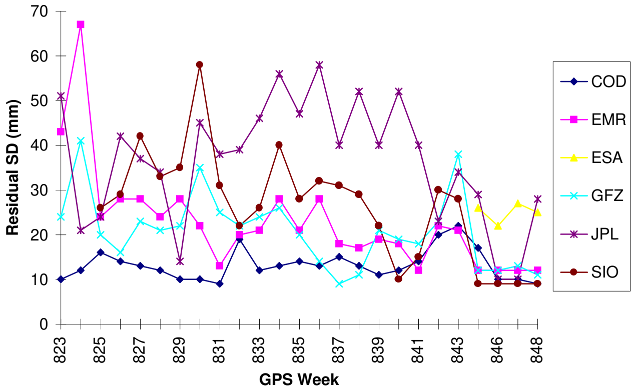

Figure 5: Loose A-Nets to Core postfit residuals SDs

distributed processing project. This will enable GNAACs to carry out their second 'P-network' task of integrating the regional networks with the G-network using Anchor Stations. Regional observations will not influence the G-network, so the work and data products described in this report should not be affected by this development. G-Network reliability should improve as Global station redundancy in A-Networks increases.

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GNAAC Activities at the Jet Propulsion Laboratory

M. B. Heflin, D. C. Jefferson, M. M. Watkins,
F. H. Webb, J. F. Zumberge
Jet Propulsion Laboratory/California Institute of Technology
Pasadena, California

Global Network Associate Analysis Center (GNAAC) activities began at JPL starting with GPS week 813. Constraint removal was implemented on week 821 and a fully rigorous combination was computed starting with week 837. Each week a summary is mailed to the IGS. In addition, the GPS combination and summary are submitted to the CDDIS. 43 weekly comparisons have been completed to date.

Solutions submitted from COD, EMR, ESA, GFZ, JPL, NGS, and SIO are obtained from the CDDIS each week. *A priori* constraints are removed from each solution to the level of about 10 m. Internal constraints are applied to remove reference frame noise from the covariance matrix. The estimates are unchanged by internal constraints. Each pair of solutions is then compared by estimating a 7-parameter Helmert transformation to minmize the least-squares coordinate residuals. All common sites are used. The errors from each solution are then scaled to make χ^2/DOF roughly equal to one for all pairs and four-sigma outliers are removed. The transformation parameters for each pair are given in the report along with the WRMS of residuals.

A free-network combination of solutions from all centers is also computed. Each solution is scaled and edited according to the results of pair-wise comparisons. Then all free-network solutions are rigorously combined using their full covariance matrices. The free-network combination and summary report are submitted to the CDDIS. Sites common to all solutions are used to compare each solution with the combination. The comparison is carried out by application of internal constraints and estimation of a 7-parameter Helmert transformation. The WRMS residuals are tabulated in the report. Comparison of each solution with the combination began on week 837 and the mean WRMS over all weeks is given in Table 1.

The full strength of all common sites is used for the pairwise comparisons and the transformation parameters are well determined for each pair. The mean geocenter and scale offsets are given for each center relative to JPL in Table 2. Geocenter offsets are observed at the cm level and most scale differences are smaller than 1 part per billion.

Table 1: Mean WRMS for weekly comparisons since GPS week 837.

Center	*North* *mm*	*East* *mm*	*Vertical* *mm*
COD	4	4	11
EMR	5	7	10
ESA	5	7	35
GFZ	3	6	11
JPL	2	3	8
NGS	11	15	14
SIO	2	4	8

Table 2: Mean geocenter and scale offsets with respect to JPL.

Center	*TX* *cm*	*TY* *cm*	*TZ* *cm*	*Scale* *ppb*
COD	0.6	-1.2	-1.8	-0.4
EMR	2.1	-14.5	0.3	-0.7
ESA	-0.5	2.1	-2.7	2.0
GFZ	-6.7	-8.1	2.3	-0.1
NGS	1.7	-21.3	-5.8	-8.0
SIO	-0.3	-0.5	0.5	-0.7

Our goal during the pilot phase is to include as many solutions as possible regardless of the formatting details and submission dates. The daily solutions from NGS are combined into weekly solutions so that their results can contribute to the combination. Our software has been adapted to read several variations of the SINEX format. All seven analysis centers deserve credit for spending considerable time and effort to submit their solutions in the SINEX format.

The GNAAC pilot phase has been successful in comparing solutions from different centers and in demonstrating the ability to combine those results into a single solution. The original motivation for GNAAC activities was the need for distributed processing of GPS data. This need has been greatly reduced by improving analysis strategies, and several centers can now analyze data from hundreds or even thousands of GPS receivers in a consistent reference frame. In addition, yearly combinations are computed by the ITRF, and a new CSTG combination effort is underway. These advances and related activities must be considered when planning the frequency and scope of future GNAAC analysis products. Many thanks to all those who are participating in the GNAAC pilot phase. We hope that current and future GNAAC activities prove useful for the GPS community.

MIT Global Network Associate Analysis Center Report

Thomas A. Herring
Massachusetts Institute of Technology
Cambridge, Massachusetts

1 Analysis Procedures

The combination analysis is composed of several steps which can be outlined as (a) removing the analysis center (AC) constraints, (b) determining the appropriate variance scaling factor for each AC, (c) combination of the loosely-constrained AC analyses in both tightly and weakly constrained solutions, and (d) comparison between the International Terrestrial Reference Frame (ITRF) and the combined and individual AC. Each week a summary file and the constrained combined SINEX file are submitted to the Crustal Dynamics Data Information system (CDDIS). An unconstrained solution can be generated from the submitted SINEX file by removing the constraints as discussed below. The starting dates of the SINEX files processed in the MIT analyses are listed in Table 1 (along with other statistics discussed below). We discuss now the procedures used in each of these steps.

1.1 Deconstraining AC SINEX files

The procedure used to deconstrain the AC SINEX files is to transform the constrained analysis into the equivalent of weighted-least-squares (WLS) normal equations. In normal-equation space, the constraints applied during the AC analysis can be simply subtracted. New (usually weaker) constraints are then applied and the system re-inverted to form a loosely constrained analysis. Viewed from a WLS perspective, the constrained solution in the SINEX file is given by

$$\widehat{\delta x_c} = (\mathbf{N} + \mathbf{C_{ac}})^{-\mathbf{1}} b \qquad (1)$$

where $\widehat{\delta x_c}$ are adjustments to the *a priori* parameter values from constrained analysis; $\mathbf{N}$ are the normal equations formed purely from the data used in the analysis; $\mathbf{C_{ac}}$ are the constraints applied to the normal equations (this matrix is the inverse of the covariance matrix of the *a priori* constraints); and b is the "right-hand side" side of the normal equations formed by the product of

Table 1: *Summary of statistics of Centers*: The column entries are: *Start Week* first week of SINEX file submission; *Average scale* is the average value of the multiplier used to scale the AC's covariance matrix; $\langle\chi^2/f\rangle$ is the average χ^2/f of coordinate fits to linear trends over the ≈ 6 months of SINEX files; ⟨*Horz. RMS*⟩ and ⟨*Height RMS*⟩ are the average root-mean-square (RMS) scatters of the horizontal and height coordinate estimates, respectively; and # is the number of stations used in computing the statistics in the final three columns.

Center	*Start Week*	*Average Scale*	$\langle\chi^2/f\rangle$	⟨*Horz. RMS*⟩ (mm)	⟨*Height RMS*⟩ (mm)	#
COD	818	14.7	46.3	4.0	10.3	72
EMR	818	33.0	37.7	9.9	16.4	32
JPL	819	10.5	11.9	3.5	7.4	77
GFZ	819	59.9	41.7	5.9	13.9	51
SIO	822	1.9	3.4	3.5	9.1	83
NGS	822	566	820	17.7	31.5	52
ESA	840	13.5	13.1	6.1	20.5	55

the partial derivatives by the data weight matrix by the difference between the observations and the theoretical values computed using the *a priori* values of the parameters. The covariance matrix given in the SINEX file is $(\mathbf{N}+\mathbf{C_{ac}})^{-1}$ and $\widehat{\delta x_c}$ can be computed provided both the parameter estimates and *a priori* values are given. Denoting $(\mathbf{N}+\mathbf{C_{ac}})^{-1}$ by $\mathbf{V_c}$ (the constrained covariance matrix from the SINEX file) b can be computed using

$$b = \mathbf{V_c^{-1}}\widehat{\delta x_c} \tag{2}$$

Also the data-only normal equations can be computed from

$$\mathbf{N} = \mathbf{V_c^{-1}} - \mathbf{C_{ac}} \tag{3}$$

The normal equations generated from equation (3) are usually singular and so we apply weak constraints to these equations before re-inverting the system with weak constraints. When an AC applies very tight constraints to the analysis, the elements in $\mathbf{C_{ac}}$ are very large and the difference formed in equation (3) is prone to rounding errors. Rounding errors generally result in $\mathbf{N}$ being non-positive definite. For most centers, we are able to replace the AC constraints on station positions with 5 meters constraints without introducing significant rounding error. The NGS analysis is the major exception where the weak constraints need to be 0.1 meter or else the system becomes non-positive definite. However, since the variance rescaling for this center is approximately 500, the re-scaled constraint is similar in size to the other ACs. On some occasions, we need to tighten the loose constraint on the COD analysis to 0.5 meter. For ESA and SIO we do not need to remove constraints because their SINEX files have only weak constraints applied. For JPL we can not remove constraints because their SINEX files do not contain the required SINEX blocks. As far as we know, the JPL SINEX files seem to be weakly constrained at about the 1-meter level.

Analysis of the above procedure shows that the procedure is valid even when the SINEX files does not contain all the parameters in the original analysis provided that there are no constraints applied that have covariances between the parameters given and those that are not in the SINEX file. (An example would be covariances between troposphere delay constraints and station position constraints. As far as we know no centers are applying this type of correlated constraint). When constraints are applied to parameters not included in the SINEX file, the weakly-constrained solution implicitly still has these other constraints applied.

1.2 AC Variance rescaling

Each of the ACs uses its own procedures to establish the stochastic model for its analyses. Most of these procedures do not generate realistic covariance matrices for the parameter estimates in the SINEX files mainly due to the neglect of temporal correlations in the GPS phase measurements. The most optimistic estimates are obtained when the covariance matrix is scaled by the root-mean-scatter of the post-fit phase residuals. One center, SIO, uses empirical noise models for GPS data that yield covariance matrices approximately scaled to be consistent with the short-term scatter of position estimates (the phase fits with this model are considerably better than the noise model implies reflecting the correlated nature of the phase residuals). For all ACs we compute a variance scaling factor that we multiply the AC's covariance matrix by before combining with other AC analyses. We compute this factor from the χ^2 of the fit of the AC loose analysis to ITRF93 coordinates of the 13 core sites. In this analysis, we allow the coordinate system to rotate (parameterized as polar motion and UT1-UTC) but we do not allow explicit scaling or translation of the coordinate system. With this approach, those centers that yield coordinates aligned with the center of mass of the Earth (as realized through the ITRF93 coordinates) tend to have smaller rescaling values. The average value of scaling factors used between the start of SINEX file submission and Week 855 are given in Table 1 in the column labeled "Average Scale."

1.3 Combination analysis

Two combined solutions are formed each week using all information from all the centers. In our combinations we do not remove sites from any of the analyses. However, we do change some of the estimated site coordinates if an incorrect antenna height is used in the analysis. Provided the change in position is small compared to the constraints on the *a priori* station coordinates, this procedure should yield the same results as would have been obtained had the correct station height been used. The most problematic site has been IISC for which three different values ranging between 0.0 and 1.3 meters are used. We have the reduced the height to 0.0 m for all ACs. Other height changes are reported in the weekly summary files and for all centers, except JPL, can be deduced from the SINEX file eccentricity blocks. The corrections we have applied are given in Table 2.

Table 2: *Applied Position Changes*: Start and End are the start and end dates of when the positions were changed. If a date is blank, then the change was applied from the beginning of SINEX submissions or is currently being applied. Corrections are made either as North, East and Height (Up), Type NEU, or in Cartesian XYZ coordinates, Type XYZ.

Center	Site	Start (ymd)	End (ymd)	$\Delta X/N$ (m)	$\Delta Y/E$ (m)	$\Delta Z/U$ (m)	Type
EMR	IISC		96 01 01	0.0	0.0	1.3230	NEU
EM	IISC	96 04 21		0.0	0.0	1.3630	NEU
ESA	ALBH		96 02 17	0.0	0.0	0.029	NEU
ESA	ALGO		96 02 17	0.0	0.0	-0.1000	NEU
ESA	DRAO		96 02 17	0.0	0.0	0.0150	NEU
ESA	GOLD		96 02 17	0.0	0.0	-0.0954	NEU
ESA	PAMA		96 02 17	0.0	0.0	0.620	NEU
ESA	PERT		96 02 17	0.0	0.0	-0.0027	NEU
ESA	STJO		96 02 17	0.0	0.0	0.0620	NEU
ESA	USUD		96 02 17	0.0	0.0	0.0350	NEU
ESA	YELL		96 02 17	0.0	0.0	0.017	NEU
ESA	KOKB		96 02 24	0.0	0.0	0.032	NEU
GFZ	IISC			0.0	0.0	1.3230	NEU
JPL	IISC			0.0	0.0	1.3230	NEU
NGS	TSKB		95 11 23	-26.306	-38.284	2.761	XYZ
NGS	AREQ		95 11 23	18.615	-0.548	21.499	XYZ
NGS	MAS1		95 11 23	3.120	-0.845	-9.563	XYZ
NGS	YELL		96 01 11	0.0	0.0	0.028	NEU
NGS	CHAT		96 01 21	0.0	0.0	0.1069	NEU
NGS	CRO1		96 04 13	0.0	0.0	0.0486	NEU
NGS	CRO1	96 04 14		0.0	0.0	0.5526	NEU
NGS	EISL		96 04 28	32.016	12.485	-37.088	XYZ
SIO	IISC			0.0	0.0	1.3440	NEU
SIO	THUL		95 12 17	0.0	0.0	-0.0350	NEU

After correction for any station eccentricity errors, the corrected AC analyses are combined into a single analysis using the program GLOBK. The combination estimates all station positions and allows for rotations between the AC's SINEX files. No scale factors or explicit translations are estimated in this combination. In the "tight" combination submitted to the CDDIS, the 13 core-IGS sites are constrained to a few millimeters as reported in the summary file also submitted to the CDDIS. Most of the analysis of the combination is done using the loosely constrained analysis. This combination is performed the same as the tight analysis except that all stations are constrained to ±100 m. The statistics of this loose solution are reported in the summary file each week.

1.4 Comparisons with ITRF93 and Combined Analysis

Each week we compare the combined and individual AC's analyses with ITRF93, and the individual ACs with the combined solution. For all of these comparisons we use an origin and orientation constraint to translate and rotate the loose solutions to the origin and orientation of ITRF93. We also include a scale factor in the transformation. The values for the translation and scale are reported each week. Normally, we use the 13 IGS core sites to estimate the seven transformation parameters. In some weeks the performance of some of these stations is so bad that we do not use them in the transformation. These sites are noted in each week's summary. In forming the estimates of the transformation parameters and in computing the statistics of the fit to the ITRF93 coordinates, we give the height estimates 10 times less weight than the horizontal coordinates (equivalent to 3.2 times larger sigma for the heights). Each week the fit of combined solution to the ITRF93 coordinates is $\approx$ 6 mm. The best of the individual centers are about the same value but normally a little larger ($\approx$ 7 mm). We also fit the individual ACs to the combined analysis, and these fit are usually between 2-3 mm.

As an evaluation of the variance factors that we are using in the combinations and to get a general sense of the quality of the weekly GPS solutions, we have run standard analyses on all the SINEX files submitted until Week 854. For each center, we generated loose solutions each week which we then translated, rotated and scaled in the same fashion that we do each week. These analyses were performed without rescaling the covariance matrices. We then looked at the repeatabilities of the weekly solutions for each center. The results are summarized in Table 1. We give the average χ^2/f of the coordinate fits after removing the worst 5 values for each coordinate, and we give the average RMS scatters for the horizontal and vertical coordinates separately. In general, the variance factors deduced this way are similar to those found in the weekly analyses, and it is clear that the best of the analyses are achieving $\approx$ 4 mm horizontal scatters and 7-10 mm vertical scatters averaged over (nearly) all sites in the network (we removed HART, PAMA, and IISC before computing the RMS scatters).

Data Center Reports

IGN Global Data Center Report

Loïc Daniel
IGN/ENSG/LAREG, Paris, France

1 Introduction

The Research Laboratory in Geodesy at IGN has hosted a Global Data Center of the IGS since the Test Campaign of 1992. As such, it is committed to disseminate and archive the IGS data and products. The Global Data Center contributes to the routine operations of the IGS by gathering and distributing the observation files needed by the analysis centers. The other part of its activity is to provide users access to the whole set of IGS data and products, current or accumulated since the beginning of the service. In 1995, the IGN Center has set up a mirror of the IGS Central Bureau Information System (CBIS), in order to allow non-American users to access it more easily. Details about the computer and network architectures, data flow scheduling and access, various statistics on the activity of the Center during 1995 are presented below.

2 Computer system configuration

The computer architecture is based on a VAX/VMS cluster including 3 computers, one VAX 3400 and two Vaxstations, with a total of 8 Gbytes of disk space. The system is running an ORACLE DBMS. A database has been set up in order to keep track of the IGS files and to record the logs of the routine daily operations of the Center.

The data are archived on 2-sided 5.25-inch rewritable magneto-optical disks, the capacity is 325 Mbytes per side. There are backups of these disks either on 8-mm or 4-mm tapes. Since 1995, all backups are done on 4-mm tapes.

In addition to that, there is an HP 750 workstation running the HP-UX operating system. This computer stores the mirror of the IGS CBIS and provides access to the disks of the VAX cluster by NFS on the local network. The HP is equipped with a 4-mm DAT drive stacker. A small amount of actual disk space is used on this machine, about 90 Mbytes for the CBIS files and the symbolic links to the data and product files on the VAXes.

Both VMS and UNIX systems are available through TCP/IP protocols, the access is provided by FTP only, non-anonymous as well as anonymous. The VAX is running the DEC TCP/IP Services for OpenVMS (aka UCX) which, in our experience, can be rather unstable at times. This is one reason why we have included the UNIX station in the setup, as it provides a backup as an FTP server. Another reason is that we are in the process of migrating this mixed configuration to a UNIX-only one; this should be completed by mid-1997.

The local network is connected to the Internet through a 128 Kbps line.

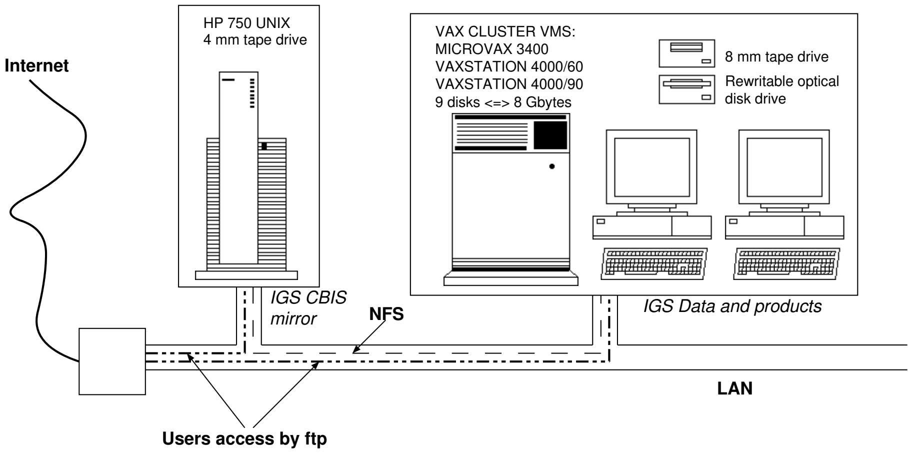

Figure 1: Computer architecture

3 Archive access

There are three ways to log in to the IGN Global Data Center and get IGS data by FTP through the Internet:

- anonymous FTP on `mozart.ign.fr` (192.33.147.225)
- non-anonymous FTP on `mozart.ign.fr`, username/password given by `igsadm@mozart.ign.fr`; this method is still available for historical reasons but is bound to disappear when the new UNIX configuration is ready
- anonymous FTP on `schubert.ign.fr` (192.33.147.230); the archive seen from this host is exactly the same as the one on `mozart.ign.fr` 24 hours back (this is the periodicity of the updates of the links)

Both FTP servers are available 24 hours per day and 7 days per week. They implement the usual set of FTP commands necessary to list directories and get files.

The directory structure on `mozart.ign.fr` (see Table 1) is based on a root named `IGS$FTPDEV` which is a pseudo-device referring to the full set of 9 different physical magnetic disks. This is a practical way to refer to a particular IGS file without needing to know on which physical device it is stored. This is actually a synonym of **`IGS$DATA$`***i* where *i* ranges from 1 to 9.

Table 1: Directory Structure on **`mozart.ign.fr`**

Directory	Filenames	Description
`IGS$FTPDEV:[CORE.`*ddd*`]`	`OSTAT`*ddd*`.`	IGN data flow summary file for day *ddd*
	SSSSddd`0.`*yy*`O_Z`	compressed RINEX obs files for stations *SSSS*, day *ddd*, year *yy*
	`IFAG`*ddd*`0.`*yy*`N_Z`	global european compressed RINEX nav file
	`BRDC`*ddd*`0.`*yy*`N_Z`	global compressed RINEX nav file (all stations)
`IGS$FTPDEV:[CALC.`*wwww*`]`	`OSTAT`*wwww*`.`	IGN data flow summary file for week *wwww*
	CCCwwwwd`.EPH`	Orbits produced by center *CCC* for GPS week *wwww* and day *d* in SP3 format. $d = 7$: Full week.
	CCCwwwwd`.SP3`	Same
	CCCwwwwd`.SP1`	Same in SP1 format
	CCCwwwwd`.ERP`	Earth Rotation Parameters file produced by center *CCC* for GPS week *wwww* and day *d*
	CCCwwwwd`.SNX`	Network coordinates solution in SINEX format
	CCCwwwwd`.SUM`	Summary file

The directory structure on **`schubert.ign.fr`** (see Table 2) is basically the same as on **`mozart.ign.fr`**, the difference being the root which is **`/pub/igs`**. The naming conventions are those of UNIX, i.e., the compression suffix is translated from `_Z` to `.Z`. There is actually no data on **`schubert`**; all the files are symbolic links to physical locations on the VAXes accessed by NFS. Most of the IGN IGS Center users get data through this station.

The off-line archived files are provided to the users on request, either by restoring them on-line or on tape when the volume is too important to fit on-line.

4 Data handling

The daily operations of the Data Center (see Figure 2) are done automatically, all the data transfers are done via Internet, they are initiated by IGN, and no IGS data are put to IGN by another center. Basically, according to a list of sources of data and a schedule, a dispatcher module runs the necessary tasks to get the data and redistribute it. This is interfaced with a DBMS in order

Table 2: Directory Structure on `schubert.ign.fr`

Directory	Filenames	Description
/pub/igs/obs/*ddd*	OSTAT*ddd*	IGN data flow summary file for day *ddd*
	*SSSSddd*0.*yy*O.Z	compressed RINEX obs files for stations *SSSS*, day *ddd*, year *yy*
	IFAG*ddd*0.*yy*N.Z	global european compressed RINEX nav file
	BRDC*ddd*0.*yy*N.Z	global compressed RINEX nav file (all stations)
/pub/igs/calc/*wwww*	OSTAT*wwww*	IGN data flow summary file for week *wwww* All other files unchanged wrt `mozart.ign.fr`
/pub/igscb		mirror of CBIS

to store control information (log files of the automatic transfer, archive and ancillary procedures) as well as keep an inventory of data available and be able to know where it is (offline data included). The routines are written in DCL scripts or C.

Every day, one day of observation is deleted from the archive after a check that the files are actually archived.

The transfers are run in parallel, with the restriction that all those accessing the same source or destination are sequentials. Some of the jobs are synchronized, for example when a "put" transfer can only start after a "get" one is completed. At the beginning of a transfer, the content of the remote archive is listed and new data are retrieved, looking back 15 days for the observation files and 6 weeks for the product files. A file is considered new if it is not in the IGN archive but also if the size is bigger or the date more recent than the local file at IGN. A particular effort is made to equalize daily the data holdings between the two other Global Data Centers and IGN. This is is done several times per day to shorten the delay as much as possible.

The data are archived every day on magneto-optical disk and every month on tape.

5 Archive statistics

The on-line capacity is 160 days of observations files and 40 weeks of product files. There are 70 stations in the nominal daily set, representing a volume of about 40 Mbytes. The average set of weekly product files represents about 15 Mbytes, half of it being the SINEX coordinates solution files.

There is a partial mirror of the CBIS on `schubert.ign.fr`, updated once

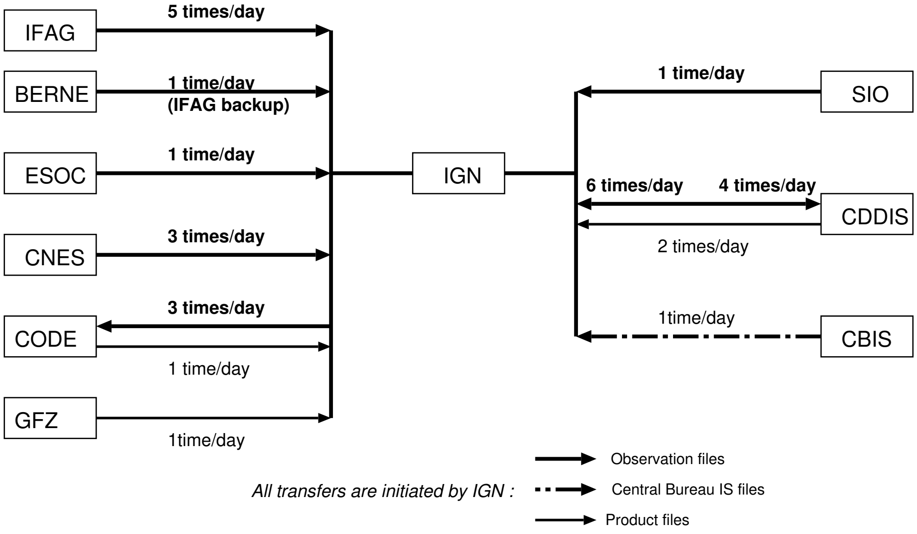

Figure 2: Data flow schedule

per day. All the CBIS information files are mirrored, but the IGS product files are not because they are already stored in the Global Data Center area.

5.1 IGS Products

On average, the ephemerides, clock, and ERP product files are available within 5 days, and among all the analysis centers, the average delivery delay does not vary much. The IGS rapid service has a delivery delay of 8 days, or 2 days more than the largest individual Analysis Center delay, which is six.

In 1995, terrestrial solution files have been introduced in the system as a new product. The average delay of availability is 12 days, except for NGS, which distributes daily files instead of weekly ones from the other Analysis Centers. See Figures 3–5.

5.2 Tracking network data

70% of the data from the tracking network is available within one day. This is an overall value. If applied to the subset of stations data provided to IGN by IFAG and BERNE; the corresponding figure is 80%. These figures come from the IGN database which is independent but should not differ significantly from Werner Gurtner's check_import statistics provided by the CBIS.

At IGN, CDDIS is set up as the primary path to non-european IGS data, which is why SIO figures are lower in Figure 6. In fact data come from SIO to IGN only if there has been a problem with the CDDIS-IGN link, and this

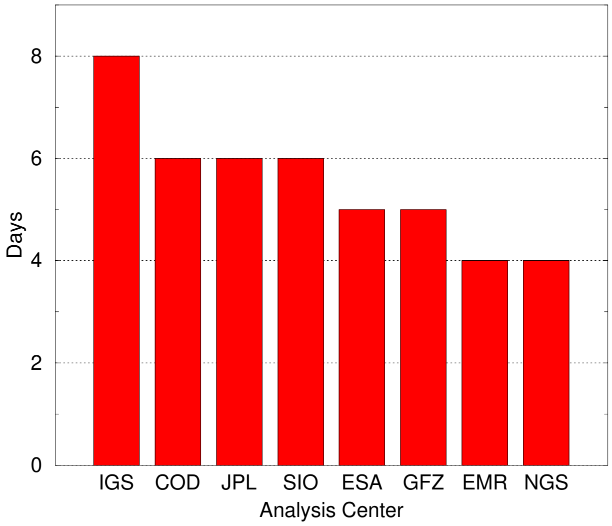

Figure 3: Ephemerides files availability

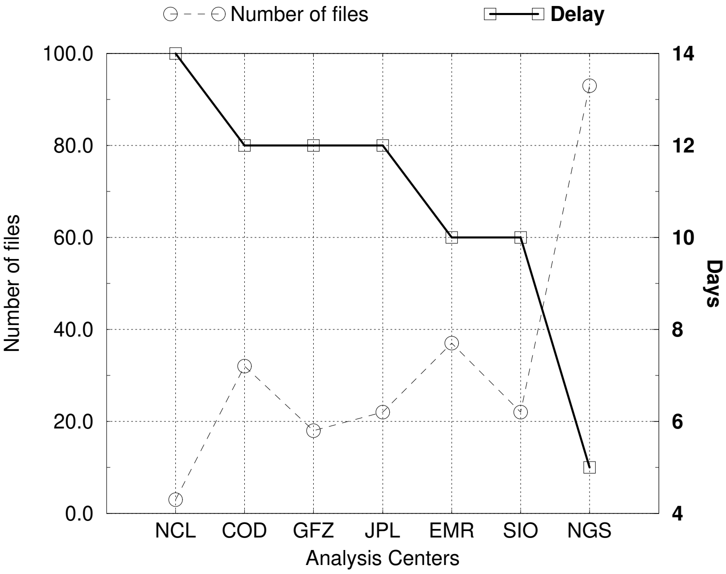

Figure 4: Coordinates files availability (SINEX)

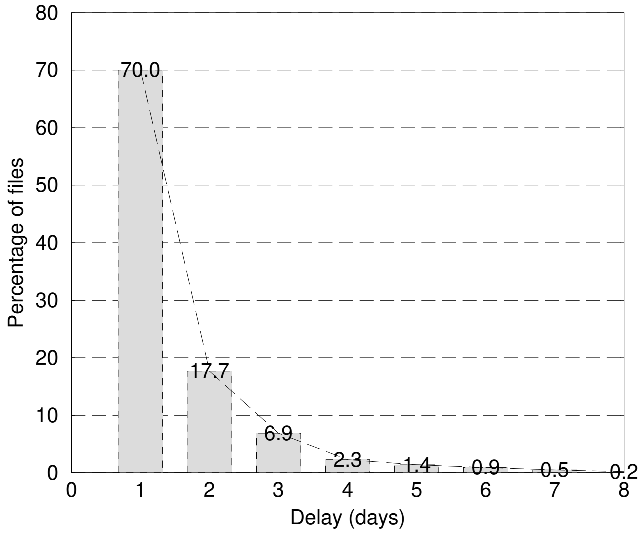

Figure 5: Observation files availability

accounts for the smaller number of files retrieved from SIO. This is the same with IFAG and BERNE, IFAG is the nominal data source and BERNE a backup. As can be seen in Figure 6, CDDIS and IFAG are the main data providers of IGN.

IGN also puts tracking stations data files to CODE[1] and CDDIS. In particular it is in charge of the distribution of the European files as collected by IFAG to the rest of the IGS data network. This is done 4 times a day by putting them to CDDIS and synchronized with the IFAG→IGN transfers.

6 User activity

In 1995, there has been a total of 35,000 files retrieved from the on-line archive by users of the IGN Global Data Center, representing a volume of 16 Gbytes. This averages to 1.3 Gbytes per month which is a large increase compared to the 200 Mbytes/month average of 1994. The off-line volume requested by the users has amounted to 4 Gbytes. 80% of the files retrieved are GPS observation ones, 20% are product files (almost all of them being precise ephemerides). See Figure 7.

All users of the Global Data Center at IGN are from European countries.

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[1] Although BERNE and CODE are actually at the same Internet address, we assign two different names to the University of Berne's computer facility to discriminate the Analysis Center role from the backup Data Center role.

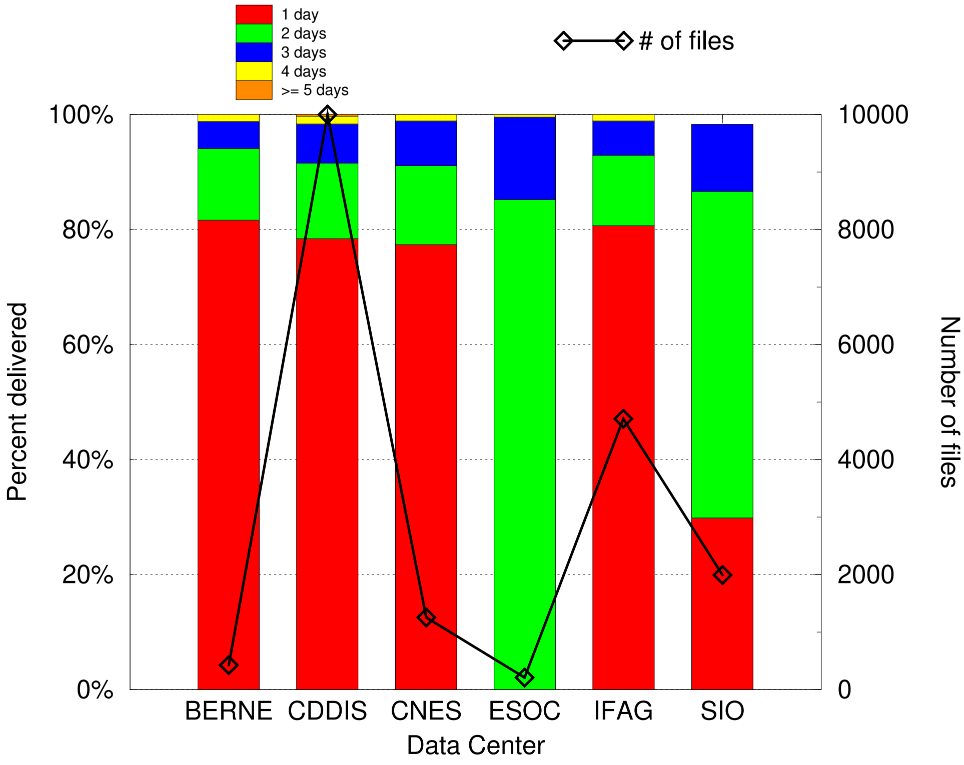

Figure 6: Observations availability by source

Actually, those that generate a significant activity over the year 1995 are respectively from Germany, France, Belgium, Italy and UK. These figures describe the on-line activity only. All users that made requests for off-line data are from France. Thus, overall, France and Germany are generating the same level of users activity at the IGN Center, representing 98% of the total volume. See Figure 8.

The user accesses over Internet originate from 100 different networks, and most of them are universities or educational sites.

In addition to this, 2000 files have been transferred by 40 different hosts from the CBIS mirror on the Unix system.

7 Plans

The computer systems will migrate to Unix in 1997, and the new configuration is expected to be operational by mid-1997. This will include a jukebox of CD-ROMs. The objective is to be able to keep a large portion of the archive on-line, relieving the staff from the painstaking task of restoring data on request. The

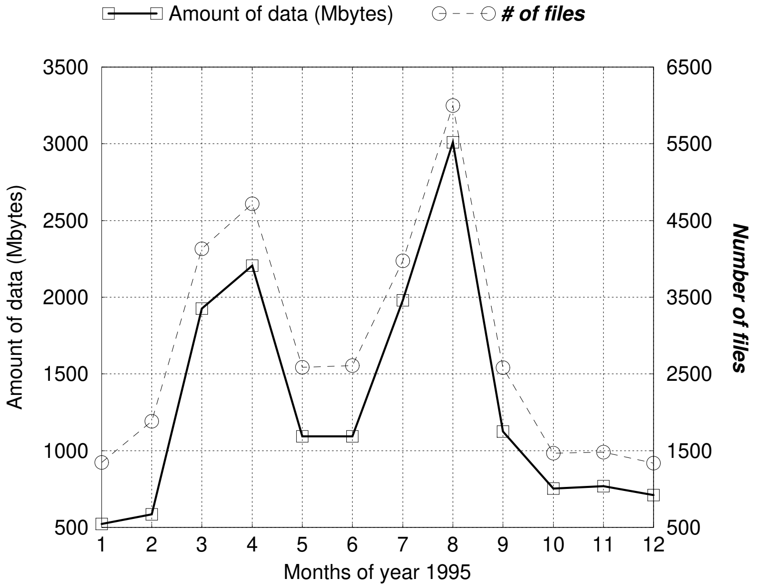

Figure 7: Volume of data transferred by users

directory structure of the Data Center will be changed because it can presently deal with less than a year of data. In this set up, the CD-ROM will become the primary storage media for the IGS archive, replacing magneto-optical disks. This CD-ROM writing capacity will also be used as an alternate means of data distribution to the users.

The IGN Global Data Center will move to another place in 1996; this is expected to take place in December. The computers will have a new Internet network name and number. The community will be advised in time and a reminder system will be installed at the old Internet address in order to inform the users about the change of address. At the new site, the Internet connection will have a 2-Mbps capacity.

A Web site is in construction, which will provide users with means of searching the archive by sending requests to the database system. The service will be opened when the new computer configuration is ready and the move is complete, by mid-1997.

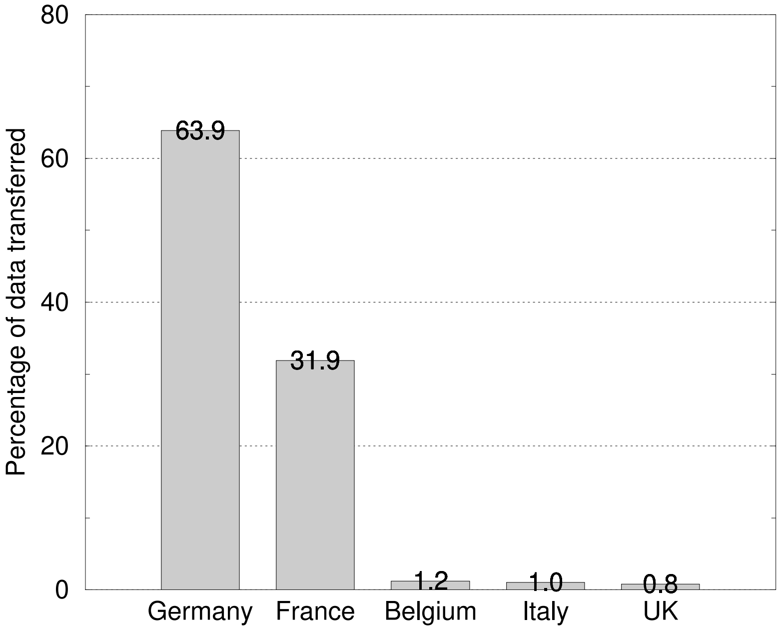

Figure 8: Users access to on-line data by country

CDDIS Global Data Center Report

Carey E. Noll
Computing Systems Office,
NASA/Goddard Space Flight Center, Code 920.2,
Greenbelt, MD 20771

1 Introduction

The Crustal Dynamics Data Information System (CDDIS) has supported the International GPS Service for Geodynamics (IGS) as a global data center since the IGS Test Campaign was conducted in June 1992. The CDDIS activities within the IGS during 1995 are summarized below; this report also includes any changes or enhancements made to the CDDIS during the past year. General CDDIS background and system information can be found in the CDDIS data center summary included in the IGS 1994 Annual Report [1].

2 System Description

The CDDIS archive of IGS data and products is accessible worldwide through 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, and data availability.

2.1 Computer Architecture

The CDDIS is operational on a dedicated Digital Equipment Corporation (DEC) VAX 4000 Model 200 running the VMS operating system. 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 (currently, up to 9600-baud) and through the GTE SprintNet system. The CDDIS computer facility currently has nearly nineteen Gbytes of on-line magnetic disk storage.

During 1995, new disk drives were purchased to increase the on-line disk storage available to the CDDIS user community. At this time, two magnetic disk drives, totaling 6.4 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 as well as the long-term archive medium for GPS data on the CDDIS. With the current nearly 100 station network, only five days of GPS tracking data can be stored on a single side of one of these platters. The older data continue to be stored on these optical disks and can easily be requested for mounting and downloading remotely by the user. Alternatively, if the request for older data is relatively small, data are downloaded to magnetic disk, providing temporary on-line access. A 4.3-Gbyte magnetic disk drive is devoted to the on-line storage of IGS products, special requests, and supporting information.

3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to GPS data from the global IGS network as well as the products derived from the analysis of these data.

3.1 GPS Tracking Data

The GPS user community has access to the on-line and near-line archive of GPS data available through the global archives of the IGS. Operational and regional data centers provide the interface to the network of GPS receivers for the IGS global data centers. For the CDDIS, the following operational or regional data centers make data available to the CDDIS from selected receivers on a daily basis:

- Australian Survey and Land Information Group (AUSLIG) in Belconnen, Australia
- NOAA's Geosciences Laboratory (GL/NOAA) Operational Data Center (GODC) in Rockville, Maryland
- Natural Resources of Canada (NRCan) in Ottawa, Canada
- European Space Agency (ESA) in Darmstadt, Germany
- GeoforschungsZentrum (GFZ) in Potsdam, Germany
- Geographical Survey Institute (GSI) in Tsukuba, Japan
- Institute of Space Science and Astronomy in Daejeon, Korea
- Jet Propulsion Laboratory (JPL) in Pasadena, California
- University NAVSTAR Consortium (UNAVCO) in Boulder, Colorado

In addition, the CDDIS accesses the other two IGS global data centers, Scripps Institution of Oceanography (SIO) in La Jolla, California and the Institut Geographique National (IGN) in Paris, France, to retrieve (or receive) data holdings not routinely transmitted to the CDDIS by a regional data center. Table 1 lists the data sources and their respective sites that were transferred daily to the CDDIS in 1995; Table 2 presents detailed information on the sites whose data were archived in the CDDIS during the past year, with data availability information.

Table 1: Sources of GPS Data Transferred to the CDDIS

Source	*Sites*								*No. Sites*
AUSLIG	CAS1	DAV1	HOB2	MAC1					4
CIGNET	BRMU	FORT	HNPT	KELY	RCM5	SOL1	USNA	WES2	9
	WUHN								
NRCan	ALBH	ALGO	DRA0	STJO	YELL				5
ESA	KIRU	KOUR	MALI	MAS1	PERT	VILL			6
GFZ	KIT3	LPGS	POTS	ZWEN					4
GSI	TAIW	TSKB							2
IGN	ANKR	BOR1	BRUS	EBRE[1]	GRAS	GRAZ	HART	HERS	24
	IRKT	JOZE	KERG	KOSG	MATE	MDVO	METS	NYAL	
	OHIG	ONSA	PAMA	REYK	TROM	WETT	WTZR	ZIMM	
JPL	AOA1	AREQ	AUCK	BOGT	CARR	CASA	CAT1	CHAT	42
	CICE	CIT1	CRO1	EISL	FAIR	GODE	GOLD	GUAM	
	HARV	IISC	JPLM	KOKB	LBCH	MADR	MCM4	MDO1	
	NLIB	OAT2	PIE1	QUIN	SANT	SEY1	SHAO	SNI1	
	SPK1	THU1	TIDB	UCLP	USC1	USUD	WHC1	WHI1	
	WLSN	YAR1							
KOREA	TAEJ								1
SIO	MONP	PIN1	PVEP	SIO3	VNDP				5
UNAVCO	POL2								1
Totals:									103 sites from 11 data centers

Notes: [1]EBRE data currently delivered by ICC but will be delivered by IGN upon resolution of communication issues.

These data are summarized and archived to public disk areas in daily subdirectories; the summary and inventory information are also loaded into an on-line data base. Typically, the archiving routines on the CDDIS are executed several times a day for each source in order to coincide with their automated delivery processes. Table 3 presents the typical data delivery and processing times for data delivered to/retrieved by the CDDIS. 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.

Table 2: 1995 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	48°23′	−123°29′	ALBH	NRCan	ROGUE SNR-8000	01-Jan-95	—	365
Algonquin	45°57′	−78°04′	ALGO	NRCan	ROGUE SNR-8000	01-Jan-95	—	365
Ankara	39°53′	32°45′	ANKR	IGN	ROGUE SNR-8000	01-Nov-95	—	55
Annapolis	38°36′	76°18′	USNA	CIGNET	ROGUE SNR-8000	04-May-95	26-Dec-95	230
AOA, Westlake	34°10′	−118°50′	AOA1	JPL	ROGUE SNR-8000	01-Jan-95	—	364
Arequipa	−16°28′	−71°38′	AREQ	JPL	ROGUE SNR-8000	01-Jan-95	—	341
Auckland	−35°33′	174°28′	AUCK	JPL	ROGUE SNR-8000	06-Oct-95	—	81

Table 2: (continued)

Site Name	*N. Lat.*	*E. Long.*	*Mon. Name*	*Source*	*Receiver Type*	*Start Date*	*End Date*	*No. Days*
Bangalore	12°59′	77°40′	IISC	JPL	TRIMBLE 4000SSE	18-Jan-95	01-Oct-95	101
					ROGUE SNR-8000	01-Oct-95	—	84
Bermuda	32°21′	−64°39′	BRMU	CIGNET	ROGUE SNR-8000	01-Jan-95	—	365
Bishkek	42°32′	74°28′	POL2	UNAVCO	ROGUE SNR-8000	25-May-95	—	208
Bogotá	04°38′	−74°05′	BOGT	JPL	ROGUE SNR-8000	01-Jan-95	29-Sep-95	176
Borowiec	52°17′	17°05′	BOR1	IGN	ROGUE SNR-8000	16-Feb-95	—	302
Brasília	−15°57′	−47°53′	BRAZ	JPL	ROGUE SNR-8000	04-Mar-95	29-Oct-95	219
Brussels	50°18′	04°13′	BRUS	IGN	ROGUE SNR-8000	02-Jan-95	—	362
Carr Hill	35°53′	−120°26′	CARR	JPL	ROGUE SNR-8000	01-Jan-95	—	365
Casey	−66°16′	110°32′	CAS1	AUSLIG	ROGUE SNR-8100	01-Jan-95	—	352
Catalina Island	32°13′	−118°12′	CAT1	JPL	ROGUE SNR-8000	20-Jul-95	—	165
Chatham Island	−43°58′	−176°34′	CHAT	JPL	ROGUE SNR-8000	04-Oct-95	—	89
CIT, Pasadena	34°09′	−118°08′	CIT1	JPL	ROGUE SNR-8000	01-Jan-95	—	363
Davis	−68°34′	77°58′	DAV1	AUSLIG	ROGUE SNR-8100	01-Jan-95	16-Nov-95	288
Easter Island	−27°09′	−109°23′	EISL	JPL	ROGUE SNR-8000	23-Jan-95	—	332
Ensenada	31°15′	−116°09′	CICE	JPL	ROGUE SNR-8000	26-Mar-95	17-Dec-95	239
Fairbanks	64°58′	−147°29′	FAIR	JPL	ROGUE SNR-8	01-Jan-95	—	348
Fortaleza	−03°45′	−38°35′	FORT	CIGNET	ROGUE SNR-8000	01-Jan-95	—	363
Goldstone	35°15′	−116°47′	GOLD	JPL	ROGUE SNR-8	01-Jan-95	—	361
Grasse	43°45′	06°55′	GRAS	IGN	ROGUE SNR-8100	22-Feb-95	—	295
Graz	47°04′	15°30′	GRAZ	IGN	ROGUE SNR-8	01-Jan-95	—	356
Greenbelt	39°01′	−76°50′	GODE	JPL	ROGUE SNR-8100	01-Jan-95	—	364
Guam	13°28′	144°45′	GUAM	JPL	ROGUE SNR-8000	18-Jan-95	—	337
Hartebeesthoek	−25°53′	27°42′	HART	IGN	ROGUE SNR-8	26-Jan-95	—	334
Harvest Platform	34°28′	−120°41′	HARV	JPL	ROGUE SNR-8000	01-Jan-95	—	364
Herstmonceux	50°52′	00°20′	HERS	IGN	ROGUE SNR-8A	01-Jan-95	—	353
Hobart	−42°48′	147°26′	HOB2	AUSLIG	ROGUE SNR-8100	01-Jan-95	16-Dec-95	280
Horn Point	38°36′	−76°08′	HNPT	CIGNET	ROGUE SNR-12	19-Dec-95	—	13
Irkutsk	52°18′	104°15′	IRKT	IGN	ROGUE SNR-8000	21-Sep-95	—	99
Jozefoslaw	51°02′	21°30′	JOZE	IGN	TRIMBLE 4000SSE	01-Jan-95	—	363
Kellyville	66°59′	−50°57′	KELY	CIGNET	ROGUE SNR-8000	23-Jul-95	27-Dec-95	128
Kerguélen	−49°21′	70°16′	KERG	IGN	ROGUE SNR-8C	01-Jan-95	—	365
Kiruna	67°32′	20°09′	KIRU	ESA	ROGUE SNR-8100	01-Jan-95	—	353
Kitab	39°08′	66°53′	KIT3	GFZ	ROGUE SNR-8000	01-Jan-95	29-Dec-95	336
Kokee Park	22°08′	−159°40′	KOKB	JPL	ROGUE SNR-8	01-Jan-95	08-Dec-95	334
Kootwijk	52°11′	05°49′	KOSG	IGN	ROGUE SNR-8	01-Jan-95	—	353
Kourou	05°08′	−52°37′	KOUR	ESA	ROGUE SNR-8C	01-Jan-95	—	364
La Plata	−34°31′	−57°33′	LPGS	GFZ	ROGUE SNR-8000	02-Jul-95	30-Dec-95	136
Lake Mathews	33°52′	−117°27′	MATH	SIO	TRIMBLE 4000SSE	01-Jan-95	04-Oct-95	244
Lhasa	29°25′	91°07′	LHAS	IGN	ROGUE SNR-8000	17-May-95	—	228
Limon	09°59′	−83°06′	MOIN	JPL	ROGUE SNR-8000	07-Sep-95	15-Nov-95	61
Long Beach	33°28′	−118°09′	LBCH	JPL	ROGUE SNR-8000	01-Jan-95	—	365
Macquarie Island	−54°30′	158°56′	MAC1	AUSLIG	ROGUE SNR-8100	01-Jan-95	—	213
Madrid	40°26′	−04°15′	MADR	JPL	ROGUE SNR-8	01-Jan-95	—	365
Malindi	−03°14′	40°08′	MALI	ESA	ROGUE SNR-8C	17-Nov-95	—	40
Mammoth Lakes	37°38′	−118°57′	CASA	JPL	ROGUE SNR-8000	01-Jan-95	—	360
Maspalomas	27°46′	−15°38′	MAS1	ESA	ROGUE SNR-8100	01-Jan-95	—	352
Matera	40°39′	16°42′	MATE	IGN	ROGUE SNR-8	01-Jan-95	—	360
McDonald	30°41′	−104°01′	MDO1	JPL	ROGUE SNR-8000	01-Jan-95	—	358
Mendeleevo	37°14′	56°02′	MDVO	IGN	TRIMBLE 4000SSE	31-Mar-95	—	222
McMurdo	−77°51′	166°40′	MCMU	JPL	ROGUE SNR-8000	01-Jan-95	17-Jan-95	16
			MCM4			25-Jan-95	—	339
Metsahovi	60°13′	24°24′	METS	IGN	ROGUE SNR-8C	01-Jan-95	29-Apr-95	113
					ROGUE SNR-8100	30-Apr-95	30-Dec-95	229
Monument Peak	32°53′	−116°25′	MONP	SIO	ASHTECH Z-XII3	01-Jan-95	02-Aug-95	191
					ASHTECH LPZ-XII	03-Aug-95	—	148
Mount Wilson	34°13′	−118°04′	WLSN	JPL	ROGUE SNR-8000	01-Jan-95	—	358
North Liberty	41°46′	−91°34′	NLIB	JPL	ROGUE SNR-8000	01-Jan-95	—	365

Table 2: (continued)

Site Name	*N. Lat.*	*E. Long.*	*Mon. Name*	*Source*	*Receiver Type*	*Start Date*	*End Date*	*No. Days*
Ny Ålesund	78°56′	11°52′	NYAL	IGN	ROGUE SNR-8	01-Jan-95	—	317
O'Higgins	−63°19′	−59°54′	OHIG	IGN	ROGUE SNR-8000	31-Mar-95	01-Dec-95	193
Oatt Mountain	34°20′	−118°36′	OATT	JPL	ROGUE SNR-8000	01-Jan-95	27-Jan-95	26
			OAT2			28-Jan-95	—	338
Onsala	57°24′	11°56′	ONSA	IGN	ROGUE SNR-8000	01-Jan-95	—	363
Palos Verdes	33°45′	−118°24′	PVEP	SIO	TRIMBLE 4000SSE	01-Jan-95	—	362
Pamate	−17°34′	−149°34′	PAMA	IGN	ROGUE SNR-800	01-Jan-95	18-Dec-95	333
					ROGUE SNR-8100	20-Dec-95	29-Dec-95	10
Pasadena	34°12′	−118°10′	JPLM	JPL	ROGUE SNR-8100	01-Jan-95	31-May-95	144
					ROGUE SNR-8000	01-Jun-95	—	204
Penticton	49°19′	−119°37′	DRAO	NRCan	ROGUE SNR-8000	01-Jan-95	—	365
Perth	−31°58′	115°49′	PERT	ESA	ROGUE SNR-8100	01-Jan-95	—	251
Pie Town	34°18′	−108°07′	PIE1	JPL	ROGUE SNR-8000	01-Jan-95	—	365
Pinyon Flat	33°37′	−116°27′	PIN1	SIO	ASHTECH Z-XII3	01-Jan-95	02-Aug-95	213
					ASHTECH Z-XIID	03-Aug-95	—	151
Potsdam	52°23′	13°04′	POTS	GFZ	ROGUE SNR-8000	05-Mar-95	—	285
Quincy	39°58′	−120°56′	QUIN	JPL	ROGUE SNR-8000	01-Jan-95	—	365
Richmond	25°37′	−80°23′	RCM5	CIGNET	ROGUE SNR-8000	01-Jan-95	—	357
Saddle Peak	34°04′	−188°39′	SPK1	JPL	ROGUE SNR-8000	16-May-95	—	221
Saint John's	47°36′	−52°41′	STJO	NRCan	ROGUE SNR-8000	01-Jan-95	—	365
San Nicolas Island	33°15′	−119°31′	SNI1	JPL	ROGUE SNR-8000	28-Nov-95	—	34
Santiago	−33°09′	−70°40′	SANT	JPL	ROGUE SNR-8	01-Jan-95	—	342
Scripps	32°52′	−117°15′	SIO3	SIO	ASHTECH Z-XII3	01-Jan-95	—	362
Seychelles	−04°41′	55°30′	SEY1	JPL	ROGUE SNR-8000	08-Aug-95	15-Dec-95	86
Shanghai	31°11′	121°26′	SHAO	JPL	ROGUE SNR-8100	09-Jan-95	—	338
Solomons Island	38°19′	−76°27′	SOL1	CIGNET	TRIMBLE 4000SSE	04-May-95	—	240
St. Croix	17°45′	−64°35′	CRO1	JPL	ROGUE SNR-8000	13-Oct-95	—	80
Taejon	36°12′	127°16′	TAEJ	KOREA	TRIMBLE 4000SSE	20-Nov-95	—	42
Taiwan	25°01′	121°32′	TAIW	GSI	ROGUE SNR-800	01-Jan-95	—	351
Thule	76°21′	−68°18′	THU1	JPL	ROGUE SNR-8000	06-May-95	—	197
Tidbinbilla	−35°24′	148°59′	TIDB	JPL	ROGUE SNR-8	01-Jan-95	—	365
Tromsø	69°40′	18°56′	TROM	IGN	ROGUE SNR-8	01-Jan-95	—	358
Tsukuba	36°06′	140°05′	TSKB	GSI	ROGUE SNR-8100	01-Jan-95	—	315
					ROGUE SNR-8000	03-Aug-95	21-Sep-95	50
UCLA,Los Angeles	34°04′	−118°27′	UCLP	JPL	ROGUE SNR-8000	08-Jan-95	—	357
USC, Los Angeles	34°01′	−118°18′	USC1	JPL	ROGUE SNR-8000	01-Jan-95	—	363
Usuda	36°08′	138°22′	USUD	JPL	ROGUE SNR-8000	01-Jan-95	—	354
Vandenberg	34°34′	−120°30′	VNDP	SIO	ASHTECH Z-XII3	01-Jan-95	02-Aug-95	204
					ASHTECH LPZ-XII	03-Aug-95	—	141
Villafranca	42°11′	−01°27′	VILL	ESA	ROGUE SNR-8100	12-Jan-95	—	353
Westford	42°37′	−71°29′	WES2	CIGNET	ROGUE SNR-8000	01-Jan-95	—	356
Wettzell	49°09′	12°53′	WETT	IGN	ROGUE SNR-800	01-Jan-95	—	361
Whittier College	33°59′	−118°02′	WHC1	JPL	ROGUE SNR-8000	05-Apr-95	—	271
Whittier Library	33°59′	−118°02′	WHI1	JPL	ROGUE SNR-8000	15-Mar-95	—	290
Wuhan	30°35′	114°19′	WUHN	CIGNET	ROGUE SNR-8000	31-Dec-95	—	1
Yaragadee	−29°03′	115°21′	YAR1	JPL	ROGUE SNR-8	01-Jan-95	—	364
Yellowknife	62°29′	−114°29′	YELL	NRCan	ROGUE SNR-8000	01-Jan-95	—	364
Zimmerwald	46°53′	07°28′	ZIMM	IGN	TRIMBLE 4000SSE	01-Jan-95	—	362
Zvenigorod	55°24′	36°30′	ZWEN	GFZ	ROGUE SNR-8000	16-Mar-95	—	271
Totals:	114 occupations of 104 sites							30,138 station days

The CDDIS GPS tracking archive consists of observation and navigation files in compressed (UNIX compression) RINEX format as well as summaries of the observation files used for data inventory and reporting purposes. During 1995, the CDDIS archived data on a daily basis from an average of 90 stations; toward the end of the year, this number increased to nearly 100 stations. Under

Table 3: CDDIS Data Processing Schedule

Source	*Put/Get*	*No. Times/ Day*	*Put/Get Times*	*CDDIS Processing Times*
AUSLIG	Get	1	11:30	11:30
CIGNET	Put	1	04:45	05:15, 16:00[1]
ESA	Put	1	02:00	03:00, 05:30, 12:30
GFZ	Put	4	01:00, 07:00, 13:00, 19:00	01:30, 08:30, 13:30, 20:30
GSI	Put	1	00:30	01:00, 06:30
IGN	Put	4	00:00, 07:00, 12:30, 19:00	01:00, 08:00, 13:00, 20:00
JPL	Get/Put	1	06:30, 08:30, 10:00, 22:00	06:30, 08:30, 10:30, 22:00[2]
KOREA	Put	1	00:30	02:45, 06:15
NRCan	Put	1	03:45	04:00, 21:00[1]
SIO	Get	1	09:30	09:30
UNAVCO	Put	1	17:00	18:30

Notes: All times are in UTC.
[1] Processing software is executed a second time in order to archive any late data.
[2] JPL PUT process to CDDIS executes 05:00; CDDIS executes GET procedures several times to retrieve data quicker for selected sites.

the current 100 station network configuration, approximately 150 days worth of GPS data are available on-line to users at one time. Each site produces approximately 0.6 Mbytes of data per day; thus, one day's worth of GPS tracking data, including the CDDIS inventory information, totals nearly 55 Mbytes. For 1995, the CDDIS GPS data archive totaled over 18 Gbytes in volume; this represents data from over 30,000 observation days. Of the ninety 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.

The majority of the data delivered to and archived on the CDDIS during 1995 was available to the user community within 24 hours after the observation day. As shown in Figure 1, 75% of the data from all sites delivered to the CDDIS were available within one day of the end of the observation day; nearly ninety percent were available within two days. These data delivery statistics are also true for the current set of 59 'global stations', processed by three or more IGS Analysis Centers on a daily basis. Figure 2 presents the data availability information by site for these global stations, with an overlay showing how many observation days were available during 1995; a few of the sites were not operational for a majority of 1995, 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 developed by the IGS Central Bureau and executed several times each day on the CDDIS.

Figure 1: Delay in GPS Data Delivery (All Sites) to the CDDIS in 1995

3.2 IGS Products

Seven IGS data analysis centers (ACs) retrieve the GPS tracking data daily from the global data centers to produce daily orbit products and weekly Earth rotation parameters and station position solutions; the IGS ACs are listed in this Annual report within the section *Organization of the IGS*.

The CDDIS also archives these products, which include 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 and stored in their respective user accounts. These are then copied to a central disk archive and made available in uncompressed ASCII on the CDDIS by automated routines that execute several times per day. 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

Figure 2: CDDIS GPS Data Availability Statistics in 1995 (Global Stations Only)

comparisons. Users interested in obtaining precision orbits for use in general surveys and regional experiments can also download the IGS products. The CDDIS currently provides on-line access to all IGS products generated since the start of the IGS Test Campaign in June 1992.

During 1995, the seven IGS Analysis Centers began generating weekly station solutions of the global IGS network in the Software Independent Exchange (SINEX) format. Global Network Associate Analysis Centers (GNAACs) also began their comparison of these files during 1995 and submitted the resulting SINEX files to the CDDIS. The three participating GNAACs are:

- Jet Propulsion Laboratory
- Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts
- University of Newcastle-upon-Tyne in Newcastle, United Kingdom

The station position solutions and covariance matrices from both types of analysis centers were available from the global analysis centers starting in 1995. The GNAACs accessed the SINEX files from the individual analysis centers and produced combined station position solutions.

The derived products from the IGS Analysis Centers are typically delivered to the CDDIS within ten days of the end of the observation week. Figure 3 presents the average delay during 1995, in days and by source, of products delivered to the CDDIS, including the two GNAACs operational during 1995. The statistics were computed based upon the arrival date of the solution summary file for the week. The time delay of the IGS rapid products and the combined SINEX solutions are 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 and is typically available to the user community within eleven days. The combined SINEX solutions from the GNAACs were on average available within thirteen days.

3.3 Meteorological Data

In 1995, the CDDIS and GSFC's Very Long Baseline Interferometry (VLBI) group began providing meteorological data from selected global GPS stations collocated with VLBI antennas. Meteorological data from the VLBI stations at Greenbelt, MD; Fairbanks, AK; Kokee Park, HI; and Westford, MA have been sent to the CDDIS routinely. 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. These data are stored on CDDIS with the daily GPS observation and navigation data files (in the `[GPSDATA.`*yyddd*`.`*yy*`M]` subdirectories). The GSFC staff planned to make a general request to all global collocated GPS/VLBI sites for this type of

Figure 3: Average Delay in GPS Product Delivery to the CDDIS (by Source) in 1995

data; however, very little user access of the meteorological data from these four stations was seen during 1995.

3.4 Supporting Information

Ancillary information to aid in the use of GPS data and products are also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data archived at the CDDIS are generated on a routine basis and distributed to the IGS user community through IGS Report mailings. These summaries are now accessible through the World Wide Web (WWW) at URL `http://cddis.gsfc.nasa.gov/gpsdata/gpsdata_list.html`. The CDDIS also maintains an archive of and indices to IGS Mail and Report messages.

4 System Usage

Figures 4 and 5 summarize the monthly usage of the CDDIS for the deposit and retrieval of GPS data during 1995. These figures were produced daily by automated routines that peruse the log files created by each network access of the CDDIS. Figure 4 illustrates the amount of data retrieved during 1995. Over 1.2 million files were transferred in 1995, totaling approximately 320 Gbytes in volume. Averaging these figures, users transferred 105,000 files per month, totaling nearly 30 Gbytes in size. The chart in Figure 5 details the total number of host accesses per month with the number of distinct (i.e., unique) hosts per month shown as an overlay. Here, a host access is defined as an initiation of

Figure 5: Number of Hosts Accessing GPS Data on the CDDIS in 1995

Figure 6: Distribution of IGS Users of the CDDIS (1995)

present 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 4 summarizes the type and amount of special requests directed to the CDDIS staff during 1995. 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.

5 Publications

The CDDIS staff attended several conferences during 1995 and presented papers on or conducted demos of their activities within the IGS:

Table 4: Summary of Special Requests for GPS Data and Information in 1995

Type of Request	*Totals*
General IGS/CDDIS information	≈125 requests (phone, fax, e-mail)
Off-line GPS data	≈125 requests (phone, fax, e-mail)
Amount of off-line data requested	≈50,650 station days[1]
Volume of off-line data requested	≈30 Gbytes

[1] In this context, a station day is defined as one day's worth of GPS data (observation and navigation file in RINEX format)

- demonstration of the exchange of GPS data over the Internet through the CDDIS was given at the Global Observation Information Networks (GOIN) Initiative workshop, held in Silver Spring in June 1995

- *Global GPS Data Flow from Station to User Within the IGS* (Carey E. Noll and Werner Gurtner/AIUB) was presented at the International Union of Geodesy and Geophysics in Boulder, CO in July 1996 and has been published in the proceedings from the IAG Symposium, GPS Trends in Precise Terrestrial, Airborne, and Spaceborne Applications, edited by Beutler, Hein, Melbourne, and Seeber 1996

- *Flow of Global GPS Data and Products From Station to User* (Carey E. Noll) was presented at the Science Information Systems Interoperability Conference (SISIC) in College Park, MD in November 1995

- Hypertext versions of these and other publications can be accessed through the CDDIS background page on the WWW at URL `http://cddis.gsfc.nasa.gov/cddis_full.html` .

6 Future Plans

6.1 Computer System Enhancements

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 respond to 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 and the CDDIS is equipped with only two optical disk drives. 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 for the IGS (totaling over sixty Gbytes in size) on a mass 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.

6.2 Changes in the Data Archive

The CDDIS staff has recently developed software to create and maintain daily status files of GPS data holdings. The automated CDDIS archiving procedures will be modified to execute the data quality checking program developed by UNAVCO that analyzes the daily observation file and generates a summary file containing various statistics on these data. Routines then browse these summary files and update the daily status file with statistics on number of data points, cycle slips, and multipath. Furthermore, information from the RINEX header, such as receiver and antenna type, antenna height, marker name and number, are extracted to provide checks against the system configuration information available through the IGS Central Bureau Information System (CBIS). Data latency (in hours) is also computed and provided for each station. Replacement data will be processed and reflected in this file by way of a version column. The summary files created by the QC program will also be stored on the CDDIS, and will replace the current CDDIS-generated summary file. The daily status files will be loaded into the CDDIS data base for reporting purposes. The staff can then easily generate reports on the timeliness of data deliveries and data quality of the IGS stations. The user community can receive a quick look at a day's data availability and nominal quality by downloading a single file. The staff hopes to have this new software operational in early 1996.

Starting in January 1996, the IGS Analysis Center Coordinator began generating rapid orbit, clock, and Earth rotation parameter combinations based on the individual analysis centers' rapid solutions. These solutions, designated IGP (for IGS Preliminary), are available within 38 hours of the end of the observation day. The IGS global data centers, including the CDDIS, will make these products available as soon as possible each day to ensure the timely utility to the user community. The IGS analysis centers will also start producing one- to two-day predicted orbits in 1996, and it is hoped that an official IGS predicted orbit will soon be a product available at the global data centers.

The IGS has recently been investigating the generation of other new products, particularly tropospheric delay estimates and ionospheric products. The IGS has the potential to make available such data with a high temporal and spatial resolution on a routine basis for atmospheric research. As with the current set of IGS products, these new atmospheric analyses would be available through the global data centers.

The IGS also hopes to soon routinely flow meteorological data from selected sites within the IGS network. These data would be automatically downloaded from the stations, translated to RINEX format and made available from the IGS data centers. These meteorological data are not large in volume and could easily be stored at regional and global data centers with the daily observation and navigation data files.

7 Contact Information

To obtain more information about the CDDIS or a username and password to access the IGS archive of data and products, contact:

Ms. Carey E. Noll
Manager, CDDIS
Code 920.1
NASA/GSFC
Greenbelt,MD 20771

Phone (301) 286-9283
FAX (301) 286-0213
E-mail `noll@cddis.gsfc.nasa.gov or CDDIS::NOLL`
WWW `http://cddis.gsfc.nasa.gov/cddis.html`

8 Acknowledgments

The author would once again like to thank members of the CDDIS staff, Dr. Maurice Dube and Ms. Ruth Kennard (Hughes-STX). Their enduring professionalism and enthusiasm for these activities continue to make the CDDIS a successful contributor to the IGS.

References

[1] C. E. Noll, CDDIS Global Data Center Report, in *IGS 1994 Annual Report*, edited by J. Zumberge, R. Liu, and R. E. Neilan, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena, CA, 1995, JPL Publication 95–18.

IGS Station Reports

SOPAC Site Report

Report to the IGS Regarding Changes at PGGA and DGGA Sites
January–December 1995

Jeff Behr

Scripps Orbit and Permanent Array Center (SOPAC)

Changes and improvements at SOPAC Permanent GPS Geodetic Array (PGGA) and United States Geological Survey (USGS) DGGA sites during 1995 consist of three main developments: the addition of 9 new sites, the installation of choke ring antennae at 19 of 22 SOPAC-USGS sites, and the installation of improved receiver firmware to provide greater receiver storage capacity and shorter download times.

1 New DGGA/PGGA Sites

Nine new permanent GPS stations were installed during 1995 by the USGS and SOPAC as part of the Southern California Integrated GPS Network (SCIGN) expansion. The majority of these were part of the developing Dense GPS Geodetic Array (DGGA), the LA Basin component of the SCIGN. The following list summarizes the new sites.

Site	*Network*	*Location*	*Date Installed*	*Receiver Type*
CLAR	DGGA	Claremont, CA	095/95	Ashtech Z-XII
CMP9	DGGA	Firecamp 9, CA	173/95	Ashtech Z-XII
DAM1	DGGA	Pacoima Dam, CA	215/95	Ashtech Z-XII
DAM2	DGGA	Pacoima Dam, CA	235/95	Ashtech Z-XII
HOLP	DGGA	Hollydale, CA	095/95	Ashtech Z-XII
LEEP	DGGA	Mt. Lee, CA	096/95	Ashtech Z-XII
ROCK	DGGA	Rocketdyne, CA	126/95	Ashtech Z-XII
TABL	DGGA	Table Mtn, CA	276/95	Ashtech Z-XII
COSO	PGGA	China Lake, CA	228/95	Ashtech Z-XII

The Chatsworth site in the LA Basin was removed from continuous operation. That TurboRogue SNR-8000 receiver was re-deployed to the Brand Debris Basin (BRAN) site on 199/95, replacing an Ashtech Z-XII.

2 Choke Ring Antenna Installation

Following the 1994 UNAVCO report, an effort was begun to install a version of the choke ring antenna compatible with the Ashtech receiver at all

SOPAC/USGS sites. By May 1995, all existing USGS DGGA sites had completed the change to the choke ring design, and by August, seven PGGA sites had also been upgraded. The following table lists the timing of these upgrades.

Site	*Network*	*Installed*	*Antenna Type*
BRAN[a]	DGGA	001/95	Dorne-Margolin T/Ashtech Choke Ring
CHIL	DGGA	151/95	Ashtech Choke Ring
CLAR	DGGA	140/95	Ashtech Choke Ring
CMP9	DGGA	173/95	Ashtech Choke Ring
DAM1	DGGA	215/95	Ashtech Choke Ring
DAM2	DGGA	235/95	Ashtech Choke Ring
HOLC	DGGA	147/95	Ashtech Choke Ring
HOLP	DGGA	140/95	Ashtech Choke Ring
LEEP	DGGA	140/95	Ashtech Choke Ring
LONG	DGGA	140/95	Ashtech Choke Ring
ROCK	DGGA	142/95	Ashtech Choke Ring
TABL	DGGA	276/95	Ashtech Choke Ring
BLYT	PGGA	215/95	Ashtech Choke Ring
CRFP	PGGA	215/95	Ashtech Choke Ring
MONP	PGGA	214/95	Ashtech Choke Ring
PIN1	PGGA	214/95	ROGAOA modified for Ashtech
SIO3	PGGA	207/95	ROGAOA modified for Ashtech
TRAK	PGGA	217/95	Ashtech Choke Ring
VNDP[b]	PGGA	216/95	Ashtech Choke Ring

[a] Year 1995 began with a TurboRogue at BRAN, which was later replaced by an Ashtech Z-XII, which was subsequently replaced by a TurboRogue. See IGS site log for details on the timing of these changes.

[b] The initial choke ring antenna at VNDP failed approximately 7 days after installation and was replaced from 228/95 to 312/95 by an older model Ashtech Geodetic L1/L2 P antenna. A replacement choke ring antenna was installed on 313/95.

3 Firmware Improvement

An additional improvement in PGGA sites equipped with the Ashtech receiver was the introduction of a new data compression algorithm in the Z-XII firmware which allowed roughly 45% increase in the storage capacity and more than a two-fold decrease in phone download times. Firmware employing the new compression was installed at SIO3, MONP, PIN1, TRAK, VNDP and CRFP during the fall and early winter of 1995 and will be deployed at remaining PGGA sites and at USGS DGGA sites after further testing.

More information on the Southern California sites maintained by SOPAC and the USGS can be found at these Web addresses:

SOPAC: `http://toba.ucsd.edu`
USGS: `http://www.scecdc.scec.org/scign/`
`http://www-socal.wr.usgs.gov/hudnut/`

CNES 1995 IGS Annual Report

H. Burger
Centre National d'Etudes Spatials, Toulouse, France

1 Introduction

Since 1991, CNES, the French Space Agency, has contributed to the International GPS Service for Geodynamics. Through its Toulouse Operational Center, CNES currently manages four stations which are part of the International Network:

- Grasse, France
- Hartebeesthoek, Rep. of South Africa
- Kerguelen Islands, Southern Indian Ocean
- Pamatai, Tahiti Island, French Polynesia

CNES sites are equipped with permanently installed receivers, which are dedicated to continuous GPS satellites tracking.

2 Toulouse Operational Center

An Operational Center at CNES in Toulouse performs Network management, which includes tasks such as data management, network maintenance or users interface.

The four CNES stations have access to direct communications links with the Toulouse Operational Center. GPS raw data, along with meteorological surface measurements (HART and PAMA), are transmitted daily to Toulouse. The data are also stored at each site for backup. CNES personnel in Toulouse:

- overview data transfer from the stations to Toulouse,
- assess performance of the data taking by the stations of the network,
- ensure data are made available to the users within the proper time delay,
- answer to special requirements from the users in term of data availability,
- manage data storage at the Toulouse Operational Center.

At the Toulouse operational center, data are uncompressed and converted to the RINEX format; data completeness is checked and a quality control is performed. RINEX files are then stored on a workstation to be retrieved by users. Every day data are transfered from Toulouse to the IGN Global Data Center in Paris which provides on-line access to the community.

Besides data formatting and validation, the Toulouse Operational Center performs Network maintenance:

- to assist station personnel for first-level maintenance,
- to perform diagnosis on GPS receivers in case of anomaly,
- to direct and coordinate equipment shipment if maintenance can not be performed on-site,
- to provide the interface between the network and the industrial maker when required to perform maintenance actions,
- to ensure that the necessary equipment to perform first-level maintenance is available or can be secured for each station.

3 Grasse

In February 1995 a TurboRogue (SNR-8100) was installed near Grasse, South-east of France, at the Calern Observatory which is part of "Observatoire de la Côte d'Azur" (OCA). It is co-located with SLRs and LLRs; the GPS antenna, which is stationed close to a mobile VLBI mark, is mounted on a dedicated concrete pillar on bedrock with a forced-centering plate.

The GPS receiver is operated and monitored by OCA personnel; data are retrieved daily by the Toulouse Operational Center through Internet.

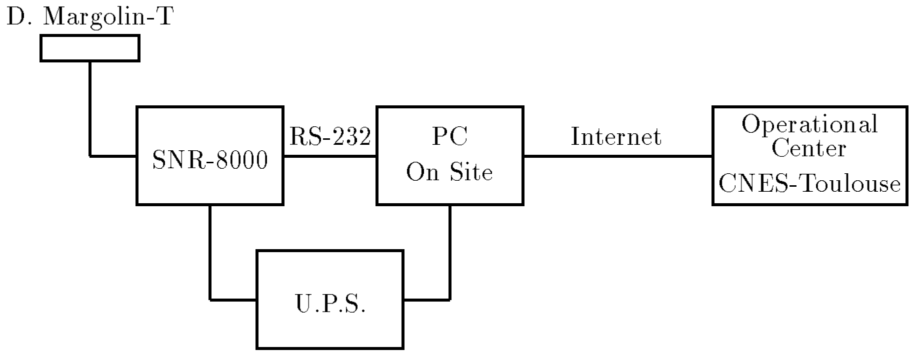

Figure 1: GPS System Configuration — Grasse

4 Hartebeesthoek

The GPS receiver at Hartebeesthoek, Rep. of South Africa, has tracked GPS satellites continuously since January 1991. The receiver is set up at the CNES satellite tracking station, near the radio-observatory of Hartebeesthoek, which provides a VLBI reference point.

This GPS station was part of the 6-station Global Network for the Topex-Poseidon project. It is operated and monitored by Satellite Applications Center personnel from CSIR, who also staff the CNES satellite tracking station 24 hours a day. Raw data are transfered daily to Toulouse through a permanent link (9600 bps) set up for satellite tracking applications.

In April 1996, a new Rogue SNR-8000 was installed at Hartebeesthoek in place of the Rogue SNR-8.

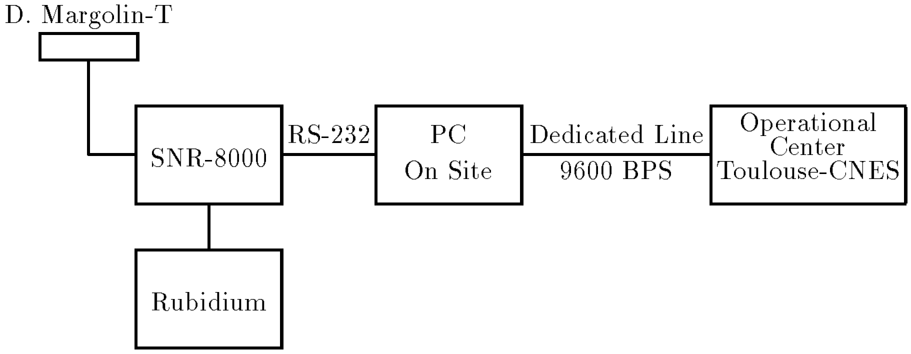

Figure 2: GPS System Configuration — Hartebeethoek

5 Kerguelen

A Rogue SNR-8C (mini-rogue) has been operational since mid-November 1994 in the Kerguelen islands, in the southern Indian Ocean. The site is located on the main island, at Port-aux-Français, in IFRTP (Institut Français pour la Recherche et la Technologie Polaire) facilities and close to a CNES satellite tracking station.

The receiver is operated and monitored by IFRTP personnel from the Geophysics Laboratory. Raw data are transfered daily to Toulouse through a permanent link (9600 bps) set up for satellite tracking applications.

6 Pamatai

The GPS Receiver at Pamatai on the French Polynesian island of Tahiti has been tracking GPS satellites continuously since January 1992. The receiver is set up

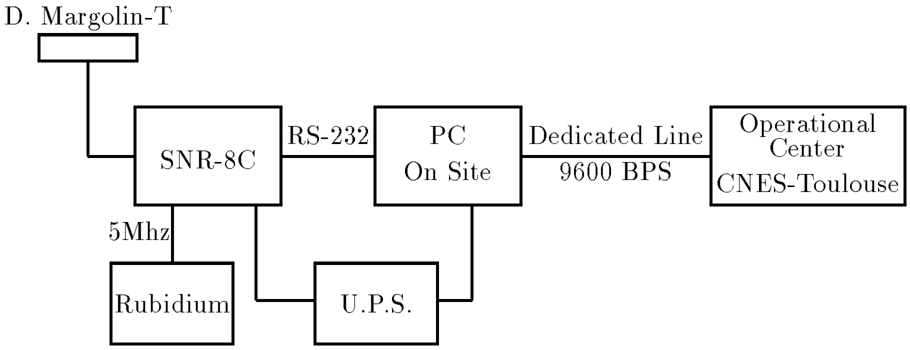

Figure 3: GPS System Configuration — Kerguelen

in the facilities of the CEA (Commissariat à L'Energie Atomique) Geophysics Laboratory (LDG).

The receiver is operated and monitored by LDG personnel. Raw data are transfered daily to Toulouse through a NUMERIS type link (64 bps). NUMERIS is a service for data transfer offered to general customers by France Telecom.

In April 1995, a new Rogue SNR-8100 was installed at Pamatai in place of the Rogue SNR-800.

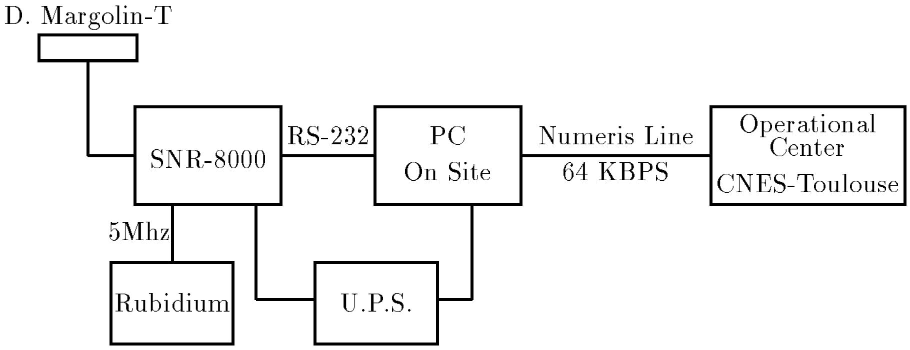

Figure 4: GPS Configuration: Pamatai

7 Receiver Tracking Performance

For 1995, the overall tracking success rates are the following:

Hartebeesthoek	91.7 %
Kerguelen	100 %
Pamatai	95.4 %
Grasse	97.5 %

The Permanent GPS Tracking Station UPAD of the University of Padova

Alessandro Caporali, Matteo Apollonio,
Veronica de Perini, Antonio Galgaro
University of Padova, Italy

1 Introduction

The University of Padova has operated a permanent GPS station since 1994. The initiative supports research in Geodesy and Geodynamics at the Department of Geology, Paleontology and Geophysics, and in Space Sciences and Technology at the Interdepartmental Center for Space Activities (CISAS) "Giuseppe Colombo". The station is located downtown Padova, on the roof of the University's Main Building, near a dome used in the past century for astrogeodetic optical observations. A number of trigonometric vertices are in view, so that coordinates are available both in the WGS84/ITRF system and in the national Datum.

2 Technical Summary

Station full name	University of Padova, Italy
Station 4 letter name	UPAD
DOMES #	12750M002
Receiver	TRIMBLE 4000SSE Geodetic Surveyor System with Geodetic antenna L1/L2 and groundplane
Location	downtown Padova, NE Italy
Coordinates	Lat: 45°24′25″ N; Long: 11°40′52″ E: h: 90 m.
Antenna height above ground marker	1.962 m (measured from Bottom of Preamplifier)
Contact	Prof. Alessandro Caporali, Dr. Antonio Galgaro, Dipartimento di Geologia, Paleontologia e Geofisica, Via Giotto 1, I-35137 Padova (Italy).
Telephone	+39 (49) 8272052
Fax	+39 (49) 8272070
E-mail	`alex@epidote.dmp.unipd.it`

3 Station Setup

The operational procedures are conceived with the constraints:

- the station runs automatically and is fully autonomous as to the IGS activities of tracking and communications
- the IGS activities are compatible with other tasks and research projects, in particular support to local surveys and real time DGPS.

The configuration is very simple: the GPS receiver is connected to a dedicated PC 486/66MHz via serial interface at 115 Kbaud. The PC is connected to a Colorado streamer for daily backup on magnetic cassette (250 Mb capacity). Connection to the VAX 8600 of the University's Computer Center is done via Ethernet. High speed modem access is available with a dedicated number.

The daily data logging is done with the data buffered on the receiver's internal memory. Download to the local PC is done daily at 00:01 UTC using the TRIM4000 program driven by a binary file containing the necessary commands for the data download and cleanup of the internal memory. The data download is done in parallel with the data acquisition of the current day. This procedure leaves the local PC available for other activities, such as communications, download of windows of data of the current session and data processing.

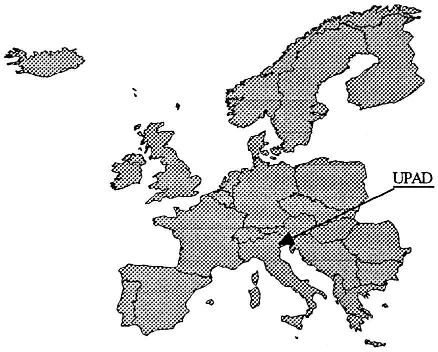

Figure 1: Location of the UPAD GPS station

After RINEXing, compression and backup, the data are sent via Internet to the IGS Regional Data Center and IGS Global Data Center via the Center for Space Geodesy of the Italian Space Agency in Matera, and to the Technical University of Graz in support to the GPS activities under the Central Europe Initiative. The automatic station management procedure runs under MS DOS and has been exported to run the newly established permanent GPS station of the Geological Survey of the Provincia Autonoma di Trento (Trentino Alto Adige Region).

4 Performance of the Station UPAD in 1995

Since April 1995 the data produced daily are screened with the program QC developed by UNAVCO, University of Colorado (USA), as part of the daily automatic activities. A subset of the information produced by QC is used to generate the following graphical information:

- code multipath on L1 and L2
- number of cycle slips, observations/cycle slip, number of edited data
- r.m.s. position error QC-RINEX
- clock drift

Summary statistics for the period April 1, 1995–December 31, 1995 follow:

station	total obs.	edited obs.	% edited	mpath L1 (m	mpath) L2 (m)	daily average cycle slips	daily average obs/cycle slip
UPAD	4,226,548	33,397	0.8	0.52	0.71	107	576

More information is given in Figures 2 and 3. Figure 2 shows the code multipath mean daily value (in a “QC sense”) on L1 and L2. The periods in which Anti Spoofing was turned off (April 19 to May 10; June 19 to July 10; October 10 to October 31, 1995) clearly affects the receiver performance. The receiver tracks the P code only during these periods of time, and a meaningful assessement of code multipath on both frequencies is possible.

Figure 3 shows the behavior of the clock drift, with a strong seasonal component. The spikes which are occasionally visible in Figure 3 do not represent a true sudden change in the oscillator frequency but are the consequence of the way the daily mean clock drift is computed. An analysis of the clock drift on those particular days shows that the data acquisition was temporarily stopped, but this event was misinterpreted by the clock computation program and produced an incorrect estimate of the clock drift.

5 Additional Activities

In addition to the contribution to the IGS, the following local projects are supported:

- applied geology: in the Euganei Hills, about 15 km from Padova, water pumping results in subsidence. A structural model of the deformation uses height changes determined by a local network of GPS receivers which make reference to the IGS site UPAD;
- cadastral surveying: roving single frequency receivers are used by surveyors to map borders of plots of land. Up-to-date measurements of the areas are obtained in support of the management of agricultural resources. The IGS site UPAD serves as unique reference for the local surveys.

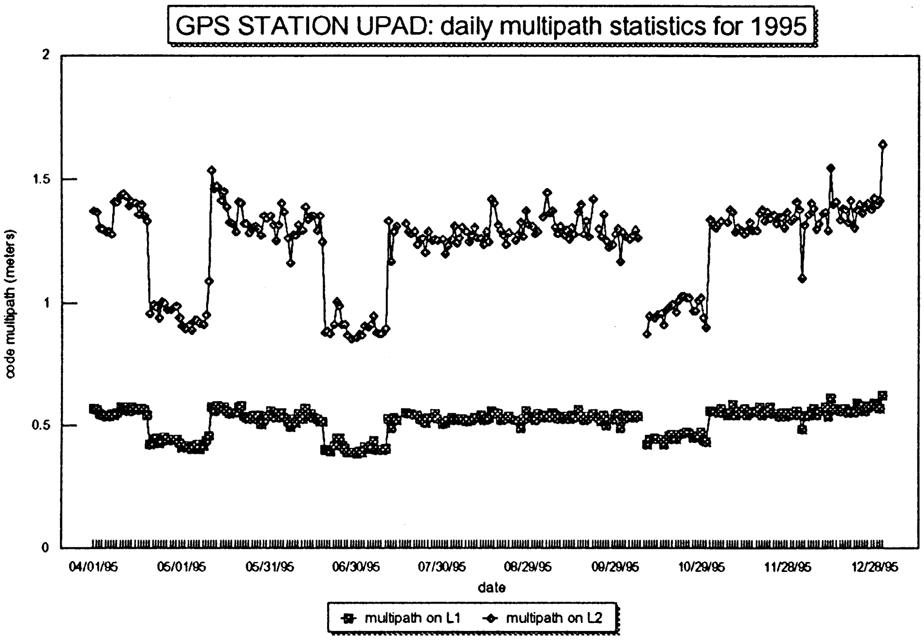

Figure 2: P-code pseudorange multipath statistics in 1995

- aircraft navigation: two single frequency stations are operated in cooperation with the local Command of the Air Traffic Control to experiment with the procedures for monitoring the integrity of the GPS signals by repeated computation of the known baseline joining the receivers, with reference to the UPAD site.

6 Future Plans

Future plans include the improvement of the capability to provide GPS related services to the local community, such as GPS data and ephemeris, RTCM corrections, trigonometric and leveling data, geoidal undulations and digital terrain models.

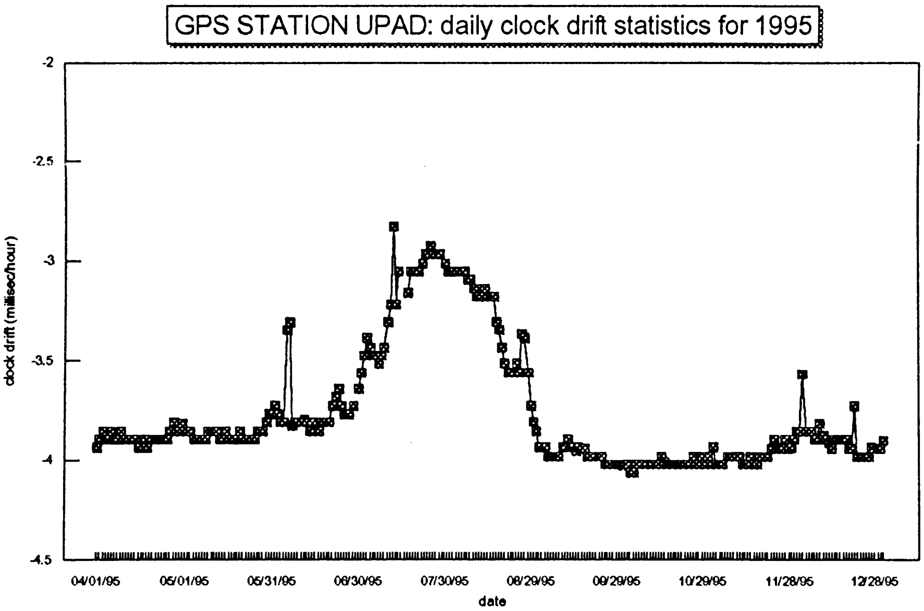

Figure 3: Clock drift statistics in 1995

Status of the IGS Stations Provided by GFZ

Roman Galas
GeoForschungsZentrum Potsdam, Division 1
Potsdam, Germany

1 Introduction

The GFZ is operating a network of permanent GPS stations in order to close gaps in the IGS Global network, and to support GFZ geodynamic activities in Central Asia, South America, and Southeast Asia. Presently this GFZ network of permanent stations consists of 17 sites. Four of them, Kitab, La Plata, Potsdam, and Zwenigorod, allow a fast transfer of data to Potsdam. These data are provided routinely to IGS.

2 Network Control Center

The Network Control Center (NCC) has been established in Potsdam to manage the continuously operating GFZ networks. The center performs such tasks as: network maintainance and control, software development, hardware design and upgrade, data handling, installation and upgrade of stations, and user interface.

The software sub-system consists of a UNIX-based scheduler and task-monitoring programs. The raw data from the sites are automatically downloaded via Internet, or are sent through an Inmarsat-A Mobile Terminal to the Inmarsat Base Station in GFZ. Some of the non-IGS stations send data to GFZ on floppy disks by mail. In the GFZ-NCC the binary files are converted from receiver to the RINEX format, and merged into daily files. The daily files are automatically distributed, via Internet, directly to CDDIS and to the Regional data Center at IfAG/Frankfurt. Raw data and daily files are archived in the UNITREE at the GFZ Data Center. The raw data files are additionally stored on DAT tapes.

The NCC also processes on a daily basis the GPS data from the non-IGS permanent stations, using the IGS products.

The remote sites are equipped with TurboRogue or Trimble receivers, a power back-up unit, and a notebook computer with monitoring software for automatic system control and data download. Depending on existing infrastructure for data transfer, a data communication unit is optionally installed.

3 Short description of sites

Kitab (Uzbekistan)

The TurboRogue SNR-8000 has been continuously operating since 1994; it was described in the IGS 1994 Annual Report. The Dorne Margolin T antenna was upgraded in 1995 to 582 RFI, in order to avoid interferences with the Inmarsat-A Mobile Station, used for the high speed data communication link. Collocated with the GPS receiver is a PRARE and DORIS station.

Potsdam (Germany)

Location and operation of the Potsdam station were described in the 1994 Annual Report. Some interferences of the GPS signals with unknown radio emitters degraded station tracking performance. For that reason the Dorn Margolin T antenna was upgraded to 582 RFI in autumn 1995. Collocated with the GPS receiver is a PRARE and an SLR system at the site.

Zwenigorod (Russia)

The Zwenigorod IGS station (ZWEN) has been operated jointly by GFZ and the Institute of Astronomy of the Russian Academy of Sciences (INASAN) since March 16, 1995.

Location

The Zwenigorod Observatory was established by the Astronomical Council of the USSR Academy of Sciences in 1959 as a main experimental and research center for satellite tracking techniques. The Observatory is located 80 km south of the center of Moscow, near the ancient Russian town Zwenigorod. Zwenigorod station was included in many international satellite geodesy programs. In 1969 the first results were obtained with the use of a new big satellite camera VAU, designed for the tracking of high and geostationary satellites. In 1976 one of the first satellite laser ranger INTERCOSMOS for low satellite tracking was installed.

Instrumentation

The station is equipped with the TurboRogue SNR-8000 receiver with Dorne Margolin T antenna, power back-up unit and a monitoring computer. One Word Blazer telephone modem in Zwenigorod and the second one installed in Moscow make possible the data transfer to the Internet node in the Institute of Astronomy.

Monumentation

The antenna is mounted on the roof of the main building of the Astronomical Observatory. There are no visibility obstructions.

Data link to GFZ

Within 48 hours the data files are sent via telephone modems to the Work Station in the Institute of Astronomy in Moscow, which has Internet access. There the files are prepared for automatic download by the GFZ Network Control Center. Unfortunately, the quality of the telephone line does not allow application of procedures for automatic data transfer between Zwenigorod and INASAN in Moscow.

Collocation

Presently there is no collocation with other systems. However there are plans to set up in 1997 a new satellite tracking laser system (MUSTANG). The laser will serve for experimental investigations.

La Plata (Argentina)

The La Plata IGS station (LPGS) is operated jointly by GFZ and the Astronomical Observatory in La Plata since June 1995.

Location

The Astronomical Observatory belongs to the Faculty of Astronomy and Geophysics of the La Plata National University (Facultad de Ciencias Astronomicas y Geofisicas de la Universidad Nacional de La Plata). La Plata is the capital of Buenos Aires province and is located about 60 km south of Buenos Aires city. In the past the Observatory took part in international optical astrometry programs, among them in the International Polar Motion Service.

Equipment

The station is equipped with the TurboRogue SNR-8000 receiver and Dorne Margolin T antenna, power back-up unit and a monitoring computer. Since the Internet connection is available there, no dedicated communication unit has been installed on the site.

Monumentation

The GPS antenna is mounted on a pillar, which is located about 50 meters from the nearest building. Unfortunately it is surrounded by trees, at an average distance of 30 to 40 m, limiting the visibility up to 20 degrees.

Data link to GFZ

There is a monitoring computer installed, which at UT midnight automatically offloads the data from the TurboRogue receiver. Later the data files are transferred to the computer with the Internet access, for automatic downloading by the GFZ Network Control Center.

Collocation

A PRARE station is continuously operating in La Plata. The system is set-up only 9 meters north to the GPS pillar.

The GPS Receiver Network of ESOC: Malindi, Maspalomas, Kourou, Kiruna, Perth, and Villafranca

C. Garcia Martinez, J. M. Dow,
T. Martin-Mur, and M. A. Bayona-Perez
European Space Operations Centre
Darmstadt, Germany

ESOC (European Space Operations Centre) is currently involved in the establishment of a network of high precision geodetic receivers on ESA (European Space Agency) ground sites. So far, six installations have been carried out at the sites of Malindi, Maspalomas, Kourou, Kiruna, Perth and Villafranca. The establishment of this network is one of the objectives of the ESA GPS-TDAF (Tracking and Data Analysis Facility). Figure 1 shows the geographical distribution of the receivers.

1 Location of the Receivers

The ESOC receivers are being installed at the ESA ground stations. In this way they can take advantage of the facilities that the stations provide. They are integrated in racks in rooms with temperature and humidity control, connected to the frequency standards of the stations and to the permanent communication links between the stations and the control centre at ESOC. They also provide, along with the rest of the GPS-TDAF, several services. Examples are the monitoring of the behaviour of the timing system, the 1PPS output, and the ionosphere monitoring over the station.

Malindi: The receiver is located at the base camp of the San Marco Scout launching site, which is a complex of facilities situated near the equator in Formosa bay near Malindi, Kenya. The station is on the coast about 115 km north of Mombasa.

Maspalomas: The GPS receiver is installed at the Maspalomas ground station, that is property of the Spanish institute INTA. It is located in the southern part of the Gran Canaria Island, municipal district of San Bartolome de Tirajana, Spain. The site is approximately 1750 metres from the coast.

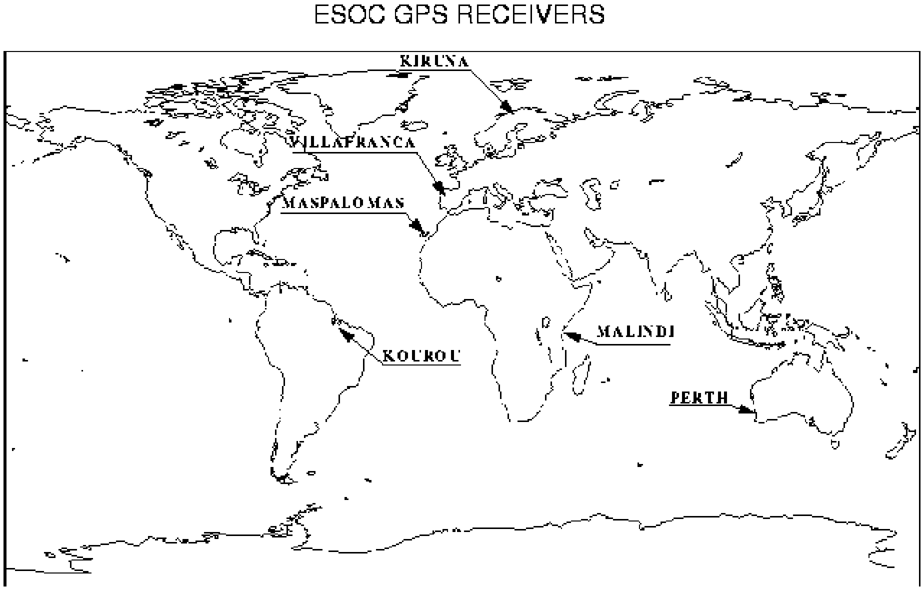

Figure 1: ESOC Receiver Locations

Kourou: The GPS receiver is installed at the ESA Kourou Ariane station that is located about 27 km from the town of Kourou, in French Guiana.

Kiruna: The GPS receiver is installed in the ESA Kiruna ground station, that is at Salmijarvi, 38 km east of Kiruna in northern Sweden.

Perth: The receiver is located at the ESA Perth station, that is approximately 20 km north of the city of Perth on the western coast of Australia. The station is situated on the Perth International Telecommunications Centre Complex, which is operated by Telstra Corporation Limited.

Villafranca: The receiver is situated in the Villafranca (VILSPA) ground station, located in Villafranca del Castillo, 30 km west of Madrid, Spain.

2 History and evolution

The development of the network started at the beginning of 1992 when two MiniRogues SNR-8C, the most advanced receiver then, were ordered from AOA (Allen Osborne Associates). After a period of testing in ESOC, the first installation was completed in the week before the start of the IGS campaign at Maspalomas. Data were available from 22/06/92. The antenna was mounted on a monument belonging to the Spanish IGN, that participated in several geodetic campaigns with the marker name MPA1. For IGS the selected marker name was MASP.

ESOC constructed another monument and on 11/04/94 installed a new GPS system with a TurboRogue SNR-8100. Both systems were operated in parallel for several weeks until the decommission of the old receiver. The marker name of the new monument is MAS1, and the IERS DOMES Number 31303M002 was assigned to it.

In the last months of 1995 the TurboRogue SNR-8100 experienced a degradation in the quality and quantity of the data that made necessary the replacement of the unit. Two new TurboRogues SNR 12 had been ordered, and in April 96, shortly after the delivery and testing in ESOC, one of the new units was installed in Maspalomas.

The second of the MiniRogues was installed on late July 1992 at Kourou. Initially the data were downloaded directly from the receiver to ESOC using Telebit modems. Unfortunately the quality of the public telephone lines between Europe and French Guiana was very irregular. The data were obtained for a period of 10 days in August, and sporadically thereafter. Attempts made from JPL to dial up the Kourou modem were also unsuccessful. The low transfer rates and the irregular quality of the telephone lines made very problematic the completion of the file transfers using XMODEM. A new solution had to be implemented. It was based on the permanent links between the station and the control centre ESOC shared by several ESA projects. The regular operation of the receiver started on 18/10/92 when the connection to the new data link was completed. During the period when communications were not possible, a permanent concrete monument was constructed for the antenna there (see IGS mail No. 144). The antenna was moved by about -3.0,-1.1,1.1 m in longitude, latitude and height respectively from its previous position. The software of the MiniRogue was upgraded to version 7.8 on 06/10/94. The receiver has been operated permanently without hardware problems for almost four years.

A set of five receivers model TurboRogue SNR-8100, was ordered at the end of 1992. After the testing period in ESOC, the first receiver was dispatched to Kiruna and installed on July 1993. The receiver was placed in a building several metres away from the main building of the station. From here the distance to the monument is shorter. The monument is on top of a slope surrounded by trees. The antenna was replaced in May 95.

The second TurboRogue SNR8100 installation was performed on 13/08/93 at Perth. Unfortunately, a few days after the beginning of the operation, the receiver was damaged during a lightning storm on 03/09/93. A new receiver was immediately delivered. The grounding of the antenna has been improved to try to avoid the same problem happening again. The original receiver and antenna were repaired and reinstalled on 27/04/94.

Villafranca was set up on 12/11/94. At this site the cabling from the monument to the racks of the main building, where the receiver is integrated, is about 150 metres long. This is 50 m longer than the standard setup of the receiver. This made necessary the installation of an additional line amplifier close to the antenna. With this modification the signal level has nominal values.

The last installation has been Malindi. A MiniRogue SNR-8C was deployed to the station and started data collection at the end of 1995. The data retrieval was initially via an analogue line that at the beginning of 1996 was replaced by a 64 Kbit/s digital circuit. This facility depends on other ESA projects and will be discontinued. A test with dial-up modems using the recently improved PSTN at Malindi has been carried out successfully in May 96. The receiver is connected to a external 5-MHz quartz reference.

3 Monumentation

Figure 2 shows the monument specially developed for the GPS-TDAF. It is basically a reinforced concrete cylinder of 50-cm diameter that is situated over a foundation. On top of the cylinder there is an embedded horizontal metal plate. The marker is the centre of this plate, on the upper surface.

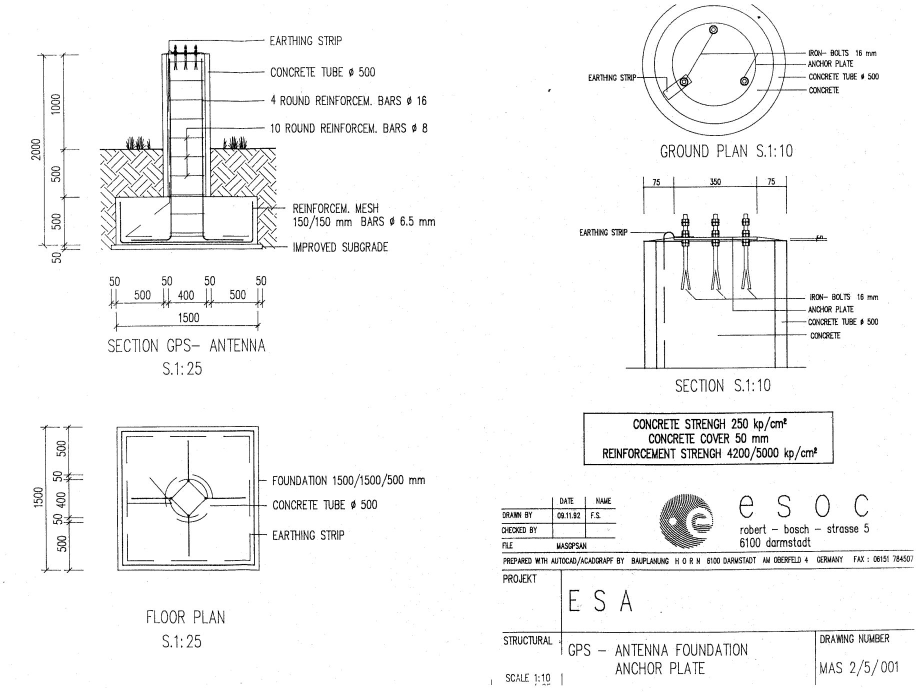

Figure 2: GPS-TDAF Monument

Three iron bolts are used to fix the antenna mounting in a horizontal position. The antenna is screwed to the mounting.

4 Equipment

The physical configuration of all the equipment involved in the remote stations part of the GPS TDAF is summarized in Figure 3.

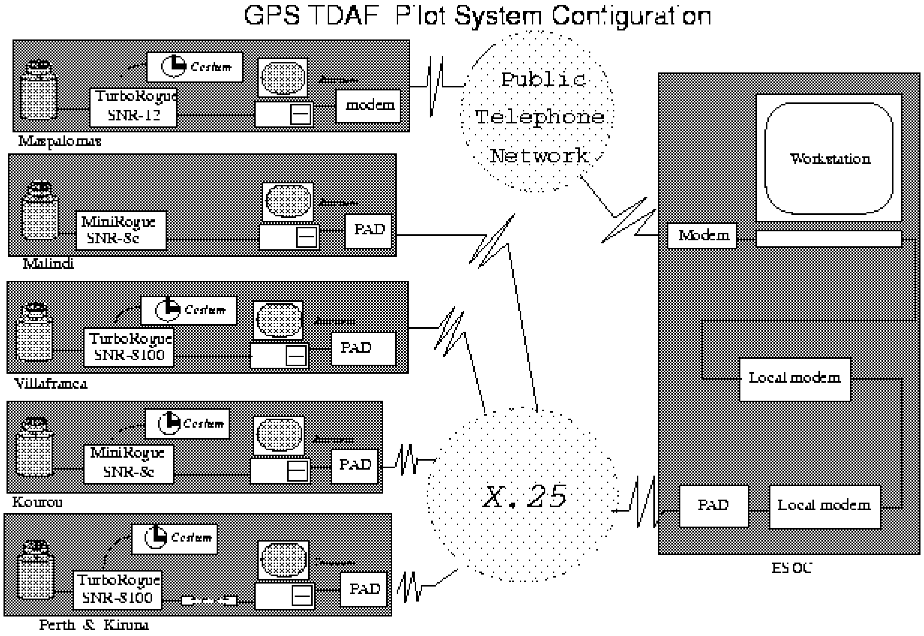

Figure 3: GPS-TDAF Plot System Configuration

The remote stations are continuously tracking the GPS satellites. The antenna is connected to the receiver normally with a standard 300-ft RG-214 coaxial cable. Only Villafranca has a cable 450 feet long, as remarked in Section 2.

The timing system of each station is used as the 5-MHz reference frequency. They are cesium timing systems manufactured by OSCILLOQUARTZ with long-term drift controlled by timing GPS system.

There are three different receivers in the ESA stations. The MiniRogue SNR-8C, currently in Kourou and Malindi, the TurboRogue SNR 12 RM at Maspalomas and the TurboRogue SNR8100 in the rest of the stations. An effort is made to try to update them with the latest well tested software releases. The TurboRogues SNR 8100 are running software version 2.8 and will be upgraded to 3.2.32.1 in June 1996. The MiniRogues of Kourou and Malindi run Meenix 7.8 and Ruse 4.2. The TurboRogue SNR 12 of Maspalomas runs firmware 3.2.32.1.

One of the serial ports of the receivers is connected to a device that provides for communications and optionally for data storage. This device is a PC that runs a script of a communications package. Shortly after 00:00 UTC the PC downloads the data from the receiver with the XMODEM protocol, waits the remainder of the day for the call from the control centre ESOC and allows the remote control of the computer.

There are two main reason for the necessity of the intermediate device. First it buffers data. Several months can be stored on the disk. In addition it allows the data transfer to ESOC using a wide range of protocols. The XMODEM protocol, the only one supported by the receivers, is not suitable for the packet-switched networks that are sometimes involved in the communications with the control centre. It also provides flow control with the DCE (Data Communication Equipment).

The communication with the receiver is performed using the same line that is used for data downloading. The commands are sent to the PC that stores them and immediately changes the active communications port to the one connected to the receiver, sends them, waits for the answer and stores it. The active port is swapped again to the one connected to the communication device and the answer of the receiver is echoed. Several attempts have been done with a secondary line (PAD or modem) connected to the free port of the receiver for interaction with it in terminal mode, but the system has been shown to be more reliable without this secondary link.

For the communications with ESOC the permanent links between ESOC and the stations are used whenever possible. They are very reliable and do not introduce additional costs due to the small amounts of data involved.

At ESOC there is one workstation with two serial ports. One is attached to a Telebit modem and the other to an internal LAN of ESOC that gives access to the ESA ground station via X.25/PAD. This workstation retrieves, decompresses, reformats, validates, archives, recompresses, and distributes every day the data automatically. The nominal time when all the processes are finished is 02:00 UTC.

The data are available to the IGS community in RINEX format via the official data centres.

At Malindi the receiver is a MiniRogue SNR-8C. The antenna is Dorne Margolin B with a height of 0.222 m and is located at the centre of the station. The data are retrieved by means of a permanent digital circuit but there are plans to use the PSTN in the future.

In Maspalomas the receiver is a TurboRogue SNR 12 RM. The antenna, Dorne Margolin T, is mounted over a monument located several metres east of the Main Equipment Room. The antenna height is 0.033 m. The data retrieval is performed with a Telebit T2500 modem. A PAD (Packet Assembler-Disassembler) that runs over a 64 Kbit/s line has been used in the past.

Kourou is equipped with a MiniRogue SNR-8C. The antenna is Dorne Margolin B with a height of 0.132 m and is located about 25 m from the MCR (Main Control Room) building.

Kiruna has a TurboRogue SNR-8100 and a Dorne Margolin T antenna with a height of 0.062 m. The communications are performed using a PAD that runs over a permanent circuit between ESOC and Kiruna Station.

The TurboRogue of Perth is connected to a Dorne Margolin T antenna which has a height of 0.0595 m. The communications are carried out by means of a PAD that is situated in a different building of the station. To overcome this problem, two local modems had to be used. They provide for communications between PC and PAD.

Villafranca has also a TurboRogue with a Dorne Margolin T antenna. The antenna height is in this case 0.0437 m.

5 Plans for the future

There are currently two ESA sites that offer possibilities for future installations. They are Odenwald (Germany) and Redu (Belgium). They are really more interesting for other projects than for IGS. The plans for the future, concerning IGS, more than new installations, are to upgrade current stations with the latest hardware and software available and to provide even more robust communications tending towards real-time data availability at ESOC.

References

[1] C. Garcia Martinez, J. M. Dow, T. Martin-Mur, J. Feltens, and M. A. Bayona-Perez, The GPS receiver network of ESOC, in *IGS 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena, CA, 1995, JPL Publication 95–18.

[2] European Space Operations Center, Darmstadt, Germany, *GPS TDAF Stations Configuration Manual*, version 1.1 edition, 1995.

The Tsukuba IGS station

Yuki Hatanaka
Geographical Survey Institute
Kitasato-1, Tsukuba, Ibaraki, Japan
`hata@geos.gsi-mc.go.jp`

The Tsukuba IGS has been operated since December 15, 1993 by the Geographical Survey Institute (GSI). The station is located in the campus of GSI nearby the VLBI site. Figure 1 shows the equipment at the site. The choke-ring antenna (Dorne Margolin T) is situated on the top of the pillar of 2-meter height with ground base of 60-cm depth. A notch filter is installed in the antenna to avoid the radio frequency interference. The TurboRogue SNR8100 is equipped in a room near the site. A Cesium frequency standard and a backup electric charge are supplied for the receiver. The data are downloaded in CONAN BINARY format and transferred to the GSI's main building by telephone line. Then, the data are sent to CDDIS through Internet after being converted into RINEX format by using BERNESE RGRINEXO software at GSI. Figure 2 shows

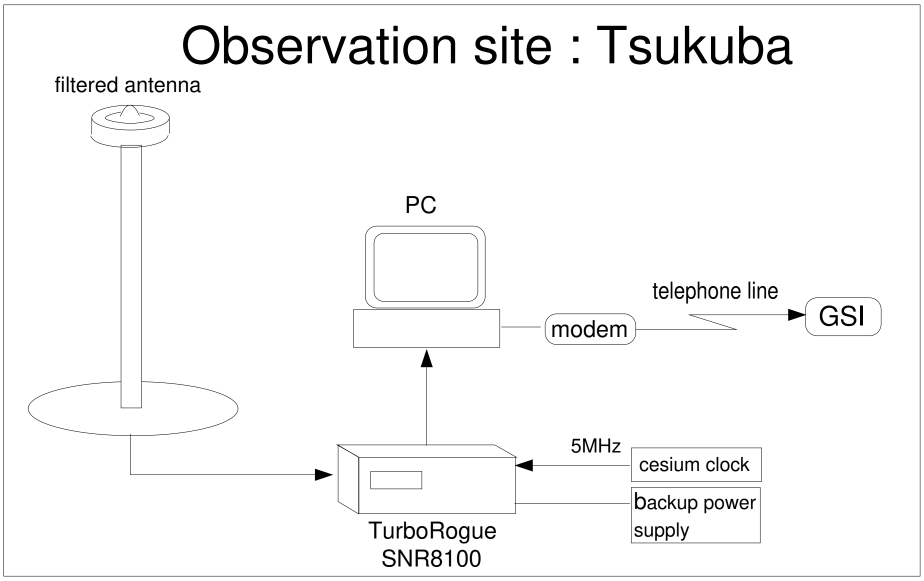

Figure 1: equipment on the Tsukuba site

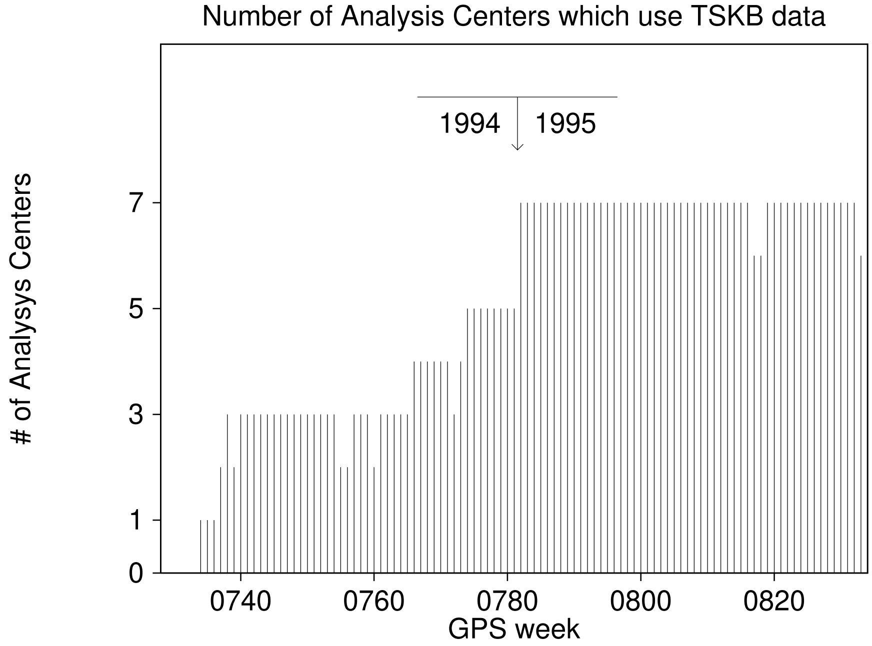

Figure 2: Number of the IGS Analysis Centers which Use the TSKB Data

the number of the IGS Analysis Centers which are using TSKB data for their routine analysis. The number increased during the first year, and the TSKB data have been used by all analysis centers since the beginning of 1995.

Table 1: Site troubles in 1995

DOY	Description	IGS mail No.
087	missing data by receiver trouble	0919
212-263	SNR8100 was replaced by SNR8000 for repair	1038, 1065
354-008/1996	unstable clock	1177

Statens Kartverk (SK) Operational Stations

Heming Herdlevaer
Statens Kartverk (Norwegian Mapping Authority)

Since 1992, Statens Kartverk (SK) has been contributing to the International GPS service. SK is responsible for distributing GPS data to the IGS data centers (Jet Propulsion Laboratory and IFAG) from 5 permanent tracking stations which are:

Tromsø	(TROM)
NyÅlesund	(NYAL)
Onsala	(ONSA)
Metsahovi	(METS)
Thule	(THU1)

1 Ny-Ålesund (NYAL) and Tromsø (TROM)

The receivers are operated and monitored by SK. Raw data from the receiver are daily downloaded to a PC at SK at 00:01 UTC by a modem. Then the data are forwarded to a HP735 computer, transfered to RINEX format and distributed to IFAG and JPL. See Table 1.

2 Metsahovi (METS) and Onsala (ONSA)

The receivers at Onsala and at Metsahovi are operated and monitored respectively by Onsala Space Observatory and Metsahovi Geodetic Observatory. Data are daily downloaded directly from the receiver, converted to RINEX format, and made available for Statens Kartverk through Internet. At SK the data are forwarded to the two IGS data centers; IFAG and JPL. See also the report from Onsala and Metsahovi, or information in the station logs on the Central Bureau Information System (CBIS).

3 Thule (THU1)

Data from Thule are collected directly from the TurboRogue, transfered to RINEX format at SK, and sent to IFAG and JPL.

Table 1: Station Information for Ny-Ålesund and Tromsø

	Ny-Ålesund	Tromsø
4-char ID	NYAL	TROM
Full name	Ny-Ålesund	Tromsø
DomesNo	10317MOO1	10302MOO3
Location	Ny-Ålesund, Spitsbergen	Tromsø, Norway
Lat	$78°55'46.4996''$	$69°39'45.8890''$
Long	$11°51'54.2940''$	$18°56'17.9727''$
Ellip. h	78.427	132.438
GPS receiver	Rogue SNR-8	Rogue SNR-8
Firmware	CONAN release 4 9/15/92	CONAN release 4 9/15/92
Antenna	Dorne Margolin B	Dorne Margolin B
Antenna Height	5.216 meters (BCR)	2.4734 meters (BCR)
Clock	Hydrogen Maser	Hydrogen Maser
Collocation	VLBI Absolute Gravity SATREF	Absolute Gravity SATREF
Contact	Heming Herdlevaer	Heming Herdlevaer
telephone	+47 32 11 82 20	+47 32 11 82 20
e-mail	`heming@gdiv.statkart.no`	`heming@gdiv.statkart.no`

AstroGeodynamical Observatory at Borowiec

Waldemar Jaks and Marek Lehmann
Space Research Centre, Polish Academy of Sciences
Borowiec, Poland

The Observatory at Borowiec was founded in 1955 to begin astronomical observations for Earth rotation research. Observations started in the International Geophysical Year 1957 using transit instruments and visual zenith telescopes. From the beginning, at the Observatory the local time service laboratory has been developed. At present it is equipped with two cesium frequency standards. In the 1980s the astronomical observations were replaced with the satellite methods. From 1981 to 1991 the Observatory carried on Doppler observations of the TRANSIT system satellites participating in international campaigns and researches: WEDOC-1, WEDOC-2, MERIT, MEDOC, FINPOLDOC and ICDDOC. The Observatory participates in several international projects including DOSE, IGS, WEGENER, and IERS. An SNR-8100 TurboRogue GPS receiver was put into permanent operation at the BOR1 site (IERS DOMES Nr: 12205M002) in September 1993. A 5-MHz reference frequency is provided by an external cesium beam EUDICS 3020 frequency standard. A meteorological sensor unit (HPTL3A, NAVI Ltd. Poland) records data every 30 minutes. A PC takes care of the automatic download of the GPS data in the compressed Rogue data format. This takes place every day a few minutes after 00:00 UTC. The PC is connected via a Sun server to the Internet. After the download of the data file, the binary data are saved, converted to RINEX format, and checked using the QC v 3.0 program (UNAVCO). Compressed RINEX data are directly passed to the Global Data Center CDDIS and to the TUG Graz. An archive copy of data is stored on the magneto-optical discs for future use and they are available on special request by ftp. The GPS receiver is collocated with the Borowiec SLR system (IERS DOMES Nr 12205M001) and connected to the local reference network of 6 points within a 250-m radius. The EUREF 0216 marker BORO is one of them. The coordinates of BORO and BOR1 markers were obtained from the EPOCH 1992 project, and from that time are periodically compared.

Status Report of the IGS GPS Station in Taejon, Korea

Pil-Ho Park, Jong-Uk Park, Jeong-Ho Jo
Korea Astronomy Observatory
Taejon, Korea

1 Introduction

The Korea Astronomy Observatory (KAO) has been operating the present GPS station since July 3, 1992. It is located at Taedok Science Town in Taejon, Korea. KAO had participated in the IGS/Epoch'92/WING campaign with the site name of "DAEN" and Trimble 4000SST GPS receiver until 1994. In 1995, KAO introduced the new Trimble 4000SSE GPS receiver and changed the station name to "TAEJ". Our station started to send its GPS data to the IGS Data center(CDDIS) from November 20, 1995.

2 GPS Station Configuration

Station name	Taejon
char ID	TAEJ
IERS DOMES Number	23902M001
Installation Date	1992.7
Receiver type	Trimble 4000SSE
Antenna type	Compact L1/L2 with groundplane
Antenna height	0.6604m
Antenna Reference Point	Bottom of preamplifier
Approximate Station Coordinate	$36°22'27.91''1$ N, $127°21'57.88'$ E 77.6m

3 Data Handling

The Trimble 4000SSE GPS receiver is connected to a personal computer (IBM & OS/2) which is connected through a LAN to the station main computer (AST BRAVO & Windows NT). The receiver and PC are connected to a UPS for protection against power failure. The program, Trimble URS^{TM} OS/2 (Universal

Reference Station), downloads data to the PC continuously and makes the data files hourly. The sampling rate is 15 seconds because the Taejon station is not only an IGS station but also a reference station for domestic surveying. At 00:05 UTC every day, the URSREXX (OS/2 scripts files) program transfers the last 24 hours of data to the main computer through LAN. The main computer converts the last day's data to RINEX files with a 30-second sampling rate and saves all the data, including RINEX, on magneto-optical disk for permanent backup. After that, a workstation gets the RINEX files from the main computer and compresses them using the UNIX compress utility, and sends them to CDDIS by FTP. These procedures are automatically done.

4 Contact point

Contact	Pil-Ho Park
Agency	Korea Astronomy Observatory
Address	San 36-1, Whaam-Dong, Yusong-Ku, Taejon 305-348, Korea
Phone	+82-42-862-2526
Fax	+82-42-862-2526, +82-42-861-5610
E-mail	`phpark@daen.kaist.ac.kr` `phpark@hanul.issa.re.kr`
WWW	`http://kaogps.kaist.ac.kr`

GPS Permanent Tracking Sites operated by the Institut für Angewandte Geodaesie (IfAG)

Wolfgang Schlueter, Reiner Dassing, Dieter Feil,
Klaus Roettcher, Rudolf Stoeger
Institut für Angewandte Geodaesie
Fundamentalstation Wettzell
Sackenrieder Straße 25 D-93444 Koetzting

Andreas Reinhold
Institut für Angewandte Geodaesie
Aussenstelle Leipzig
Karl-Rothe-Str. 10-14
D-04105 Leipzig

In cooperation with host agencies the Institute for Applied Geodesy (IfAG) is operating permanent GPS-receivers in order to support the IGS at the locations in

- Wettzell (Germany)
- O'Higgins (Antarctica)
- Lhasa (Tibet)
- Reykjavik (Iceland) and
- Ankara (Turkey).

Preparations for the installation of permanent tracking stations have been carried out at locations in Nicosia (Cyprus) and Sofia (Bulgaria).

1 Wettzell/Germany

Permanent GPS observations at Wettzell have been carried out since November 1987. In the period from November, 1987 to May, 1989 GPS data had been taken with a TI4100-receiver. The receiver was replaced by a MiniMac 2816AT in May, 1989. Since July 23, 1991 a Rogue receiver type SNR 800 and since

February 9, 1995 a TurboRogue receiver type SNR 8000 have been in operation. Observations from both the TurboRogue and the Rogue receivers are delivered to IGS. The four-character identifications are

WETT for the Rogue SNR 800 and
WTZR for the TurboRogue SNR 8000.

The receivers are installed in the main operational building of the Fundamentalstation Wettzell. Both antennas are located on the observation platform of the building separated by only a few meters:

$$dx = -2.105\,\mathrm{m} \quad dy = -0.981\,\mathrm{m} \quad dz = +1.994\,\mathrm{m}$$

The Rogue SNR 800 is connected to a Dorne Margolin B, and the TurboRogue SNR 8000 is connected to a Dorne Margolin T antenna. Both receivers are driven by an external oscillator (H-maser, EFOS 13). The data transmission is realized through Internet to the regional IGS data base in Frankfurt, after the data have been converted into the RINEX format. Since March 1996 only the data collected by the TurboRogue are transmitted to the IGS. The Rogue SNR 800 is still in operation as a back-up system; the data are stored in the local data base at Wettzell only and can be made available on request.

At the Fundamentalstation Wettzell, the GPS permanent tracking receivers are collocated with

- the SLR/LLR-system WLRS (Wettzell Laser Ranging System)
- the VLBI - 20 m radiotelescope
- the permanent installed Super Conducting Gravity meter and
- a seismometer.

The meteorological surface data (such as pressure, temperature and humidity) are taken from the local meteorological system. The data are made available along with the GPS observations.

2 O'Higgins/Antarctica

At the station O'Higgins/Antarctica the IfAG in cooperation with the DLR (Deutsche Forschungsanstalt füar Luft- und Raumfahrt) operates the ERS/VLBI-telescope. In collocation with the telescope, the following have been installed:

- a permanent GPS tracking station (TurboRogue SNR8000)
- a PRARE system and
- a tide gauge system.

The permanent GPS tracking station with the TurboRogue SNR 8000 receiver started operation on February 14, 1995. The Dorne Margolin T-antenna has been mounted on a separate pillar covered with a radome. The receiver itself is housed in the operating room for the VLBI-Antenna in the VLBI-container. For data transmission, an INMARSAT system is installed permanently. Through an automatic routine the data are sent daily after midnight (with respect to UTC) via the INMARSAT facilities to the operating center at the Fundamentalstation Wettzell. Data control and conversion into the RINEX format are carried out at the operating center before the data are released through Internet to the IGS data bases. The INMARSAT system is a critical component. On June 10, 1995, the INMARSAT failed due to a blown fuse. As the station usually operates unmanned, the problem could be solved only during the VLBI operation in September/October 1995. The TurboRogue data have been recorded continously on the local control PC. The data from the period June 29 to September 30, 1995 have been transfered into the IGS database offline. Data from October and November have been transfered through INMARSAT again. On December 2, 1995 the power system completly failed. In January 1996, the power system was repaired.

The meteorological surface data are taken continously from a local meteorological device. The data are made available along with the GPS oberservations.

3 Lhasa/China-Tibet

In cooperation with National Bureau of Surveying and Mapping in Beijing, China, the IfAG operates the permanent GPS tracking station Lhasa/China-Tibet. The TurboRogue SNR 8000 has operated since May 2, 1995. The system is installed in the office building of the TBSM (Tibet Autonomous Regional Bureau of Surveying and Mapping). The Dorne Margolin T antenna is placed on the roof of the office building. For the data transfer an INMARSAT A system is employed. The data are sent automatically every day after midnight (with respect to UTC) to the operating center at the Fundamentalstation Wettzell. The operating center at Wettzell converts the data into RINEX and makes the data available to the IGS through Internet via the IGS regional data base in Frankfurt. The INMARSAT system turned out to be unreliable for the automatic data transfer. The system failed on November 24, 1995, while the TurboRogue SNR 8000 continued the tracking. The data collected since November 24 have been transferred offline into the IGS database, after mailing diskettes from Lhasa to Wettzell. Some activities are underway in order to increase the reliability of the data transfer through INMARSAT.

4 Reykjavik/Iceland

In cooperation with the Iceland Geodetic Survey/Reykjavik the IfAG operates the permanent GPS tracking station Reykjavik. The TurboRogue SNR 8000 receiver is installed in the building of the Engineering Research Institute of the University Reykjavik. The Dorne Margolin T antenna and local meteorological sensors are placed on top of the roof of the building. The permanent tracking started on November 2, 1995. A direct Internet connection is providing a realiable data transfer for the tracking and the meteorological data files to the operating center at Wettzell. After the RINEX conversion the data are made available to IGS through the regional database in Frankfurt. On request from JPL, every hour a datafile is made available through anonymous FTP for ionospheric and atmospheric investigations.

5 Ankara/Turkey

In cooperation with the Harita Genel Komutanligi (General Command of Mapping (GCM))/Ankara, the IfAG operates a permanent GPS tracking station in Ankara. A special building and a pillar was built by the GCM for housing the receiver facilities and for mounting the antenna within the area of the GCM in Ankara.

Permanent GPS tracking in Ankara started in June 1989. The first receiver was the TI-4100, which was replaced by a MiniMac 2816AT. The TurboRogue SNR 8000 was installed in June 1995; the antenna is the Dorne Margolin T. Data transmission is done through Internet to the operating center Wettzell since the TurboRogue has started tracking. Before the availability of the Internet, the data were transfered offline by mailing data cassettes. The data are converted into RINEX by the operating center Wettzell and made available to IGS through the regional data center in Frankfurt. At the permanent GPS tracking station Ankara the facilities for operating a mobile Laser Ranging Systems (laser pad) also exist. A collocation with the TLRS1 (Transportable Laser Ranging System) was completed.

Update on Western Canadian Deformation Array Sites Albert Head and Penticton

Michael Schmidt and Herb Dragert
Pacific Geoscience Centre
Geological Survey of Canada

1 Introduction

The following information is meant as a 'heads up' advisory and concerns the effect of changes to the antenna and antenna environment at Albert Head (ALBH) and Penticton (DRAO) (as well as all other Western Canadian Deformation Array (WCDA) sites). This information is preliminary and is meant to advise users of our data of some recent findings. It is also hoped that this information might generate further discussions of what might be a widespread problem stemming from (undocumented) antenna changes.

A re-analysis of GPS data from our WCDA sites is currently underway in order to quantify the apparent positional changes due to changes in antenna types (Dorne Margolin B to Dorne Margolin T), antenna heights, the addition of antenna domes, and the addition of antenna RF skirting. To date we have identified apparent changes in the mean phase centre heights at all WCDA sites ranging from 4 to 18 mm that are coincident with the physical antenna changes such as the ones listed above. At ALBH, there appears to be a significant horizontal offset (≈ 5 mm) of the phase centre introduced by a change of a Type B to a Type T DM antenna, which, incidentally, also necessitated a change in the way the antenna was mounted on the forced-centre monument. It should be noted that since the apparent changes in the phase-centre positions are a near-field/ scattering effect, the size of the step as determined from the analysis of our data will be dependent on the elevation cut-off angle used.

2 Present Antenna Installations

2.1 Penticton (DRAO)

The AOA Dorne Margolin Type-T (TurboRogue) antenna is centre-mounted directly on an anodized, solid aluminum cylindrical base, 10 cm in height and 10 cm in diameter, which in turn is centre-mounted on a standard brass forced-centre plate embedded in the top of the concrete pier. The aluminum base

```
             DRAO: DORNE MARGOLIN T (not to scale)

                         -----
                     /     +     \                        <-- 0.128  L2
                    |      +      |                       <-- 0.110  L1
   +--------------------------------------------------+   <-- 0.102  TCR
   |                                                  |
   |                                                  |
   |                                                  |
   |                                                  |
|+-+--------------------------------------------------+-|+  <-- 0.038
|+-------------------+-------------+--------------------|+  <-- 0.035  BCR
|                    |             |                    |
|                    +------x------+     <----          |  <-- 0.000  ARP
|                    *             *         |          |
|                    *             *         |          |
|                    *             *         |          |
|                    *             *       10cm         |< metal screening
|                    *             *         |          |  (RF skirt)
|                    *             *         |          |
|--------------------*------*------*--------------------| TOP OF CONCRETE PIER
|                                                       |
|                                                       |
```

Figure 1: Antenna Schematic for Penticton (DRAO) GPS Station

permits orientation of the antenna while maintaining forced centering. Consequently, the height of the antenna, i.e., the distance between the reference surface of the monument and the antenna reference point is 10 cm (0.100 m). An RF skirt consisting of aluminum screening has been clamped around the outer perimeter of the antenna ground-plane and draped over the upper end of the concrete pier thereby enclosing the open space between the bottom of the antenna and the top of the pier with a conducting screen. At this point, the screening has been tied tightly to the pier with wire, and no additional electrical grounding of this mesh has been attempted.

2.2 Albert Head (ALBH)

The antenna installation at ALBH (and all other WCDA sites) is identical to the one described above for DRAO except that an aluminum flange ring has been installed on the bottom of the antenna ground plane and extends about 3 cm beyond the outer perimeter of the ground plane. An acrylic, hemispherical dome is attached to this flange ring, and the aluminum skirting is clamped to the outer perimeter of the flange ring as opposed to the antenna ground plane. The acrylic dome covers the entire antenna / choke ring assembly.

Note that the use of the 'RF skirt' was first suggested by Tom Clark as a means to reduce multipath / near-field effects from the cavity between the top of the pier and the bottom of the antenna ground plane and such skirts have now been installed at all WCDA sites.

```
              ALBH: DORNE MARGOLIN T (not to scale)

                  .      .      .       .     .      .
           .                                              .<-- ACRYLIC DOME
       .                          -----                       .
     .                        /     +     \                     .  <--0.128  L2
   .                         |      +      |                      .<--0.110  L1
  .      +---------------------------------------------------+     .<--0.102 TCR
 .       |                                                  |      .
 .       |                                                  |      .
 .       |                                                  |      .
 .       |                                                  |      .
 .     +------------------------------------------------------+     . <-- 0.038
 .     +-------------------+-------------+--------------------+     . <--0.035  BCR
|==========                |             |             ============| FLANGE RING
|                          |             |                         |
|                          +------x------+     <----               | |<--0.000  ARP
|                          *             *         |               |
|                          *             *         |               |
|                          *             *         |               |
|                          *             *       10cm              |< metal screening
|                          *             *         |               |(RF skirt)
|                          *             *         |               |
|--------------------------*------*------*-------------------------|TOP CONCRETE
|                                                                  |PIER
|                                                                  |
|                                                                  |
```

Figure 2: Antenna Schematic for Albert Head (ALBH) GPS Station

3 Apparent Step Functions

As outlined above, preliminary analysis has identified apparent changes in the mean position of antenna phase centres at the following times:

- change in antenna types and cavity height: ALBH at 1994 day 104
- change in cavity height: ALBH at 1995 day 11; DRAO at 1995 day 102
- addition of RF skirts: ALBH at 1995 day 202; DRAO at 1996 day 10

Note that any physical changes in the height of the reference point of the antenna have been correctly logged in the site information files for both ALBH and DRAO and the observed changes in the phase centres are in addition to the recorded height changes. The additions of the RF skirts have *not* been logged in the site information files. In retrospect, it now appears that any changes in the near-field of the GPS antennas should be logged in the IGS site-information files.

The maximum change in the vertical that we have observed coincident with any one (or a combination of) the noted antenna changes approaches 2 cm. Such steps have been identified from day-to-day baseline analyses as well as from the weekly SINEX analyses produced by NRCan. Our conclusion is that any regression analyses on DRAO or ALBH data must allow for step functions at the noted dates, or resulting estimates of long-term linear trends will be biased. As soon as our analyses are complete, we will post our best estimates of apparent changes in the phase centres of the affected sites. This preliminary note is to indicate to the IGS community that we are aware of the problem and to suggest caution in the interpretation of secular trends at GPS sites where such antenna changes have taken place.

Please address any comments or questions directly to us: Herb Dragert (`dragert@pgc.emr.ca`); Mike Schmidt (`schmidt@pgc.emr.ca`).

IGS Operational Station Pecny

Jaroslav Simek
Research Institute of Geodesy, Topography and Cartography
Geodetic Observatory Pecny
Ondrejov, Czech Republic

1 Technical Data

Station	GOPE
Full Name	Geodetic Observatory Pecny
Location	Ondrejov, Czech Republic
Latitude	49°54′49.3″ N
Longitude	14°47′08.2″ E
Ellipsoidal Height	592.6 m
GPS Receiver	Trimble 4000 SSE
Antenna	Trimble 4000 ST L1/L2 GEOD
Meteorological data	Temperature, humidity and air pressure recorded every 60 minutes
Agency	Research Institute of Geodesy, Topography and Cartography, CZ - 250 66 Zdiby 98; Geodetic Observatory Pecny CZ - 251 65 Ondrejov 244
Contact	Jaroslav Simek
Telephone	+ 42 204 85 235
Fax	+ 42 204 85 236
E-mail	`gope@asu.cas.cz`

2 General Station Description

The IGS station GOPE is located at the Geodetic Observatory Pecny of the Research Institute of Geodesy, Topography and Cartography which is about 40 km southeast of Prague, the Capital of the Czech Republic. The observatory is close to the large campus of the Astronomical Institute of the Academy of Sciences of the Czech Republic (AI ASCR). The observatory is a geodetic reference station of the Czech Republic including vertical and gravity reference point. It has a laboratory and a thermo chamber for testing gravity meters and geodetic instruments. Its PC-LAN consists of 13 PCs linked to the LAN of the Astronomical Institute.

A permanent GPS station has been in operation since September 1993 and since September 1995 it has been regulary contributing to the International GPS Service for Geodynamics. The antenna is mounted in a metal plate with a forced centering embedded on the top of a concrete pier over the roof of the main observatory building. The pier passes through the building and is embedded in its grounds. Around the upper part of the pier there is an observing platform containing a meteorological box with a sensor for recording meteorological data (temperature, air pressure, humidity).

The daily observation data are downloaded at 00:05 UTC and RINEX daily files are routed via the Internet to the Data Center of the Central European Initiative (CEI) in Graz and further forwarded to the IGS Regional Data Center IfAG. The data are then processed in the IGS Analysis Center CODE in Bern. At present the station operates fully automatically.

3 Collocation measurements

At the Geodetic Observatory Pecny the astrometric time and latitude observations have been regulary performed since 1957. At present the data are supplied for further processing to the World Center of Optical Astrometry, Shanghai, China and to the GOSSTANDARD, Russia.

Permanent gravimetric observations of earth tides have been performed by several gravimeters in the tidal laboratory since 1970. In addition to on-site continuous data processing and analysis the results are supplied to the International Center on Earth Tides in Brusseles, Belgium. Finally, seven repeated absolute gravity measurements have been performed at the observatory with different absolute gravity meters in the period 1979–1995.

In the past the photographic satellite tracking was almost continuously performed in the period 1969–1990, the satellite laser ranging on an experimental level since 1970 and the Doppler observations in 1984–1989. At present the experiments are being made with observations of meteorites and little planets by the Schmidt satellite tracking camera.

4 Other activities

- A continuous evaluation and analysis (day by day solution, sub-daily solution for selected epochs) of observations of a cluster of five IGS stations (GOPE, Wettzell, Graz, Onsala, Jozefoslaw) has been performed since September 1993;
- The station GOPE serves as one of the analysis centers of the international geodynamical project CERGOP (Central Europe Regional Geodynamics Project);
- The station takes an active part in international GPS-projects-EUREF-CS H-91, EUREF-POL 92, EXTENDED-SAGET 91-95, CERGOP/CEGRN 1994-95 and others.

- GOPE serves as a reference station and analysis center in Czech national geodetic and geodynamical projects (NULRAD-92- Czech zero order reference network, DOPNUL 93-94 - densification GPS network, consisting of 176 stations, GEODYN 95 - Czech Reference Geodynamical Network).
- A part of the realization team of the observatory makes scientific research in the fields of physical geodesy (boundary value problems), satellite orbit dynamics and satellite altimetry and theory of earth tides.