

IGS

**International GPS Services
for Geodynamics**

1997 Technical Reports

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IGS Central Bureau

Jet Propulsion Laboratory
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Abstract

Applications of the Global Positioning System (GPS) to Earth Science are numerous. The International GPS Service (IGS), a federation of government agencies and universities, plays an increasingly critical role in support of GPS-related research activities. Contributions from the IGS Governing Board and Central Bureau, analysis and data centers, station operators, and others constitute the 1997 Annual Report. This report has a companion publication, the 1997 Technical Reports. Hard copies of each volume can be obtained by contacting the IGS Central Bureau at the Jet Propulsion Laboratory.

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Introduction

The U.S. Global Positioning System (GPS) constellation of satellites plays a major role in regional and global studies of Earth. In the face of continued growth and diversification of GPS applications, the worldwide scientific community has made an effort to promote international standards for GPS data acquisition and analysis, and to deploy and operate a common, comprehensive global tracking system.

As part of this effort, the International GPS Service for Geodynamics (IGS) was established by the International Association of Geodesy (IAG) in 1993 and began formal operation in January 1994. The IGS, with a multinational membership of organizations and agencies, provides GPS orbits, tracking data, and other data products in support of geodetic and geophysical research. In particular, since January 1994, the IGS has made available to its user community the IGS official orbit, based on contributions from the seven current IGS Analysis Centers. The IGS also supports a variety of governmental and commercial activities and develops international GPS data standards and specifications.

Highly accurate and reliable data and data products supplied by the IGS meet the demands of a wide range of applications and experimentation. They can be accessed on the Internet through the Information System maintained by the IGS Central Bureau, which is sponsored by the National Aeronautics and Space Administration (NASA) and managed for NASA by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology. In 1996, the IGS became a member of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

The Central Bureau Information System can be accessed using the World Wide Web (WWW) or via anonymous File Transfer Protocol (FTP) as follows:

- WWW — <http://igscb.jpl.nasa.gov>
- FTP — [igscb.jpl.nasa.gov](ftp://igscb.jpl.nasa.gov) (or 128.149.70.171)

Use the directory `/igscb`. See `README.TXT` for online help, and `TREE.TXT` and `IGSCB.DIR` for directory and file information.

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Executive Reports

The Development of the IGS in 1997 - The Governing Board's Perspective

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1 Overview

It was stated many times that the IGS, as a very active service in support of Earth Sciences and Astronomy, is in continuous development. Many changes have occurred recently.

One of these recent changes concerns the format of the IGS annual reports. The first IGS annual report was written in 1994 (although IGS activities started as early as 1992), and the annual reports for 1995 and 1996 followed. The 1994 Annual Report contains 330 pages, the 1995 Volume 282 pages (using a more dense format than the 1994 report), and the 1996 report contains 446 pages (using essentially the same format as in 1995). On one hand, this increase in size was viewed as a positive development which highlighted and documented many new activities (e.g., the work performed in the context of the densification of the ITRF). On the other hand, it became increasingly difficult for non-IGS-experts to get a concise overview of IGS activities.

This was why the IGS Governing Board, at its 1998 Darmstadt Business Meeting on Sunday, February 8 1998, decided to produce the IGS Annual Report for 1997 in two corresponding volumes. Volume 1 would contain the top level information (CB report, IGS Analysis Center Coordinator report, report about current projects, etc.), and Volume 2 would contain the technical reports (analysis center reports, the station reports, etc.).

As a matter of fact, Volume 1 has been completed and should be distributed in summer 1998. Volume 2 is being finalized in September 1998. Volume 1 was edited by the Central Bureau much the way the 1996 Annual Report was done, and Volume 2 will be published to closely resemble "camera ready manuscripts." Volume 1 contains about TBD pages and will be broadly distributed (approximately 1500 copies) inside and outside the IGS. Volume 2 is primarily designed for internal IGS use and will be distributed to the IGS participants, associates, and libraries. Both reports will be made available in electronic form.

The Table of Contents of Volume 2 indicates the high documentary value of Volume 2: Here, the IGS Analysis Center Coordinator and all IGS Analysis Centers and Associate Analysis Centers summarize their latest and greatest improvements and changes, the IERS (Rapid Service and Predictions and Central Bureau) provide technical feedback and comments to the IGS. This again underlines the excellent relationship

between the two services in support of science. In subsequent sections, the Data centers discuss the issues of data handling, and an overview is provided concerning the state of the IGS network.

The development of the IGS in size and quality since 1992 is remarkable. Crucial to this development are its pilot projects, working groups, and committees. The final section of Volume 2 gives an overview of these IGS components that are currently active. The topic is also addressed in the next subsection of this report.

Volume 2 contains another first; an executive chapter. Initially, it was important that the topic of this new section does not restate that which is contained in Volume 1 of the 1997 Annual Report. I was therefore initially reticent to write a new contribution for Volume 2. However, after some reflection, I found that the Governing Board clearly states that the Technical Reports volume of the 1997 Annual Report was different in content but of equal importance as Volume 1.

So that I do not repeat that which is in Volume 1, the development of the IGS as an IAG- and a FAGS-Service, the essential IGS Events in 1997, and a few remarks concerning the IGS Retreat 1997 may be found in my report in the first part of the 1997 IGS Annual Report.

Let me address here two topics which kept the Governing Board (and others) quite busy in 1997 and 1998. (As opposed to the first part of the annual report, I am thus also addressing events which took place in 1998 – a practice which was always followed in the IGS Analysis Center Reports). The first topic addresses the future IGS policy regarding pilot projects and working groups, the second the IGS retreat -- which will then be handled in detail in the second contribution to this introductory chapter.

2 IGS Policy for the Establishment of IGS Projects and Working Groups

As one may conclude from Section 5 (Pilot Projects/Committees) of this report there are quite a few pilot projects or working groups active within the IGS. These working groups were set up in the past by the Governing Board on a more or less spontaneous "ad hoc" basis, where the goals and responsibilities were not always clearly defined. When the Governing Board saw the smooth development of the ambitious "IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons" it became obvious that the IGS needed well-defined rules for how to set up pilot projects and working groups.

This issue was addressed at the Business Meeting of the IGS Governing in Darmstadt because of the request to create an IGS ionosphere working group. It was decided that John Dow and the IGS Chairman should

- draft a general "charter" for setting up Working Groups or Pilot Projects within the IGS, and to circulate this draft within the Governing Board, and
- develop, in close cooperation with the "ionosphere club," the charter for the ionosphere working group and circulate this draft within the "ionosphere group."

Such general rules and a draft charter for the ionosphere working group were actually set up and presented to the Governing Board at its ninth meeting in Boston, Mass, at the end of May 1998. The outcome may be found in IGS Mail Message No. 1916: The rules were accepted by the Board and will be applied whenever new IGS working groups or pilot projects are created. Moreover, the ionosphere working group was created with Dr. Joachim Feltens from ESA as chairman.

It is the explicit wish of the Board that existing IGS Working Groups, Pilot Projects, etc., should follow the same rules in the future. This process will be invoked soon and will eventually lead to a clearer and better structure of the IGS. The accepted rules are stated in a special document which will have the status of a "by-law" of the IGS. The document will be referred to in the new Terms of Reference (to be adapted by the end of 1998). Some of the essential points of the document are:

- An IGS Working Group deals with a particular topic related to the IGS components. An IGS Pilot Project aims at the development of one or more particular IGS product(s) using data from the IGS network.
- Working groups and projects are operating autonomously under the leadership of the chairperson.
- The IGS Governing Board regularly organizes special meetings, where IGS projects and working groups are reviewed. Such meetings may be special sessions at IGS Workshops.
- IGS Working Groups and IGS Pilot Projects are set up by the IGS Governing Board at one of its regular meetings. At such a "constitutional meeting" the IGS Governing Board
 - approves the draft Working Group Charter
 - appoints the chair of the Working Group or Project for two years.
- Proposals to terminate the work, to essentially change the Charter, to (re-)appoint chairpersons are made at these meetings. These proposals are presented to the IGS Governing Board at its next regular Meeting.

3 The IGS Retreat in December 1998

At the seventh IGS Governing Board Meeting in Rio de Janeiro it was decided to organize an "IGS Retreat" in December 1997 with the IGS Governing Board Members and a very limited group of IGS Associates with the goal to come up with a plan for the

future development of the IGS which then should be discussed by the entire IGS community and the Board (IGS Mail Message No. 1683).

The retreat actually took place in Napa Valley, December 12-14, 1997. Recommendations and action items were presented at the Business Meeting of the IGS Governing Board in Darmstadt. The report was prepared by Ivan I. Mueller, who was also the program chair of the retreat. The recommendations and action items will be discussed in the next section of this introductory chapter by the same author. The report could only be discussed at the business meeting, decisions on this matter were taken at the 9th IGS Governing Board Meeting on 28 May, 1998 in Boston. Many of the proposed action items were already properly addressed at the 1998 IGS Analysis Center Workshop, others require adaptations in the Terms of Reference, a work which is underway right now.

The Governing Board considers the "recommendations and action items" of the IGS Governing Board retreat in Napa Valley, December 12-14, 1997 (as prepared by Ivan I. Mueller) as an extremely useful document defining the development of the IGS at least till the end of the millennium..

4 Acknowledgments

We should keep in mind that the IGS is based on a voluntary collaboration of a large number of scientific and survey institutions. It is also worth pointing out that the contributing organizations are not funded by the IGS, but have to raise funds for their IGS-related activities. Thus, an organization like the IGS only works properly if all contributing institutions are dedicated to the IGS mission and its performance, and if the benefit from IGS activities justifies the investments.

The other pillar of the IGS success is the personal engagement of many individuals who devote their time to the IGS. Prior to my involvement with the IGS, I was not aware of the large number of enthusiasts willing to cooperate on a voluntary basis for the benefit for the scientific community. I am convinced that most IGS associates share these feelings. On behalf of the IGS Governing Board, I would like to cordially thank all institutions and individuals devoting time and funds to the success of the IGS.

Many of us contributing to the 1997 IGS Annual Report found it difficult to submit manuscripts on time. The fact that delays stayed within "reasonable limits" is due to Prof. Ivan Mueller. His help in the editorial process allowed the Central Bureau to produce the Annual Reports in a timely manner -- which is of greatest importance for such a document. In this context I also would like to congratulate Dr. John Dow from ESA for his very efficient production and distribution of the Proceedings of the 1998 IGS Workshop in Darmstadt.

Activities of the IGS Central Bureau in 1997

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1 Overview

The end of 1997 marks a 'rite of passage' for the IGS, the first four year period devoted to nurturing this fledgling scientific service based on the Global Positioning System (GPS). The past four years have resulted in solidifying this now well known international activity and reinforcing its importance for scientific and research applications. During this time period, the IGS has become the fundamental supporting infrastructure for numerous geodetic, geophysical and geodynamic applications that depend on the utilization of GPS technology. The IGS also advocates standards and specifications for achieving excellence in precision use aspects of GPS from network operations through GPS analysis and applications, so that users worldwide can make use of the wealth of data and products afforded by the IGS.

It is quite clear that the strength of the IGS is directly due to the many participating individuals and their sponsoring agencies as noted by Gerhard Beutler above. The achievement of the IGS is something that each can lay claim to and it is the recognition that through mutual cooperation much greater benefit is realized by all.

2 Network Status and Update

The IGS network consists of precision, geodetic dual-frequency GPS stations that observe the GPS satellites on a continuous, 24-hour basis. These globally distributed stations are funded, implemented and operated by one of the IGS participating. At the end of 1997, nearly 200 stations were listed as part of the IGS network, an increase of nearly 70 stations registering with the IGS in 1997. Currently, the data files from each station span a 24-hour period, although the IGS is planning sub-daily data retrievals in the future, on an hourly or four to six hour basis. A Network Workshop is planned in November 1998 to address the current and future operations of the network, and many new requirements that affect these operations. This is in response to increasing demands on the infrastructure.

3 IGS / CB Activities in 1997

The IGS Terms of Reference, the relations by which the IGS is governed (i.e., by-laws) were established at the beginning of the service in 1994. These terms state that the "Central Bureau of the International GPS Service is responsible for the overall coordination and management of the Service". In order to fulfill this role, the CB has been actively engaged in the many activities of the IGS. Given the current scope of IGS activities, the on-going fundamental processes and the new projects and directions of related GPS applications, the personnel of the CB must have a number of different talents to collectively perform the necessary tasks in order to coordinate with the various components of the service.

The CB is in the process of reorganizing the office based on the recommendations of the Napa Retreat in December 1997, see Ivan Mueller, this volume. One of the most noticeable results will be a nearly full-time Director and a full-time position of a Deputy Director. These staffing allocations are appropriate given the necessity of the CB to assume more of the daily coordination of the IGS, especially with regard to the robust performance of the ~200 station network, and the need to assume the role of the Executive arm of the Governing Board. In the first year or two of IGS operations the contributing agencies were all working to achieve their objectives as part of the IGS, in the spirit of the IGS mission statement. During this period, it took time to develop and solidify the working relationships internal to the IGS. Today, we are increasingly aware that additional effort is warranted in two areas: sustaining the fundamental IGS and providing interface to users, both internal and external

The Central Bureau has been actively working to completely upgrade the Central Bureau Information System (CBIS) which was made active in June of 1998. This web site and FTP server contain all of the fundamental information of the IGS. All IGS products are held here, as well as at the Global Data Centers (GDC). Most external users access the CBIS, while internal IGS users generally access the GDCs of choice. The CBIS will continue to evolve so that information is easily accessible and web based tutorials on the use of IGS products will be developed.

One of the other duties of the Central Bureau is to organize workshops and meetings, much effort was devoted to the first joint workshop between the Permanent Service for Mean Sea Level (PSMSL) and the IGS, the Workshop on Methods for Monitoring Sea Level and Altimeter Calibration, a joint IGS and Permanent Service for Mean Sea Level (PSMSL) workshop. This resulted in proceedings that are very valuable for these applications. Other workshops include supporting the 1997 Analysis Center workshop convened by Mike Watkins and Yehuda Bock. All meetings of the Governing Board are arranged by the CB, this year in held in Pasadena, Rio de Janeiro, San Francisco and the IGS Retreat in Napa Valley.

The Central Bureau managed six IGS exhibits at various international locations this year in order to promote information and use of data and products from the IGS. These exhibits include a computer slide show, back-drop of information, publications for pick-up or order and people stationed at the booth to answer questions.

The Central Bureau has devoted a great deal of time and resources to publications, which include 1996 IGS Annual Report, IGS Directory 1997, and IGS Resource Packets, updated quarterly. The IGS brochure was completely redesigned and rewritten: IGS Brochure Monitoring Global change with Satellite Tracking, this brochure is also available in Spanish and future revisions will be available in other languages also.

The direction of the Central Bureau in the future will be to shift the focus somewhat from publications, exhibits, and meeting organization, and move to coordinate the Service in a more active fashion, as recommended by the Governing Board. To achieve this objective, the current reorganization of the CB will result in closer working relations with the various IGS components, including the Analysis Center Coordinator, the IGS working groups and committees. .

Recommendations and Action Items - IGS Governing Board Retreat Napa Valley, December 12-14, 1997

Ivan I Mueller

1 Overview

One of the conclusions reached at the Retreat was that the IGS Terms of Reference (January 1996 version), with some “fine tuning”, still reflects the current needs of the IGS. For this reason, and also to provide a framework for the Retreat’s Recommendations (Rs) and Action Items (As), relevant portions of the terms are reproduced below, in **bold** letters between dotted lines, with the Rs and As inserted at the appropriate locations.

In order to keep the Retreat as conducive to open discussion as possible, formal Minutes were not kept. A “short hand”/informal record, suitable to jog the memories of the participants, is available from the Central Bureau.

The Recommendations/Action Items and the explanatory text as presented below are based on the final summary discussion of the Retreat Coordinators on December 14, 1998, and on correspondence and conversations held after the Retreat.

2 International GPS Service for Geodynamics - Terms of Reference

The term “Geodynamics” within the name IGS, at its inception, was meant to indicate that the primary users of the service are scientists involved in geodynamics, specifically using GPS for determining and/or monitoring positions on the surface of the Earth with the highest accuracy. Since other types of users (especially from the atmospheric and oceanic science communities) are appearing on the horizon, the suggestion was made to eliminate the term “Geodynamics” from the title of IGS.

- **R1:** The name of the Service be the “International GPS Service”.
 - **A1:** Governing Board (GB) needs to consider R1 and vote.
-

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 Terrestrial Reference Frame (ITRF)
 - monitoring deformations of the solid earth
 - monitoring earth rotation
 - monitoring variations in the liquid earth (sea level, ice-sheets, etc.)
 - scientific satellite orbit determinations
 - ionosphere monitoring
 - climatological research, eventually weather prediction.
-

In the past, the IGS combined products used primarily have been those related to the **IGS Reference Frames**, both terrestrial and inertial, recommended for GPS users. These are the station coordinates with their variations in time (defining the terrestrial frame) and the orbits of GPS satellites (defining the inertial frame), and the transformation parameters relating the two (the earth-rotation parameters). There have been some questions as to the internal consistencies of the above products.

Due to user requirements for using the GPS signals in various efficient modes and/or leading to more accurate results, it appears necessary for IGS to produce combined, timely, and consistent additional products. Specifically, this includes GPS clock corrections (possibly an IGS time scale), tropospheric zenith biases and global and/or regional ionosphere models. These, together with the reference frames (all based on the IERS Conventions, 1996), constitute the **IGS Reference System**, assuring consistency for all GPS users of positioning in all modes.

Although non-positioning GPS user requirements are not clear at this time, it appears that there is (or will be in the near future) an increasing demand for rapid (real-

time) and more accurate GPS orbits, as well as the inclusion of other non-GPS satellites in the IGS framework (primarily the GLONASS and LEO satellites).

- **R2:** IGS is to produce combined, internally consistent, global products based on GPS observations as follows (several of these to a fair extent are already accomplished):
 - a) station coordinates and velocities (incl. IGS SINEX products)
 - b) orbital parameters
 - c) earth rotation parameters
 - d) GPS clock corrections
 - e) IGS time scale
 - f) tropospheric zenith delays
 - g) ionosphere models
- **A2.1:** The Analysis Center Workshop in Darmstadt should address the issues a) - d) and f) and g) and make recommendations.
- **A2.2:** The recently established IGS-BIPM Pilot Project should address issues as already decided by the GB.
- **R3:** IGS should continue producing accurate orbits based on rapid and/or high rate data, investigate new requirements (e.g., for real time meteorology forecasting a twenty-station network providing 30s data down loaded every 6-12 hours is suggested. For LEO see A4.2 below) and suggest and implement improvements in availability (IGR) and precision (IGP).
- **A3:** The Analysis Center Workshop in Darmstadt should address this issue and make recommendations.
- **R4:** IGS should support the tracking of GLONASS and LEO satellites.
- **A4.1:** The GB should support tracking of GLONASS satellites by actively promoting within IGS the International GLONASS Experiment (IGEX), currently scheduled Sep.-Dec.,1998, pending on the discussion on GLONASS at the GB business meeting in Darmstadt.
- **A4.2:** The LEO Working Group should continue its work (in collaboration with various groups involved in the use of LEOs for atmospheric science). Specific recommendations are to be made on the appropriate number of tracking stations and sampling rate (1-5s?) and on the feasibility of IGS processing of occultation and/or other flight data.

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**

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....

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).

The IGS global network needs an overall enhancement. The IGS Infrastructure Committee is involved considering issues related to the existing network e.g., instrumentation, monumentation, reporting, performance, data communication and flow, quality control, archiving, site and RINEX standards. Plans for a coordinated systematic effort to expand/densify the network to the proposed (about 200 stations) Polyhedron are still lacking. On the other hand, the regional densification efforts are progressing, and limits are to be set up as to the inclusion of the regional stations into the IGS Polyhedron (being pro-active at the same time). Use of the network for climatology would also require the installation of high stability accurate barometers.

- **R5:** The global IGS Network should be enhanced in the overall sense.
- **A5.1:** The IGS Infrastructure Committee is to continue its work and report to the GB at its next regular meeting in Boston.
- **A5.2:** The GB should consider appointing a Network Manager/ Coordinator, within or outside the CB, to coordinate a systematic effort to complete the IGS Polyhedron.

The responsibility would include the formulation of network standards and checking performance.

- **A5.3:** The CB/GB should make a systematic and concerted effort to request stations to install high stability/accuracy barometers (the alternative of using routinely produced atmospheric pressure grids should be explored, although their availability in near real time might be a challenge).
 - **A5.4:** The GB should consider organizing an IGS Network Workshop to have an open discussion on network/station issues and to develop a direct interaction between the GB and the stations, upon which rest all IGS activities.
-

DATA CENTERS

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

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.**
-

It was noted that, with the exception of CDDIS (which is doing an admirable job), not all Global Data Centers are regularly producing their Access Reports. In view of the importance of keeping track of the users of IGS products, it is recommended that such reports be published on a regular basis.

- **R6:** It is recommended that all Global Data Centers publish Access Reports on a monthly basis.
 - **A6:** The CB is to contact the relevant Global Data Centers and encourage them to comply with R6.
-

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.

- R7: Depending on the outcome of the Analysis Center Workshop in Darmstadt the above descriptions of the Analysis and Associate Analysis Centers should be reviewed. The GB decisions in San Francisco/Napa Valley re. the GNAACs/RNAACs, may also have an effect.
 - A7: The AC Coordinator together with the Chair of the Densification Project recommend the necessary changes to the Terms of Reference as per R7, if necessary.
-

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.

In view of R2 above, the present Analysis Coordinator's role will be significantly expanded and it is unlikely that a single person (or organization) will be able to handle the responsibilities related to all the different combined global products now contemplated. There is also a question of coordinating the regional densification projects (connected to the Polyhedron) in some central way. One of the responsibilities here would also be the education of users on how to use IGS products.

- R8: It is recommended that Working Groups be appointed for **Tropospheric Products**, for **Ionospheric Products**, for **ITRF Densification** and possibly others (pending on the recommendations of the Analysis Center Workshop in Darmstadt). The Analysis Center Coordinator should be an ex-officio member of all Working Groups. The alternative of appointing individual "Coordinators" for each application (instead of the Working Groups) may also be considered.
- **A8.1:** Based on the recommendations of the Darmstadt Analysis Workshop, the GB should appoint new Working Groups or Coordinators as per R8 and clarify their relationship/interaction (reporting requirements, etc.) with the CB and the GB.
- **A8.2:** The concept of Working Groups or additional Coordinators, together with their responsibilities and reporting/interaction requirements should be incorporated in the Terms of Reference.

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 compatibility 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....

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.

The Central Bureau has performed well, especially in the areas of coordinating the network and communication. However, due in part to the rapid expansion of IGS over the past several years, other CB tasks described in the Terms of Reference either had to be farmed out to persons (usually volunteers) outside the CB, contracted to other organizations (e.g., UNAVCO), or neglected.

In addition to the rapid expansion of IGS, the other major difficulty faced by the CB is in trying to fulfill its responsibilities which are primarily structural and organizational in nature. Although it is difficult to assess the situation from the outside, it seems evident that because no single person has full time responsibility within the CB, every one is “spread too thin” and fragmented. The Director of the CB has at least three jobs and it appears that only one person reports to her (the liaison to UNAVCO). The UNAVCO contract to help with the network involves one staff position spread out over six persons. Others working for the CB, instead of reporting to the Director, in fact report to one of JPL’s Group Supervisors, who in turn reports to certain Section/Division heads, and is not directly in charge of the Director of the CB. It appears that such a structure (although maybe efficient for other purposes), combined with the fragmentation of individual responsibilities, lead to difficulties in meeting JPL’s original commitment to IGS and in some cases even to conflicts of interests within JPL.

- R9: It is recommended that the tasks of the CB as described in the Terms of Reference be reviewed and the future tasks of the CB clearly defined, with the “left-over” responsibilities appropriately assigned to organizations or individuals outside the CB, which will closely interact with the CB.

- R10: It is recommended that the host organization of the CB review and streamline the CB organization, with fragmentation reduced to a minimum and lines of reporting and responsibilities clearly defined.
 - R11: It is also recommended that at least two persons should be given full time responsibility within the CB. One of these should be the Director, the other may be the Network Coordinator (see A5.2 above).
 - R12: It is recommended that, provided that the recommendation for the additional Coordinators are adopted (see R8 above), their interaction with the CB be clearly defined.
 - A9: The Director of the CB should discuss R9-11 with the appropriate officials of the host organization and present a plan to eliminate the above difficulties to the GB and the progress at its next regular meeting in Boston.
 - A10: A10: The GB should appoint a sub-committee to work with the Infrastructure Committee and the Director of the CB to accomplish R9 and R12.
 - A11: The Central Bureau section of the Terms of Reference will have to be modified after the fact.
-

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

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

The experiences of the past several years indicate that the nomination procedure for both groups of elected GB members (i.e., those nominated by the IGS Associates and those by the CB), may be improved to assure wider participation in the nomination process. In addition, it has been suggested to include all (or most) Coordinators in the deliberations of the GB. The appointed representation of IAG and FAGS on the GB needs clarification as well.

- A12: The GB should appoint a sub-committee to review the current nomination/appointment procedures for GB membership and to recommend improvements by the end of 1998.
-

Additional Recommendations/Action Items:

- A13: Periodic performance review requirement for each IGS component be incorporated in the Terms of Reference. The GB is to set up procedures for such regular reviews (how often and how?) and for the follow up of the recommendations (whether positive or negative).
- R13: The GB should consider forming an Advisory Committee for Commercialization of IGS products. The Committee should include representatives of organizations experienced in such ventures, e.g., WMO, UCAR/NCAR, IRIS, ESA (its business arm).
- R14: The GB should consider forming a committee, with external participation, with the task to prepare the IGS Long Range and Strategic Plan. Reporting should be at the IAG General Assembly in 1999.

(January 31, 1998)

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Analysis Centers

Analysis Center Coordinator

1997 Analysis Coordinator Report

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1 Introduction

This report is a complement to the 1997 Analysis Coordinator Report found in Volume I of the 1997 IGS Annual Report (Kouba, 1998). Changes, enhancements and new products implemented during 1997 as well as the combination and evaluation procedures and statistics of orbits, clocks and Earth Orientation Parameters (EOP) are reviewed. In 1997, three IGS combinations were routinely performed: the IGS Prediction (IGP/daily), Rapid (IGR/daily) and Final (IGS/weekly) combinations. The United States Naval Observatory (USNO), an Associate Analysis Centre (AAC) joined the Rapid IGS production group in April 1997 (Wk 902) but does not contribute to the Prediction or the Final IGS products.

2 Changes, Enhancements and New Products in 1997

In 1997, all IGS products continued to be oriented to ITRF94 which had been introduced, along with many other changes, on June 30, 1996 (Wk 860) (Kouba and Mireault, 1997). This year's changes and enhancements were mostly related to the IGS LOD/UT and clock correction combinations. The IGS Rapid solution deadline, to make IGS Rapid (IGR) orbits available to the Analysis Centres (AC) participating in the combined Prediction products, was advanced by two hours, from 24 to 22 hr UTC. The changes and enhancements are summarized in Table 1.

2.1 IGS Orbit Prediction Combination (IGP)

As mentioned in last year's Annual Report (Kouba and Mireault, 1997), the IGS orbit Prediction combination, a 2-day orbit prediction (i.e. 24 to 48h) was officially introduced on March 2, 1997 (GPS Wk 895). This year, more comprehensive statistics regarding AC and IGS orbit/clock prediction (IGP) performance have been incorporated (see section 5). The accuracy code found in the IGP sp3 file is based on the comparison with IGR, which is reported daily with a 2-day delay, as part of the IGR combinations. Predicted satellite orbits, with missing comparison information with respect to IGR, are assigned an accuracy code of 15 (i.e. precision of ~33 m) in the sp3 file for that day. Comparison RMS between IGR and IGP below 10 m are left with the accuracy codes estimated by the combination program. Accuracy codes for satellites with comparison RMS above 10 m are adjusted according to the RMS.

Table 1.

Wk/Day	Products	Changes
894/0	Final	IGS LOD combination/integration officially implemented using only the IERS Bulletin A UT1 values that included 24h VLBI data.
895/0	Rapid	
896/0	Final	IGS LOD combination/integration using observed IERS Bulletin A UT1 values.
898/0	Rapid	
902/0	Rapid only	IGS Rapid submission deadline shortened by two hours (from 24 to 22 hr UTC).
907/0	Final	IGS LOD combination/integration using up to five days prior to the most current observed IERS Bulletin A UT1 values.
908/3	Rapid	
917/0	Final	New EOP comparison table implemented.
919/0	Rapid	
929/0	Final	New IGS LOD weighting scheme based on the AC LOD RMS bias calibration ($1/\text{RMS}^2$) with respect to IERS Bulletin A.
931/0	Rapid	
933/0	Rapid only	Use of EMR UT-derived LOD values in the IGS Rapid LOD combination/integration.
935/0	Final	Non-SA based AC clock alignment and weighting abandoned for a more reliable method using one reference AC, all broadcast satellites and the absolute deviation of AC aligned clocks with respect to the unweighted mean for AC clock weighting.
936/1	Rapid	
938/0	Final	New alignment correction to AC clocks based on the difference in the radial component between AC and IGS combined orbits.
940/1	Rapid	

2.2 IGS LOD/UT Combination

IGS LOD/UT combination was briefly described in the 1996 IGS Annual Report (Kouba and Mireault, 1997) although officially implemented in 1997 only. The IGS Rapid and Final LOD/UT combinations were respectively implemented on Wks 895 and 894.

To summarize, IGS combined LODs are now based on a weighted average of AC LOD solutions that are first calibrated/aligned with respect to IERS Bulletin A over a 21 day period ending five days prior to the last observed (i.e. non-predicted) IERS Bulletin A UT1 value (also called the *anchor* point). The combined IGS LOD values are then integrated into IGS UT starting from the *anchor* point and up to the day required. The integration period is generally 6-10 days for the Rapid combinations and 1-4 days for the Final combinations. Figure 1 presents a schematic view of the LOD combination and integration procedure while section 4 describes in more detail the combination method used.

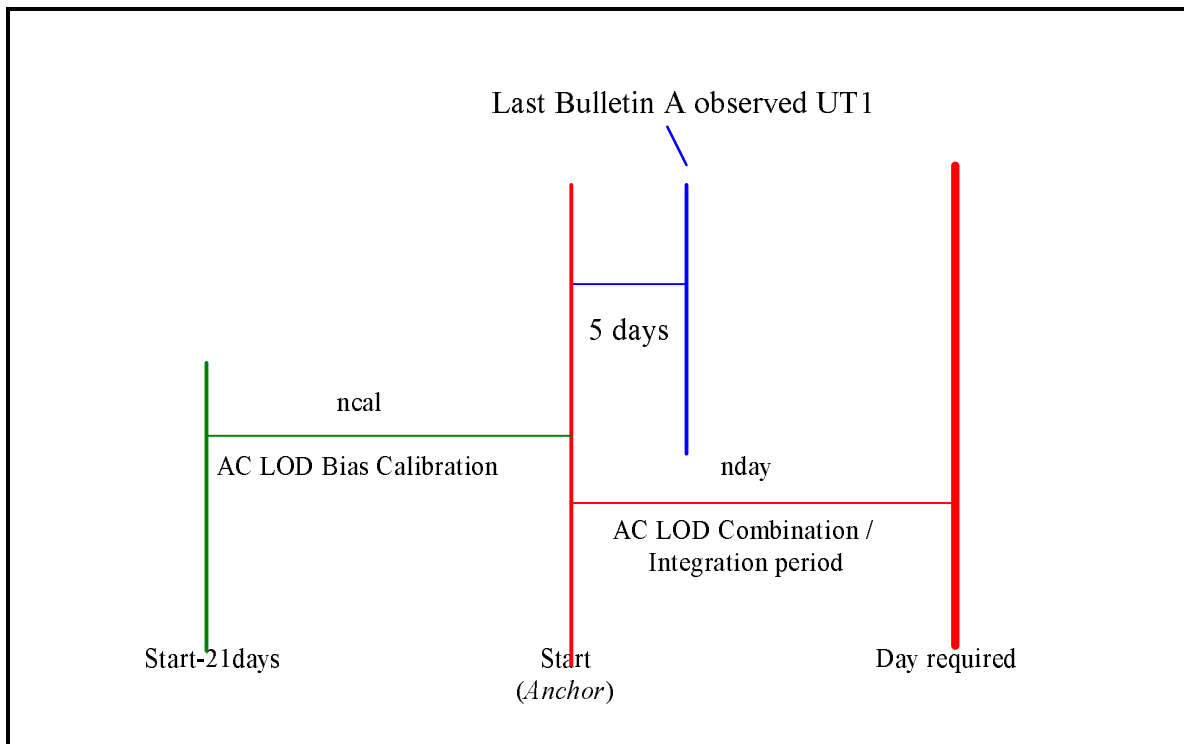


Figure 1.

Initially, only the IERS Bulletin A UT1 values containing 24h VLBI data were used for the LOD calibration and integration. The strategy was modified a few weeks later to also include all observed, i.e. non-predicted values. After extensive testing, it was shown that using IERS Bulletin A UT1 values ending five days prior to the last observed UT1 value would give more optimal and reliable results (Mireault et al., 1997).

At first, as in the IGS Polar Motion (PM) combinations, AC orbit weights were used for AC LOD weights. Other weighting strategies based on AC LOD calibration standard deviation ($1/\sigma^2$) and calibration RMS ($1/\text{RMS}^2$) were tested. The $1/\text{RMS}^2$ weighting scheme produced the best results overall (when compared to IERS Bulletin A) and was therefore implemented. Another improvement (as already noted by (Ray, 1996)) was realized when EMR UT-derived LOD values were used instead of its estimated LOD. Tests were conclusive and the new strategy was immediately implemented (strategy IGR-C-3* in Table 2). LOD strategy changes that occurred in 1997 are listed in Table 1 while Table 2 contains a sample of the results from some of the LOD tests performed.

Table 2. Comparison of strategies of IGS LOD/UT combination and IERS Bulletin A
Product tested: IGS Rapid (IGR)
Period covered: Wk 921/day 0 to Wk 937/day 6

Strategy used	UT Comparison wrt IERS Bulletin A RMS (μ sec)	RMS Improvement (%)
IERS Bulletin A (originally)	377	---
IGR-A-1	162	57
IGR-B-1	158	58
IGR-C-1	137	64
IGR-C-2	127	66
IGR-C-3	121	68
IGR-C-3*	96	75

Description of IGR LOD combination/integration strategies used:

IERS Bulletin A (originally): UT values taken directly from IERS Bulletin A (at the time of the combination);

(A): IGR LOD combination with AC LOD bias calibration based on IERS Bulletin A UT1 values that included 24h VLBI data;

(B): IGR LOD combination with AC LOD bias calibration based on all observed (i.e. non predicted) IERS Bulletin A UT1;

(C): IGR LOD combination with AC LOD bias calibration based on IERS Bulletin A UT1 values ending five days prior to its last observed UT1 value;

(1): AC LOD weights from AC orbit combinations;

(2): AC LOD weights based on the standard deviation of AC LOD bias calibration wrt IERS Bulletin A ($1/\sigma^2$);

(3): AC LOD weights based on the RMS of AC LOD bias calibration with respect to IERS Bulletin A ($1/\text{RMS}^2$);

(*): Use of EMR UT-derived LOD and use of AC LOD for all others.

2.3 New EOP Comparison Table

In order to have a closer look at the AC EOP performance, a new EOP comparison table was introduced in the IGS/IGR summary reports (August, 1997). The new table shows the difference between IGS/IGR combined values and the AC individual contributions for the Earth Rotation Parameters (ERP: Xpole, Ypole, Xrt, Yrt) and Length Of Day (LOD). Table 3 shows an example of the new table (*Table 4. www.d*) for the IGS Rapid combination of GPS Wk 933 day 2. It includes a header describing the EOP involved, the units and some short explanatory comments on flags used. The table is divided into 3 sections: (1) AC names and flags used; (2) ERP (i.e. Xpole, Ypole, Xrt,

Yrt) and LOD comparisons of IGR versus each AC (IGR-AC) and (3) LOD bias estimation summary with respect to IERS Bulletin A.

Table 3.

Table 4: Earth Orientation Parameters daily summary.

Daily Centre ERP, ERP Rates and LOD differences with respect to IGR combined values.

Xpole,Xrt: x pole and x pole rate (10^{-5} ")
 Ypole,Yrt: y pole and y pole rate (10^{-5} " /day)
 LOD: Length Of Day (μ sec)

AC LOD BIAS: 21-day mean LOD bias with respect to Bulletin A (us)
 AC LOD BIAS RMS: RMS of AC LOD BIAS (us)

FLAG: "u" (used), "x" (excluded), "-" (no submission)
 for Xpole, Ypole, Xrt, Yrt and LOD

A star ("*") beside the AC name indicates that AC LOD values were derived from AC UT1-UTC values.

Table 4.0933.2 GPS week: 0933 Day: 2 MJD: 50777.5

CENT	FLAG		Xpole	Ypole	Xrt	Yrt	LOD		AC LOD	
									BIAS	BIAS RMS
cod	uuuuu		-30	44	-6	48	-27		-14	55
emr*	uuuuu		25	-48	102	-102	12		4	29
esa	uuuuu		-5	16	-90	-41	-9		3	61
gfz	uuuuu		-1	-5	11	13	-9		-1	32
jpl	uuuuu		59	-49	27	71	1		7	32
ngs	uuuuu		-81	-87	-148	-75	-15		28	56
sio	uuuuu		-54	76	-18	68	-29		-14	185
usn	uuuuu		34	-29	21	-70	24		12	48

For the Final combinations, one week of daily EOP Tables (*Table 7.www.d*) are generated preceded by a weekly summary Table (*Table 6.www.d*) compiling statistics for the whole week.

2.4 Clock Combinations

Almost from the beginning of the IGS, the AC clock weighting strategy has been based on the absolute deviation of AC initial clock alignment with respect to the broadcast satellites without Selective Availability (SA) (3 satellites at the beginning). Now, since only one non-SA satellite remains (PRN15) this clock weighting strategy has become unreliable.

Given the good performance of AC clock corrections during 1997, it was decided to change from the clock combination weighting strategy based on non-SA satellites, to the following one: a chosen reference AC is aligned to the broadcast GPS clocks using all satellites, then all other ACs are aligned to that reference AC. The clock weights are computed from the absolute deviation of the AC aligned clock corrections with respect to the unweighted mean. This strategy was used whenever the alignment using non-SA

satellites gave inappropriate weights and unrealistic clock RMS. It was also used early in 1994 (Kouba et al., 1995) before the non-SA strategy weighting scheme was introduced. A strength of this method is that it does not really matter which AC is chosen for reference as long as it has a very high number of relatively good clock corrections and no clock resets. Its biggest advantage is that AC solutions showing poor performance are greatly down-weighted resulting in more precise and consistent IGS combined clock corrections without having to explicitly exclude any AC solutions, thus making the procedure easier and faster to execute. This strategy was reinstated in the Rapid and Final clock combinations starting Wk 936/day 1 and Wk 935/day 0 respectively.

To further improve the consistency of IGS orbits and clocks, a new alignment correction to AC clocks, based on the difference in the radial component between AC and IGS combined orbits, was implemented. A first attempt was made almost 3 years ago but no improvement was noticed at that time due to the then higher AC clock RMS (~ 1.0 ns then compared to ~ 0.3 ns now). Considering the above two changes, tests using precise point positioning (Springer et al., 1998) have shown a factor of two improvement over using the former non-SA satellite weighting method. With the latest implementations in the IGS satellite clock combination, typical repeatability of 10 mm horizontal and 14 mm vertical was found for stationary site coordinates (Springer et al., 1998). This strategy was implemented on Wk 938/day 0 and Wk 940/day 1 (late 1997 and early 1998) for both the Final and Rapid combinations respectively.

3 Orbit and Clock Evaluations

The Long Arc (LA) orbit evaluation was described in more detail in the IGS 1994 Annual Report (Kouba et al., 1995) and, therefore will not be described here. Note though, that LA evaluation is only performed for the Final orbit products that are generated on a weekly cycle. LA RMS are presented in Figure 29.

Between January 1996 and March 1998, the IGS combined orbits/clocks as well as all AC solutions which contain both the orbit and clock corrections data, have been further evaluated by an independent single point positioning program (navigation mode) developed at NRCan (GPSPACE or GPS Positioning from Active Control System (ACS) Clocks and Ephemerides). This was done to verify clock solution precision and orbit/clock consistency for both the Rapid and Final orbit/clock products. Pseudorange data from three stations (BRUS, USUD and WILL) were used daily and their corresponding position RMS (with respect to ITRF94) are summarized in the Rapid/Final summary reports. Tables 4a and 4b summarize the point positioning results obtained from both the Rapid and Final orbit/clock products for 1997. Note that the IGR orbits/clocks are included in the Final IGS summary reports for performance comparison, i.e. they are not used in the IGS Final combinations. For most ACs, both Rapid and Final 3D Navigation RMS ranged from ~ 30 cm to ~ 65 cm overall (depending on the station processed) with the height component being the least precise.

Starting March 1998, the daily precise navigation statistics found in the IGS reports are now based on receiver phase data using JPL's GISPY-OASIS II point positioning capability recently installed at NRCan. Section 6 gives more details.

Table 4a. 1997 IGS Rapid Combination Point Positioning RMS using GPSPACE
(Pseudorange data - navigation mode) for ACs providing orbit/clock solutions

ACs	BRUS				USUD				WILL			
	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
emr	47	36	93	63	37	29	79	53	27	18	47	33
esa	88	55	126	94	61	52	138	92	37	30	70	49
gfz	52	37	101	69	53	32	87	62	31	20	54	38
igr	48	35	91	63	38	29	81	54	27	18	48	33
jpl	48	35	92	63	37	27	78	52	27	17	46	32
usn	48	38	98	67	41	31	89	59	29	19	50	35

Table 4b. 1997 IGS Final Combination Point Positioning RMS using GPSPACE
(Pseudorange data - navigation mode) for ACs providing orbit/clock solutions

ACs	BRUS				USUD				WILL			
	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
cod	49	36	97	66	37	29	79	53	26	17	46	32
emr	50	36	99	67	37	29	79	53	27	18	48	33
esa	57	39	100	70	43	33	89	60	33	23	57	40
gfz	51	39	96	67	39	31	82	55	29	21	53	37
igs	48	36	96	65	37	29	80	53	27	17	48	33
jpl	49	36	98	66	36	28	79	53	27	16	46	32

Period covered: GPS Wks 886-937 (Dec.29/1996-Dec.27/1997)

Units: centimeters (cm)

RMS \geq

4 IGS Orbit, Clock and EOP Combinations by Weighted Average: Method Description

Table 5 summarizes the Prediction, Rapid and Final combination procedures for the orbit, clock and EOP products at the end of 1997. Changes that occurred during the year are listed in Table 1. A more detailed description including the formulas involved in the orbit/clock combinations can be found in the IGS 1994 Annual Report (Kouba et al., 1995). Two different procedures for the EOP combination are used, one for Xpole, Ypole, Xrt and Yrt (group I) and another for LOD/UT (group II).

Table 5. Orbit, clock and EOP combination/evaluation procedures at the end of 1997

<p>1. Long Arc Ephemerides Evaluation for each AC: <i>Final Combination:</i> seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined; <i>Prediction and Rapid Combinations:</i> none</p>
<p>2. Transformation to Common Reference: (a) Orbit <i>Prediction, Rapid and Final Combinations:</i> performed directly in the ITRF94 reference frame without EOP alignment; (b) Clock <i>Rapid and Final Combinations:</i> are aligned with respect to broadcast GPS clock corrections. First, a reference AC is aligned to the broadcast GPS clocks using all satellites and then each AC is aligned to the reference AC. <i>Prediction Combination:</i> none</p>
<p>3. Orbit and Clock Combinations: <i>Prediction, Rapid and Final Combinations:</i> AC orbit weights are computed from absolute deviations with respect to unweighted mean orbits; satellite ephemerides are then combined as weighted averages of AC solutions. <i>Rapid and Final Combinations:</i> AC clock weights are computed from the absolute deviation of the AC aligned clock corrections with respect to the unweighted mean; Satellite clock corrections are then combined as weighted averages of AC solutions. <i>Prediction Combination:</i> none (CODE's predicted clock corrections are used for IGP predicted clock corrections).</p>
<p>4. EOP Combination: <i>Rapid and Final Combinations:</i> PM x and y and PM rates are combined as weighted averages from available AC EOP values using orbit weights. <i>Rapid and Final Combinations:</i> AC LOD alignment is based on comparisons with the IERS Bulletin A during the three week period ending five days before the last observed Bulletin A daily value. AC LODs are then combined as weighted averages according to the AC LOD alignment RMS. IGS LODs are then integrated into IGS UTs. <i>Prediction Combination:</i> PM x and y, PM rates, LODs and UTs are taken directly from the most current IERS Bulletin A.</p>
<p>5. Long Arc Ephemerides Evaluation for the IGS Combined Orbits: <i>Final Combination:</i> seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and RMS residuals are examined. <i>Prediction and Rapid Combinations:</i> none.</p>
<p>6. Independent Point Positioning Evaluation (navigation mode): <i>Rapid and Final Combinations:</i> all AC solutions which contain orbits and clocks (including IGS/IGR combinations) are evaluated using the three IGS stations: BRUS, USUD and WILL. <i>Prediction Combination:</i> none.</p>

Group I: ERP (Xpole, Ypole, Xrt, Yrt)

The parameters in the first group are combined as a straightforward weighted mean of AC (Cent) available values using AC orbit weights (eqn. 1).

$$\overline{\text{ERP}}_{\text{Comb}} = \sum_{\text{Cent}}^{\text{Ncent}} \text{ERP}_{\text{Cent}} \cdot W_{\text{Cent}}^{\text{Orb}} \quad (1)$$

where: $W_{\text{Cent}}^{\text{Orb}}$ is the AC orbit weight (Kouba et al., 1995) and

$\overline{\text{ERP}}_{\text{Comb}}$ is the combined IGS value of one of the parameters of group I.

Group II: LOD/UT

Initially, each AC LOD series is calibrated with respect to the IERS Bulletin A. This is done by estimating a 21-day calibration (ncal) bias between IERS Bulletin A and each AC individually (eqn. 2). AC LOD values from day “Start” (or *anchor* point) and up to the day required (nday total) are then properly corrected (eqn. 3) before combining them to form IGS combined LOD values (eqn. 4). AC LOD weights are based on the bias calibration RMS from (eqn. 2) and given explicitly in (eqn. 5 and 6). Finally, IGS combined LODs from (eqn. 4) are integrated into IGS UTs (eqn. 7) from the *anchor* point up to the day required. All the equations are given below. Figure 1 illustrates the general procedure.

$$\text{Bias}_{\text{Cent}} = \frac{\sum_{\text{ical}}^{\text{ncal}} (\text{LOD}_{\text{Bull.A}} - \text{LOD}_{\text{Cent}})}{\text{ncal}} \quad (2)$$

$$\text{LOD}'_{\text{Cent}_{\text{iday}}} = \text{LOD}_{\text{Cent}_{\text{iday}}} + \text{Bias}_{\text{Cent}} \quad \text{iday} = 1, \text{nday} \quad (3)$$

$$\overline{\text{LOD}}_{\text{comb}_{\text{iday}}} = \sum_{\text{Cent}}^{\text{Ncent}} W_{\text{LOD}_{\text{Cent}}} \cdot \text{LOD}'_{\text{Cent}_{\text{iday}}} \quad \text{iday} = 1, \text{nday} \quad (4)$$

where:

$$W_{\text{LOD}_{\text{Cent}}} = \frac{1}{\text{RMS}_{\text{Bias}_{\text{Cent}}}^2} \quad (5)$$

$$\text{RMS}_{\text{Bias}_{\text{Cent}}} = \sqrt{\frac{\sum_{\text{ical}}^{\text{ncal}} (\text{LOD}_{\text{Bull.A}} - \text{LOD}_{\text{Cent}})^2}{\text{ncal}}} \quad (6)$$

Finally,

$$\overline{UT}_{comb_{iday}} = UT_{Bull.A_{Start}} - \sum_i^{iday} \overline{LOD}_{Comb_i} \quad iday = 1, nday \quad (7)$$

where:

- “Start” is 5 days prior to the IERS Bulletin A last observed UT1,
- $LOD_{Bull.A}$ is IERS Bulletin A UT1-derived LOD,
- LOD_{Cent} is the AC LOD or AC UT-derived LOD (in the case of EMR),
- $Bias_{Cent}$ is the AC LOD calibration bias,
- LOD'_{Cent} is the corrected AC LOD or AC UT-derived LOD (e.g. EMR),
- \overline{LOD}_{Comb} is the estimated IGS combined LOD,
- “ncal” is the number of calibration days (maximum 21),
- “nday” is the number of combination/integration days,
- $UT_{Bull.A_{Start}}$ is the IERS Bulletin A UT1 starting or *anchor* value, and,
- \overline{UT}_{Comb} is the estimated IGS combined UT.

5 IGS Prediction, Rapid and Final Combination Results in 1997

In this section, results for the fourth year of IGS service, i.e. December 29, 1996 to December 27, 1997 (Wks 886-937), are presented.

Tables 6 and 7 show the Prediction and Rapid product statistics of the translation, the rotation, and the scale parameters from the daily Helmert transformations with respect to the IGS Rapid (IGR) orbits. Similarly, Table 8 shows the Final product statistics of the same parameters but this time with respect to the IGS Final orbits. A complete series in each table would have 364 days except for EMP (Table 6) which started on Wk 887 / day 5 (352 days), ESP (Table 6) which started on Wk 899 / day 3 (270 days) and USN (Table 7) which started its Rapid contribution on Wk 902 / day 3 (249 days). Note also that rotations (RX, RY and RZ) greater than 5 mas in Table 7 were excluded from the AC means and standard deviations for more meaningful AC overall statistics.

Figures 2-9 (Prediction products) and Figures 10-17 (Rapid products) display, for each AC, the daily translations, rotations and scales of the X, Y and Z satellite coordinates with respect to the IGS Rapid orbits (IGR). Broadcast results (Figure 2) are included for comparison only and do not contribute to the IGS orbit and clock combinations except for the AC Rapid clock alignment. In Figure 2, each translation and rotation series are offset by 1.0 m and 20 mas respectively for visibility.

Table 6. IGS Prediction Combination - GPS Wks 886-937 (performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (m)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
brd	μ	0.01	0.03	0.02	0.52	-0.50	4.36	-3.1	364
	σ	0.12	0.13	0.28	2.69	4.44	6.92	2.8	
cop	μ	0.00	0.02	-0.03	-0.52	0.11	0.15	-0.2	364
	σ	0.02	0.02	0.06	0.97	1.30	3.32	0.5	
emp	μ	0.00	0.02	-0.01	0.35	0.08	-0.04	-0.1	346 ⁽¹⁾
	σ	0.02	0.02	0.04	1.16	1.75	7.09	0.7	
esp	μ	0.00	0.02	-0.01	0.67	0.21	0.66	0.2	256 ⁽²⁾
	σ	0.02	0.02	0.04	0.98	1.59	5.52	0.5	
gfp	μ	0.00	0.02	0.01	0.42	0.25	-0.45	-0.3	342
	σ	0.01	0.01	0.03	1.78	1.63	2.47	0.6	
jpp	μ	0.00	0.02	0.00	0.07	-0.44	-0.13	0.2	363
	σ	0.01	0.01	0.04	2.10	2.65	2.66	0.7	
sip	μ	0.00	0.02	0.00	-0.44	0.05	-2.21	-0.1	337
	σ	0.03	0.03	0.07	1.26	1.26	8.20	1.2	
igp	μ	0.00	0.02	0.00	0.02	0.00	-0.25	-0.1	364
	σ	0.01	0.01	0.03	0.92	1.13	2.57	0.4	

(1): emp submissions started only on Wk 887 day 5 (Maximum 352 days)

(2): esp submissions started only on Wk 899 day 3 (Maximum 270 days)

In Figures 3-9, each translation and rotation series are offset by 0.2 m and 10 mas respectively. Finally, in Figures 10-17, the translation series are offset by 0.1 m and each rotation/pole difference series are offset by 2 mas respectively.

Figures 18-25 show the Final results for the same daily transformation parameters but this time with respect to the Final IGS orbits. IGR results (Figure 25) are included for comparison only and do not contribute to the IGS orbit and clock combinations. Again for visibility, the same offsets, i.e. 0.1 m for the translation series and 10 mas for the rotation/pole difference series were used. Figures 10-25 (middle plots) display, in addition to the rotations in X, Y and Z, the PM differences with respect to IGR/IGS. This was added to monitor AC orbit/EOP consistency and performance. PM differences in y/x should correspond to orbital X/Y rotations respectively. A perfect correlation would be translated as a 1.0 value in Figure 26, which shows the correlation coefficient of each AC X/Y rotations versus AC PM differences in y/x for the same period as shown in Figures 10-25.

Table 7. IGS Rapid Combination - GPS Wks 886-937 (performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (m)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
cod	μ	0.00	0.02	-0.01	-0.59	0.11	0.09	-0.2	363
	σ	0.01	0.01	0.01	0.35	0.29	0.29	0.2	
emr	μ	0.00	-0.01	0.00	0.36	-0.02	0.12	-0.1	325
	σ	0.01	0.02	0.01	0.47	0.39	0.44	0.2	
esa	μ	0.00	0.01	0.00	0.03	-0.20	0.19	0.2	334
	σ	0.01	0.02	0.01	0.35	0.38	0.38	0.2	
gfz	μ	0.00	-0.03	0.01	0.23	0.10	-0.33	-0.1	322
	σ	0.01	0.01	0.01	0.44	0.35	0.44	0.2	
jpl	μ	0.01	0.02	0.00	-0.06	-0.14	0.06	0.1	283
	σ	0.01	0.02	0.01	0.35	0.28	0.31	0.2	
ngs	μ	0.00	-0.04	-0.01	0.22	0.14	-0.06	-0.2	315
	σ	0.02	0.02	0.02	0.58	0.50	0.47	0.3	
sio	μ	0.00	0.02	0.00	-0.34	0.02	-0.44	0.2	311
	σ	0.01	0.02	0.02	0.67	0.40	1.90	0.5	
usn	μ	0.00	-0.03	0.00	0.34	0.00	0.22	0.2	219 ⁽¹⁾
	σ	0.02	0.04	0.02	0.48	0.43	0.37	0.2	

(1): usn submissions started on Wk 902 day 3 (Maximum 249 days)

Note also that Rotations (RX,RY,RZ) greater than 5.0 mas were not included in AC means and standard deviations for more meaningful annual statistics. Number of outliers: esa:2; gfz:1; jpl:3; sio:22; usn:4.

The AC Rapid correlations show a slightly more consistent orbit/EOP series than the Final. However, in almost all cases, the consistency improved between the first and second half of 1997.

Figure 27 shows the orbit coordinate RMS of all AC Prediction submissions with respect to the IGS Rapid (IGR) combinations. Two types of RMS are displayed: the combination RMS median (i.e. the median of all AC satellite combination RMS) and the weighted combination RMS (WRMS). Similarly, Figure 28 shows orbit coordinate RMS of all AC Rapid submissions with respect to the IGR combinations. Finally, Figure 29 shows the AC Final submission orbit RMS results where the combination RMS median was replaced by the 7-day Long Arc RMS. Figures 30-31 show the AC Prediction and Rapid clock RMS respectively with respect to IGR and Figure 32 displays AC Final clock RMS with respect to the IGS Final clocks.

Table 8. IGS Final Combination - GPS Wks 886-937 (performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (m)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
cod	μ	0.00	0.01	-0.01	-0.27	0.11	0.22	-0.2	364
	σ	0.00	0.01	0.01	0.18	0.13	0.22	0.1	
emr	μ	0.00	-0.01	-0.01	0.38	-0.07	0.43	-0.1	357
	σ	0.01	0.01	0.01	0.21	0.17	0.38	0.2	
esa	μ	0.00	0.00	0.00	0.05	-0.13	0.15	0.1	364
	σ	0.01	0.01	0.01	0.23	0.20	0.21	0.1	
gfz	μ	0.00	0.00	0.01	0.11	0.06	-0.21	-0.1	364
	σ	0.00	0.01	0.01	0.16	0.13	0.20	0.1	
jpl	μ	0.00	0.01	0.00	-0.04	-0.12	0.02	0.3	357
	σ	0.01	0.01	0.01	0.16	0.10	0.12	0.1	
ngs	μ	0.00	-0.05	0.00	0.20	0.25	-0.13	-0.1	364
	σ	0.01	0.01	0.02	0.45	0.30	0.36	0.2	
sio	μ	0.00	0.01	0.00	-0.01	0.17	-0.36	0.2	336
	σ	0.01	0.01	0.01	0.31	0.66	0.30	0.4	
igr	μ	0.00	-0.01	0.00	0.10	0.10	-0.03	0.0	364
	σ	0.01	0.01	0.01	0.23	0.21	0.25	0.1	

The predicted broadcast clocks (IGP) are provided by COD (COP). BRD and IGR clocks/orbits are always used for comparison purposes only. Note that COD (Rapid) and NGS (Rapid and Final) clocks correspond to broadcast clocks as provided by the satellite navigation message (therefore not included in the clock combination) and that SIO (Rapid and Final) does not provide any clock corrections. As mentioned in previous Annual Reports, erroneous satellite orbit and clock solutions are excluded from the combination if they bias the IGS combined solution but are always included in the RMS computation.

All exclusions are reported in the IGS weekly/daily combination reports. IGS predicted clocks (IGP) are at the same precision level as the broadcast clocks but with more outliers. IGS Rapid and Final clock results have reached the 0.2-0.3 ns precision level with the Final combination results being slightly more consistent. The predicted orbit precision (IGP) has reached the ~50 cm RMS median level which is considerably better than the ~200 cm for the broadcast orbits. As expected, predicted orbits have occasional outliers caused by unpredictable satellite events. Rapid and Final orbit position precision are below the 10 cm and at, or below, the 5 cm level respectively. Again, the Rapid results are somewhat noisier than the Final results due mostly to the very short delivery time which causes occasional lack of tracking data (submission deadline of 21 hours).

6 1998 and Future Improvement

By the time this report is published, at least two new major enhancements will have already been implemented. Starting March 1, 1998 (Wk 947), the new ITRF96 reference system will be used for all IGS products. Also in March 1998, (Wks 948 and 950 for IGS Final and IGS Rapid respectively), a new precise point navigation program utilizing phase instead of pseudorange data, will have been implemented. A brief summary was already given in the Volume I of this year's Annual Report (Kouba, 1998) and a more thorough analysis will be presented in next year's Annual Report. Figure 33 shows an example of IGR and IGS performance using this point positioning approach. When fixing IGS orbits/clocks, navigation positioning precision of only a few cm is now possible anywhere in the world without the need for any base station data. Current IGS sp3 clock sampling of 15 minutes and SA limit navigation to 15 min intervals only. For higher sampling, more frequent IGS clocks are needed to allow precise interpolation of the SA clock effects.

6 Summary

1997 was again a very busy year for both the ACs and the IGS AC coordinator. ACs have again improved the reliability and precision of their products or at least maintained the quality level already reached in the past, which in itself is quite an accomplishment. By the end of 1997, the best AC orbit solutions were at or below the 5 cm level for the Final solutions and between 5-10 cm for the Rapid solutions. Prediction orbit precision, a new product made available in 1997, has a RMS median of ~50 cm or lower compared to ~200 cm for the broadcast orbit. Better AC clock corrections along with improved clock combination strategies resulted in combined clock correction precision reaching an unprecedented 0.2–0.3 ns level (and as precise as 0.1 ns on some occasions!) for both the Rapid and Final solutions. The IGS LOD combination and integration into IGS UT were also introduced in 1997. Several combination strategies were tested and implemented throughout the year resulting each time in a more precise and consistent IGS LOD/UT series when compared to IERS Bulletin A. A new EOP comparison table to monitor AC EOP performance was also added to the IGR/IGS summary reports. Finally, AC Rapid combination submission deadline was advanced by 2 hours, i.e. from 24 to 22 hours UTC, allowing ACs to use IGR in their orbit predictions.

7 References

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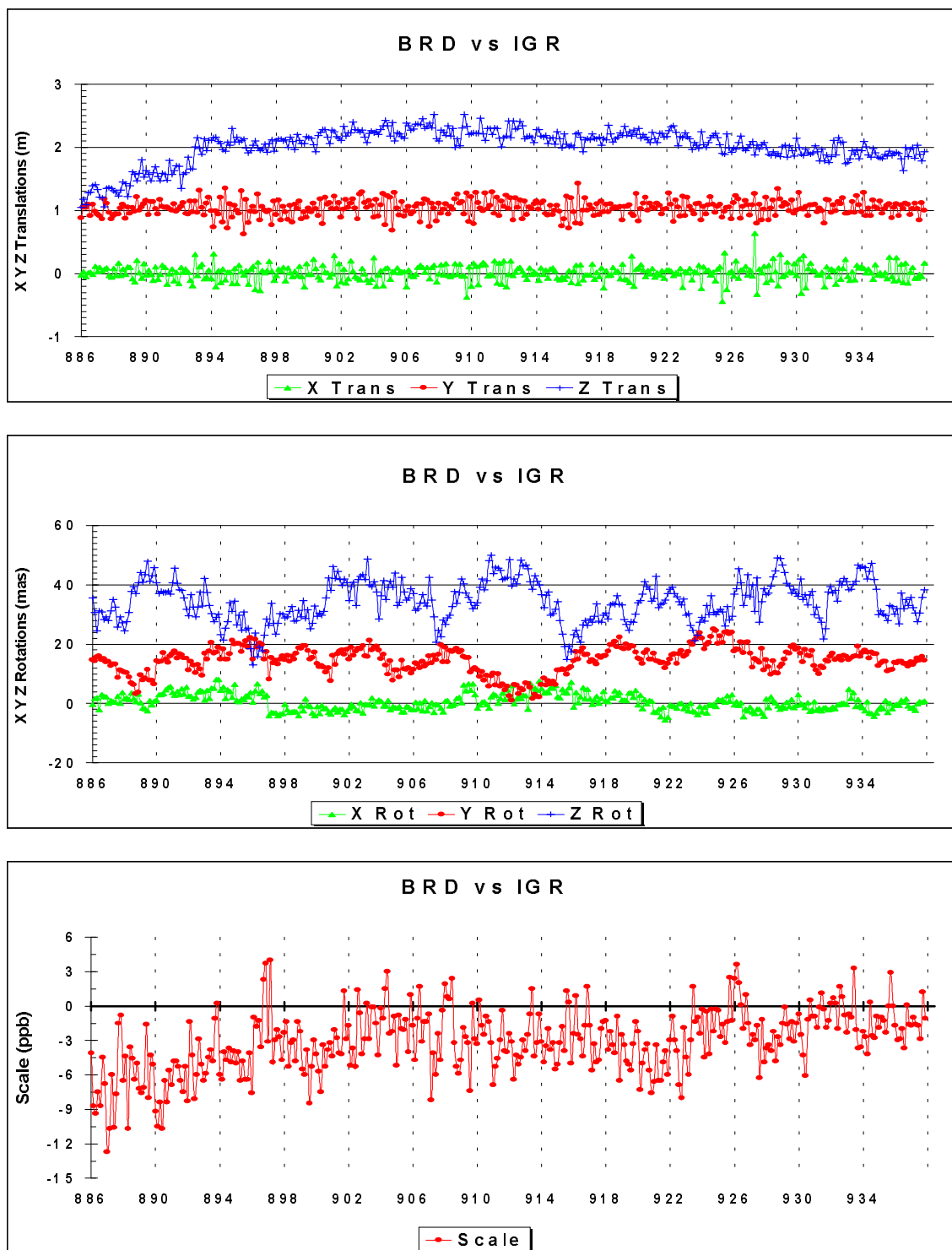


Figure 2. Daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 20 mas)

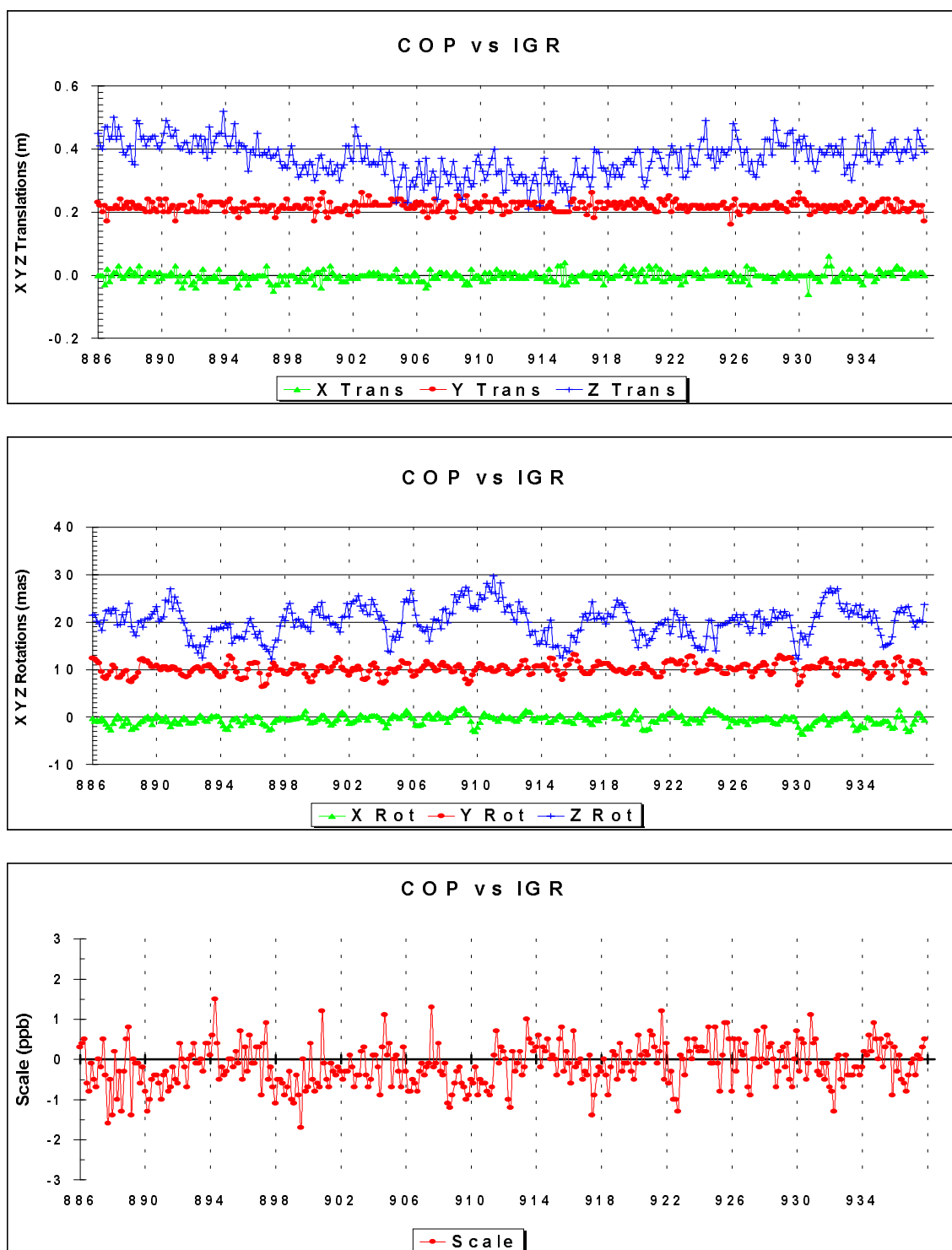


Figure 3. COP 1997: Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 0.2 metre; X, Y and Z Rotations are each offset by 10 mas)

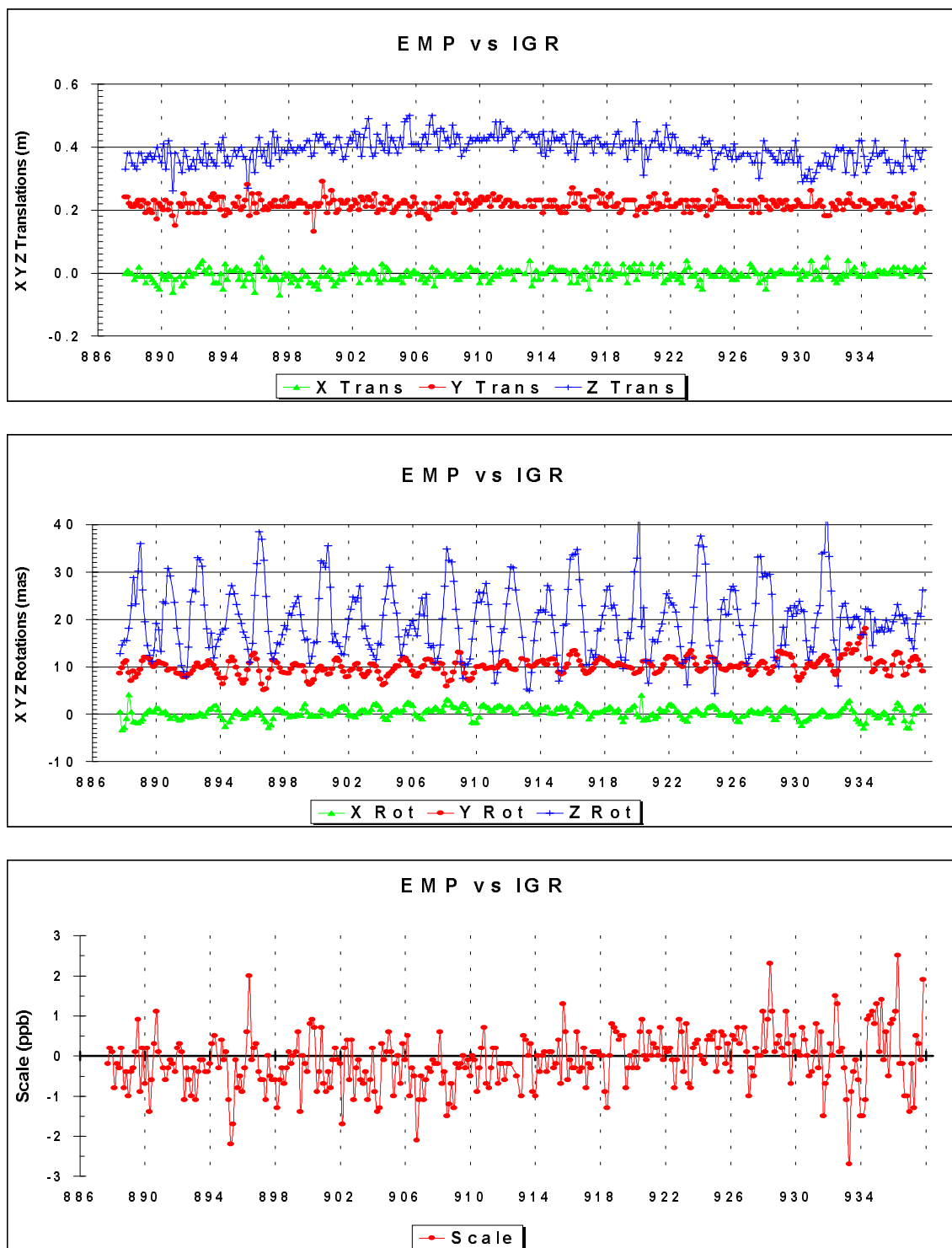


Figure 4. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

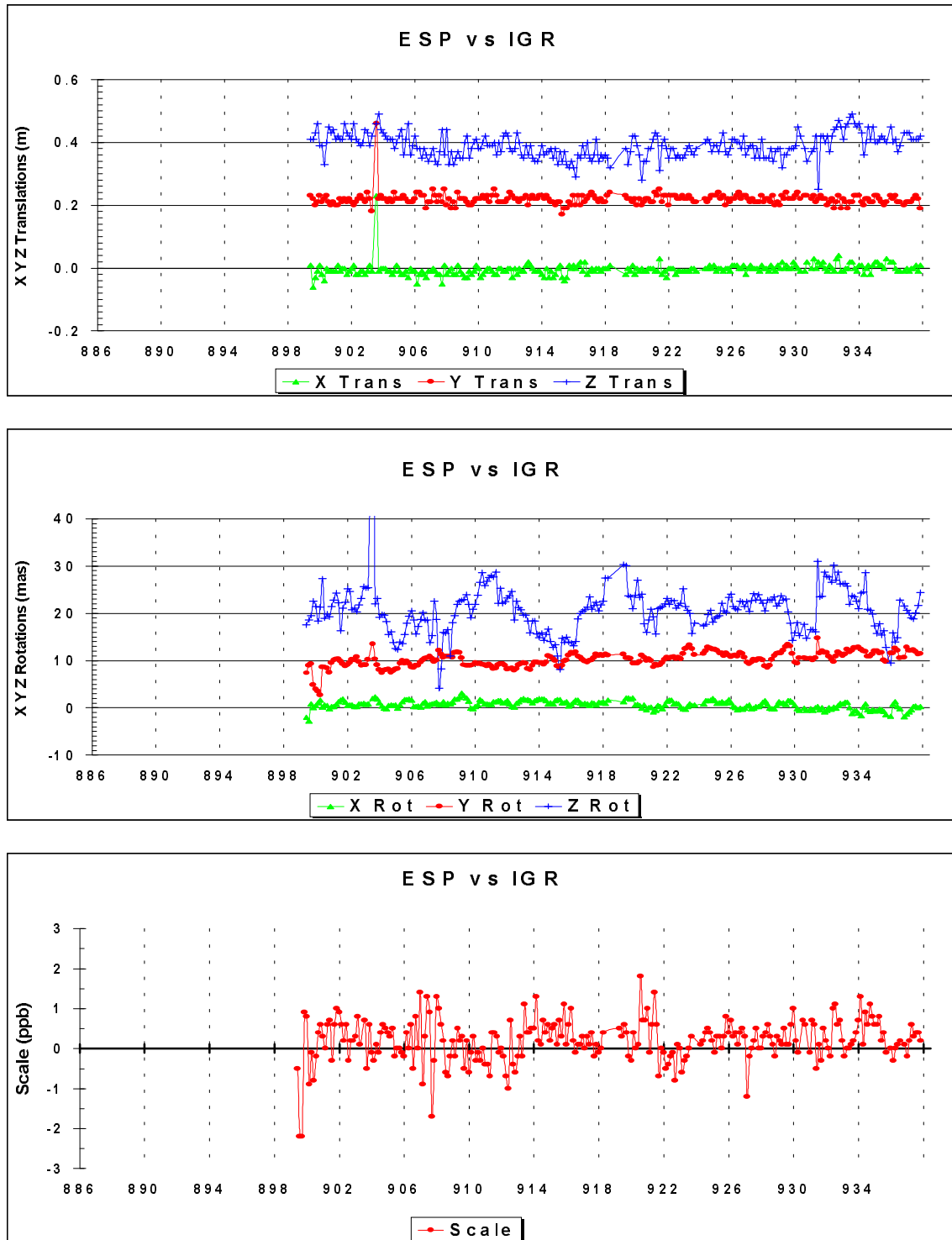


Figure 5. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

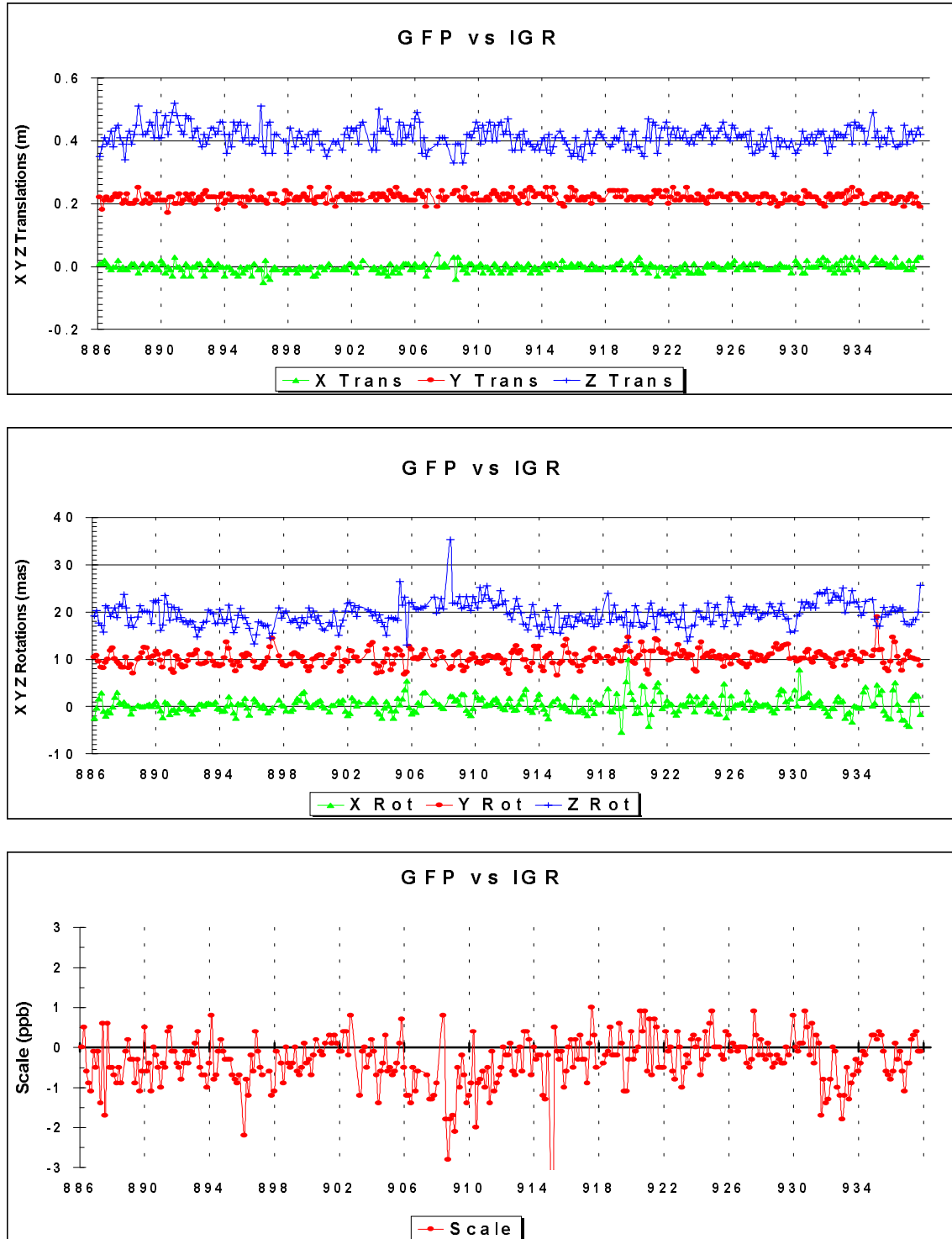


Figure 6. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

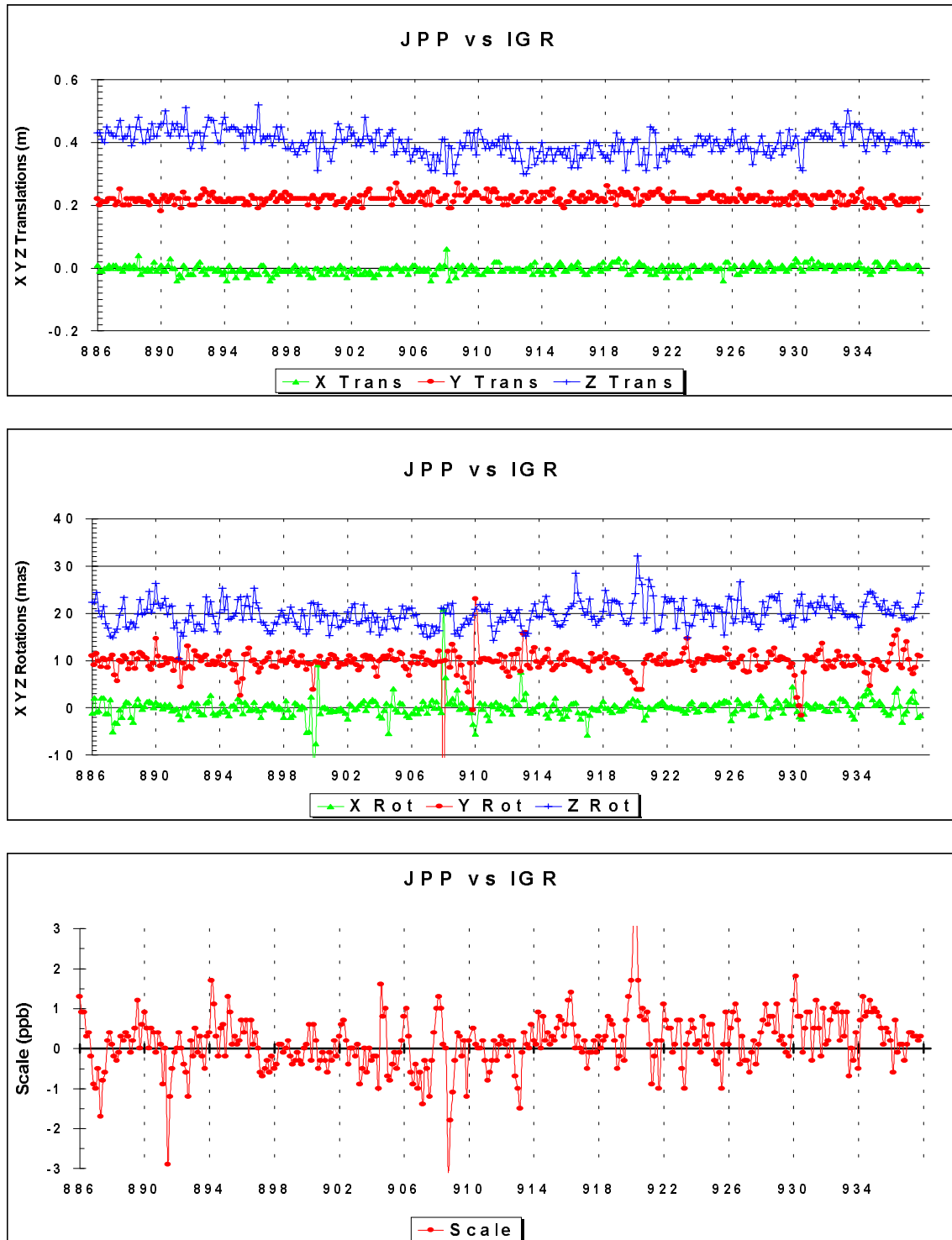


Figure 7. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

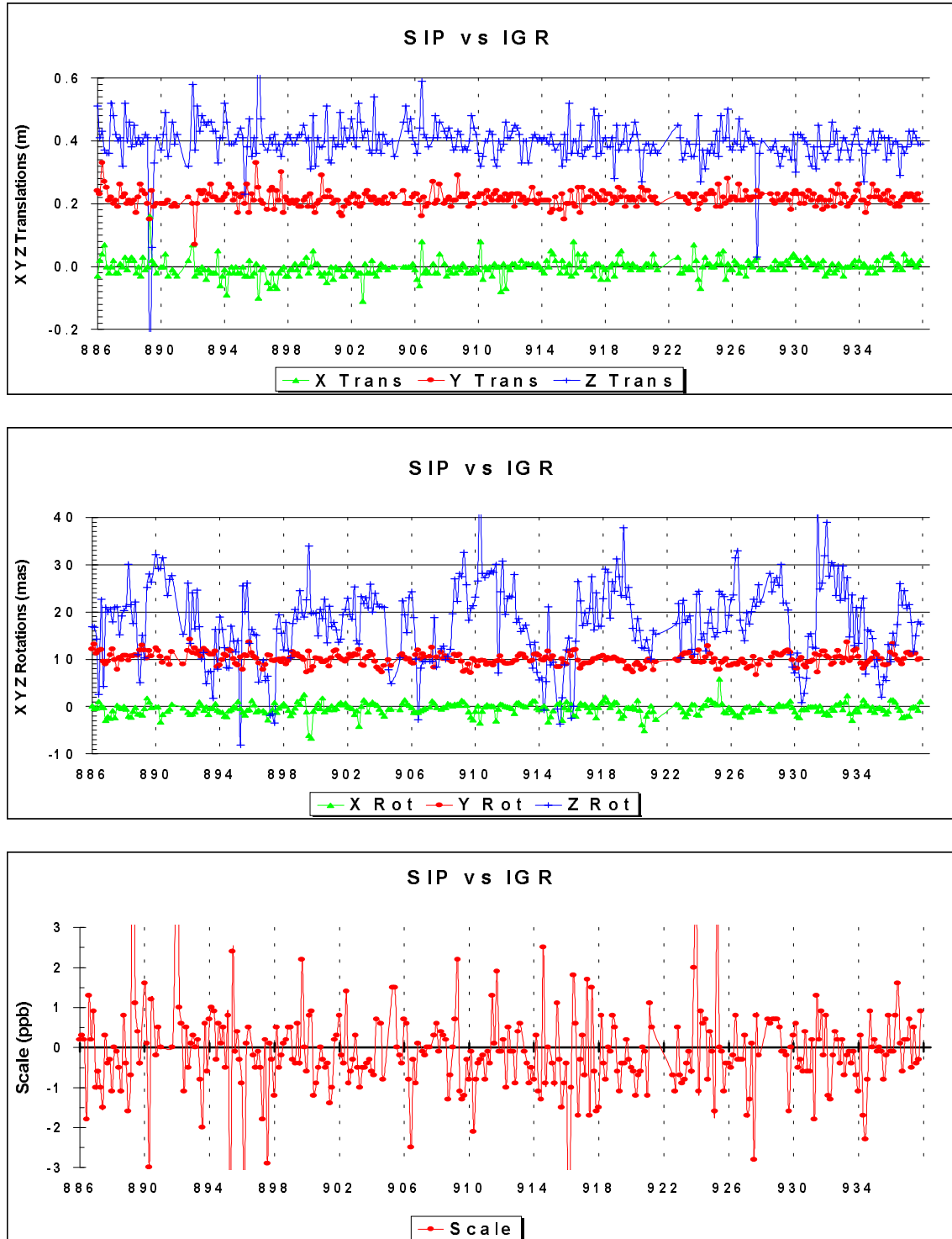


Figure 8. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

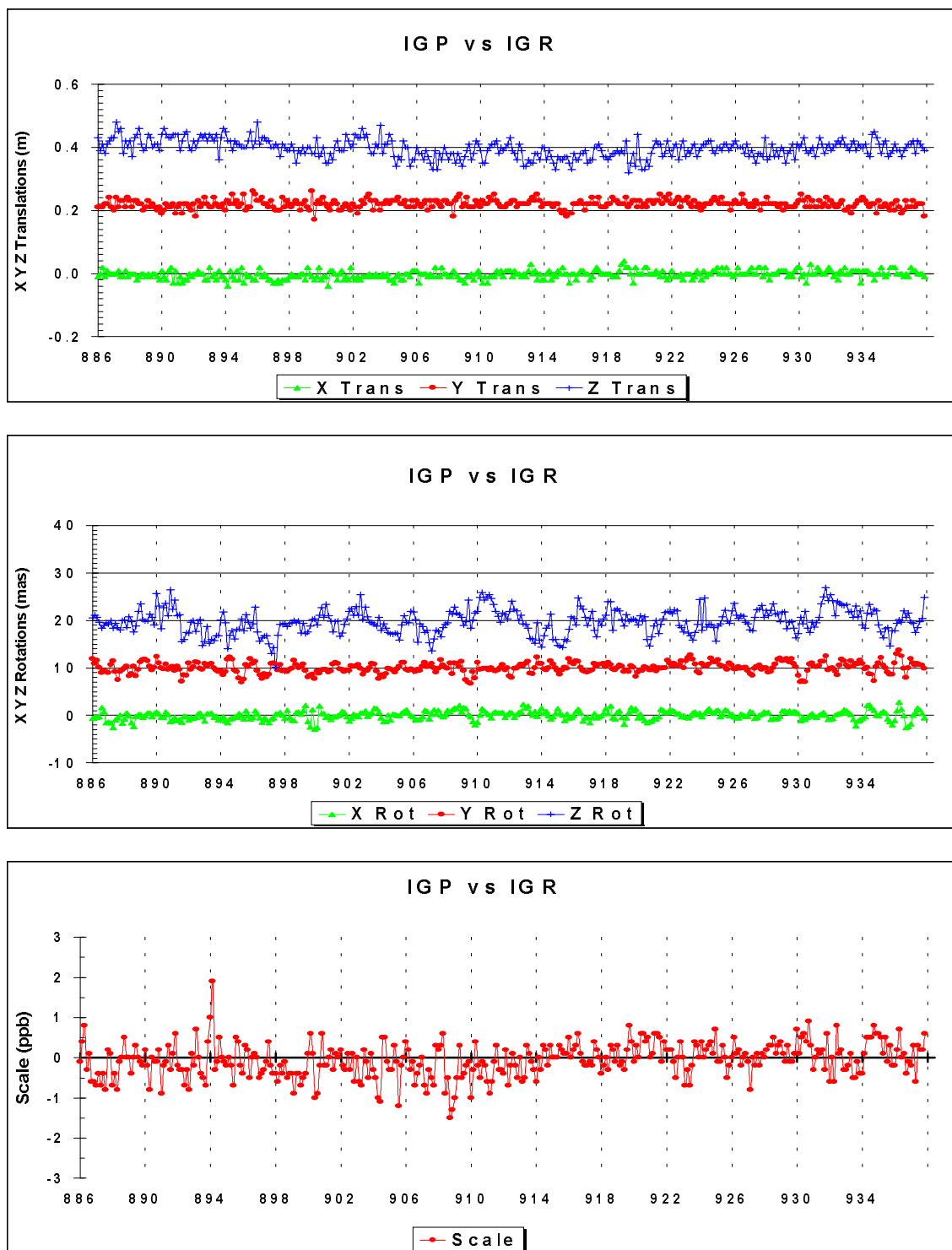


Figure 9. Prediction daily seven-parameter Helmert (X, Y and Z Translations are each offset by 1 metre; X, Y and Z Rotations are each offset by 10 mas)

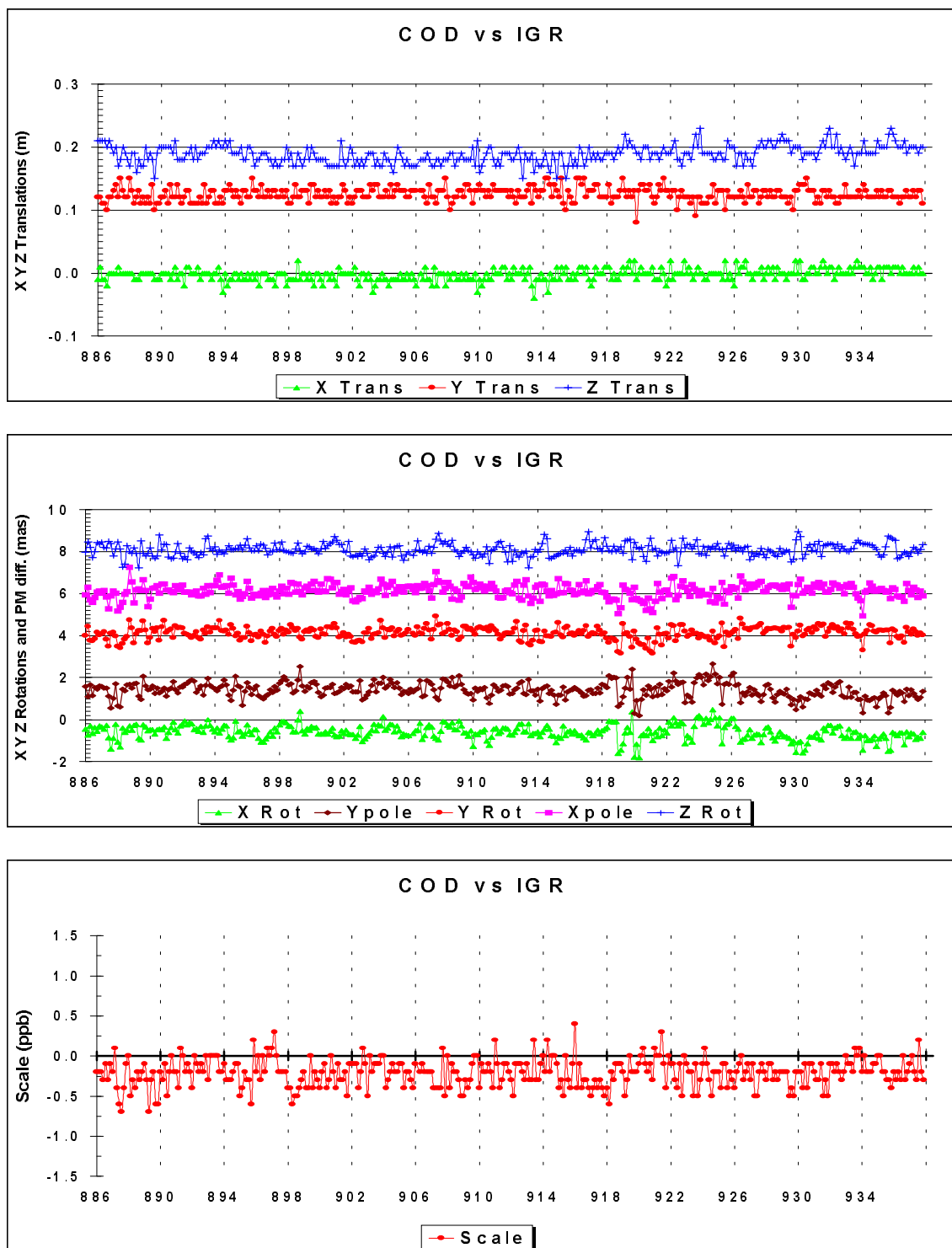


Figure 10. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

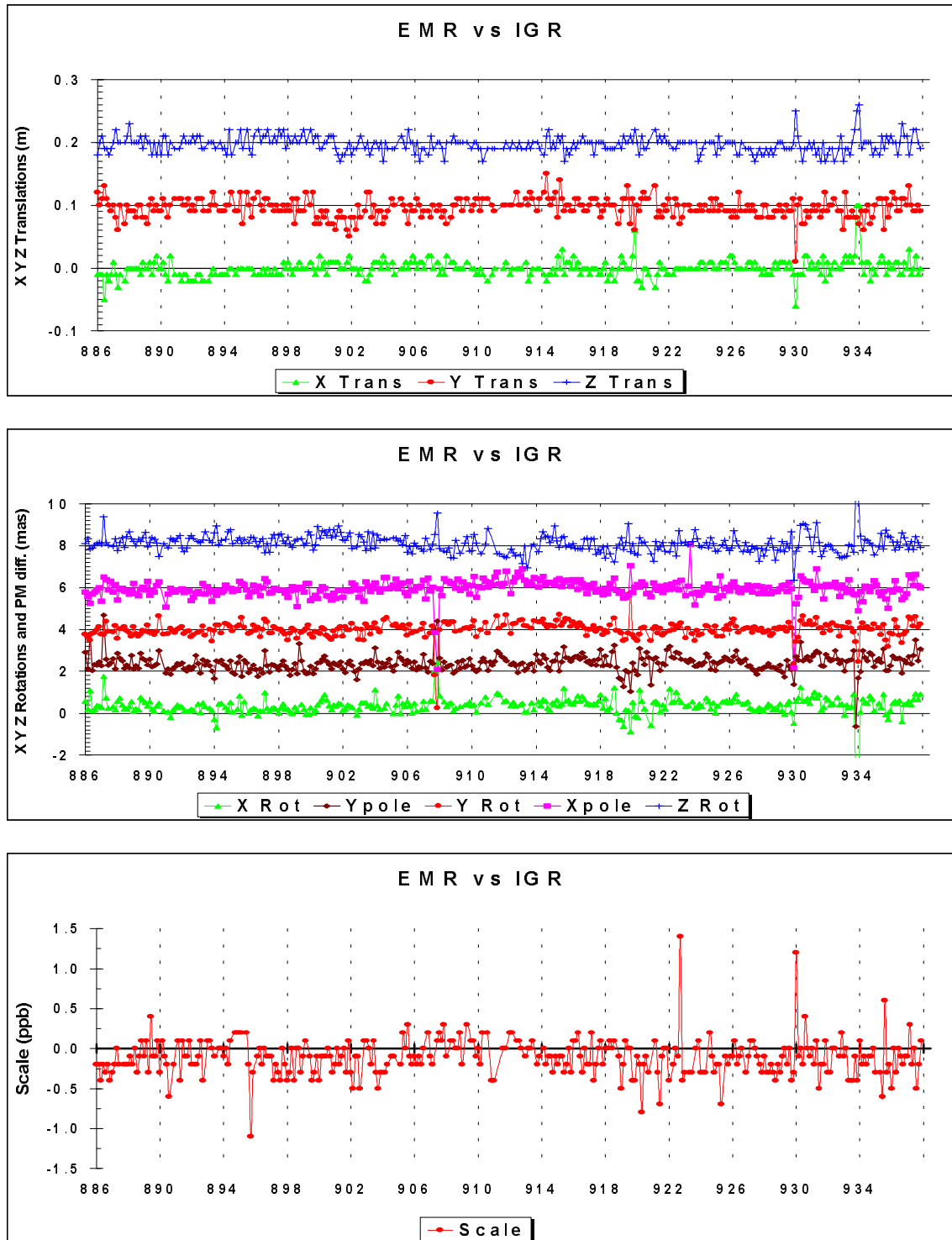


Figure 11. EMR 1997: Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

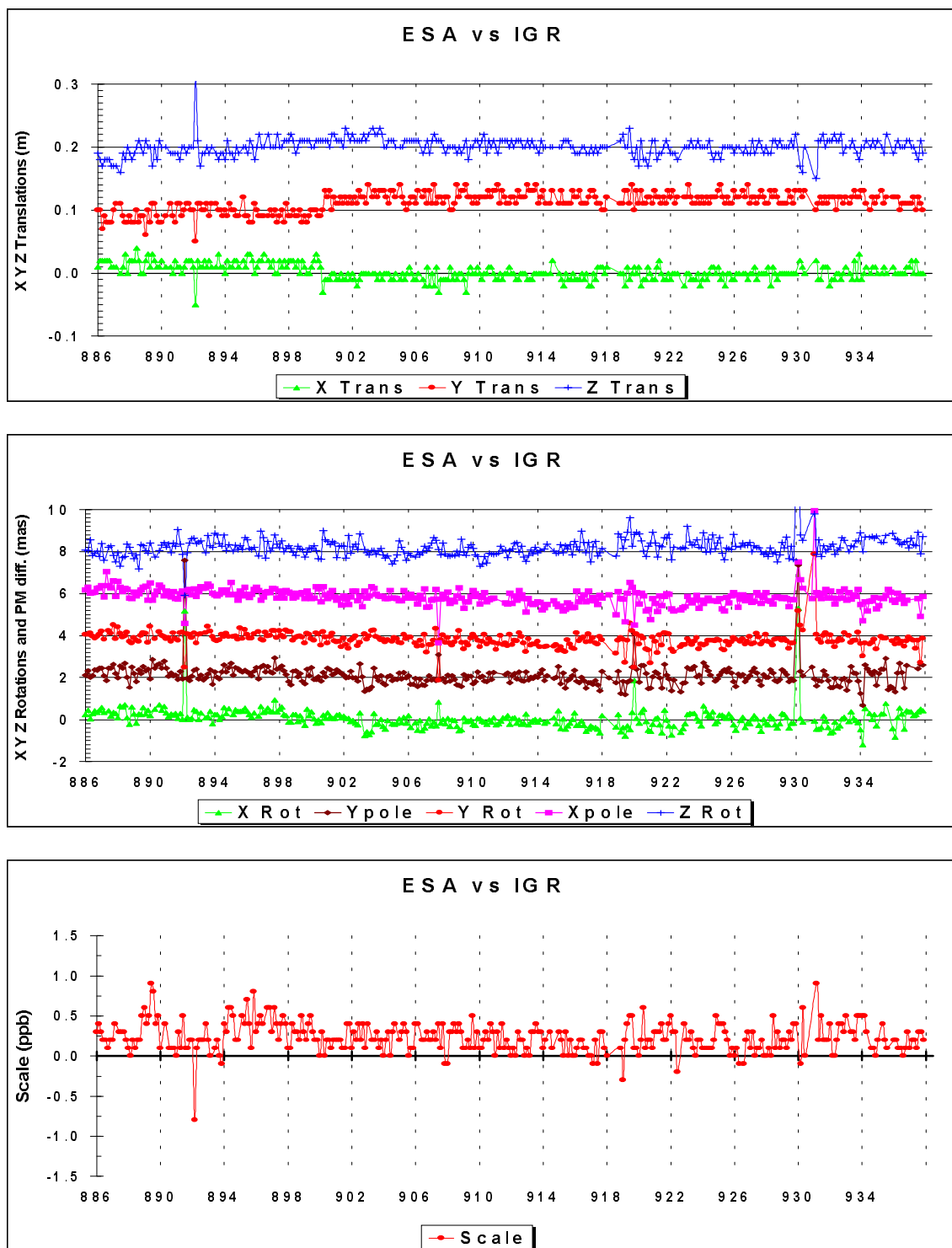


Figure 12. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

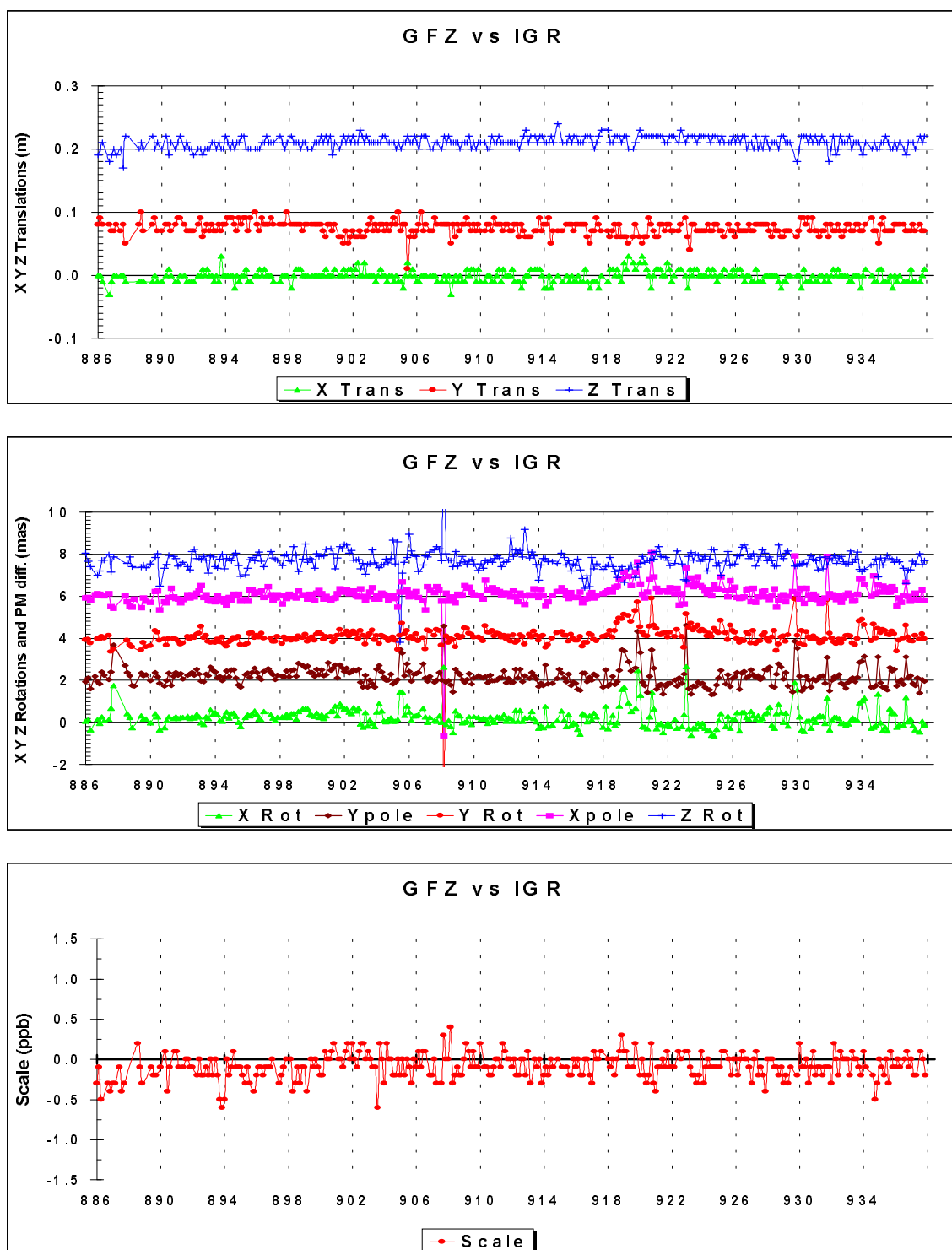


Figure 13. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

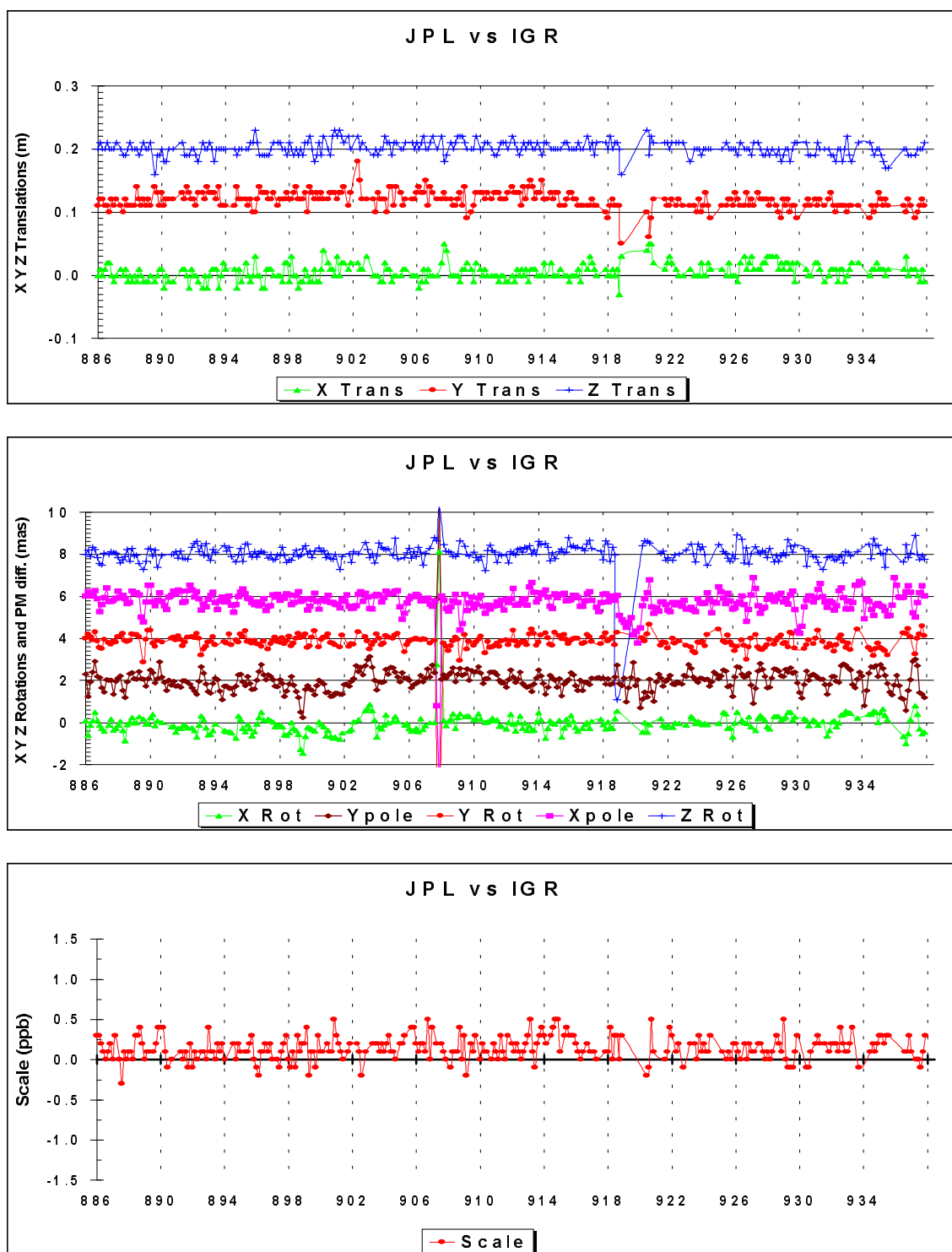


Figure 14. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

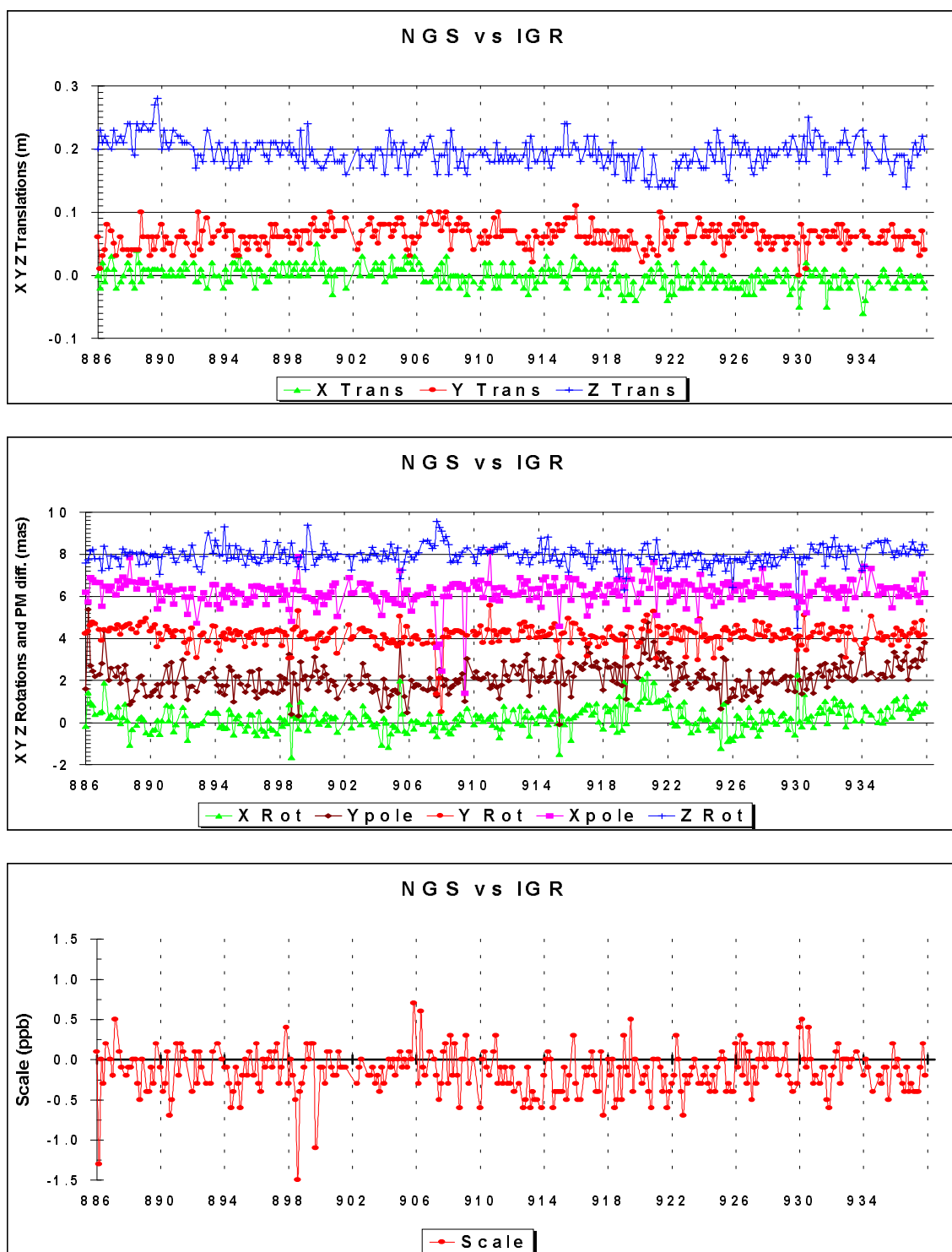


Figure 15. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

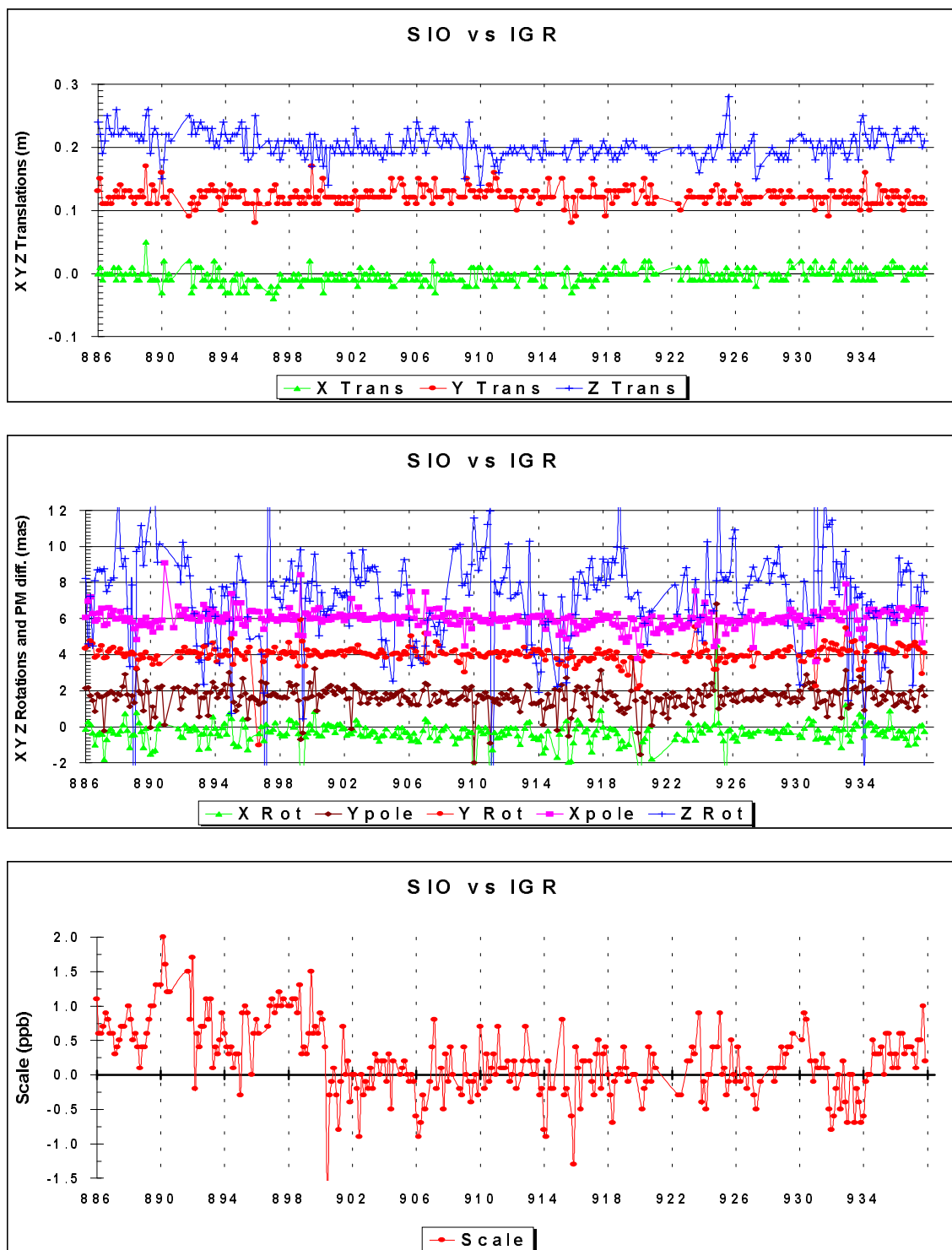


Figure 16. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

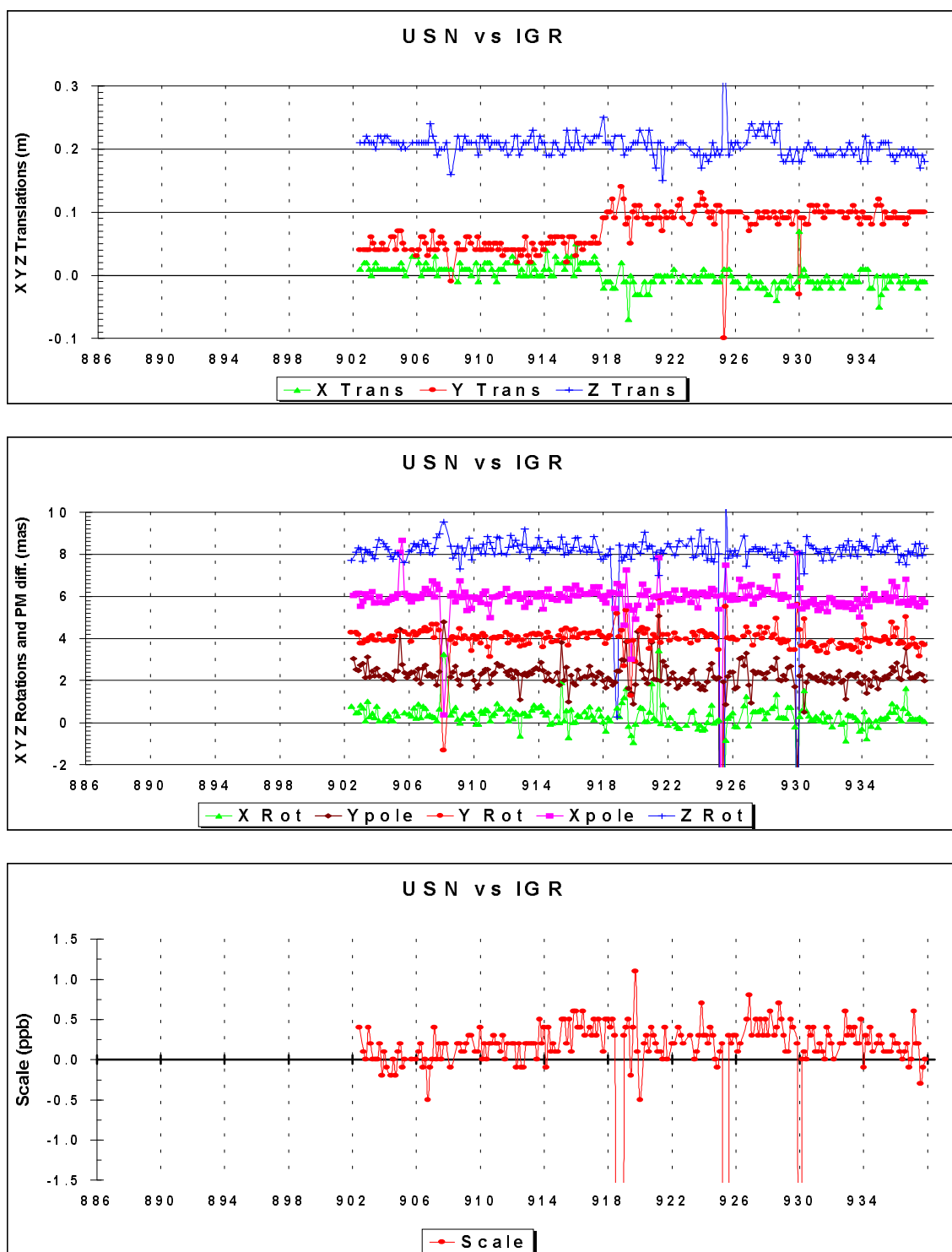


Figure 17. Rapid daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

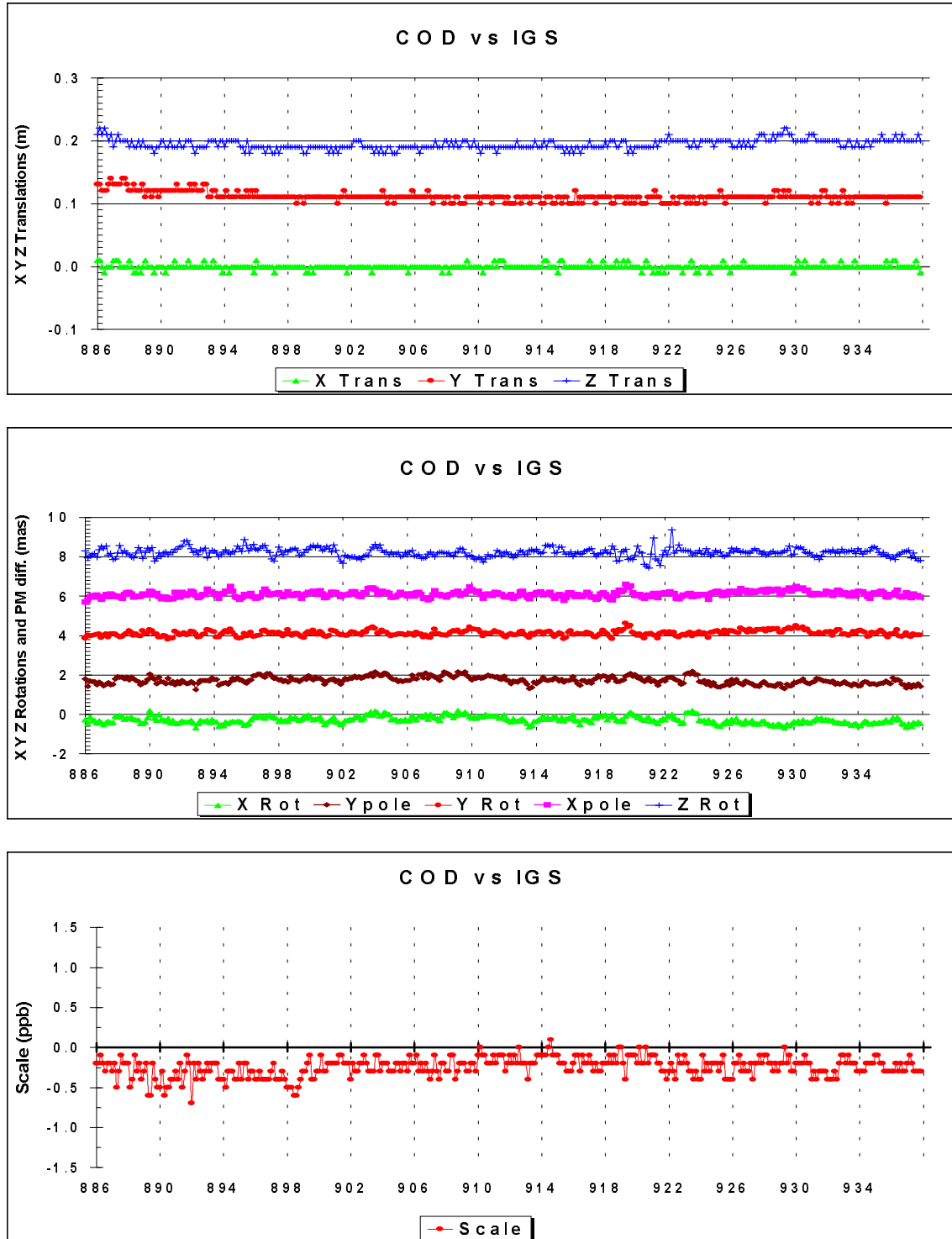


Figure 18. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

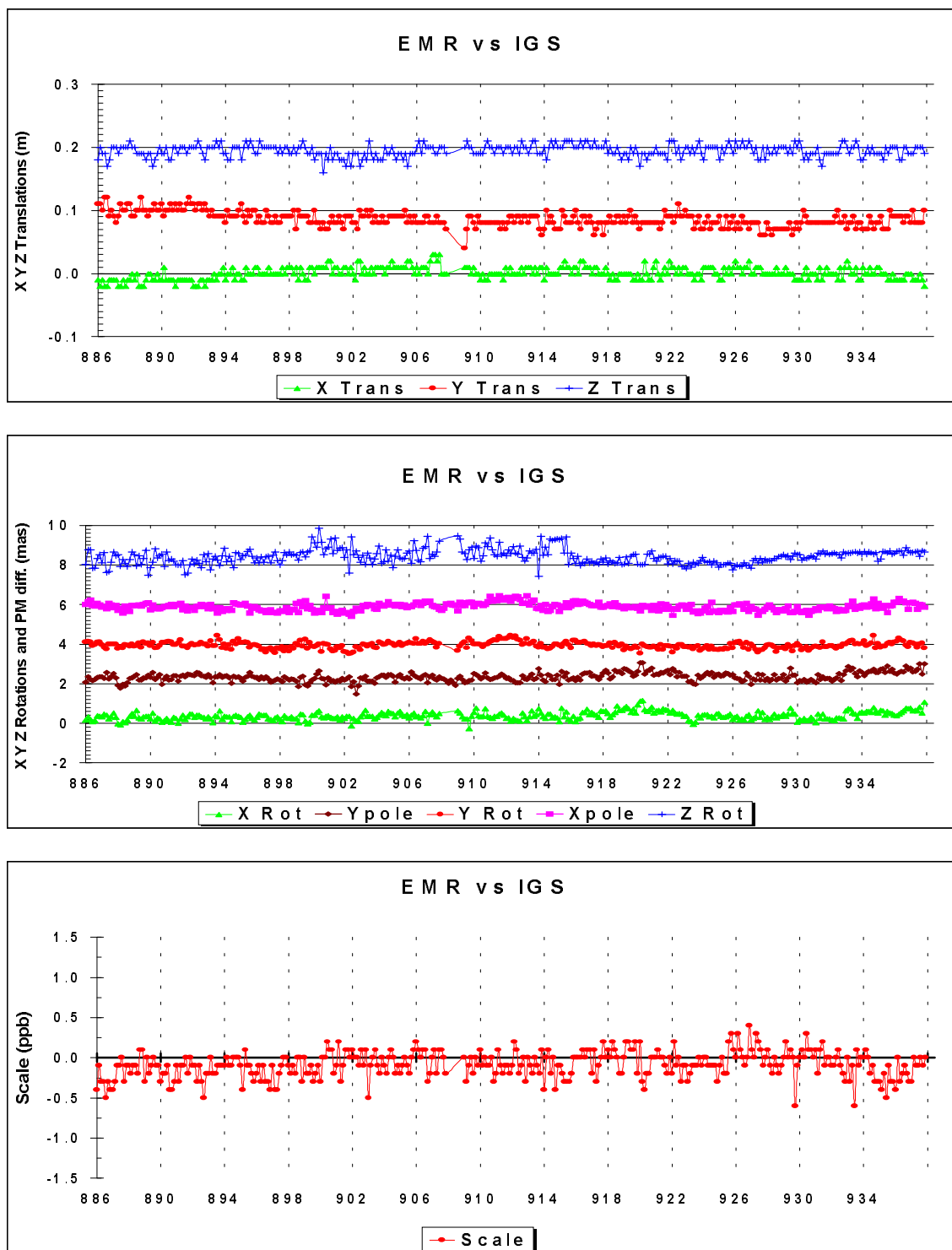


Figure 19. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

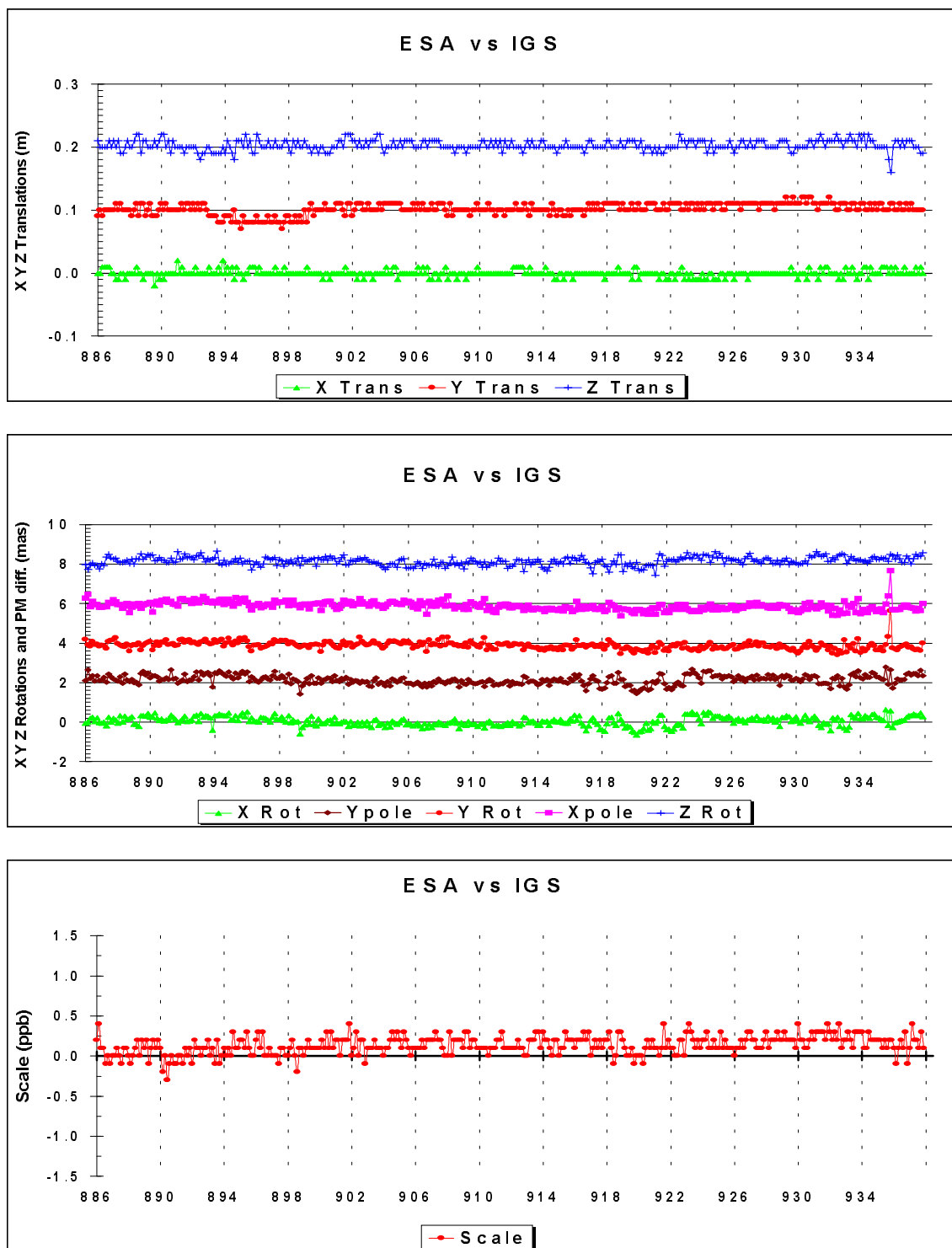


Figure 20. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

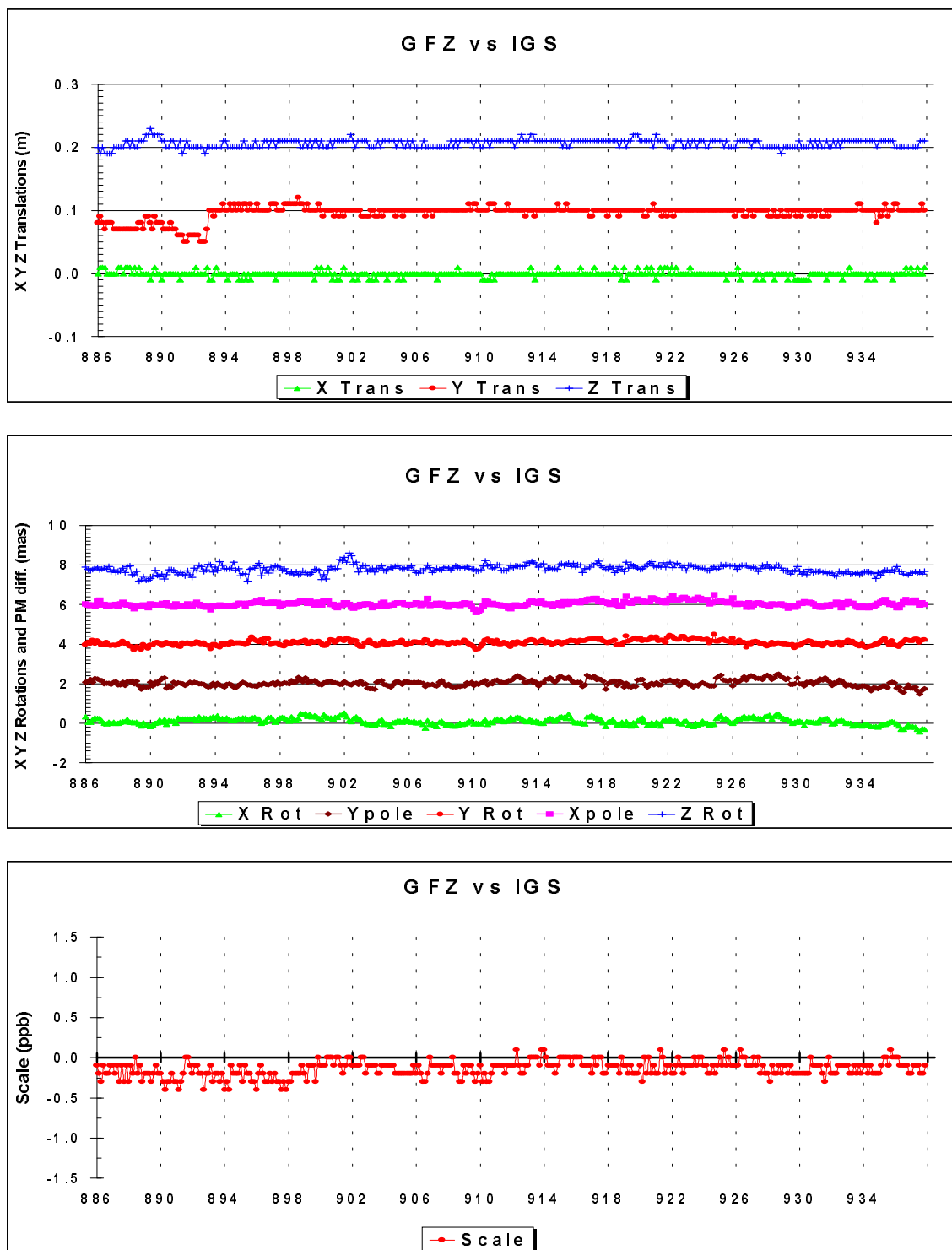


Figure 21. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

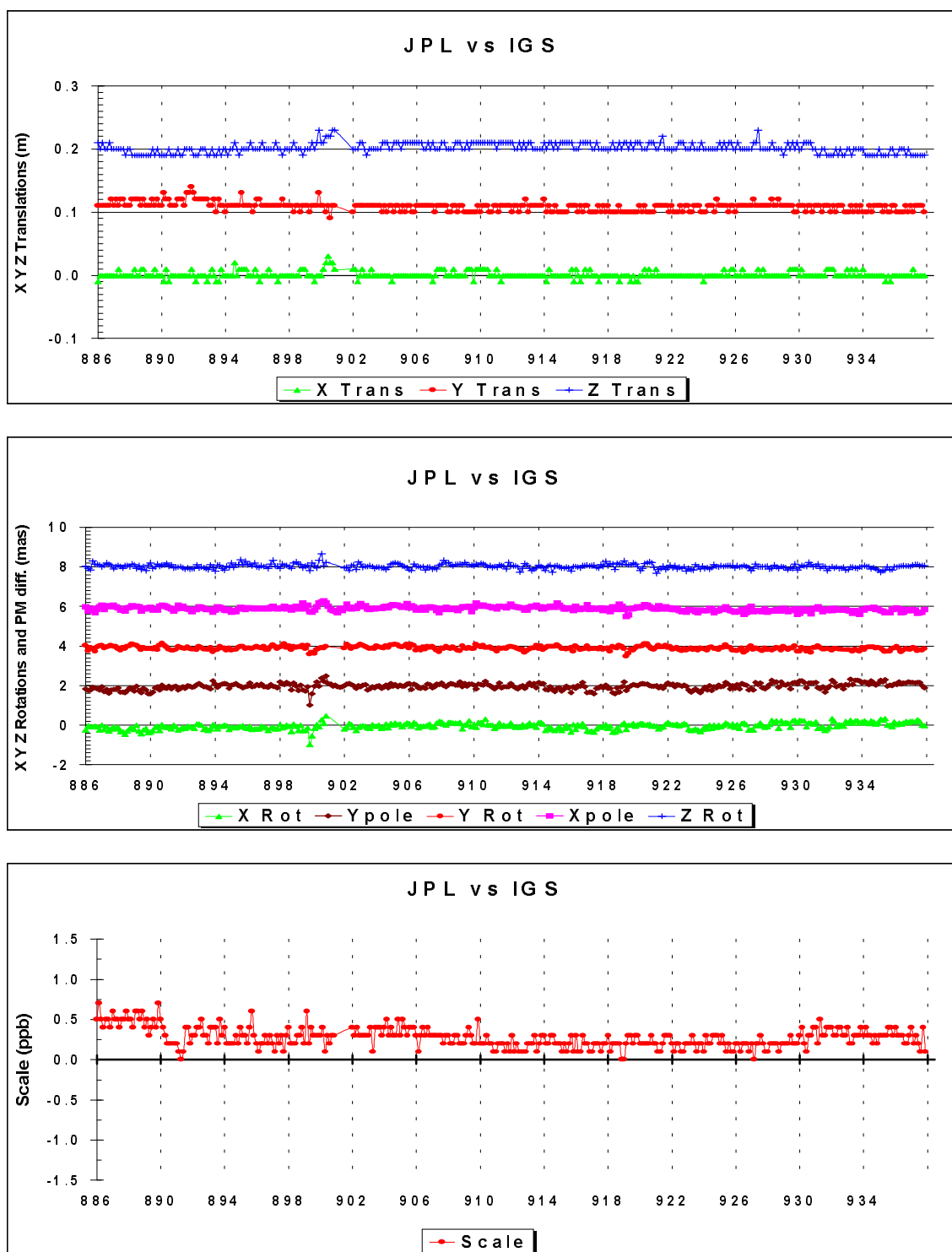


Figure 22. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

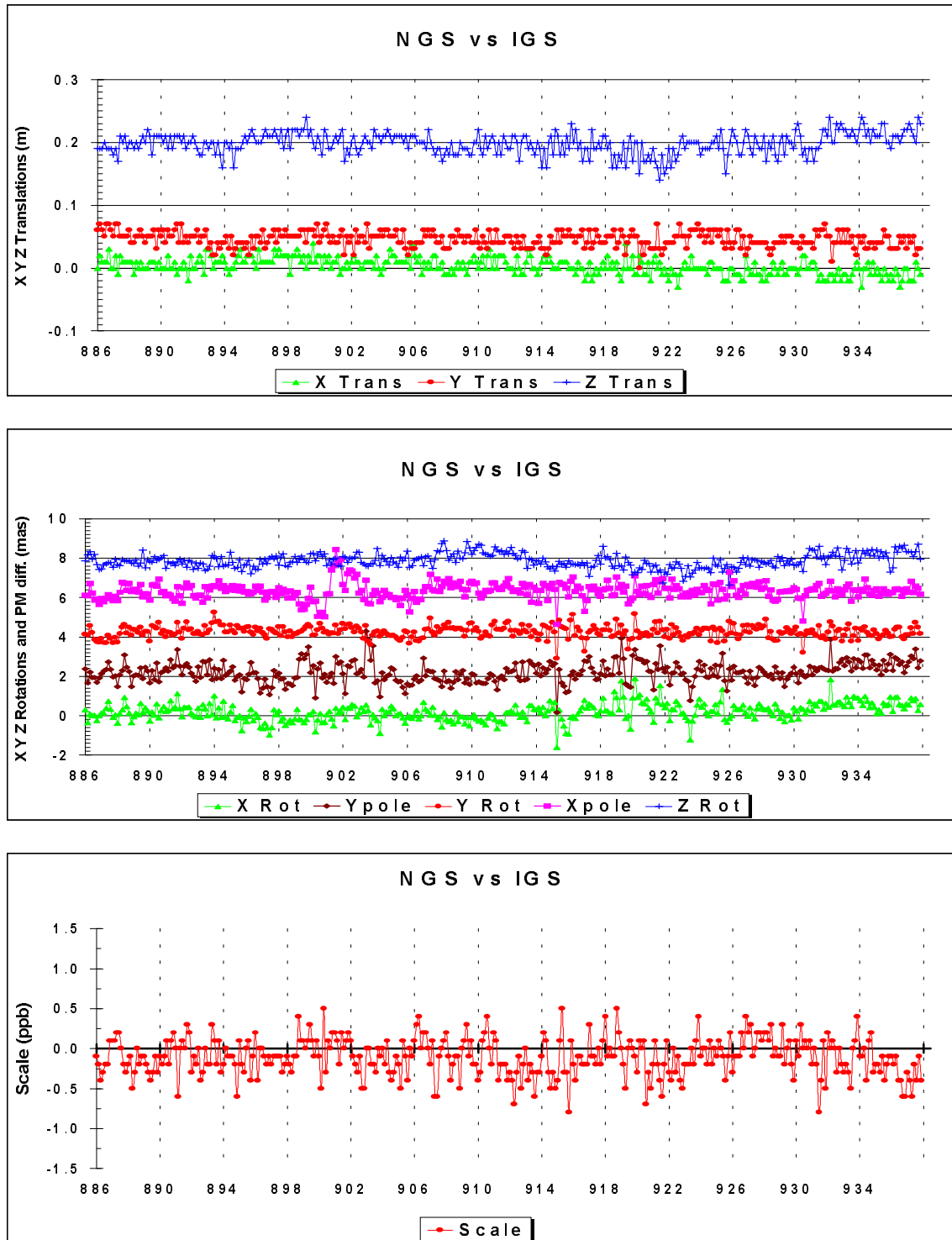


Figure 23. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

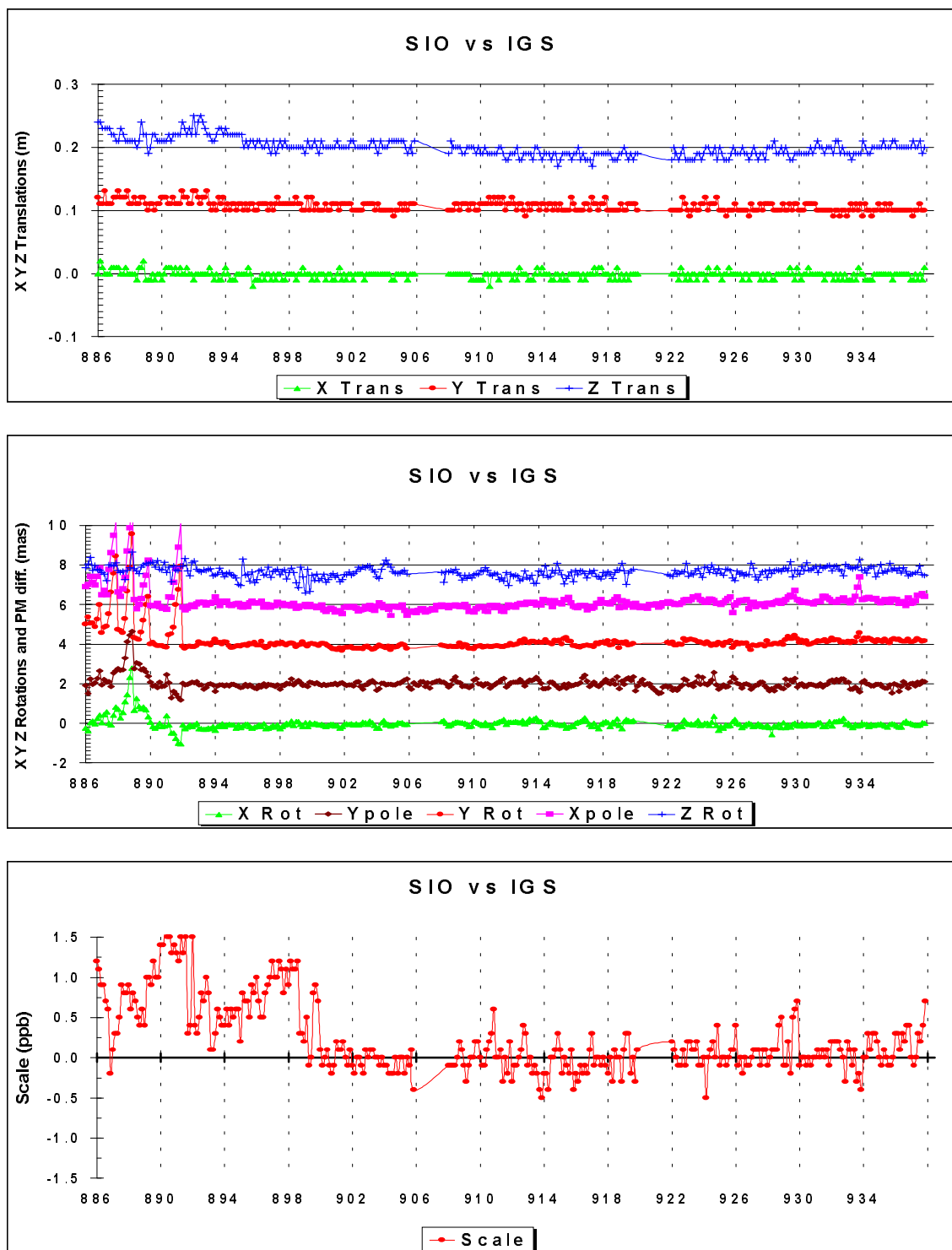


Figure 24. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

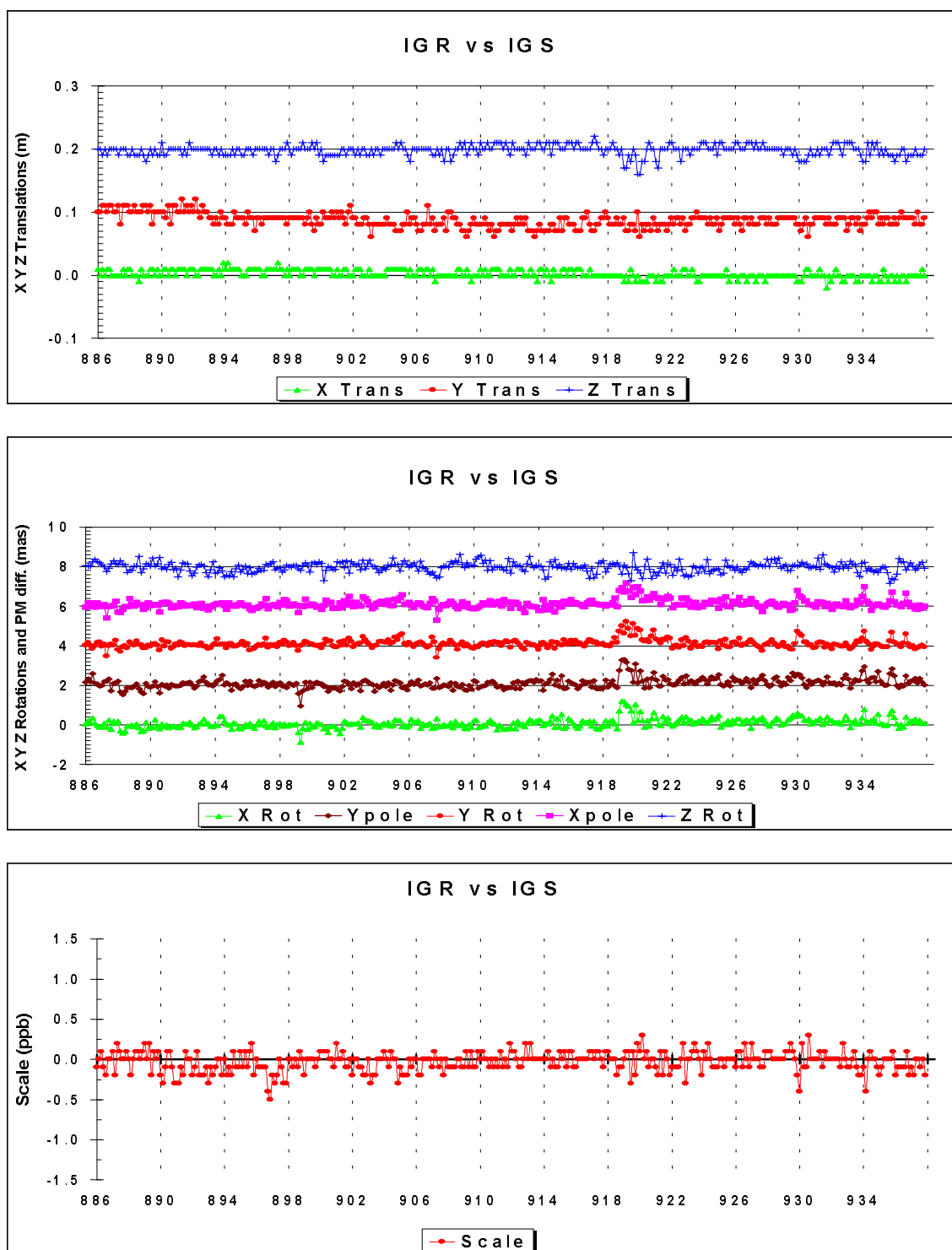


Figure 25. Final daily seven-parameter Helmert transformations (X, Y and Z Translations are each offset by 0.1 metre; X, Y, Z Rotations and Y and X pole differences are each offset by 2 mas)

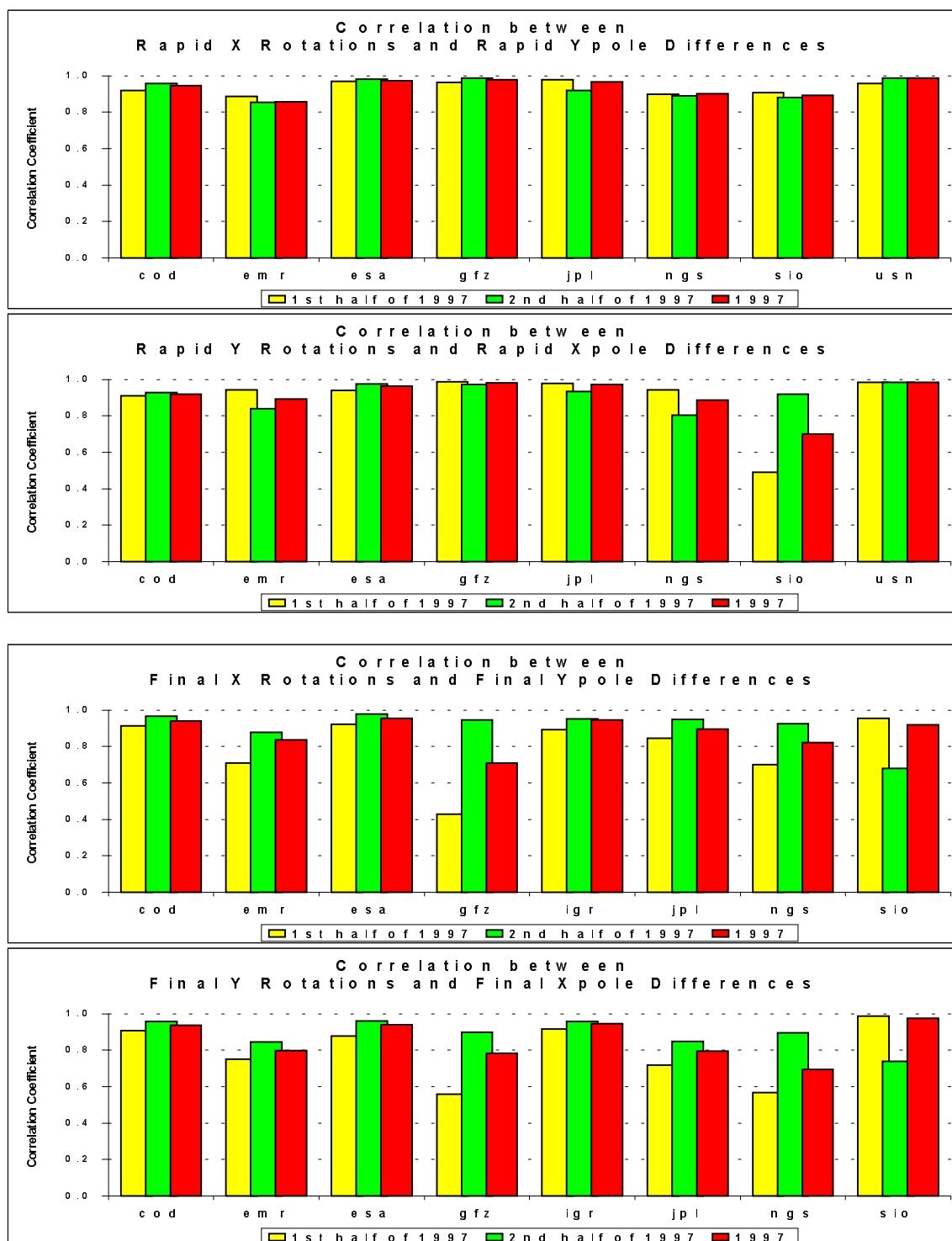
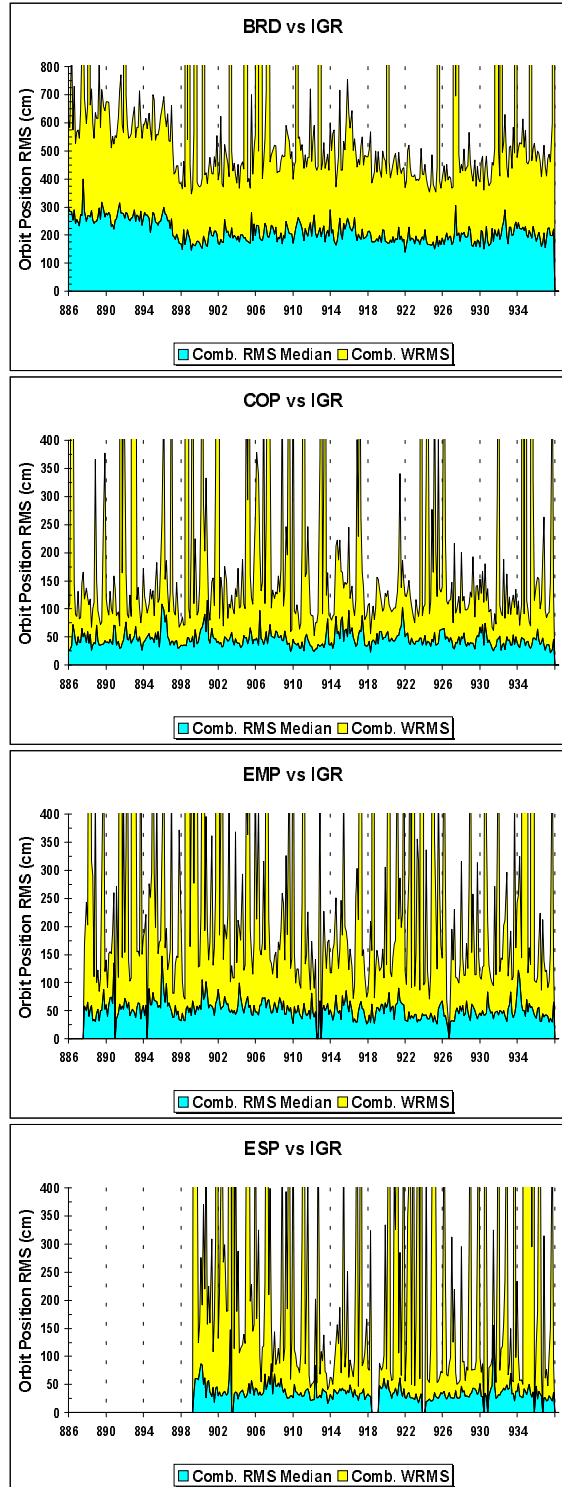


Figure 26. 1997 correlation coefficients between AC X/Y rotations and AC PM differences in y/x with respect to IGR/IGS.



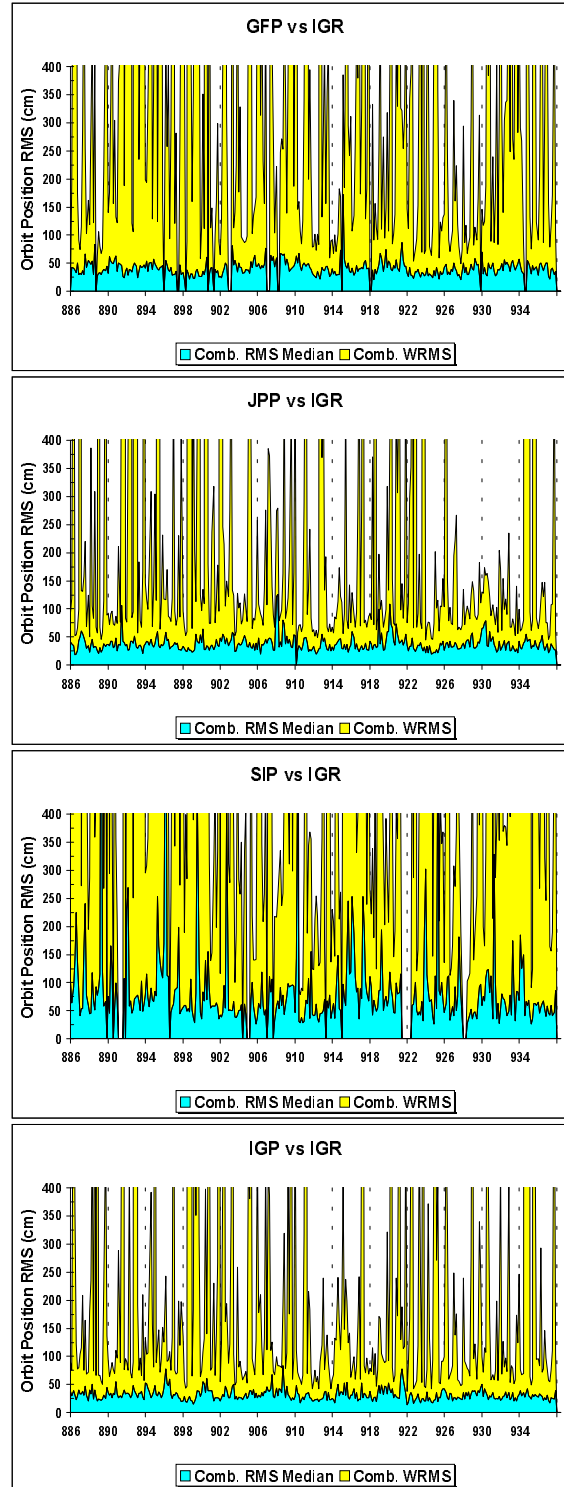


Figure 27.

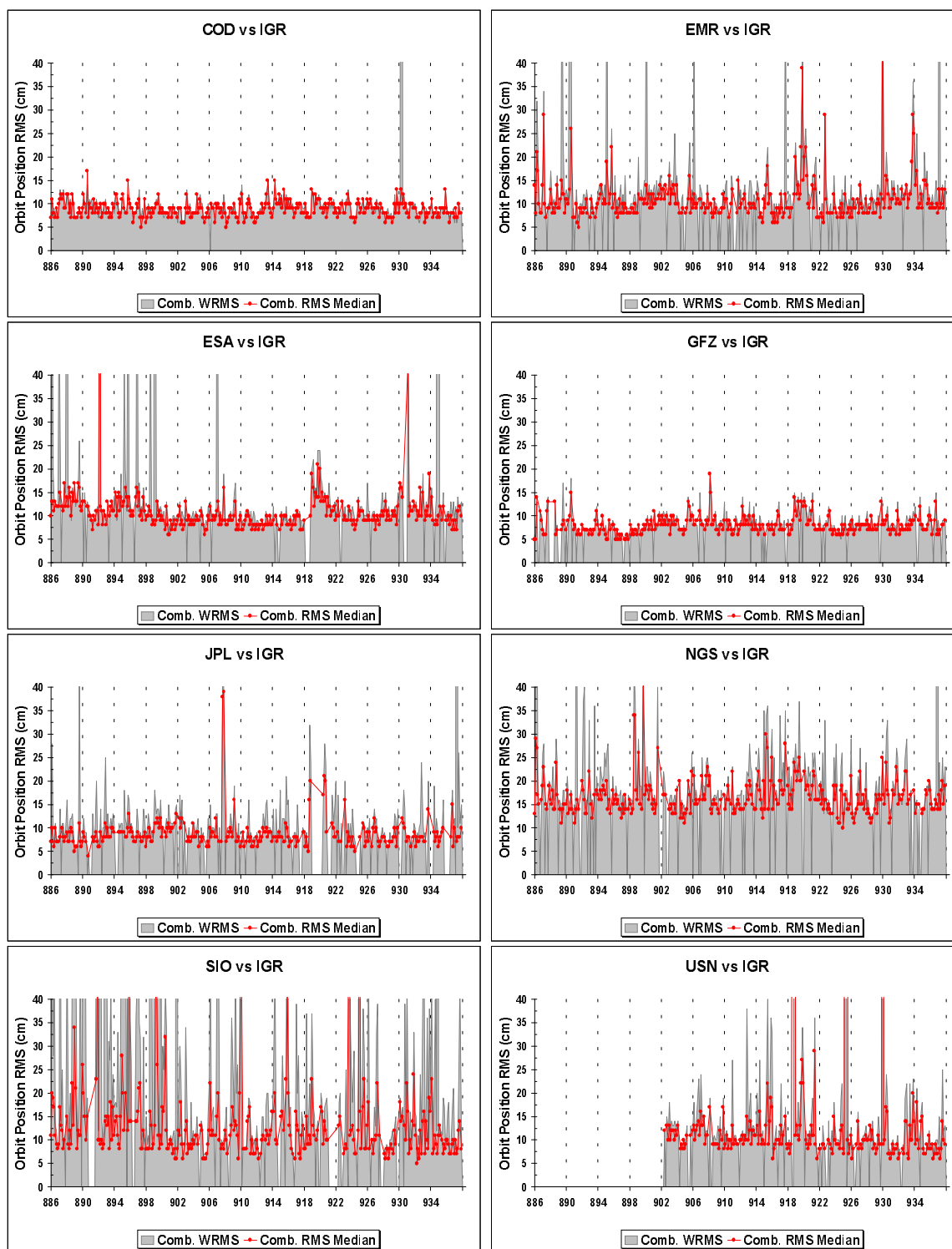


Figure 28.

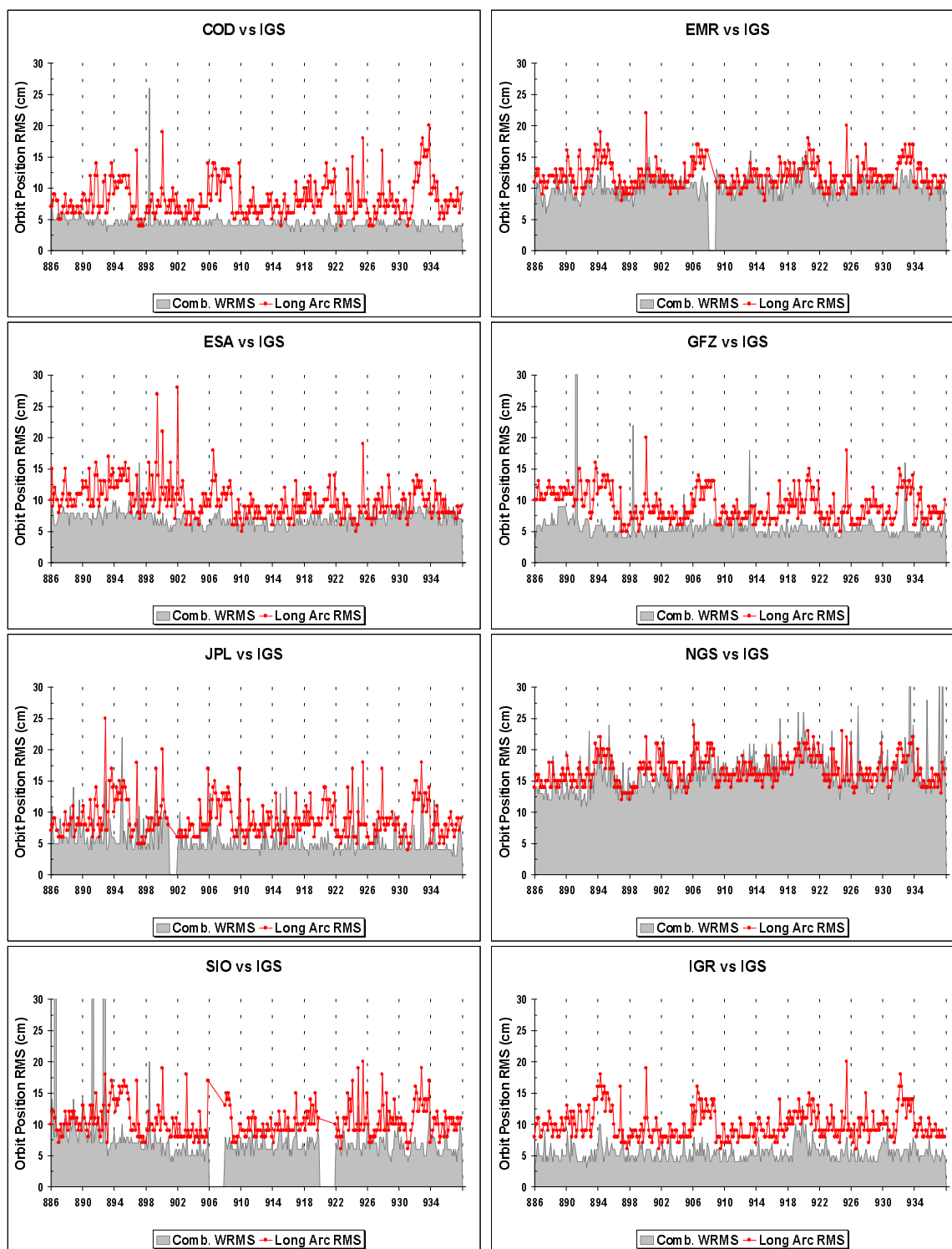


Figure 29.

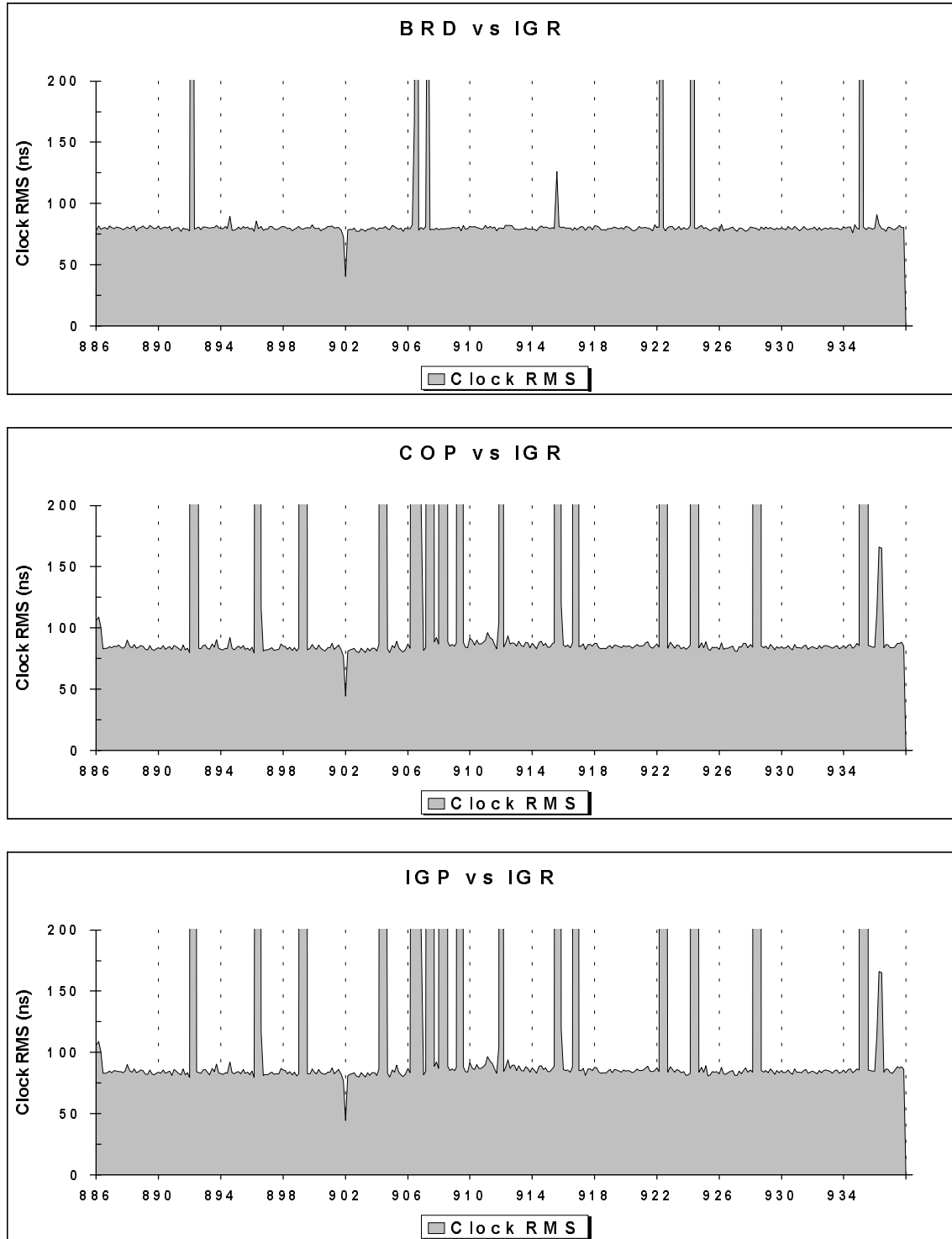
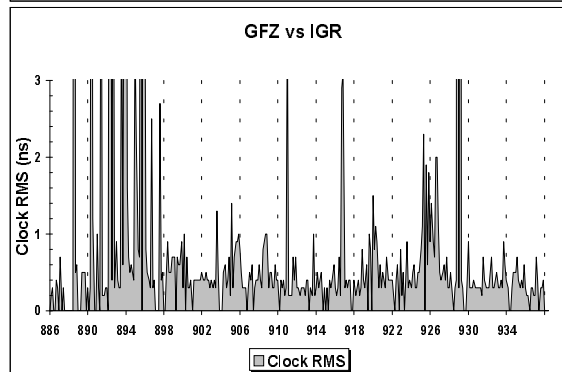
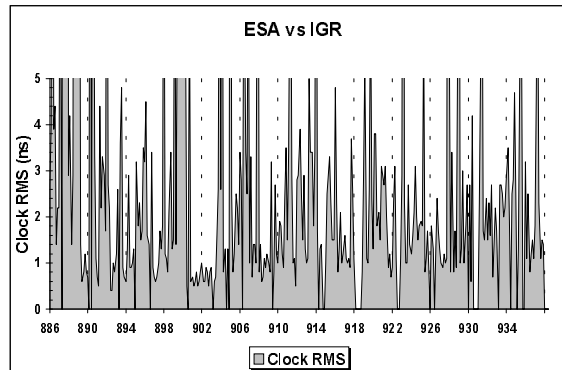
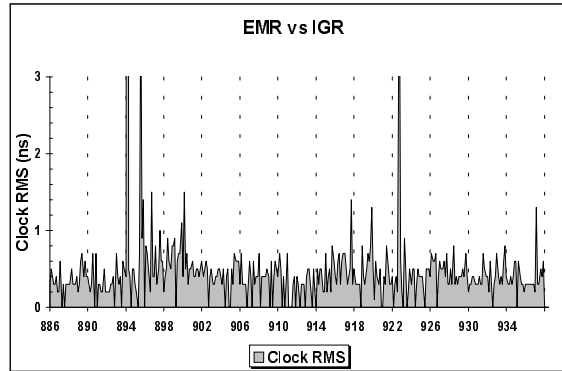
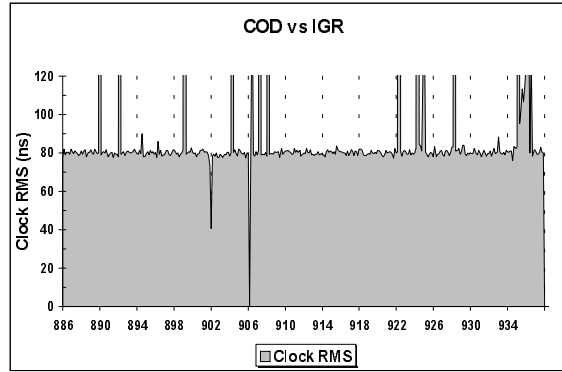


Figure 30.



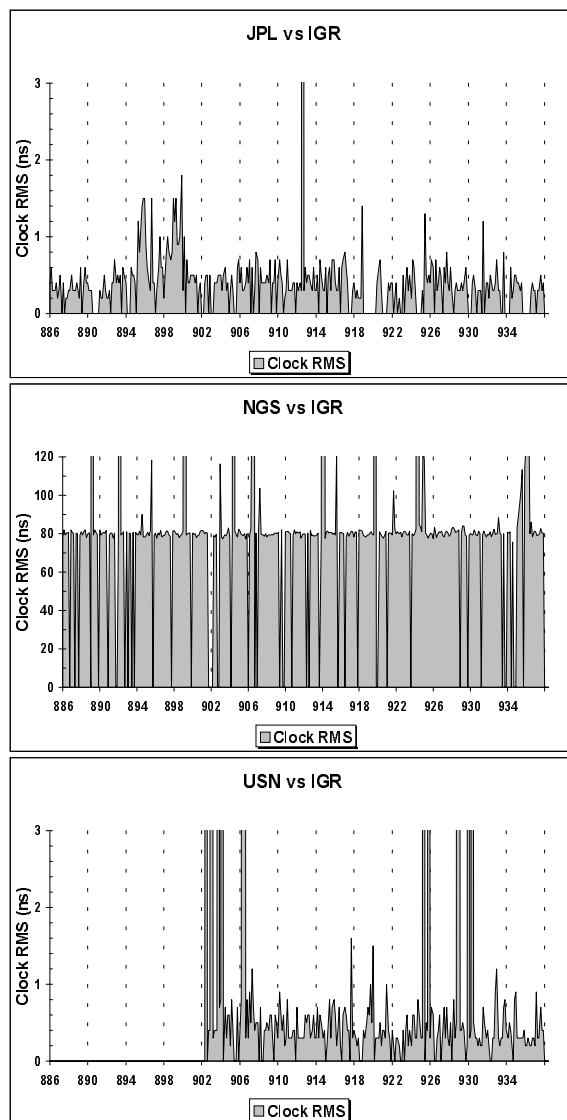
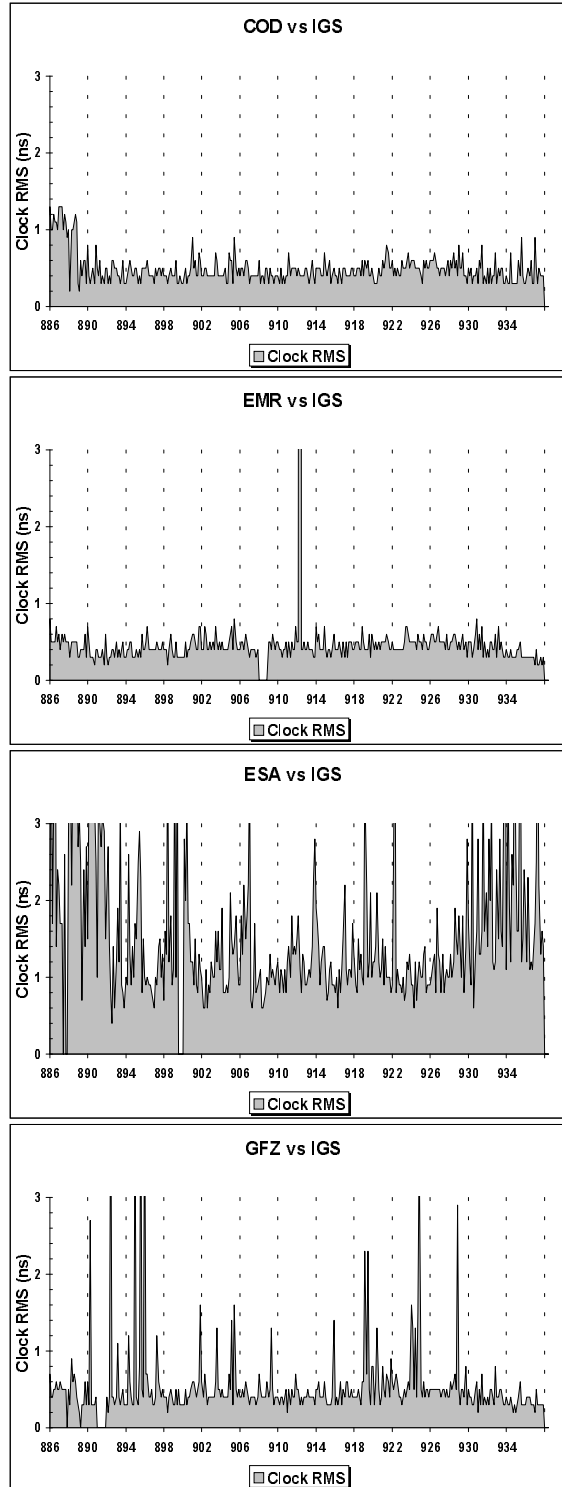


Figure 31.



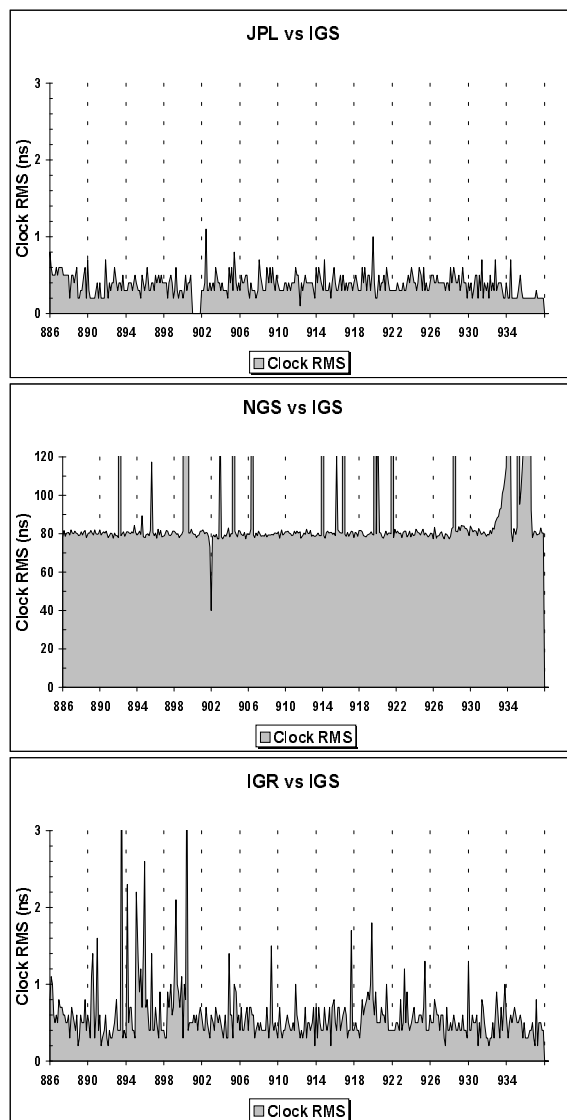


Figure 32.

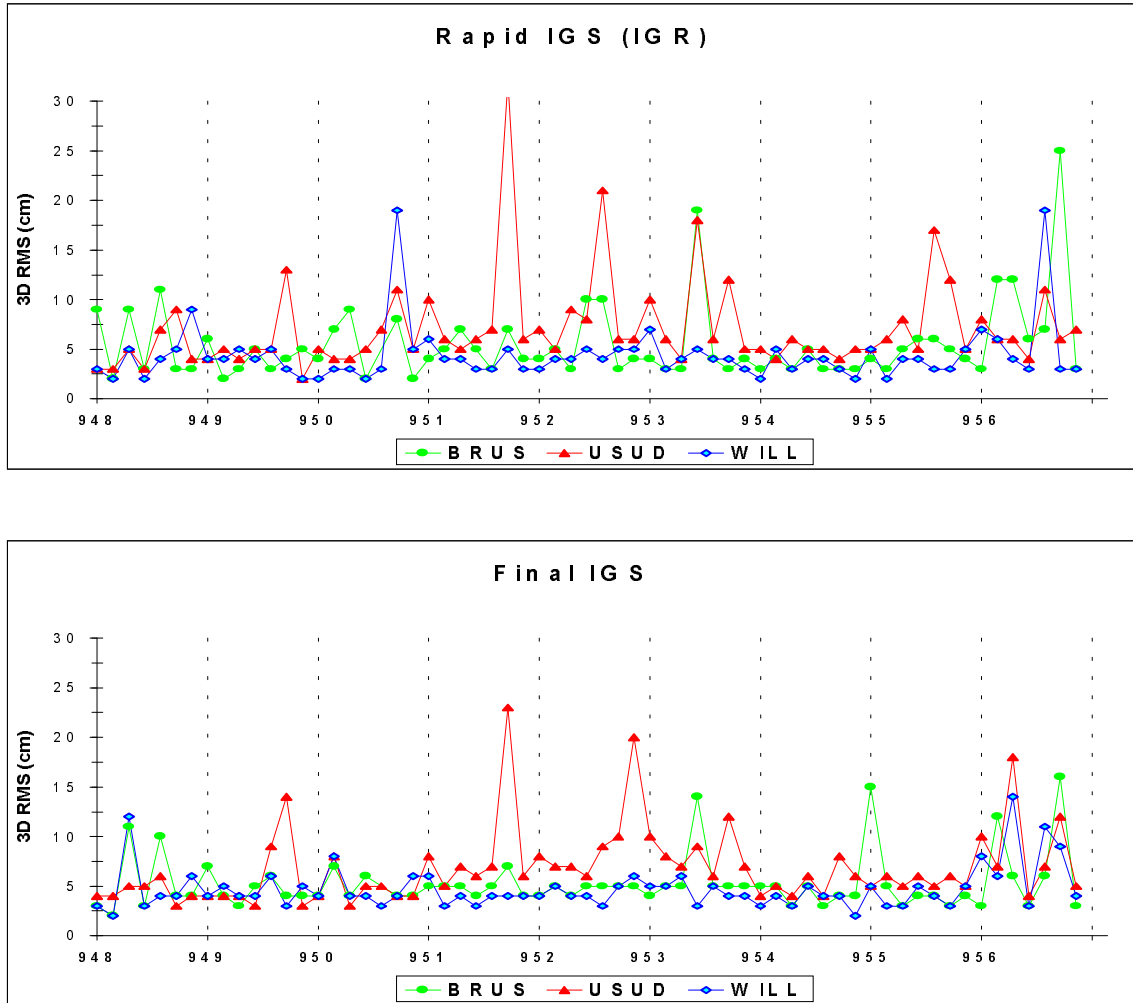


Figure 33. Precise Point Positioning (Navigation) using phase data and JPL's GIPSY-OASIS II software. The top graphic shows the 3D-RMS for the Rapid IGS (IGR) while the bottom one shows the 3D-RMS for the Final IGS.

Analysis Centers

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1997 Annual Report - Code Analysis Center of the IGS

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1 Introduction

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 Federal Agency of Cartography and Geodesy (BKG), Frankfurt, Germany,
- the Institut Géographique National (IGN), Paris, France, and
- the Astronomical Institute of the University of Berne (AIUB), Berne, Switzerland.

CODE is located at the AIUB. All solutions and results are produced with the latest version of the Bernese GPS Software [Rothacher and Mervart, 1996].

This report covers the time period from *May 1997* to *June 1998*. It focuses on the major changes in the routine processing during this period and shows the new developments and products generated at CODE. The processing strategies used till *April 1997* are described in the annual reports of previous years [Rothacher *et al.*, 1995, 1996a, and 1997a].

Figure 1 shows the number of global IGS stations and the number of double-difference phase observations processed at CODE for each day in the time interval from January 1997 to June 1998. The number of stations increased from about 80 to 100. An upper limit of 100 for the number of sites to be processed has been set in May 1998. If there is data available from more than 100 sites, the sites with long data gaps are removed first and then sites are selected according to their importance and data quality. The number of observations shows a jump in October 1997 (day 278), where the elevation cut-off angle for the global data processing was changed from 20 to 10 degrees (see next sections for more details).

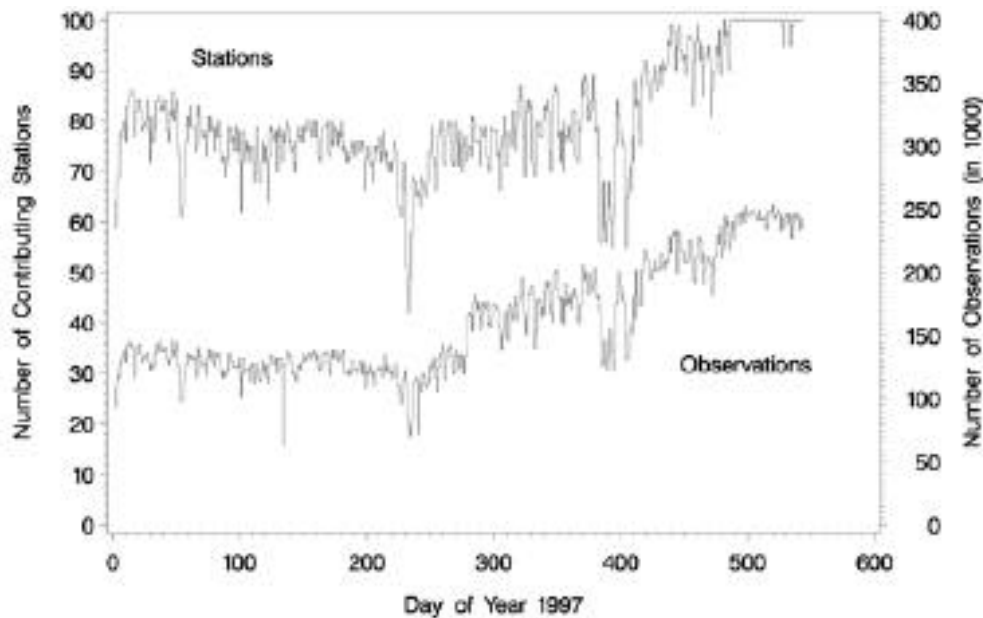


Figure 1. Statistics of the global 1-day solutions computed at CODE

Due to this processing change and due to the increase in the number of sites with time the number of observations has roughly doubled from January 1997 to June 1998. The significant decrease in the number of stations and observations in February 1998 was caused by a computer problem at one of the operational centers and clearly shows that backup components are needed for such cases.

2 Changes in the Routine Processing

The major changes implemented in the CODE routine analysis since May 1997 are listed in Table 1. Modifications prior to this date have already been reported in the annual report of last year [Rothacher *et al.*, 1996a].

3 Product Quality and Results

3.1 Change of Elevation Cut-Off Angle

The most significant changes in the last year are related to lowering the elevation cut-off angle from 20 to 10 degrees. Since April 1997, CODE has tested several processing strategies using the data of the permanent European network. The cluster of about 40 stations has been processed over many months using eight slightly different processing schemes. The eight solutions differ in the elevation cut-off angle, the tropospheric modeling, and the observation weighting model. More details about these processing strategies may be found in [Rothacher *et al.*, 1997b; Springer *et al.*, 1997].

Table 1. Modification of processing scheme at the CODE Analysis Center from May 1997 to June 1998.

Date	Doy/Year	Description of Change at CODE
23-Sep-97	266/97	Generation of IONEX files containing daily global and European ionosphere maps.
05-Oct-97	278/97	Major changes of global solutions: elevation cut-off angle set to 10 degrees (previously 20 degrees), Niell dry mapping function for troposphere delays, elevation-dependent weighting of the observations.
05-Oct-97	278/97	Solid Earth tides according to the IERS Conventions 1996. Polar tides were also included.
19-Oct-97	292/97	Troposphere gradient parameters estimated in global 1-day solution for test purposes.
26-Jan-98	026/98	Maximum degree of spherical harmonics for ionosphere models increased from 8 to 12. A global solution with station-specific ionosphere models using smoothed code observations was set up.
01-Mar-98	066/98	Switch from ITRF94 to ITRF96. Reference frame defined by 37 sites (of the set of 42 selected by the IGS).
01-Mar-98	066/98	Ocean loading model according to [Scherneck, 1991] implemented (ocean tide maps from [Le Provost <i>et al.</i> , 1994]; see also [McCarthy, 1996]).
01-Apr-98	088/98	2-hour (instead of 24-hour) time resolution for global ionosphere maps. Use of a solar-geomagnetic reference frame for ionospheric modeling.
06-Jun-98	155/98	In addition to GPS, GLONASS orbit predictions are now routinely produced for the SLR community.
11-Jun-98	160/98	1-day and 2-day ionosphere map predictions made available on anonymous ftp at CODE.
17-Jun-98	168/98	First set of global IONEX files sent to CDDIS.

The results of the different European processing strategies clearly indicate that lowering the elevation cut-off angle significantly improves the internal consistency of the station coordinate estimates. This is mainly caused by the better decorrelation of the station heights and the tropospheric zenith path delay parameters (see e.g. [Rothacher and Beutler, 1997]). It was also found that it is important to account for the increased noise of the low-elevation data by using an elevation-dependent weighting of the observations. Furthermore, a well performing tropospheric mapping function, e.g., the Niell mapping function [Niell, 1993], has to be used.

Based on these European results it was decided to decrease the elevation cut-off angle also for all global solutions. There the cut-off had always been set to 20 degrees

since the beginning of the IGS in June 1992. A small test series, based on 5 days, was generated using similar strategies as for our European network to verify if the same improvements may be seen in the global solutions. The results of the different tests are summarized in Table 2.

Table 2. Results based on global solutions from 5 days using different processing strategies.

Elev. Cut-Off (deg)	Mapp. Func.	Elev. Weight.	Coord. Repeat. (mm)	Relative to 20° solution			
				RMS (mm)	Scale (ppb)	#Obs. Inc.(%)	#Param. Inc.(%)
20	Saast.	No	3.10	---	---	---	---
15	Saast.	No	3.10	10.3	-0.7	12	30
15	Niell	Yes	3.06	6.5	-0.1	12	30
10	Saast.	Yes	2.95	10.5	-0.3	23	63
10	Niell	Yes	2.92	5.4	0.9	23	63
5	Saast.	No	3.52	29.3	0.1	26	75
5	Niell	No	3.28	14.4	0.5	26	75
5	Saast.	Yes	3.00	14.9	0.0	26	75
5	Niell	Yes	2.96	9.5	0.9	26	75

Several interesting results can be observed here. First of all, the results clearly deteriorate if the cut-off angle is decreased without proper weighting of the measurements. The results also reveal that the Saastamoinen mapping function [Saastamoinen, 1973] is not adequate for low-elevation data. Secondly, the amount of data gained is strikingly large: almost a 25% increase can be seen when lowering the elevation cut-off from 20° to 10°. Unfortunately, the amount of ambiguity parameters also increases significantly (60-70%), which reflects the higher noise level of the low-elevation data which makes the data cleaning more difficult. Nevertheless, the degree of freedom of the solutions increases significantly (21% when going from 20° to 10°). Finally, significant terrestrial scale changes are observed which are depending on the elevation cut-off angle, the weighting of the observations, and the tropospheric mapping function. These scale changes are surprisingly large considering the fact that 9 stations were held fixed to their ITRF94 positions in these tests. As a result of these tests, the solution using a cut-off of 10°, with elevation-dependent weights $w = \sin^2 e$, and using Niell's (dry) mapping function was chosen for our global IGS solutions. The 5° solution was rejected mainly due to the fact that the IGS set of antenna phase center variations (IGS_01) is only valid down to 10° [Rothacher et al., 1996b; Rothacher, 1996]. Additional information on the change of the elevation cut-off angle may be found in IGSMail #1705 and IGSREPORT #4247. Note that the change of approximately 1 ppb in the scale observed in these tests is still visible in our current official solutions. In a free network solution, the scale change is even more

pronounced (2-3 ppb), indicating once more that the scale defined by GPS is not very reliable and heavily depends on the processing strategy and modeling.

3.2 Change of Terrestrial Reference Frame

On March 1, 1998 (GPS week 0947), the IGS changed its realization of the terrestrial reference frame by switching from ITRF94 to ITRF96. At the same time, the set of the 13 “fixed” reference stations was change. A completely new and much larger set of reference stations was selected because the original set of 13 stations was no longer adequate to accurately realize the terrestrial reference frame for the IGS products. From this newly selected set of 48 reference stations CODE selected 36 stations. One more station (REYK) was added to this list. The ITRF96 positions of these 37 stations are constrained to 1 mm in our official solutions.

Although ITRF94 and ITRF96 nominally have the same orientation and origin, some small effects of the reference frame change were observed in the IGS products, namely, a small rotation around the Earth's Z-axis of about 0.3-0.4 mas and a small change in the Y-coordinate of the pole of about 0.2 mas. More information about these changes may be found in IGSMAIL #1829 and #1838 and IGSREPORT #4698. The change to ITRF96 and the use of the much larger set of reference stations significantly improved the CODE products, in particular the earth rotation parameters ERPs). The precision of the ERP estimates are now below the 0.1-mas level (see IGSMAIL #1853 for details).

3.3 The European Network Solution

Besides being one of seven IGS Analysis Centers, CODE also plays an essential role in the maintenance and densification of the European Reference Frame (EUREF). Within the framework of EUREF, CODE participates as one of currently ten Associate Analysis Centers (AACs) and is responsible for the combination of the individual AAC results into an official combined EUREF solution. Each of the EUREF AACs processes a certain subset of available permanent GPS sites in Europe. The main goal of processing the European network, apart from participating as an EUREF Analysis Center, is to study new processing techniques. Eight types of solutions, each using slightly different processing options, are currently generated each day. Two additional solutions are set up to compute regional ionosphere maps and to monitor the ionospheric activity over Europe.

Table 3 shows the internal consistency of the eight different solutions and gives a short description of the basic differences between the solutions. A significant improvement may be seen, too, when tropospheric gradient parameters are estimated, but only for those sites which actually track satellites at low elevations. This is not evident from

Because the repeatabilities listed there are dominated by a few “bad” stations, which provide little or no low elevation data. All stations with low elevation data show a highly significant improvement (up to a factor of 2), if gradients are estimated. The

improvement is mainly in the horizontal component but also the height repeatability is slightly better. For more details we refer to [Rothacher *et al.*, 1997b; Springer *et al.*, 1997].

Table 3. Overall repeatability of the daily European solutions at CODE based on days 060-157 of 1998. Repeatabilities are given in millimeters.

Sol. ID.	Amb. Fixed	Ele. Cut.	Mapp. Func.	Elev. Wgt.	Repeatability			Remarks
					N	E	U	
EG_	No	15	Saast.	No	2.1	2.6	5.7	Ambig. free
EQB	Yes	15	Saast.	No	1.9	1.9	5.6	Ambig. fixed
NMF	Yes	15	Niell	No	1.9	1.9	5.8	Niell mapping
NMW	Yes	15	Niell	Yes	1.7	1.7	5.5	Elev.dep.weighting
EQ_	Yes	10	Niell	Yes	1.8	1.7	4.9	Cut-off angle 10°
ET_	Yes	10	Niell	Yes	1.7	1.7	4.5	Global trop. intro.
NM5	Yes	5	Niell	Yes	1.8	1.8	4.8	Cut-off 5°
NMG	Yes	5	Niell	Yes	1.7	1.7	4.8	Tropo. gradients

3.4 The CODE Solar Radiation Pressure Model

The largest error source in GPS orbit modeling is the impact of solar radiation pressure. Over the last few years many improvements have been made in modeling the orbits of GPS satellites within the IGS. However, most improvements were achieved by increasing the number of estimated orbit and/or solar radiation pressure (RPR) parameters. This increase in the number of estimated satellite parameters weakens the solutions of all estimated parameters. Due to correlations, the additional parameters can cause biases in other estimated quantities like, e.g., the length of day.

A new radiation pressure model was derived by fitting 5-day arcs through all CODE final orbits since 1996. By analyzing the resulting time series of RPR parameters, a model for each of the five estimated parameters was computed. The quality of the model was tested by performing a 7-day fit using this new model and estimating only two RPR parameters: a scale term and the y-bias. Using the ROCK4/42 models the RMS of this 7-day fit was around 75 cm whereas with the new CODE model an RMS of only 6 cm resulted, an improvement by almost an order of magnitude. The new model moreover allows a reduction of the number of orbit parameters that have to be estimated. The CODE model was presented at the 1997 AGU Fall meeting and at the IGS 1998 Workshop in Darmstadt. More information may be found in [Springer *et al.*, 1998a, 1998b] and in IGSMAIL #1842.

3.5 Earth Rotation Parameters

In April 1994, CODE started to estimate nutation rate corrections in longitude and obliquity relative to the IAU 1980 theory of nutation. The series of nutation rate estimates covers by now a time interval of more than 4 years. A detailed analysis of this series by [Rothacher *et al.*, 1998] has shown, that GPS may contribute to the high-frequency part of the nutation spectrum, i.e., for periods below about 20 days. The nutation amplitudes estimated in this range of periods are comparable to the best VLBI results.

The series of 2-hourly ERP estimates, started in January 1995, is another unique product of CODE. The uninterrupted series of 3.5 years of sub-daily ERPs may be used to estimate diurnal and semi-diurnal ocean tide amplitudes. The GPS results derived from this series are of equal quality as the best ocean tide models obtained from altimeter data, from VLBI, and from SLR. A thorough discussion of the high-frequency ERP results from CODE may be found in [Rothacher, 1998].

3.6 Time and Frequency Transfer with GPS

In 1991 a common project of the Swiss Federal Office of Metrology (OFMET) and CODE/AIUB was initiated to develop time transfer terminals based on geodetic GPS receivers. The goal is the comparison of time offsets with sub-nanosecond accuracy and frequencies with an accuracy of 10^{-15} over one day for two or more (GPS-external) clocks. The OFMET is amongst others responsible for time and frequency maintenance and dissemination in Switzerland. Within this field of activities, time and frequency transfer over a wide range of distances using many different methods (among other TV methods, GPS common view techniques, etc.) are of primary interest.

The software used for this project is the Bernese GPS Software. It was originally a pure “double-difference” software package. For the time transfer project it was essential to modify the software to allow for zero-difference (undifferenced) and single-difference processing. A first step was made in September 1995, enabling zero-difference processing using code observations. In January 1997, the capability to process undifferenced *phase* data was built into the software.

It was clear from the start of the project, that optimum use should be made of the GPS code and phase measurements and that only geodetic GPS equipment should be used. The emphasis was put on the comparison of external clocks, as opposed to receiver-internal clocks. Calibration of delays in cables, temperature-dependent delays, etc., were and are of vital interest in the context of the joint OFMET/AIUB project (see Figure 2). Let us mention at this point that the control of these delays is absolutely mandatory for GPS-based time transfer. The corresponding requirements are much less stringent for frequency transfer.

Today two prototype Geodetic Time Transfer terminals (GeTT terminals) are available and a third will be ready in the near future. The terminals contain modified

Ashtech Z-12 receivers. More information about the time transfer project and the GeTT terminals may be found in [Schildknecht *et al.*, 1990; Overney *et al.*, 1998].

CODE will participate, in collaboration with the OFMET, in the IGS/BIPM time transfer project. After two experiments on European baselines in 1997 (OFMET-NPL, PTB-NPL), the GeTT terminals will be deployed on a transatlantic baseline during the second half of 1998. This will in fact be the first comparison of the GeTT method with the independent two-way satellite technique (TWSTFT) on an intercontinental baseline.

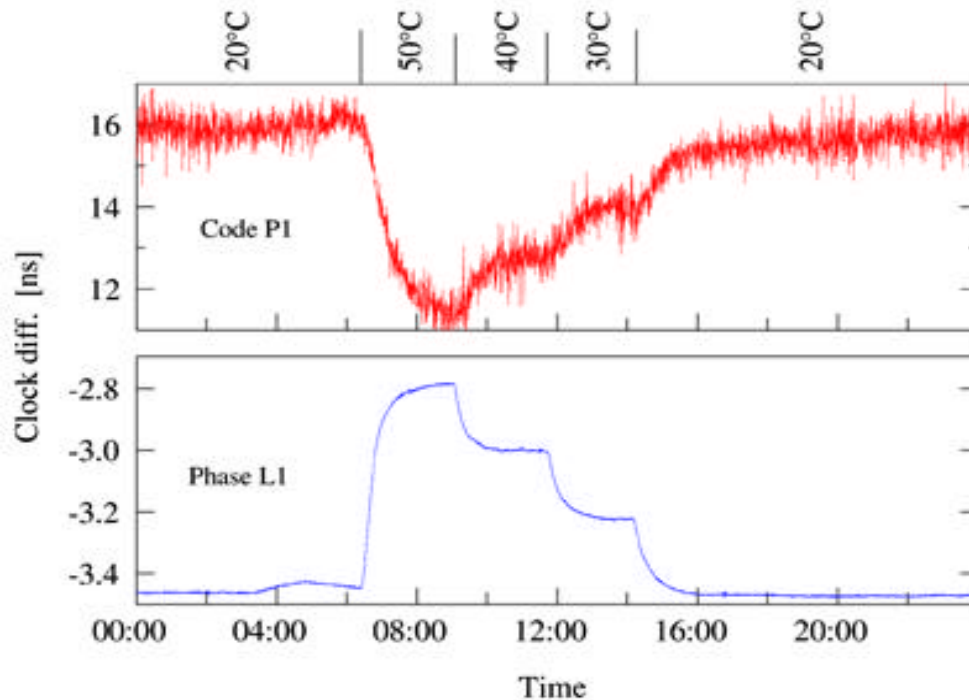


Figure 2. Temperature dependence of the GPS receiver delays for P1 code and L1 phase measurements during one day.

3.7 Troposphere Gradients

As mentioned in a previous section, tropospheric gradients have been estimated in the European solutions of CODE since April 1997 [Rothacher *et al.*, 1997b]. In October 1997, a test solution with the estimation of daily troposphere gradients was activated in the *global* CODE processing. Figure 3 shows, as an example, the troposphere gradient parameters (excess path delay at 10 degrees elevation angle) of the site Onsala for about 500 days.

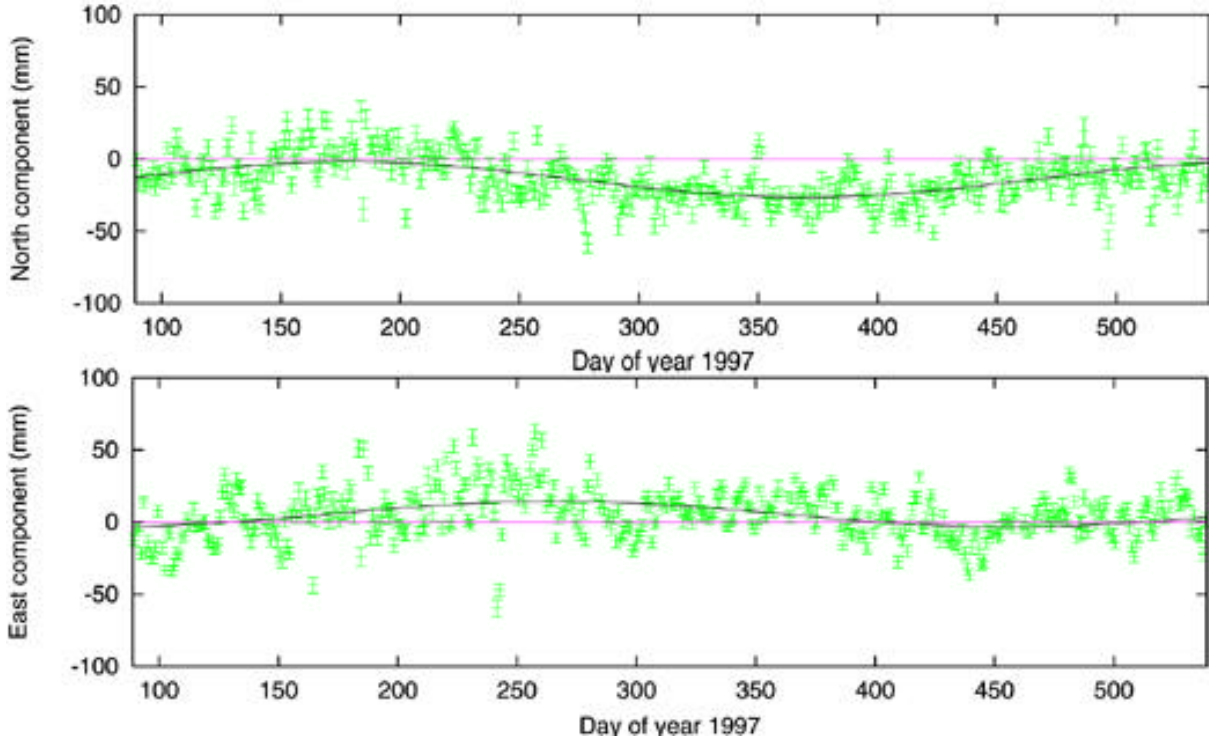


Figure 3. Troposphere gradients for Onsala at 10 degrees elevation.

We recognize a seasonal signature and an offset in both components, especially in the north. Most sites located on the northern hemisphere exhibit, on the average, significantly larger delays towards the south than the north and vice versa for sites on the southern hemisphere. The same characteristics have also been reported by the VLBI community.

3.8 Ionosphere

At present the following ionosphere products are generated on a routine basis:

- 2-hourly global ionosphere maps (GIMs) are produced using double-difference phase or phase-smoothed code observations. The phase-derived TEC maps proved their usefulness for ambiguity resolution (AR) on long baselines. Rapid global maps are available with a delay of about 12 hours, the final ones after 3 to 4 days.
- Regional (European) maps are produced as well and are also used to support AR. On the average 90% of the initial carrier phase ambiguities can be resolved reliably – without making use of code measurements.
- Daily sets of differential code biases (DCBs) for all GPS satellites (and all contributing receivers) are estimated at CODE since October 1997. The day-to-day scattering of the satellite-specific DCBs is better than 0.1 ns.

- Since June 1998, 1-day and 2-day predicted GIMs are regularly derived. The prediction procedure performed is described in [Schaer *et al.*, 1998b].

In order to improve the ionosphere estimation the following changes were made in 1997/1998: The maximum degree of the spherical harmonic (SH) expansion was increased from 8 to 12 to be able to resolve smaller TEC structures like, e.g., the equatorial anomaly. The temporal resolution was increased from 24 hours to 2 hours and slight relative constraints between consecutive sets of SH coefficients were introduced (to get reasonable TEC results for regions where no stations are located). Moreover, we recently refer the SH expansion to a solar-geomagnetic reference frame (instead of a solar-geographic one).

Starting with June 1, 1998, our final GIMs are delivered weekly to CDDIS in compressed IONEX form [Schaer *et al.*, 1998a] fulfilling the standards as stated in [Feltens and Schaer, 1998]. The CODE IONEX files also contain RMS maps and a set of DCB values for the satellites. Figure 4 shows 12 TEC snapshots of the global TEC for June 1, 1998, referring to times 01:00, 03:00, ..., 23:00 UT. Bright areas indicate low TEC, dark ones high TEC. The dotted line corresponds to the geomagnetic equator.

The long-time series of global TEC parameters available at CODE covers 3.5 years by now and includes up to 1788 SH coefficients per day. The zero-degree coefficient representing the mean TEC on a global scale characterizes the ionospheric activity pretty well. The evolution of this particular TEC parameter during a period of low solar activity is shown in Figure 5. An automatically updated figure showing the complete time series and a one-year prediction of the Earth's mean TEC can be found on the WWW page <http://www.cx.unibe.ch/aiub/ionosphere.html>.

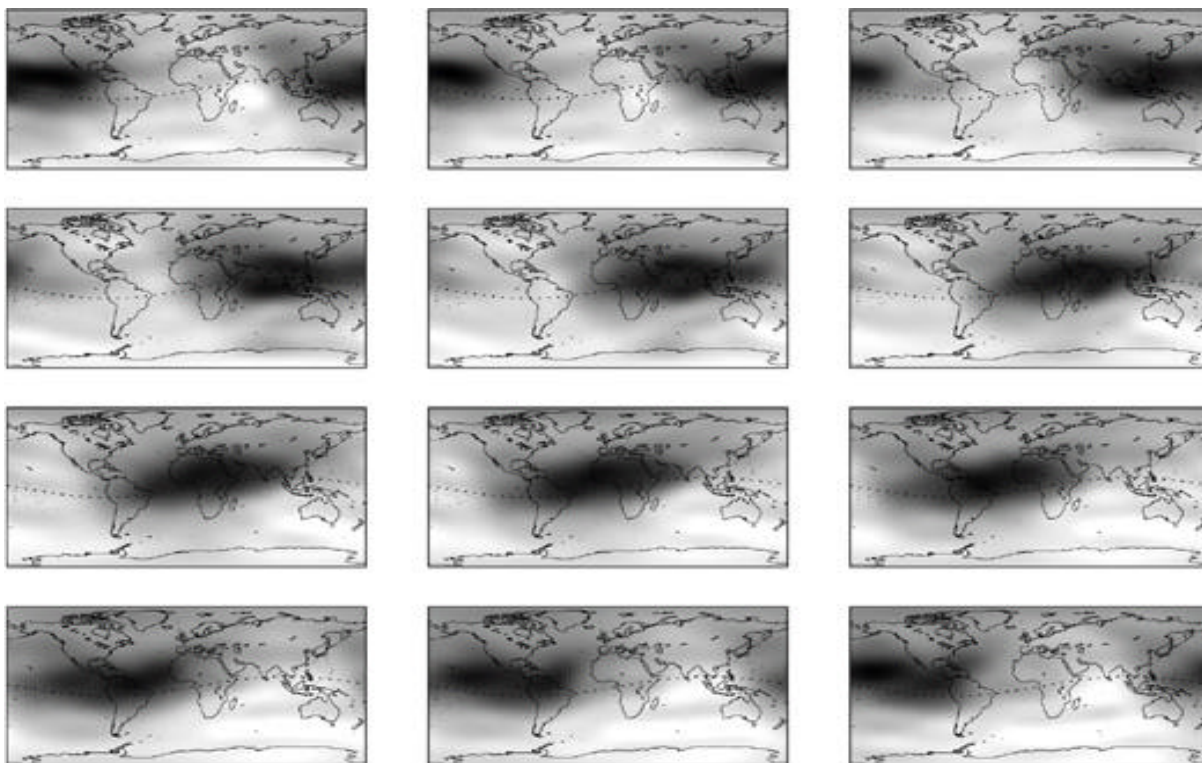


Figure 4. CODE 2-hour GIMs for day 152, 1998

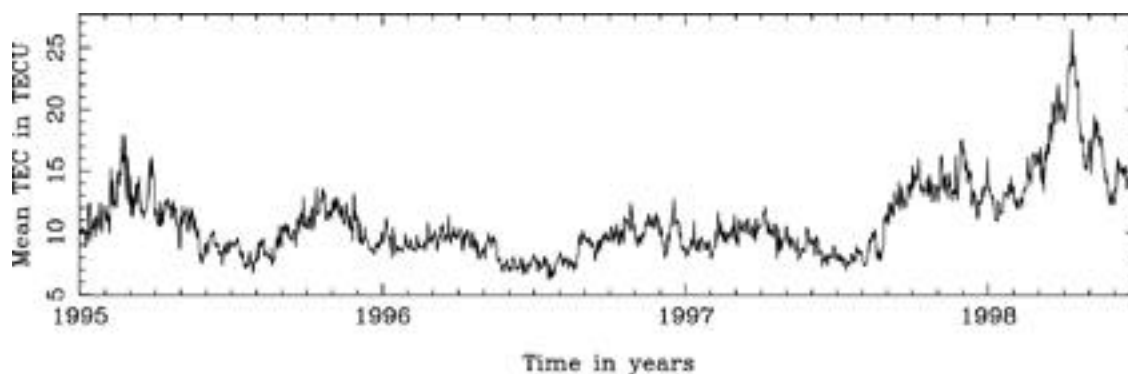


Figure 5. Evolution of the Earth's mean TEC computed by CODE since January 1, 1995

4 GLONASS

Since December 1997, a single-frequency receiver (Ashtech GG24) is running permanently at the Zimmerwald observatory. A daily single-point-positioning solution is computed and the time difference between GLONASS time and GPS time is monitored. In Figure 6 we see the systematic difference of about 2 μ sec between the time systems (after subtracting the leap seconds of UTC (Moscow)). Also, the difference varies within several ten nanoseconds.

The fit of 3-day arcs through the orbits broadcast by the GLONASS satellites indicate that the precision of the GLONASS orbits is in general 2-3 meters, a quality similar to that of the GPS broadcast orbits. As in the case of GPS, improved GLONASS orbits have to become available in order to make the GLONASS measurements useful for geodetic and geodynamic applications. Presently, the Bernese GPS Software is modified to enable the processing of dual-frequency GLONASS carrier phase data including ambiguity resolution.

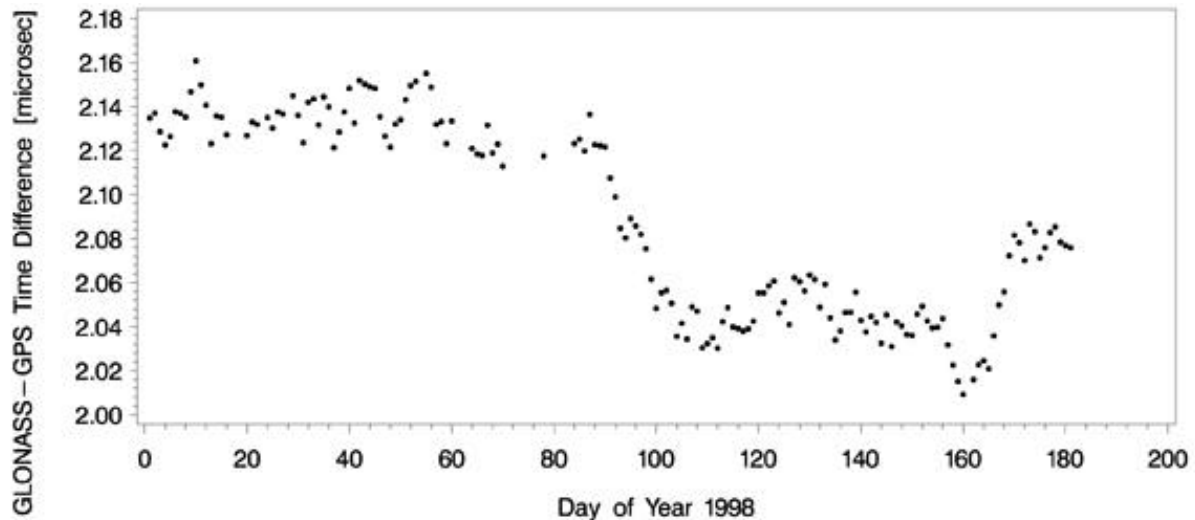


Figure 6. Time difference between the GLONASS and GPS time system.

8 Outlook

For the next year, we plan to realize a combined GPS/GLONASS solution, starting with the activities related to the International GLONASS Experiment (IGEX). It would also be beneficial (especially for tropospheric gradient parameters, that will soon be implemented into the official 3-day solutions) to include data down to 5 degrees elevation, but a new set of antenna phase center calibrations going down to 5 degrees will be needed beforehand. The increase in the amount of data due to the addition of GLONASS and low-elevation data will allow a refined modeling of the troposphere parameters. CODE will continue its special ERP series (sub-daily ERPs and nutation). In view of the present quality of the GPS ERPs and the increasing length of the series, the study of new phenomena in earth rotation (e.g. high-frequency atmospheric normal modes) may become possible. Because sub-daily site displacements are strongly correlated with sub-daily ERPs, a detailed study of ocean loading, atmospheric loading, and short-term variations in site coordinates in general, will be another important field of interest at CODE.

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The ESA/ESOC IGS Analysis Centre

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1 Introduction

In 1997 we have continued our contribution to the IGS that was initiated in 1992. We have incremented the number of products to accomplish the last IGS requirements and recommendations.

This year has been characterized by the following:

- The production of predicted orbits has been developed and initiated. We contribute regularly to the IGS predicted orbit since April 1997.
- The quality of our products has been improved by the estimation of empirical accelerations and the implementation of new tropospheric and ocean loading models.
- Further developments have been carried out in the Ionospheric Monitoring facility in preparation to the regular production of combinations and the creation of a new IGS product in 1998.
- In the field of satellites carrying GPS receivers, the TOPEX/Poseidon analysis activities, performed more than two years ago, have been resumed with the Automated Rendezvous Pre-development (ARP). The analysis of the first Flight Demonstration took place in 1997. Several of our routine IGS products have been used for the data analysis.

2 ESOC GPS Web Pages

Additional information on GPS related activities at ESOC can be found at our web pages:

[html://nng.esoc.esa.de](http://nng.esoc.esa.de)

3 ESOC IGS Analysis

An updated description of models and parameters used in our routine processing is located at:

<http://igsb.jpl.nasa.gov/igsb/center/analysis/esa.acn>

4 Computer Resources and Software Description

The software has been integrated in the last years under the GPS Tracking and Data Analysis Facility (GPS-TDAF). It is a UNIX based environment for which main tools have been developed in FORTRAN for the numerical computations and in tcl/tk for the scripts that control the automatic processing and for the graphical user interfaces.

The GPS TDAF is made up of three main tools:

- The Remote Station monitor and control. It retrieves, preprocesses and distributes the data of the ESA GPS receivers Network.
- The External Sites monitor and control. It retrieves the RINEX data that are used for the processing of our IGS products.
- The IGS processing monitor and control. It allows the operations related to of the final, rapid and predicted products.

A special emphasis has been put on the system automation, and it has proven to be robust for periods of several days with a very sparse remote operator control. The main problems arise from the computer loading at ESOC, the huge amount of involved data and the sequential nature of the products, that depend on the success of the processing of the previous days.

5 Data Archiving

A 7 Gigabytes disk is accessible to the workstations through the ESOC network. There is space for the computation of two or three weeks and then products and data are archived in a robot tape system. Old data can be put on line for reprocessing.

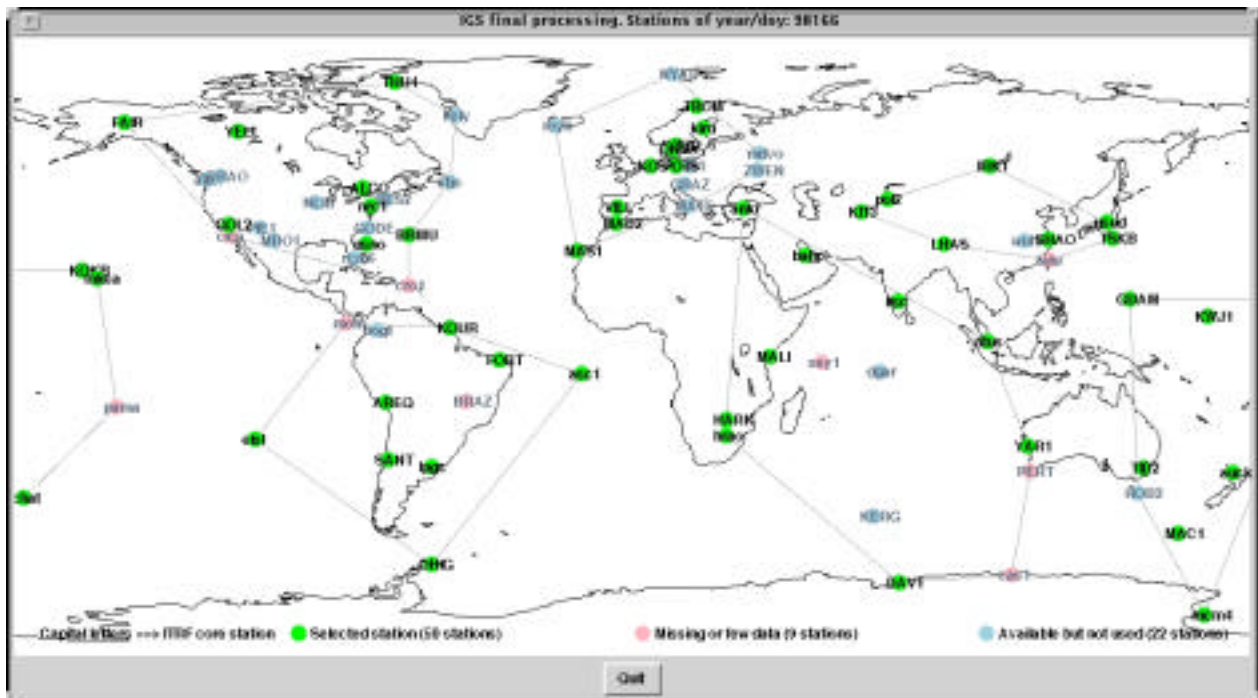
6 ESOC IGS Analysis Centre Major Routine Analysis Changes in 1997

31/03/97	Estimation of sine and cosine radial empirical acceleration instead of impulses every 12 hours
09/03/97	Saastamoinen tropospheric model replaced the Willman one
02/04/97	ESA predicted orbits available

21/04/97	Deadline of rapid orbits reduced from 23:00 to 21:00 UTC
22/07/97	Hatanaka compression implemented for the analysis and for the data distribution of the ESA receivers
30/11/97	Ocean loading implemented based on the Scherneck model

7 Tracking Network

The following panel is part of the GPS Tracking and Data Analysis Facility and shows for a given day the stations that are considered in the processing.



8 Predicted Orbits

Earth fixed positions taken from the rapid IGS solution are used as basic observable. The number of days for the fit is variable, currently set to four. If the IGR rapid orbit is not accessible our corresponding rapid solution plus eop's are used instead. Measurements of the last day have a weight three times the one of the initial days.

Per satellite are estimated ROCK4T scale factor, ybias and sine and cosine one cycle per revolution empirical accelerations in the three orbital directions. The initial state vector is taken from the corresponding rapid solution. It is also estimated.

Earth orientation parameters are taken from the rapid solution for the fit interval and from the IERS rapid service for the prediction. xp, yp and ut1 in the prediction interval are corrected for the offset with respect to the IGS rapid eop's.

Satellites are deweighted if

- they have been deweighted in the rapid solution
- are missing any of the days of the rapid combination
- are in eclipse period
- the orbit determination fit of the 4 igr orbits is poor.

Satellites with a extremely bad fit in the 4 day igr interval are replaced by the propagation of our last rapid solution. It has been proven that a propagation of a smaller arc is better.

9 Rapid and Final Orbits

Rapid and final orbits are mainly differentiated by the amount of data available. Rapid orbits are initiated at 14:00 UTC after collection of all the available data. The data arc is 12+24 hours and the processing time about 4 hours. Final orbits are initiated with a delay of several days for data collection. The data arc is 12+24+12 hours and the processing time about 12 hours in a SUN Sparc 20.

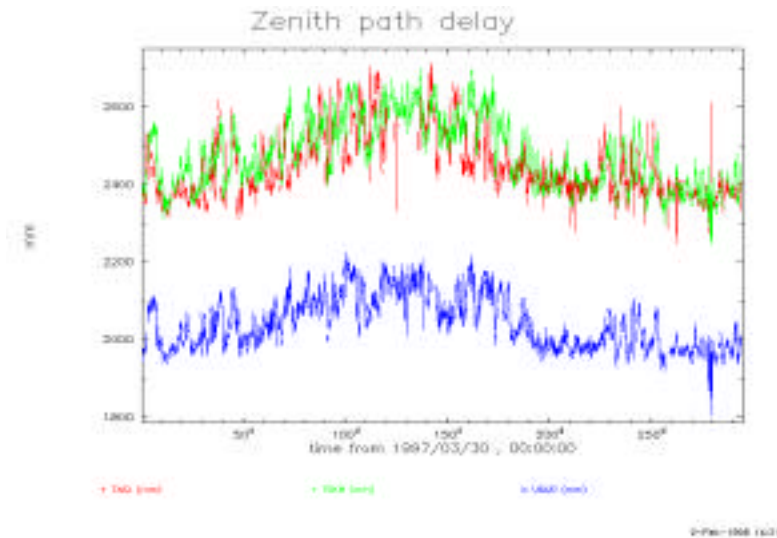
The orbit modelling is common. Per satellite we estimate the following parameters:

- Position and velocity at epoch.
- Scale for ROCK4T, y-bias, sine and cosine radial component one cycle per revolution empirical accelerations. These parameters replaced the delta-v impulses every 12 hours for all the satellites in March 1997.
- For eclipsing satellites the observations are excluded half an hour before and after the eclipse. Delta-v are estimated in the three orbital components at eclipse exit time.
- Any delta-v due to spacecraft manoeuvres.

10 Tropospheric Estimates

Tropospheric zenith path delays are produced in our routine analysis. They are estimated along with orbits, eop's and station coordinates. We use the Saastamoinen model since March 1997. The model consists of two hourly step functions with apriori values taken from the previous day.

In the following example the results for three stations, USUD, TSKB and TAEJ from the same region are presented. The three curves show the same seasonal variation. Taejon and Tsukuba are located close to the sea level while Usuda is at about 1500 meters height. That explains the difference of about 400 mm between the curves. The geographical proximity between Usuda and Tsukuba makes both profiles to look very similar in spite of the height difference.

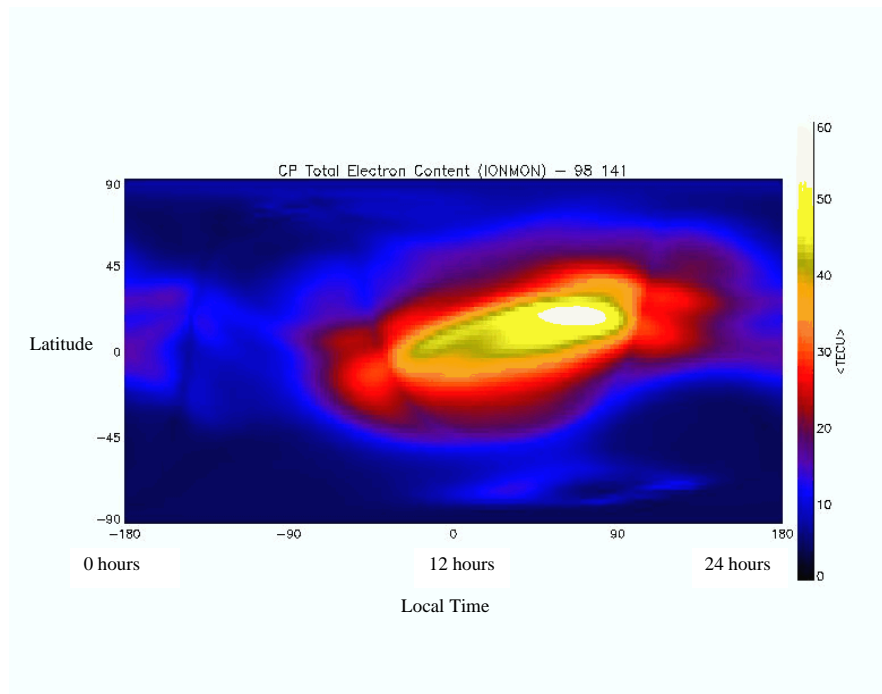


11 Ionosphere Processing

At the beginning of 1998 the routine processing of ionosphere TEC maps and satellite/receiver differential code biases (DCBs) in final and in rapid mode has been started at ESOC. The first day that was processed in final mode was the 28 December 1997, and processing in rapid mode started for 19 March 1998. 24 hours of so called TEC observables, derived from carrier phase leveled to code data, are fitted to 2-d single layer TEC models, as well as to Chapman profile models to resolve the ionosphere's electron content 3-dimensionally. The processing sequence is as follows:

- 1) A nighttime TEC data fit is made to obtain reference values for the DCBs. The nighttime TEC itself is absorbed in this fit with a low degree and order spherical harmonic. In the other fits 2) - 4) these DCBs are then introduced as constraints.
- 2) A Single layer Gauss-Type Exponential (GE) function is fitted to the TEC data. The results of this estimate are intended for the ESOC-internal interpretation of results and comparison with the other fits.
- 3) A Chapman profile model is fitted to the TEC data, where the layer of maximum electron density N_0 and its height h_0 are estimated as functions of geomagnetic latitude and local time. h_0 is restricted to achieve values within a predefined height range only, currently $400 \text{ km} \leq h_0 \leq 450 \text{ km}$.
- 4) A Chapman profile model is fitted to the TEC data, where now h_0 is fitted as a global constant.

Since the beginning of June 1998 ESOC is contributing to the IGS Ionosphere Working Group's pilot phase. Fit no 3) in final mode is currently delivered to the IGS Ionosphere pilot project. The figure below shows a TEC map from a fit of type 3).



12 Manoeuvres Estimation

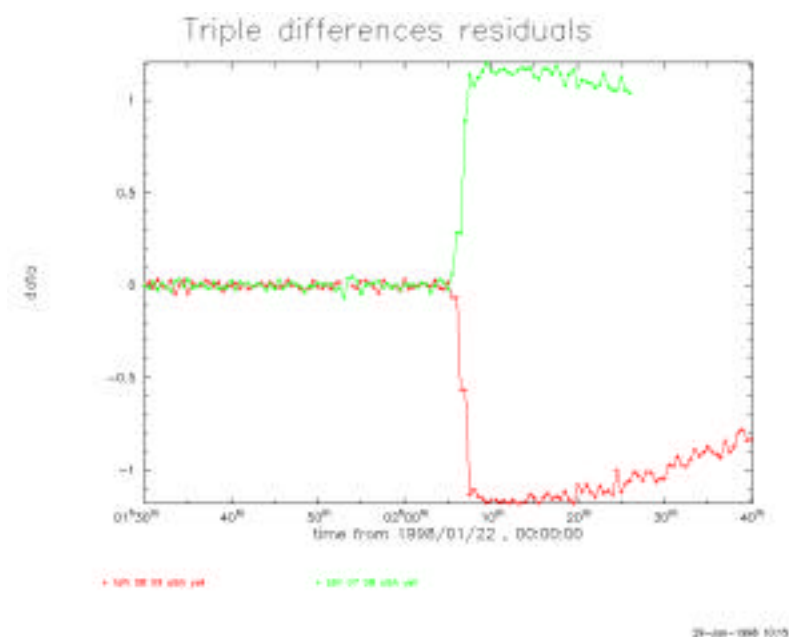
For the estimation, the manoeuvres must be previously announced in the NANU's. If at least two receivers track the manoeuvring satellite we try to detect the time when the thrusters are fired using two alternative ways:

- Studying the residuals of the phase triple differences for combinations that include the satellite. The time is determined by looking for a step in the triple differences caused by the new range rates produced by the change in velocity. The preliminary value of along track Δv is estimated by the energy change. See plot below.
- Using clock bias free ionospheric free carrier phase time differences. We have developed an algorithm to detect Δv changes based on the comparison of the observations to a propagated orbit. We obtain directly the estimate of Δv .

Once the manoeuvre time is known and with a initial estimate of Δv , our orbit determination program BAHN estimates the orbit and impulse in three directions. Radial and cross track components are normally negligible compared to the along track

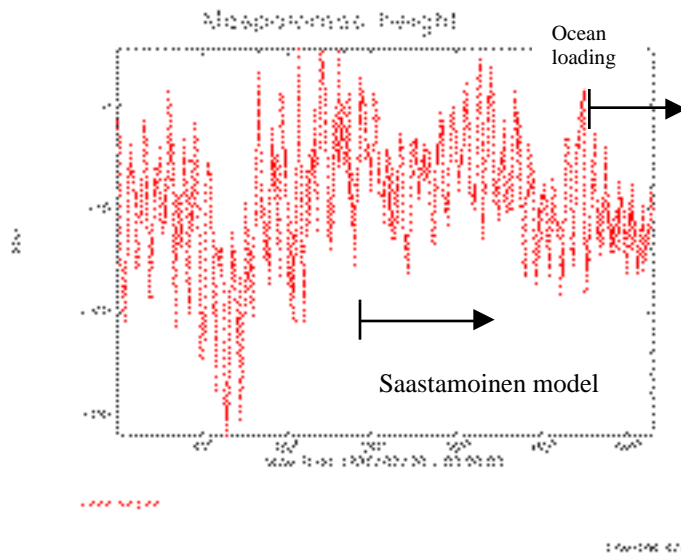
component. Observations one hour before and after the manoeuvre are not considered because of difficulties with the fit.

We have estimated all manoeuvres since the beginning of IGS. Only in a very few cases did the lack of visibility not allow us to detect the firing time. The current network densification facilitates the detection.



13 Station Coordinates

The stability of the station coordinates has been improved -specially the vertical component- with the implementation of the Saastamoinen tropospheric model in March 1997 and also with the consideration of ocean loading based on the Scherneck model. That can be clearly seen below on the height estimation of Maspalomas, a station very affected by the ocean loading effect. Several tidal effects, specially the monthly one, have been substantially reduced.



14 Products

Our routine products are the following:

- Final orbits esawwwwd.eph, being www the gps week and d the day of the week (0-6), distributed via CDDIS. 11 days delay.
- Rapid orbits esawwwwd.eph, being www the gps week and d the day of the week (0-6), distributed via EMR. 21 hours delay since April 1997
- Predicted orbits espwwwd.eph, distributed via EMR.
- daily rapid eop (pole, LODR) solutions in IERS format: esawwwwd.erp.
- weekly final eop (pole, LODR) solutions in IERS format: esawwww7.erp.
- weekly summaries: esawwww7.sum.
- weekly free network station coordinate solution in the SINEX format: esawwww7.snx
- daily tropospheric files containing Zenith Path Delay estimations esawwwwd.tro

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GFZ Analysis Center of the IGS - Annual Report 1997

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1 Introduction

In the last year, a further improvement of accuracy and quality of the products has been gained. The rapid and final orbits reached the 6 cm and 4 cm level, respectively, and the polar motion crossed the 0.1 mas “boundary.”

The software and the technology were changed to get the various products compatible to the final orbits. The clock solution was aligned to the GPS time frame.

The zenith path delay (ZPD) products from all the ACs are combined at GFZ to an official IGS product (see Gendt, this volume).

2 Routine IGS Processing - Overview

The technology for the generation of rapid and final products was already described in the last annual report. During 1997, changes were made to be more effective and to get compatible final products (see Table 1). An overview of both GFZ products, and all daily and weekly activities, is given in Table 2.

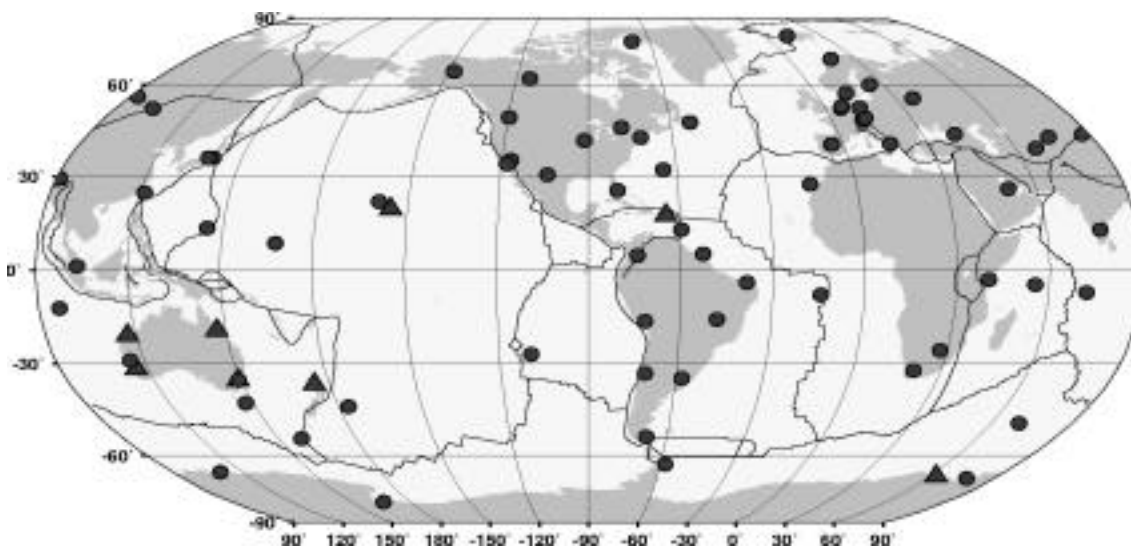


Fig. 1. Global distribution of stations used in the IGS analysis of GFZ
(♣ - sites added for rapid analysis)

Table 1. Modification in software and technology

Week	Date	Description
902	1997-04-20	Use of an optimized set of ~30 sites for rapid analysis
903	1997-04-27	ERP from 3-day arcs (middle day), UT is solved for
921	1997-08-31	Calibration of clock products (alignment to GPS time frame)
929	1997-10-26	Introduction of Niell mapping function
939	1998-01-04	Compatible clocks (use of 3-day orbits for clocks)
944	1998-02-08	5-min sampling rate, 15 degree elevation cutoff angle
945	1998-02-15	Introduction of tropospheric gradients
947	1998-03-01	Introduction of ITRF-96 with 47 core sites
949	1998-03-15	SINEX using 3-day orbits (compatible to SP3 orbits)
951	1998-03-28	Error for PRN8 corrected (IIR to IIA)
958	1998-05-17	PRN13: antenna phase center offset changed from 1.6746 m to 1.0229 m

Since March 1998, the raw RINEX data are handled in the Hatanaka format. All input files not submitted in this format are converted into this format just after ftp prior to analysis.

Starting with GPS week 944, we switched from 20 degree elevation cutoff to 15 degrees. At the same time, the sampling rate was reduced from 6 to 5 minutes, so that we could get exact satellite clock estimates for all 15-minute epochs in the sp3 product.

It should be mentioned that for PRN8 (started in November 1997), a wrong block number (IIR instead of IIA) was erroneously introduced. After correction in March 1998, our overall orbit quality improved by 1 cm (Figure 3). This demonstrates that at the level of 5 cm, such an incorrect parameter influences the orbit solutions for all other satellites.

2.1 Rapid Analysis

A set of 20-30 well-distributed sites is sufficient to get high-quality satellite orbits. Starting with GPS week 902, an optimized set of ~30 sites was selected, resulting in reduced computation time for the total rapid analysis (about 2-3 hours). To have a long history, we tack on a selected set of sites in our final analysis. However, occasionally these sites do not come in a timely manner, so for the rapid analysis, some additional sites were selected.

2.2 Final Analysis

The data cleaning part was changed to use the precise point positioning (PPP) technique based on the satellite clocks from the rapid analysis. This cleaning is more effective and more flexible than the formerly-used double difference procedure, which is now used only for the rapid analysis.

The strategy for deriving the final products was changed to get products that are compatible to each other. The old products for ERP and SINEX were based on daily orbits, whereas the sp3 product was formed using 3-day arcs.

The new technology is the following:

Table 2. Overview of IGS routine analysis and generated product (D denotes actual day)

1-day orbits		
■ Rapid analysis for D-1 (start 9:00 UT)		<i>gfzwwwwd.erp</i>
• Optimized set of ~30 sites		
	<i>gfzwwwwd.sp3p</i>	
• DD-Clean		<i>including sat-clocks</i>
• Analysis and post-fit-cleaning (iteratively)		<i>(12:00 UT)</i>
■ Predictions		<i>gfpwwwwd.erp</i>
• IGR products for D-4 to D-2 and		
GFZ rapid products for D-1 used		
■ Final analysis		
• PPP-cleaning using rapid clocks		
Final Solution, weekly		
■ 3-day orbits by combining NEQ of 1-day orbits		<i>gfzwwwwd.sp3</i>
• Output of NEQ implicitly containing		
the 3-day orbits (not fixed !)		
■ ERP are taken from the middle day of the		
3-day orbit solutions		<i>gfzwwwwd.erp</i>
■ Weekly SINEX is computed by stacking the above NEQ		
for 7 days (data of each day are used in three NEQs)		<i>gfzwwwwd.snx</i>
■ To get compatible products clocks and (real-valued)		
ambiguities are computed fixing the above sp3 orbits		<i>sat-clocks</i>
■ ZPD solutions with a higher sampling rate are effectively		<i>gfzwww.tro</i>
computed by fixing the above ambiguities		

All products are based on fixing the station coordinates of the core sites (since March 1998 47 sites of ITRF96, before that 13 sites of ITRF94). The sp3 orbits are computed using 3-day arcs (by stacking NEQs of 1-day arcs). Simultaneously with the orbit product, a 3-day NEQ is formed containing only the station coordinates and ERPs, but also implicitly including the 3-day orbits (Helmert blocking; orbits are not fixed!).

For each 3-day arc daily ERPs are computed with continuation constraints for the day boundaries (i.e., polar motion and trend as well as UT and LOD form a continuous polygon). The solution for the middle day of each arc is the official product. Each week, a UT series is compiled by concatenation of the daily values and starting at Bulletin A value.

Because the sp3 orbits are computed by stacking NEQ there are no simultaneously solved clocks. Therefore an additional step was introduced at which all clocks and (real valued) ambiguities are determined by fixing the given orbits. These products are now consistent to the best orbits. Such clocks can be used in the well-known precise point positioning. For the derivation of the ZPD product with hourly sampling rate (in the routine analysis 4 hours are used), the derived ambiguities are introduced and fixed. This way the new analysis can be done within minutes. In addition, the ZPD values are adjusted using the adjacent days (3 days in total) to smooth the solution at the day boundaries.

3 Improvement of the Clock Solution

Before GPS week 921, the GFZ clock solutions (rapid as well as final) showed significant offsets and drifts compared to the IGS combined solutions. The differences in the offset reached values up to 1 microsecond and the trend difference was normally in the range of 80-90 nanoseconds per day. To overcome the problem of singularity within the estimation process, the satellite and station clocks are reduced to a specified reference clock. Usually as a reference, one of the station clocks is taken which is known to be very stable. At GFZ, the station clock of Algonquin is used as reference most of the time. Before GPS week 921, the satellite clocks taken directly from the adjustment were delivered as the final results. However, the connection to a specified reference clock led to differences compared to GPS time because of the behavior of the reference clock. It is only stable with the exception of a small rest, and therefore includes a time-varying offset and drift. Beginning with GPS week 921, the GFZ clock solution was corrected for these effects. In a first step, possible resets or jumps of the reference clock which appear sometimes are detected and corrected by comparing the reference clock with other stable station clocks. Missing epochs of the reference clock, which normally led to gaps in the final clock solution, can now be bridged over. The offset correction is then performed by calculating an average over all satellites. The drift correction is estimated by the trend over all mean values.

Figure 2 shows the improvement of the final clocks of GFZ for both offset and trend as a result of the changes. Before week 921 the drift was nearly constant in the range of 90 nanoseconds per day (reflecting the clock characteristic of Algonquin) whereas after the software improvement it was usually a few nanoseconds.

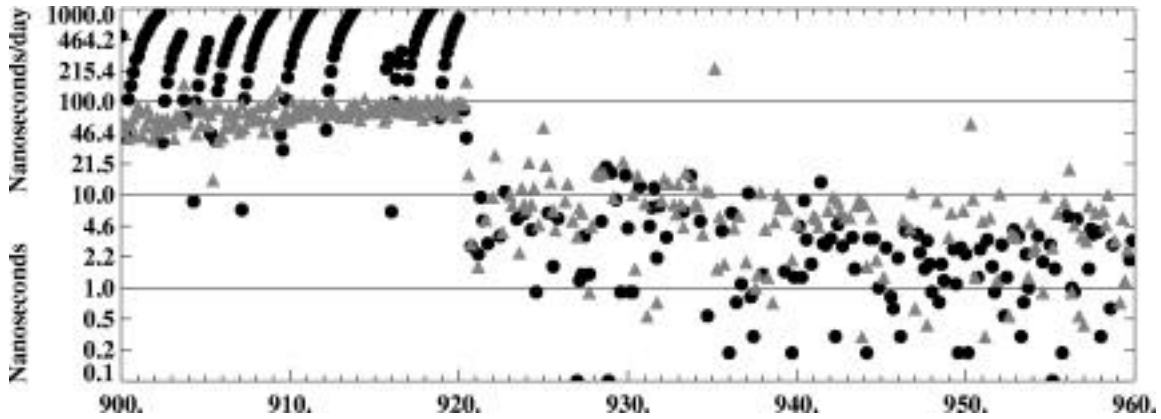


Fig. 2. Offset (●, [ns]) and trend (▲, [ns/d]) of GFZ satellite clock results as compared to the GPS time frame

It should be mentioned that there are some inconsistencies between the ACs concerning the antenna phase center offset for PRN13 which results in higher clock differences. When GFZ switched from 1.6764 m to 1.0229 m, the value used by most ACs, the level of our clock differences improved to 0.2 ns (Figure 3).

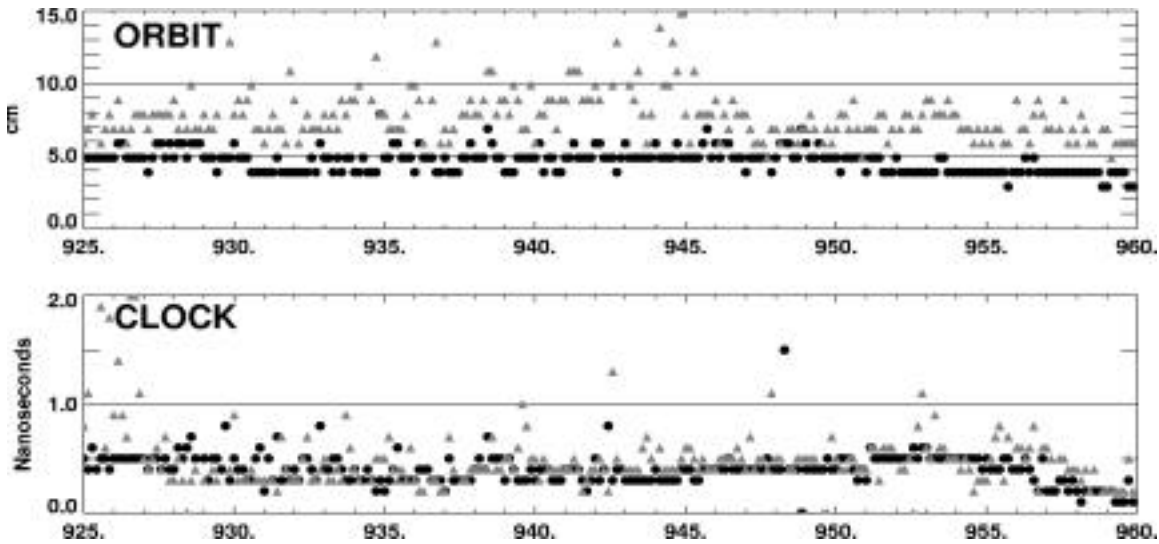


Fig. 3. Daily median of GFZ final (●) and rapid (▲) orbits compared to the official IGS Product

4 High Rate Satellite Clocks

Based on the results of the IGS final analysis which is usually done with sampled data, the computation of high-rate satellite clocks (i.e., with the original data rate) can be carried out with a small additional amount of computation time.

After the IGS final processing, precise GPS satellite orbits are available which can be introduced as fixed parameters. On the other hand, all ambiguities within the sampled data are estimated within the IGS adjustment, and all bad data and outliers are identified. With this information, the raw 30-sec RINEX data files are reduced to those parts for which the ambiguities are valid. New data before or after are neglected. As a result of such pre-processing, new ambiguities may not be found within the high rate data. Beyond this, the GPS data between the low rate epochs are separately inspected for bad records. A selection of about 20 stations seems to be sufficient for a good global coverage. Because this number of stations in general is smaller than the number of stations used in the IGS final analysis, the starting time of the ambiguities is not identical with the starting time of the original scene. Therefore, the ambiguities have to be shifted to the correct new epochs to avoid the problem that new ambiguities are automatically found by the program.

At this moment the precise high-rate clocks are not estimated routinely but a periodical and automatic computation can be installed easily. More details and results can be found in (Söhne, 1998).

5 Products

5.1 Orbits

The quality of the orbit solutions was 5-6 cm for the final and 6-10 cm for the rapid variant. The introduction of the ITRF96 with the 47 core sites to be held fixed (week 947), stabilized the realization of the reference frame and led to an improvement for the orbits, especially for the rapid solution. The orbits are now on the 4 cm level for the finals and on many days on the 6-7 cm level for the rapids (Figure 3).

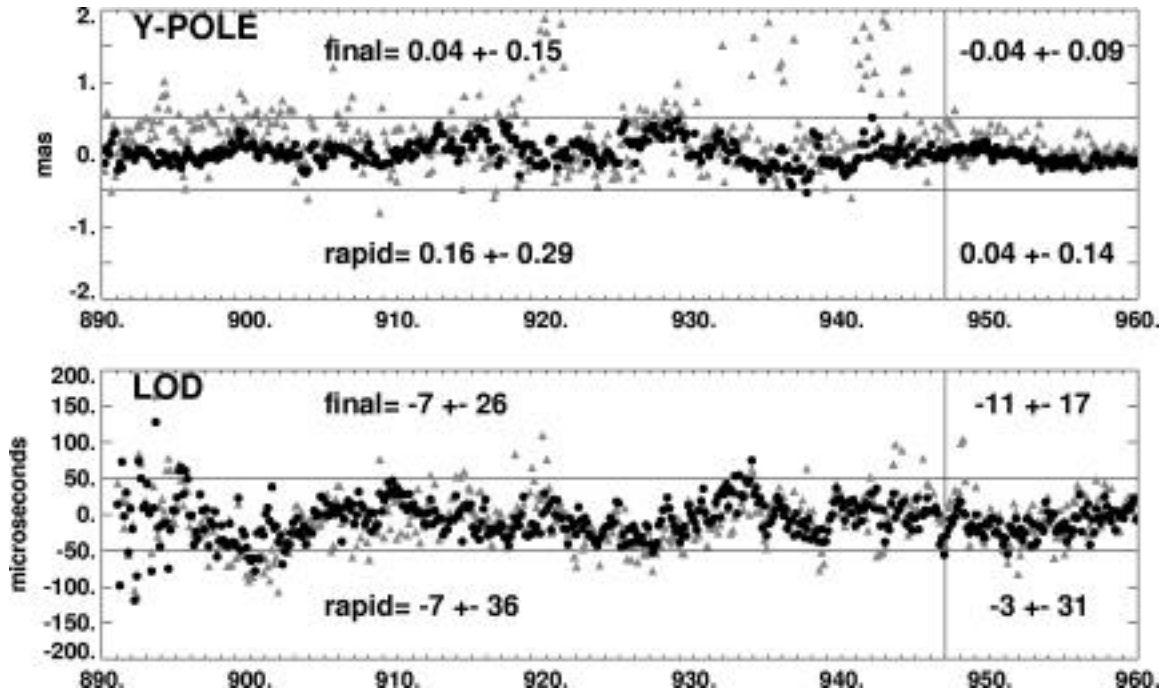
5.2 Earth Rotation Parameters

The accuracy for the ERP determination was already on a high level (see Table 3) and could even be improved during the past year. By using 3-day arcs for the determination of ERP (starting in week 904), the LOD solution improved significantly (Figure 4). A further improvement was reached in March 1998 by the introduction of the enlarged set of core sites which stabilized the reference frame realization during the daily analysis. The largest effect can be seen for the rapid products (Table 3, Figure 4), which have now an accuracy of 0.15 mas, and corresponds to the former accuracy of the final product. The improvement in the rates is not as dramatic. Since week 903, GFZ also submits UT results which are aligned to Bulletin A on the first day of each week. The accuracy within the week is at 0.07 ms.

Table 3. Accuracy of ERP determination for Rapid and Final Products

	Rapid*		Final	
	ITRF94	ITRF96	ITRF94	ITRF96
xp	± 0.29	± 0.16	± 0.11	± 0.07
yp	± 0.29	± 0.14	± 0.15	± 0.09
LOD	± 0.36	± 0.31	± 0.26	± 0.16

* outliers removed


Fig. 4. Differences of GFZ final (●) and rapid (○) ERP solutions to the IGS final results.

5.3 Global Reference Frame and Plate Kinematics

To continue our investigations of recent global tectonics and for the determination of a global reference frame, one more year of IGS data was added to our analysis. The solution for the reference frame was computed according to the description in previous reports (Gendt et al., 1997). Site velocities were adjusted for all sites which were analyzed for more than one year (65 sites). The velocity in height was loosely constrained. The orientation of the system was defined by applying no-net-rotation constraints both for the site coordinates and the site velocities, as a reference the ITRF96 reference frame including velocities was used.

The quality of the determined reference frame is on the sub-cm level. Helmert transformation to ITRF96 gives residuals in north, east and up of 1.9 mm, 7.1 mm, 5.6

mm, respectively (for the 47 core sites). Larger discrepancies in the east component were observed for SANT, AREQ and KWJ1. For the dense parts of the network in Europe and North America (28 sites), the residuals are 1.2 mm, 2.8 mm, 3.2 mm. The global residuals to ITRF96 for the site velocities are in the range of 2-3 mm/y for all three components (2 mm/y in Europe and North America). Again some sites were excluded due to large discrepancies in the velocities, e.g., SANT, AREQ, MALI, OHIG.

Figure 5 presents the station velocities from our global solution over 5 years. The corresponding values from ITRF96, so far as available, are shown for comparison. A considerable improvement can be noted for the Australian sites (e.g., YAR1, HOB2, TIDB), as well as for the sites of East Asia and Japan (TAIW, USUD, TSKB), which showed rather large discrepancies in the past. Also a number of relatively new sites like GUAM, KERG, KWJ1, CAS1 and DAV1 are in better agreement now, so that in general a better quality both of ITRF and GFZ solution can be stated. The most remarkable region with large discrepancies remains South America, where further investigations and checks of the solution quality are obviously needed.

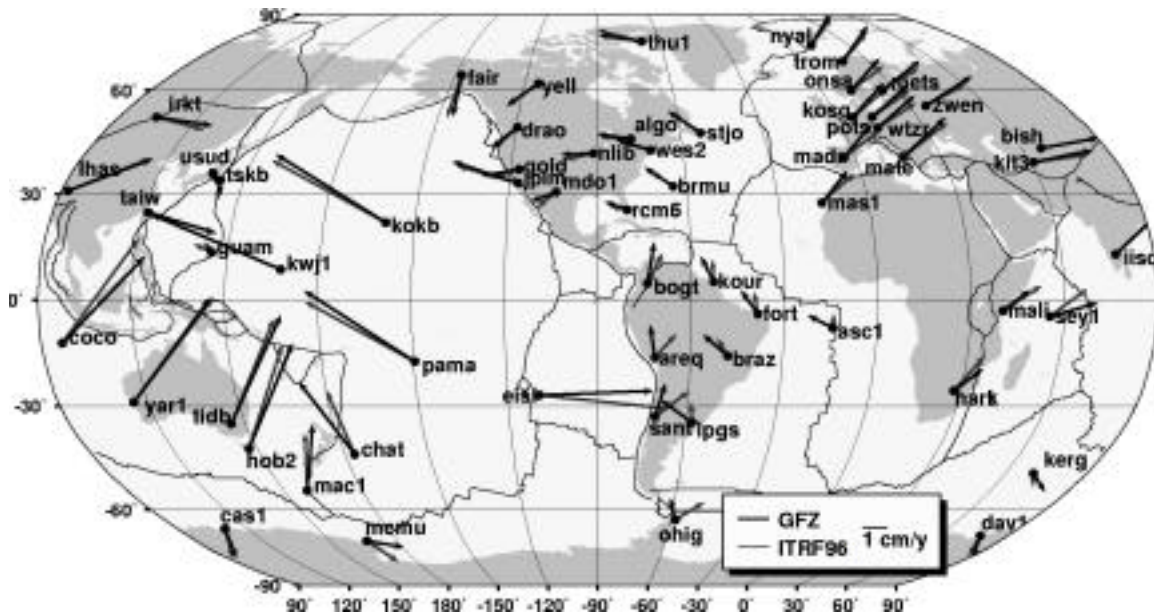


Fig. 5. Site velocities from GFZ solution from 5 year IGS data together with ITRF96 values

Figure 6 demonstrates a significant improvement of the GFZ coordinate solution achieved after the introducing of ITRF96 at week 947. Here, differences in 3 components between the GFZ coordinate solutions and the combined JPL GNAAC solutions are given.

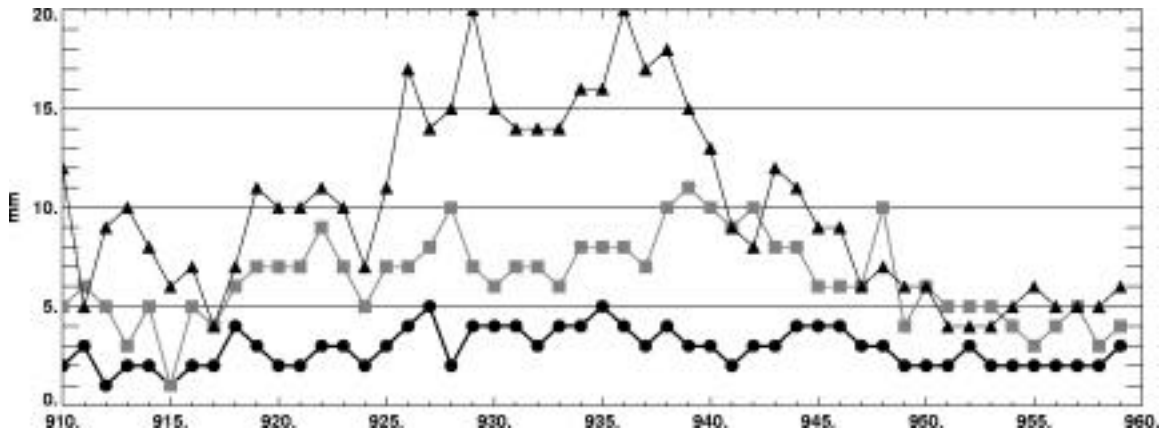


Fig. 6. Differences between GFZ coordinate solution and the combined solution of JPL GNAAC in north (●) , east (◻) and height (▲).

5.4 Troposphere

The quality of the zenith path delay solution is on the level of 3-4 mm (More details see Gendt, 1998).

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JPL IGS Analysis Center Report, 1997

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1 Summary

JPL activities as an IGS Analysis Center continued throughout 1997. Regular deliveries of rapid (1-day), precise, and high-rate (30-sec) GPS orbits and clocks, Earth orientation parameters, and free-network ground station coordinates (now in SINEX 1.0) were maintained. A new product was made available in 1997 - daily troposphere estimates in the IGS exchange format. The estimation of tropospheric gradients has further improved the accuracy of our solutions. In early 1998, a larger subset of the newly-augmented group of 47 IGS fiducial stations was put in use, and all fixed-network solutions were made to align with ITRF96. Shortly thereafter, only free-network products rotationally aligned with ITRF96 are submitted.

2 Evolution in 1997

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] describes JPL activities as a GNAAC (Global Network Associate Analysis Center).

Table 1 indicates the evolution of our activities during 1997. A major event was the estimation of tropospheric gradients (see section 5 of this document). Also, JPL station coordinate solutions now conform to the SINEX 1.0 format. We thank Remi Ferland of NRCan for providing the SINEX conversion utilities and assisting in their implementation at JPL.

Table 1: Analysis evolution, 1997 through early 1998

<u>Action</u>	<u>Date</u>
Produce troposphere files in IGS Exchange format	Jan 26
Produce station coordinate files in with SINEX 1.0 format	Jan 26
Produce free-network transformation files routinely	Apr 15
Do not process satellites deleted from rapid-service product	Apr 23
Estimate tropospheric gradients	Aug 24
Use TurboRogue MAD2 (in place of MADR) as a fiducial site	Nov 9
Correct mismodeling of SRP for PRN03	Nov 9
Use NRC1 (instead of ALGO) as default reference clock	Dec 14

Use 32-hour nominal orbit interval, map final orbits for 30 hours	Feb 1, 1998
Use ITRF96 coordinates and velocities for 22+ subset of 47 IGS fiducials	Mar 1
Use free-network estimates in troposphere products	Mar 15
Lower threshold of global site RMS isolation from 2000 to 1800 km	Mar 18
Use USNO (instead of NRC1) as default reference clock	Apr 26
Increase a priori sigma for pole rates from 0.18 to 0.50 mas/day	May 6
Use all free-network solutions for products and AC summary report stati	Jun 28

3 Product Summary

Tables 2 and 3 summarize the regular products that result from JPL IGS AC activities. New products are the daily, site-specific troposphere estimates in IGS Exchange format. These are described in Section 5 of this report. Table 4 indicates addresses of World Wide Web pages with related information.

Table 2: Regular products from the JPL IGS Analysis Center, at <ftp://sideshow.jpl.nasa.gov/pub/jpligsac>

<u>Example File</u>	<u>Contents</u>
0937/jpl0937.sum.Z	narrative summary for GPS week 0937
0937/jpl0937[0-6].sp3.Z	precise orbits for days 0-6 (Sun through Sat) of GPS week 937
0937/jpl0937[0-6].yaw.Z	yaw-rate data for eclipsing satellites, days 0-6, GPS week 937
0937/jpl09377.erp.Z	fixed-network Earth orientation parameters for GPS week 937 (free-network beginning week 964)
0937/jpl09377.snz.Z	free-network station coordinates for GPS week 937 (7-parameter transformation to ITRF beginning wk 947) (3-parameter rotation to ITRF beginning wk 964)
0937/jpl0937[0-6].tro.Z	fixed-network troposphere solutions, days 0-6, for GPS week 937 (free-network beginning week 949)
hirate/JPL0937[0-6].sp3.Z	high-rate (30-s) precise orbits and clocks, days 0-6, GPS week 937
1997.eng.Z	engineering data for 1997, sites in global solution
1997_p.eng.Z	engineering data for 1997, 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 at ftp://sideshow.jpl.nasa.gov/pub/gipsy_products

<u>Example File</u>	<u>Contents</u>
VeryRapidService/*	hourly Earth orientation, orbits, and clock data for use in GIPSY
RapidService/orbits/jpl0937[0-6].sp3.Z	quick-look precise orbits for days 0-6 (Sun through Sat) of GPS week 937
RapidService/orbits/jpl0937[0-6]_pred.sp3.Z	quick-look 3-day predicted orbit for days 0-6, GPS week 937
RapidService/orbits/1997-12-21.*	daily quick-look and predicted files for use in GIPSY
1997/clocks/1997-12-21.*	1997 daily free- and fixed-network clocks and yaw-rates for use in GIPSY
1997/orbits/1997-12-21.*	1997 daily free- and fixed-network precise orbits, polar motion, shadow-events data for use in GIPSY
hrclocks/1997-12-21.*	high-rate clocks (in TDP format) for use in GIPSY
IERSB/*	IERS Bulletin-B information

Table 4: Addresses of relevant web pages

<u>Address</u>	<u>Contents</u>
http://sideshow.jpl.nasa.gov/mbh/series.html	graphical time-series of site coordinates
http://sideshow.jpl.nasa.gov/mbh/global/table.html	table of site coordinates and velocities
http://milhouse.jpl.nasa.gov/eng/jpl_hp2.html	summaries and plots of station and satellite performance

4 Site Selection

Due to the continuous growth of the global network and the impracticality (with current computer resources) of simultaneously analyzing data from all stations, an algorithm for selecting a well-distributed subset of sites along with required sites such as the IGS fiducials was implemented in late 1994 (see [1]). This scheme chooses N ground stations on the basis of isolation. That is, the N th site is chosen so as to maximize its

distance from the nearest of the N-1 already chosen sites. The RMS isolation z (further described in [3]) is used to assess the distribution after all sites have been selected.

The site selection process has evolved since its first implementation, and currently 37 stations are selected as follows:

- Choose a reference clock station (usually NRC1 as of week 936; USNO as of week 955).
- Use 24-hour rapid-service processing results to make a separate list of stations with highly stable clocks. Although these are usually sites with H-masers, in general, these are any stations for which there are at least 250 5-minute clock solutions (out of a maximum of 288) that are smooth at the 4-cm level on timescales of 5 minutes.
- Based on isolation, choose the next 8 most isolated sites from the list of stable clock sites. These will aid in post-processed high-rate clock production.
- Add any sites not yet selected that are fiducial sites and use pseudorange observations (i.e., TurboRogue fiducials). Note that as of GPS week 947, the list of fiducials to choose from is a predetermined, well-distributed 22 station subset of the 47 sites newly designated as IGS fiducials.
- Again based on isolation, choose a number of well-distributed stations using pseudorange (typically TurboRogues), accounting for other fiducials and desired isolated stations not using pseudorange.
- Choose the remaining most isolated stations to complete the 37 total. Ensure that any of these that are of the 47-site IGS fiducial set will be constrained during the fixed-network portion of the processing.

5 Troposphere Products and Strategy Update

Beginning with GPS week 890 (January 26, 1997), JPL began to submit a contribution to the troposphere estimate combination compiled by Gerd Gendt at GFZ. These files contain our daily estimates of the total (wet + dry) zenith tropospheric delay at each site used in the fixed-network global solution. Initially, troposphere parameters were estimated using the Lanyi troposphere mapping function, a satellite elevation cutoff of 15 degrees, and a random walk model with 1.02 cm/sqrt(hr) process noise. The format of the troposphere products was designed by Yoaz Bar-Sever (JPL) and Gerd Gendt, and the JPL solution may be obtained as listed in Table 2.

Starting with GPS week 920 (August 24, 1997), tropospheric gradients were added to the list of parameters estimated for each ground station. In implementing this strategy, the following modifications were made to the estimation process:

- The Niell troposphere mapping function has replaced the Lanyi mapping function.

- Troposphere horizontal delay gradients are estimated at all the stations. The two gradient parameters are modeled as random walk with a sigma of 0.03 cm/sqrt(hour) and are estimated every five minutes.
- The random walk sigma on the estimated zenith wet delay has been reduced from 1.02 cm/sqrt(hour) to 0.30 cm/sqrt(hour).
- The carrier phase post-fit residual rejection criterion has been reduced from 5 cm to 2.5 cm.
- Beginning week 949, troposphere products are representative of the free-network estimates (fixed-network prior to this).
- The elevation angle cutoff has not changed; it remains at 15 degrees. Details of this estimation strategy are presented in [4].

6 New in 1998

Beginning with GPS week 947 (March 1, 1998), JPL adopted IGS procedures set forth at the IGS Analysis Center Workshop in Darmstadt, Germany, February 9-11, 1998 regarding the use of an augmented set of fiducial ground stations and their respective ITRF96 positions. Monument coordinates and velocities are taken from ftp://lareg.ensg.ign.fr/incoming/ITRF96_IGS_RS47.SNX (now available at ftp://igsb.jpl.nasa.gov/igsb/station/coord/ITRF96_IGS_RS47.SNX.Z), and antenna heights from <ftp://igsb/igsb/station/general/igs.snx>. (Antenna reference point to L1 and L2 phase centers are from ftp://igsb/igsb/station/general/igs_01.pcv.) As only 37 stations are used in the daily analyses, a subset of the 47 sites included in these files is selected as described in section 4 of this document. Moreover, as of this date, SINEX files submitted from JPL contain free-network station coordinates rigorously transformed into ITRF96 via a 7-parameter transformation.

It was also decided at the same AC workshop to eventually discontinue the use of the non-minimal fiducial constraints described above. Therefore, as of GPS week 964 (June 28, 1998), all orbits, clocks, EOP, station coordinates, and relevant statistics reported in our weekly AC summary reports are representative of free-network solutions that are minimally aligned with ITRF96. Only 3 rotations are applied so that geocenter and scale changes can continue to be observed. Also, JPL SINEX files now contain weekly Earth orientation parameters which are consistent with the corresponding sp3-formatted orbits and clocks.

Additionally, a slight change has been made to our automation process. As described in [5], we primarily determine “processing readiness” by periodically calculating the RMS isolation, a measure of the global distribution of available ground

sites. As more stations have become a part of the IGS network, in mid-March 1998, we lower the threshold of this value from 2000 km to 1800 km. While this may mean a longer delay in some instances, the four-day maximum wait time is still enforced.

A new set of products for GIPSY users is also now available, namely, hourly GPS ephemeris and clock solutions in the same format as analagous products found in Table 3. These solutions, based on a set of 18 global stations from which hourly data are received, have an accuracy of approximately 1 to 2 meters, and are provided on a “caveat emptor” basis.

7 Results

Figure 1 indicates the further improvement in orbit quality since 1995. As in the past, our metric for orbit quality is the day-to-day consistency of the solutions, i.e., the degree to which estimates from adjacent days agree near the midnight boundaries. Contributing factors are the continuing expansion of the global network, the use of global phase ambiguity resolution, and the estimation of tropospheric gradients.

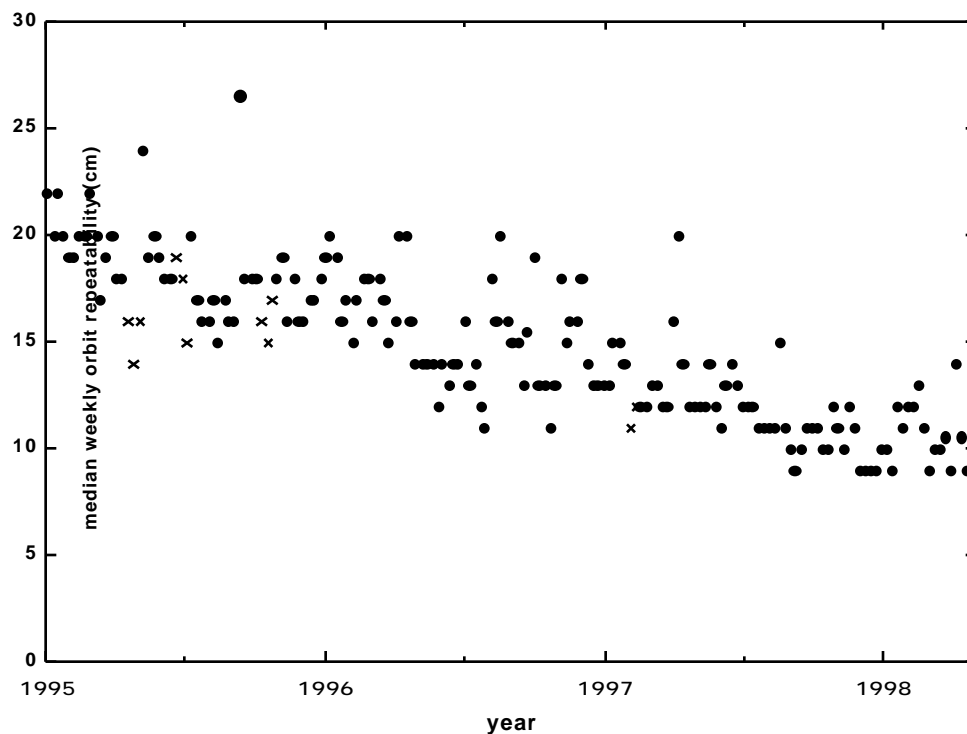


Figure 1: JPL orbit repeatability (3drms) since 1995. Each data point indicates the median over all satellites and days for a particular GPS week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Weeks during which AS was off are marked with an ‘X’.

8 Acknowledgment

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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NRCan IGS Analysis Centre Report, 1997

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1 Summary

During 1997, NRCan initiated submission of daily predicted orbits to IGS and participated in the IGS developmental work on the estimation of tropospheric and ionospheric delays. The existing NRCan processing strategy was maintained during 1997 (Tétreault et al., 1996, 1997).

2 Orbit Prediction Strategy

On January 10, 1997 (GPS Week 887), NRCan started contributing daily predicted orbits to the IGS. A 2-day prediction is obtained from 4 IGR rapid orbit solutions by estimating 6 Keplerian elements and 9 radiation pressure parameters using the Bernese software version 3.5. The IGR x and y Pole position series are used along with the Bulletin A UT1 series to provide the necessary Earth Orientation Parameters. The use of the Bulletin A UT1 series, initiated on GPS Week 934, has improved the z rotation of the NRCan predicted orbits as can be seen in Figure 1. Extrapolations of the EMR and IGR UT1 series were used prior to Bulletin A up to and including GPS Week 916 and 933 respectively. NRCan 2-day predicted orbits are currently about 50-cm median RMS with respect to IGR orbits for non-eclipsing satellites and about 100-cm for eclipsing satellites. Further evaluation of NRCan predicted orbits can be found in [Kouba and Mireault, 1998].

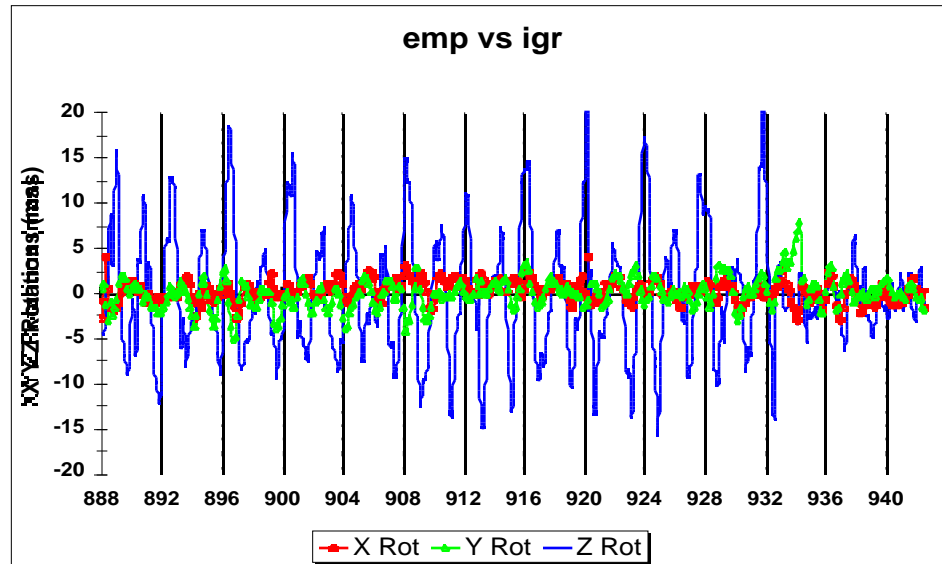


Figure 1. Seven –parameter Helmert transformation between IGR and NRCAN Predicted orbits (emp) for GPS Weeks 888 to 943

3 Tropospheric and Ionospheric Modeling

In March 1997, NRCAN started contributing to the IGS pilot project for the estimation of tropospheric zenith delay. NRCAN estimates tropospheric delays at a 7.5 minute interval using a random walk stochastic model with a $1 \text{ cm}/\sqrt{\text{hr}}$ sigma. Last epoch estimates from the previous day are weighted and used as apriori values for the current day estimation. For all stations included in NRCAN final daily solutions, Total Zenith Delay (TZD) estimates at 2 hour intervals are submitted to IGS on a daily basis (Gendt, 1998).

NRCAN, in support of the Canadian Active Control System (CACS) and in preparation for the IGS Ionospheric Pilot Project, has developed a grid model of ionospheric delays. The NRCAN regional ionospheric model is based on stations covering the Canadian territory. It is computed using carrier phase smoothed pseudo-range observations with an elevation cut-off angle of 15 degrees and an elevation dependent weighting model. A spherical single layer shell at 350 km elevation and a cosine of the zenith angle mapping function are used. The model is based on 24-hour averages computed in a sun-fixed geographical reference frame. Table 1 presents precise point positioning monthly averages of daily RMS that were achieved using four different processing strategies.

Table 1. Point positioning RMS using NRCan ionospheric modeling

Monthly Averages of Daily RMS
Station NRC1, January 1998
(from position estimates at 15 min. intervals, and
using phase smoothed pseudo-range observations)

Latitude	<u>RMS (m)</u>		<u>Processing Strategy</u>
	Longitude	Height	
1.3	0.7	3.6	L1
1.0	0.7	1.7	L1 + SLM
0.8	0.4	1.1	L1 + SLM + CAL
0.5	0.4	1.1	L3

L1 = L1 Frequency

SLM = Single Layer Ionospheric Model

CAL = Satellite Differential L1/L2 Code Bias

L3 = Ionospheric Free Combination

4 Final Product Analysis

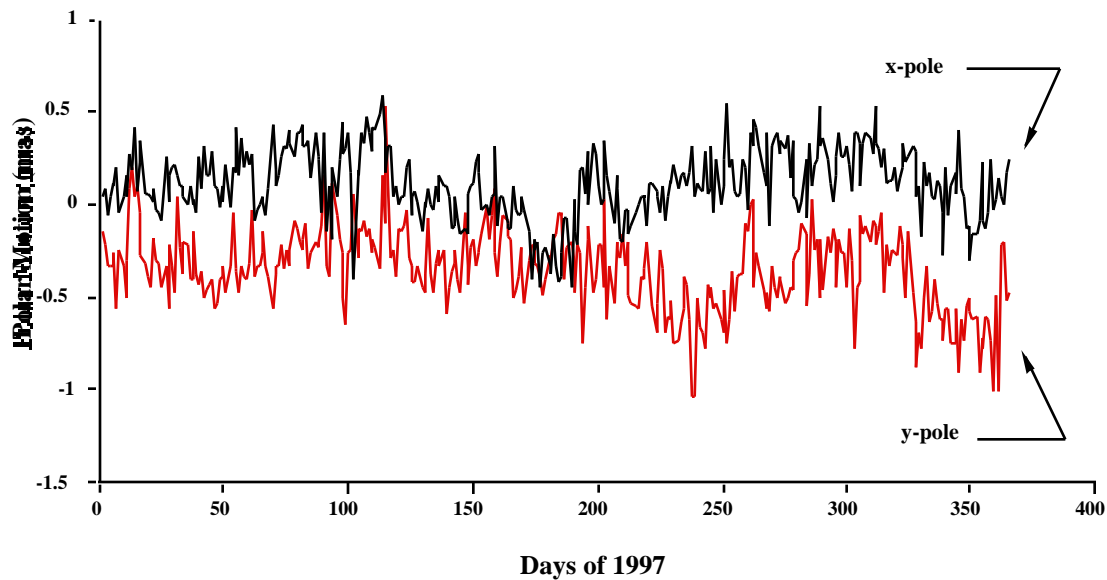
A 2.5-year spectral analysis of the NRCan station position residual series led to the discovery that the use of erroneous ocean loading coefficients were causing a 13.7-day signal. This was corrected on February 23, 1997 and a new spectral analysis for GPS Weeks 894 to 938 confirmed that the 13.7-day signal had been removed.

The consistency of NRCan products was assessed by computing the differences between NRCan and ITRF/IGS products for station coordinates, orbits and EOP's. The estimated 7 parameter transformations are listed in Table 2. UTI-UTC was not included due to its long-term drift, evident in the weekly averaged means and standard deviations. The differences between the IGS and NRCan polar motion and UT1-UTC series are shown in Figures 2 (a) and (b) respectively. The 0.3mas bias seen in the y pole series starting on day 327 was caused by mistakenly over-constraining the weekly station coordinates and EOP combinations for GPS Weeks 933 to 938 inclusively. Weeks 933 to 938 were not used to compute the transformations presented in Table 2.

Table 2. Weekly Averaged Differences Between NRCan and ITRF/IGS Products
(NRCan – ITRF/IGS)
(Weeks 886 to 932)

Solution	Translation (cm)			Rotation (mas)			Scale(ppb)
	T1	T2	T3	R1	R2	R3	Sc
Coordinates ^a	0.0	0.4	0.2	0.092	0.017	0.002	-0.47
sigma	0.1	0.2	0.1	0.044	0.025	0.016	0.33
Orbits ^b	0.0	-1.5	-0.4	0.352	-0.072	0.335	-0.08
sigma	0.8	0.9	0.6	0.145	0.129	0.285	0.09
EOP ^c				0.316	-0.116		
sigma				0.142	0.154		

- (a) Weekly averaged transformations between the combined NRCan weekly SINEX coordinate solutions and ITRF coordinates for the 13 IGS fiducial stations.
(b) Weekly averaged transformations between NRCan and IGS daily orbits.
(c) Weekly averaged differences between NRCan and IGS daily polar motion.



(a)

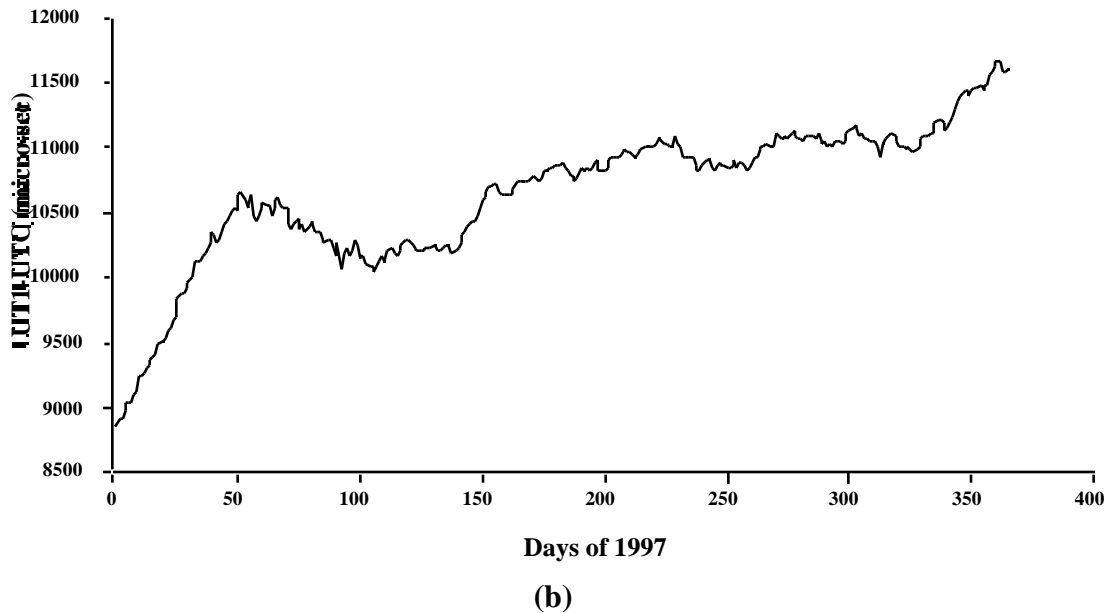


Figure 2. Difference between IGS Final EOP's and NRCan Daily EOP solutions

As in previous years, a multi-year solution of NRCan EOPs, station coordinates and velocities was computed (IERS, 1998). Specifically, the 1997 combination was performed using daily solutions from 1994 to 1997 inclusively. In order to mitigate the small misalignment present in NRCan daily solution, the daily variance-covariance matrices were unconstrained in order to remove the implicit effect of the geocentre prior to the combination. The annual solution was constrained at ITRF96, epoch 1998.0 using stations: ALGO, AREQ, DAV1, DRAO, FAIR, FORT, GOLD, GUAM, HART, IRKT, KERG, KIT3, KOKB, LHAS, MADR, SANT, TIDB, TROM, TSKB, WTZR, YAR1 and YELL.

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Scripps Orbit and Permanent Array Center 1997 Analysis Center Report

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1 Introduction

The Scripps Orbit and Permanent Array Center (SOPAC) at the Scripps Institution of Oceanography has been providing precise satellite ephemerides and Earth orientation parameters since 1991. The development of the Permanent GPS Geodetic Array (PGGA) in southern California at that time served as a catalyst for the generation of precise GPS orbits, and continues to be a catalyst with the development of the Southern California Integrated GPS Network (SCIGN).

This report will focus on SOPAC's analysis procedures and reprocessing of early IGS products. The 1997 annual report of the SOPAC Global Data Center is in a separate document.

2 Products Submitted

IGS data and products are available at SOPAC's GARNER archive, which is accessible through anonymous ftp (<ftp://ftp.lox.ucsd.edu>) or via our homepage (<http://lox.ucsd.edu>). To retrieve SIO products via ftp, change directory to /pub/products, and select the appropriate GPS week. The following SOPAC analysis products are contributed to the IGS:

Type of Product	File Format	Description
<i>Final Products</i>	SIOwwwwn.SP3	Daily ephemeris files
	SIOwww7.ERP	Weekly EOP (pole, UT1-UTC, lod)
	SIOwww7.SUM	Weekly processing summary
	SIOwww7.SNX	Weekly SINEX files
<i>Rapid Products</i>	SIRwwwwn.SP3	Daily rapid orbit solutions
	SIRwwwwn.ERP	Daily rapid EOP solutions
<i>Prediction Products</i>	SIPwwwwn.SP3	24 hour orbit predictions
	SIPwwwwn.SP3	48 hour orbit predictions

The final products are generally available within 4 days of the end of the GPS week; the rapid and prediction products are available within 18 hours of the end of the UTC day. The daily processing volume at SOPAC is about 280 stations per day.

3 Reprocessing of IGS Products (1992-1995)

During 1997 a major effort was made to reprocess GPS data from as early as June 1992. Improvements and changes in analysis software and processing algorithms makes the coordinate time series, precise ephemerides, and EOP inconsistent over longer periods of time and results derived by them may be biased. Therefore, we reanalyzed IGS data

between June 1992 and June 1995. The results are a significant improvement in our site position time series, orbit ephemerides and EOP. Also, problems encountered during this reanalysis were recorded so that future reprocessing campaigns will be as smooth as possible and therefore, less time consuming.

Since changes in the software are continuously made, re-analysis of earlier data after major improvements is necessary to acquire the best products possible. The next reprocessing which will commence in 1998 will also include data obtained before June 1992.

4 Site Selection

Various new sites were added to the IGS network in 1997. As a result, the amount of sites contributing to the daily solution increased slightly to approximately 60 per day at the end of 1997 (Figure 2). The stations used by SOPAC in the global processing are shown in Figure 1.

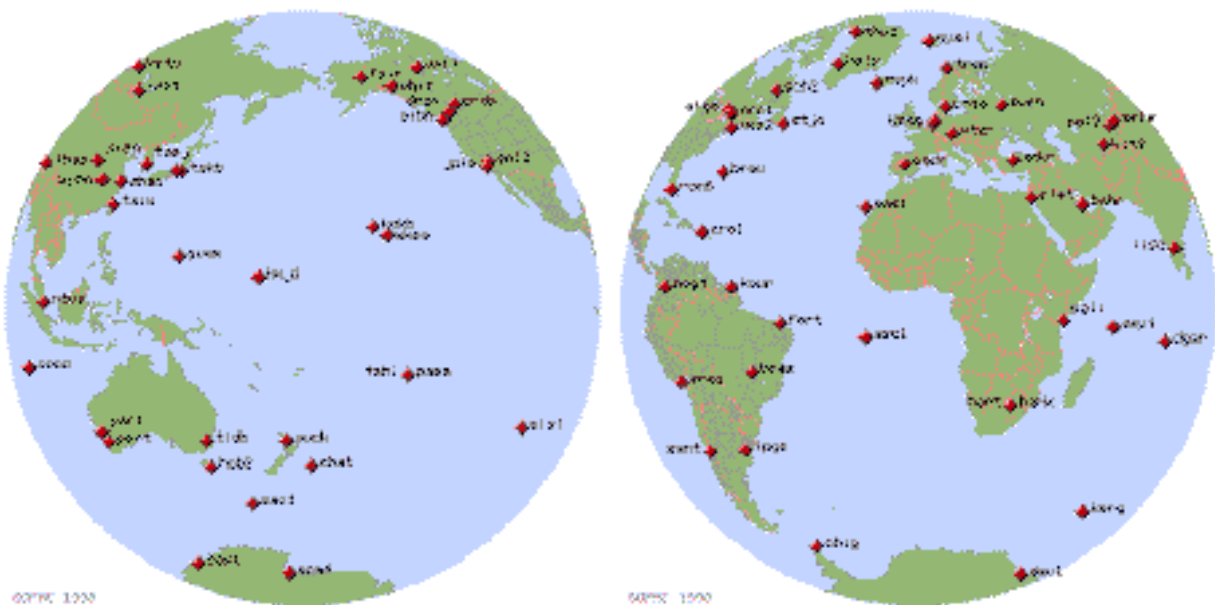


Figure 1. IGS stations processed by SOPAC

To ensure fast turn around of the rapid solution, the number of stations in this solution was limited to 47 (Figure 2), but new sites of better quality and latency were incorporated in the rapid analysis schemes to ensure higher reliability. The days for which data of less than 40 sites were available for the rapid analysis were mostly correlated with weekends. The latency of the data during this time is apparently worse than during the work week. The availability of SIO's rapid solution has improved (Figure 2) and is generally available within 18 hours after the end of the day.

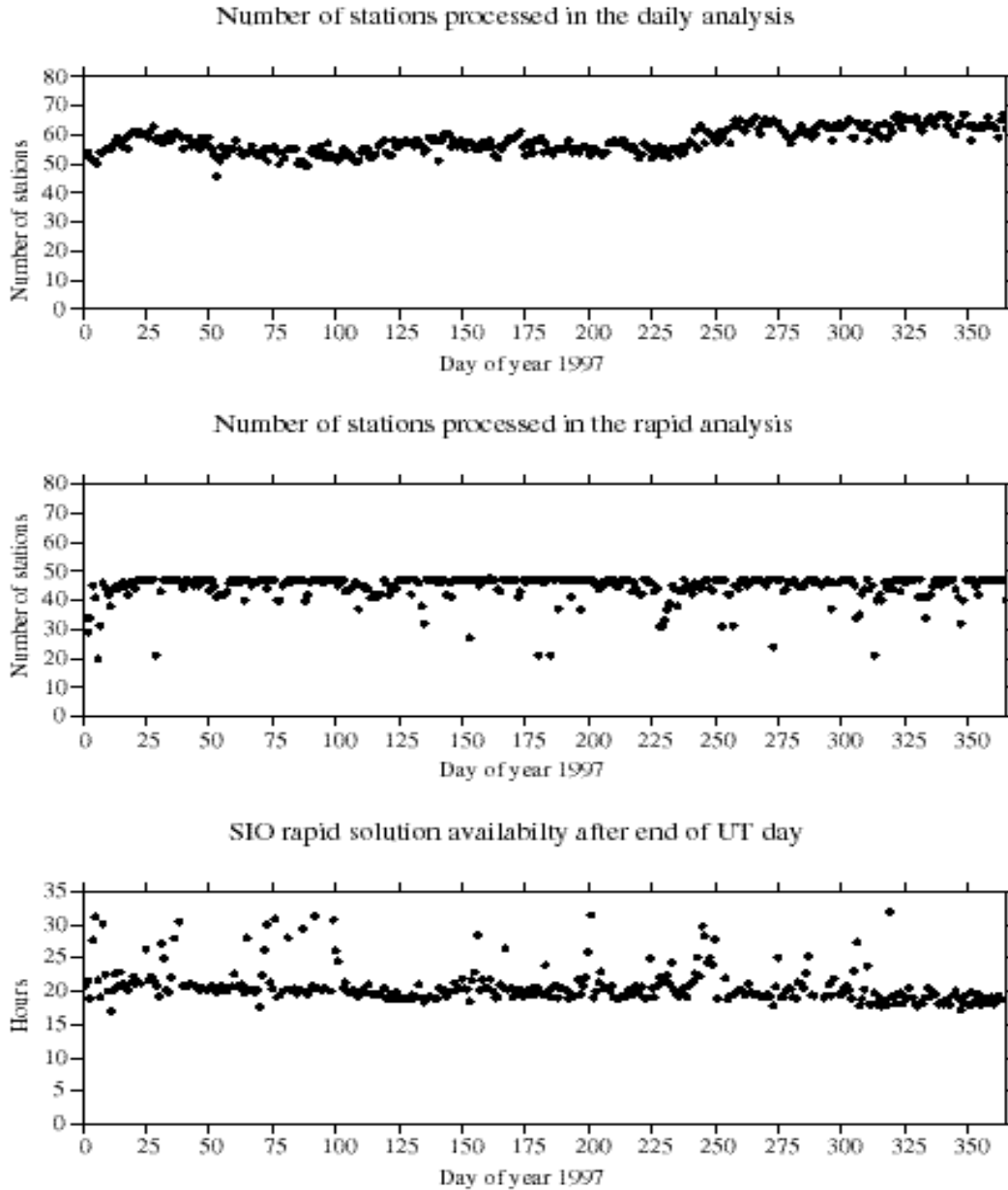


Figure 2. Number of sites included in the daily and rapid SIO analysis during 1997 and the availability of the rapid solution after the end of the UTC day.

5 Analysis Procedure

SIO continues to use a multi-day processing scheme in distributed mode for its rapid and predicted solutions. The primary reason for doing distributed processing is to increase processing efficiency by dividing a large network into smaller subnetworks. For SIO's rapid and predicted solutions, the global network is divided into two subnetworks with 5 stations in common to provide sufficient overlap when the two solutions are combined at a later stage. For these 5 common stations, there are a few near-by stations chosen as backup in the event that any of these stations' data are not available. In order to maintain a uniform processing speed, the maximum number of stations of each subnetwork

is limited to 26 which are chosen to best suit our processing hardware configuration without sacrificing product quality.

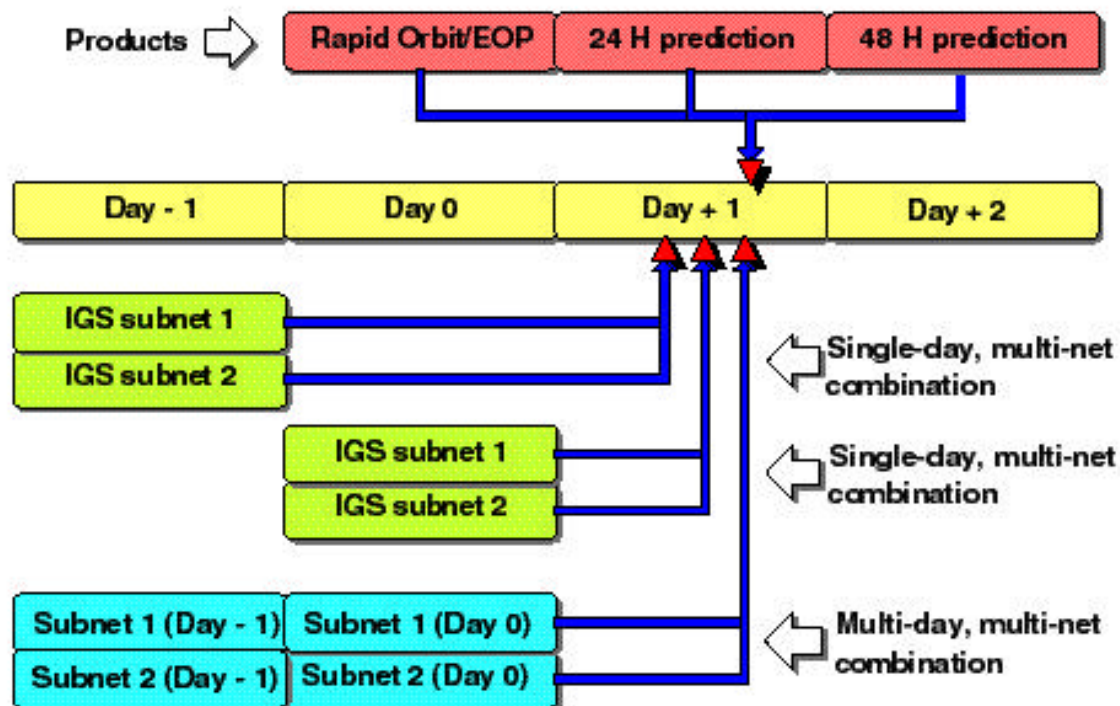


Figure 3. Processing timeline for SIO rapid and predicted solutions

Since the total number of IGS global stations is growing steadily, our processing procedure uses a prioritized station selection scheme to ensure the use of the stations that are most evenly distributed and of the highest data quality. In this scheme, good geographical location bears highest weight. This fully automated procedure and its execution timeline are illustrated in Figure 3. During processing, tight constraints are imposed on *a priori* values of ITRF96 coordinates and the UT1 values from IERS Series 7 obtained from USNO weekly (later biweekly) submissions. The main adjusted parameters are station coordinates, orbital parameters, pole-x, pole-y positions, and LOD. In addition, tropospheric delay parameters are estimated at one-hour intervals for each station. The time for orbital initial conditions (IC) is set to the midday of day 0 for both day-1 and day 0 solutions. The solutions are performed with the GAMIT software package incorporating a weighted least square approach. These two sets of 24 hour solutions on individual subnetworks are then combined with the GLOBK software incorporating a Kalman filter approach. The resulting orbits and EOP become SIO rapid products. Once the rapid orbits and EOP are generated, they are used for orbit extrapolation (through integration) further into 24 and 48 hour predicted orbits. Then the rapid orbits and EOP together with 48-hour predicted orbits are submitted to the IGS for its combination solutions. The 24-hour predicted orbits are sent to the SIO data/product server to replace the previous day's 48-hour predicted orbits. This particular arrangement has been proven very useful since many near real-time users who themselves have some data collection delays may take advantage of 24 hour predictions as they are of higher quality than 48 hour predictions. The 24-hour predicted orbits are also used as the next day's *a priori* orbits.

SIO's regular daily solution is carried out in distributed mode. Compared to the rapid solutions, the regular daily solutions are single-day solutions. The maximum number of stations in a subnetwork is set to 42 in order to include as many global stations as possible. The latency of the daily solutions is between 4 to 6 days. The main reason for this delay is to wait for more data and to take advantage of better *a priori* UTC values. The rapid orbits serve as *a priori* orbits for the regular daily solutions. The selection of stations in the global network is mainly dictated by geographical distribution. Regions with higher concentrations of stations are grouped into regional networks, such as Europe (designated as EURA), California (PGGA, DGGA, BARD), and U.S. (CORS). The CORS array is processed primarily to obtain tropospheric delay estimates at frequent time intervals (every 30 minutes).

SIO's final weekly solution is generated after 7 regular daily solutions are completed. This solution, employing a Kalman filter approach with GLOBK, uses a set of covariance matrices from unconstrained daily solutions of both global and regional subnetworks, tightly constraining a set of core IGS stations defined in ITRF96, to estimate station positions, orbits, and EOP. It should be noted that the unconstrained solutions are produced in the same GAMIT runs as the constrained solutions.

Detailed description on the modeling of parameters and other strategic settings are given in the IGS data processing center questionnaire (see appendix), also available at IGS Central Bureau homepage (<http://igsb.jpl.nasa.gov>).

Regional networks are processed with orbital parameters tightly constrained after corresponding global solutions becomes available. The relationship among the above-mentioned processes is depicted in Figure 4. (The real-time sliding window is tested but not yet operational).

Since January 15, 1996, all SIO solutions adapted the Neill mapping function [Niell, 1996] to replace the CFA 2.2 mapping function. At the same time, the elevation angle cutoff was lowered from 15° to 7°.

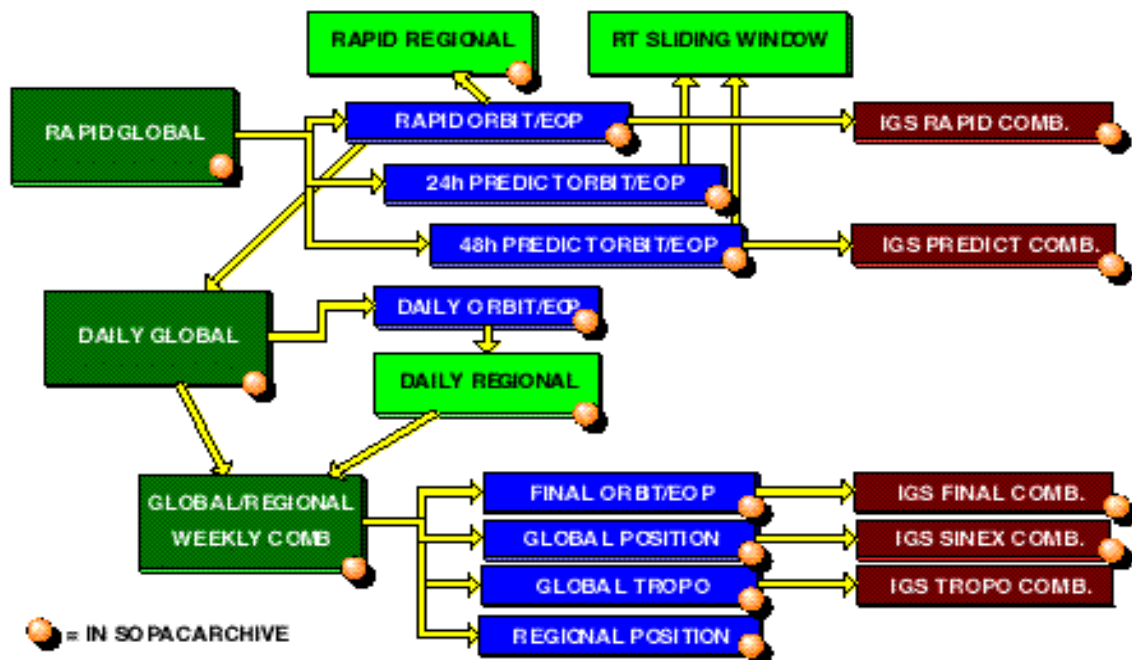


Figure 4. The relationship of various processing elements and their products.

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7 Acknowledgements

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APPENDIX

INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

SOPAC Processing Strategy Summary

Analysis Center	Scripps Orbit and Permanent Array Center (SOPAC), Institute of Geophysics and Planetary Physics (IGPP), Scripps Institution of Oceanography (SIO), University of California, San Diego (UCSD) 9500 Gilman Dr., San Diego, CA 92093-0225, USA Phone: ++ 1 619 534 0229 Fax: ++ 1 619 534 9873	
Contact Person(s)	Yehuda Bock e-mail: ybock@ucsd.edu phone : ++ 1 619 534 5292 Peng Fang e-mail: pfang@ucsd.edu phone : ++ 1 619 534 2445 Matthijs van Domselaar e-mail: mvandomselaar@ucsd.edu phone : ++ 1 619 534 2031	
Software Used	GAMIT v. 9.72, GLOBK v. 4.17, developed at MIT/SIO	
Final Products generated for GPS week 'www' day of week 'n' (n=0,1,...,6)	siowwwwn.sp3 GPS ephemeris files in 7 daily files at 15 min intervals in SP3 format, including accuracy codes computed from overlapping analysis wrt. previous day. siowwww7.erp ERP (pole, UT1-UTC) weekly solution siowwww7.sum Summary of weekly solution combining both IGS global and regional solutions. siowwww7.snx Weekly coordinates in SINEX format siowwwwn.tro Daily files of 1-h troposphere delay estimates in SINEX format (based on 1-day solutions).	
Rapid Products	sirwwwn.sp3 Daily orbits for current-1 day. ~16 hour delay. sirwwwn.erp Daily EOP for current-1 day. ~16 hour delay.	
Predictions	sipwwwn.sp3 24 hour predicted orbits. Partially real-time. This file will replaces 48 hour predicted orbits of previous day upon generation. sipwwwn.sp3 48-hour real-time predicted orbits	
Preparation Date	July 13, 1998	
Effective Date for Data Analysis	May 31, 1998	

MEASUREMENT MODELS	
Observable	Doubly differenced, ionosphere-free combination of L1 and L2 carrier phases. Pseudoranges are used only to obtain receiver clock offsets and in ambiguity resolution.
Data weighting	Sigma on doubly difference LC phase: 64 mm Sampling rate: 2 minutes Elevation angle cutoff : 7 degrees
Data Editing	Cycle slip fixing is performed at one-way level using a combination of one-way and double-difference observations. If a cycle slip cannot be fixed reliably, the data observation is flagged and an additional bias parameter estimated implicitly in the solution.
RHC phase rotation corr.	Phase polarization effects applied (Wu et al, 1993)
Ground antenna phase center calibrations	Elevation-dependent phase center corrections are applied according to the model IGS_01. The corrections are given relative to the Dorne Margolin T antenna.
Troposphere	A priori zenith delay: nominal constant; sub-daily corrections estimated as described below
	Met data input: none
	Mapping functions: (Niell, 1996)
Ionosphere	Not modeled (ionosphere eliminated by forming the ionosphere-free linear combination of L1 and L2).
Plate motions	ITRF96 velocities (see position constraints in estimated parameters and reference frame below)
Tidal displacements	Solid earth tidal displacement: constant Love number tides frequency dependent radial tide (K1)
	Pole tide: not applied
	Ocean loading: not applied
Atmospheric loading	Not applied
Earth orientation	IERS Bulletin A plus diurnal and semidiurnal variations in x,y, and UT1 models (EOP) using VLBI based model

	of Herring and Dong (1994); daily corrections to UT1 rate, pole position and rate estimated as described below
Satellite center of mass correction	Block I x,y,z: 0.2100, 0.0000, 0.8540 m
	Block II/IIA x,y,z: 0.2794, 0.0000, 0.9519 m
	Block IIR x,y,z: -0.0031,-0.0012, 0.0000 m
Satellite phase center calibrat	Not applied
Relativity corrections	Relativistic corrections applied
GPS attitude model	Yaw computed using model of Bar-Sever (1996), using nominal rates or estimates supplied by JPL

ORBIT MODELS	
Geopotential	GEM T3 degree and order 8
	GM = 398600.4415 km**3/sec**2
	AE = 6378.1363 km
Third-body	Sun and Moon as point masses
	Ephemeris: CfA PEP NBODY 740
	GMsun = 132712440000 km**3/sec**2
	GMmoon = 4902.7989 km**3/sec**2
Solar radiation pressure	A priori: nominal block-dependent constant direct acceleration; corrections to direct, y-axis, and B-axis constant and once-per-rev terms estimated (see below) (Beutler et al., 1994; Springer et al. 1998)
	Earth shadow model: umbra and penumbra
	Earth's albedo: not applied
	Satellite attitude model not applied
Tidal forces	Solid earth tides: frequency independent Love's number K2= 0.300
	Ocean tides: UT CSR model (IERS 1996)

Scripps Orbit and Permanent Array Center, 1997 Analysis Center Report

Relativity	Applied (IERS 1996, Chapter 11, Eqn.1)
Numerical Integration	Adams-Moulton fixed-step, 11-pt predictor-corrector with Nordsieck variable-step starting procedure (see Ash, 1972 and references therein)
	Integration step-size: 75 s; tabular interval: 900 s
	Arc length: 24 hours

ESTIMATED PARAMETERS (A PRIORI VALUES & SIGMAS)	
Adjustment	Batch weighted least squares
Station coordinates	Up to 50 IGS stations for rapid solutions Up to 80 IGS stations for regular daily solutions
Satellite clocks bias	Time fixed from Broadcast ephemeris; phase variations estimated for editing only, eliminated in solution by double differencing
Receiver clock bias	Time estimated from pseudoranges phase variations estimated for editing only, eliminated in solution by double differencing
Orbital parameters	6 Keplerian elements plus 9 radiation-pressure terms: constant and sin/cos once-per-rev terms for a direct, y-axis, and b-axis acceleration; all but direct and y-axis constant term constrained to 1% of zero
Troposphere	Knots of a linear spline in zenith delay estimated once per hour for each station constrained by a random-walk process to 2 cm/sqrt(hr); one N-S and one E-W gradient parameter per day for each station, constrained to 3 cm at 10 deg elevation angle
Ionospheric correction	Not estimated (first-order effect eliminated by linear combination of L1 and L2 phase)
Ambiguity	Resolution attempted for baselines < 500 km using phase with an 8 ppm ionospheric constraint and pseudo- range (Dong & Bock, 1989; Feigl et al., 1993)
Earth Orient. Parameters (EOP)	Pole X/Y and their rates, and UT1 rate estimated once per day.
GPS attitude model	Not estimated

REFERENCE FRAMES	
Inertial	Geocentric; mean equator and equinox of 2000 Jan 1 at 12:00 (J2000.0)
Terrestrial	ITRF96, with 37 stations constrained 2-3 mm in horizontal and 10-14 mm in vertical coordinates)
Interconnection	Precession: IAU 1976
	Nutation: IAU 1980

Associate Analysis Centers

**Global Network Associate
Analysis Centers**

The Newcastle Global Network Associate Analysis Center Annual Report

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1 Introduction

The Newcastle Global Network Associate Analysis Center (GNAAC) continued its activities during the year 1997. It produced the weekly combined coordinate solution for the global and the regional networks, based on ACs and RNAACs data respectively. In spite of some delays in submitting few reports; the NCL GNAAC services are fully restored now.

In this report a summary of our results and analysis are described for the period of GPS week 887 through GPS week 938. During this period, we have kept the same software and algorithms, as year 1996. Therefore, the details of our methods and algorithms are described in the 1996 annual report.

2 New Strategy

In October 1997, because of the introduction of the IGS formal station log, we have stopped using the input SINEXes for station information; and started using the logistics file, updated daily, from the IGS Central Bureau. This method has saved most of the discrepancies caused by the incorrect dome number or antenna height in the input SINEXes. However, as a result of implementing this strategy, some of the stations which do not have an official IGS log file are not analyzed. The regional stations were the most affected. We have contacted our colleagues who are running these networks and now most of the RNAACs have official stations logs for all their stations. Figure 1 shows a time series of the number of stations analyzed by NCL P-network which clearly demonstrate the drop of the number of GPS stations after October 1997.

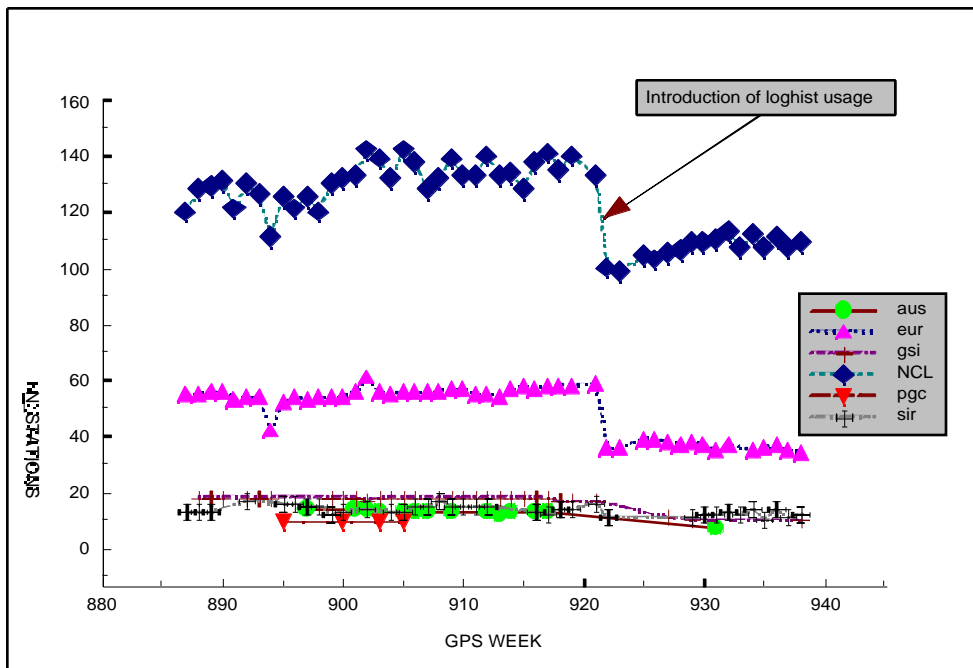


Figure 1: Time series of the number of stations analyzed by the NCL P-net.

3 GNET RESULTS

Figure 2 shows a time series of the number of input GPS stations by the ACs and the number of stations analyzed by the Newcastle GNAAC. It also shows that in 1997, we continued analyzing data from 6 Analysis Centers (COD, EMR, ESA, GFZ, JPL, NGS & SIO). It was noted that the number of stations being analyzed by the NCL GNAAC has steadily increased toward the end of the year.

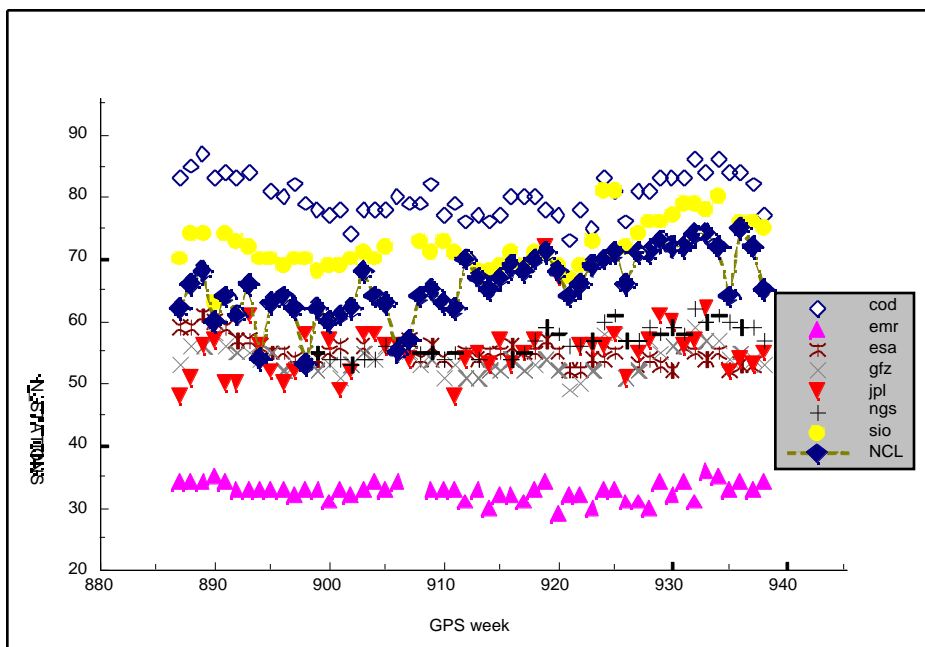


Figure 2: Time series of the number of stations analyzed by the NCL G-net.

As mentioned in the 1996 report, the G-solution is estimated as block of normal equations composed of deconstrained network in terms of coordinates without any reference frame. This loose solution is later transferred and scaled to the CORE 13-stations of ITRF94 using 7 parameters Helmert transformations. Figures 3 through 6 show the transformation and scaling parameters for X, Y, Z & scale for the ACs and NCL GNAAC to ITRF94. These figures demonstrate the relatively smooth and low-value parameters calculated for the Newcastle GNAAC transformation and scale compared to the ACs values.

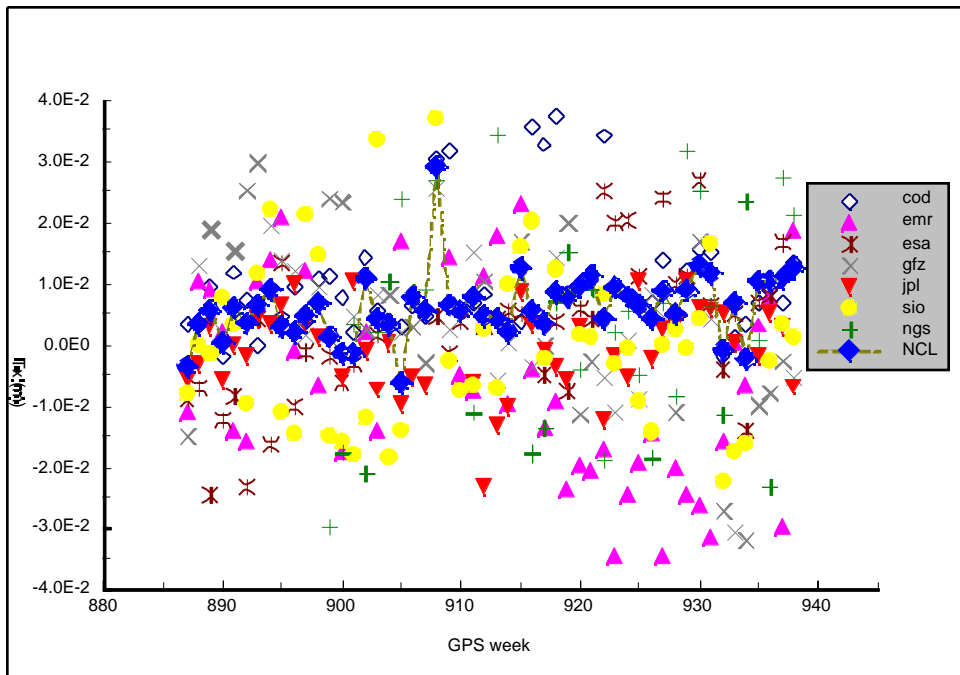


Figure 3: Time series of Tx transformation parameters for the ACs and NCL GNAAC to ITRF.

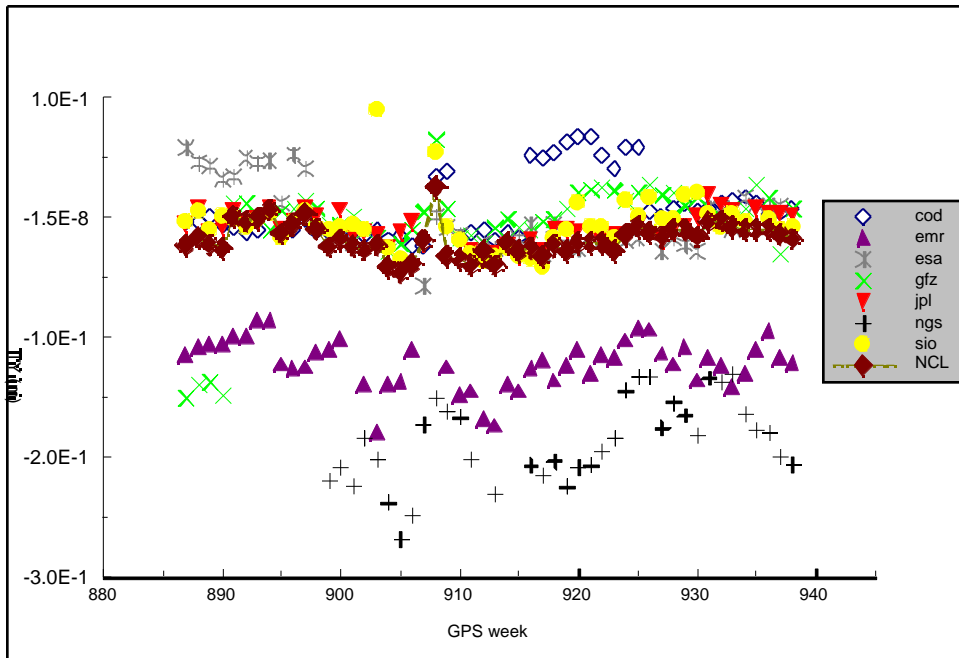


Figure 4 Time series of Ty transformation parameters for the ACs and NCL GNAAC to ITRF.

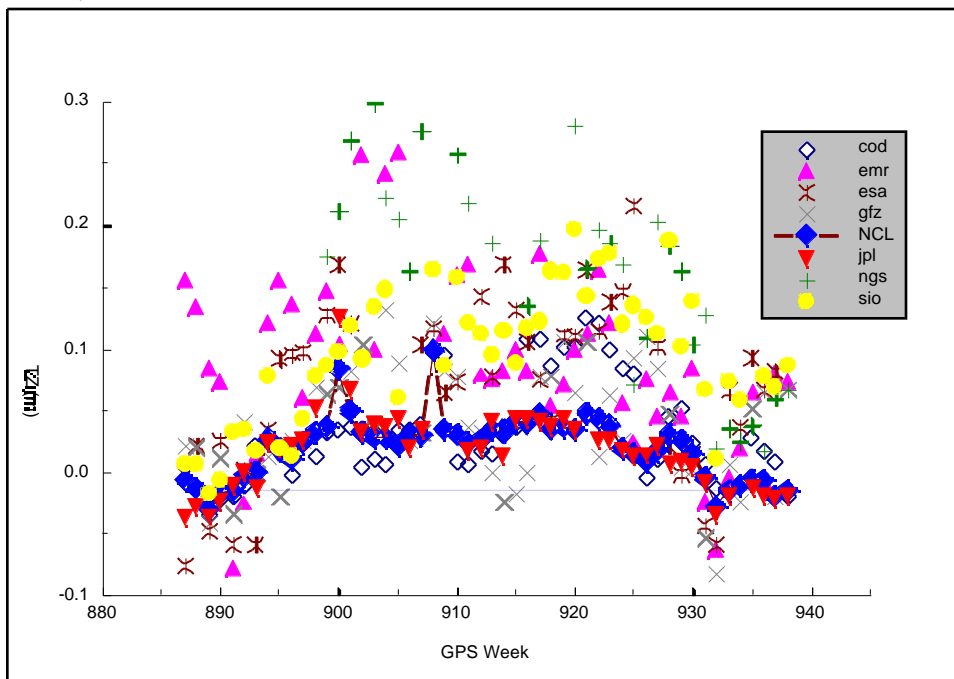


Figure 5: Time series of Tz transformation parameters for the ACs and NCL GNAAC to ITRF.

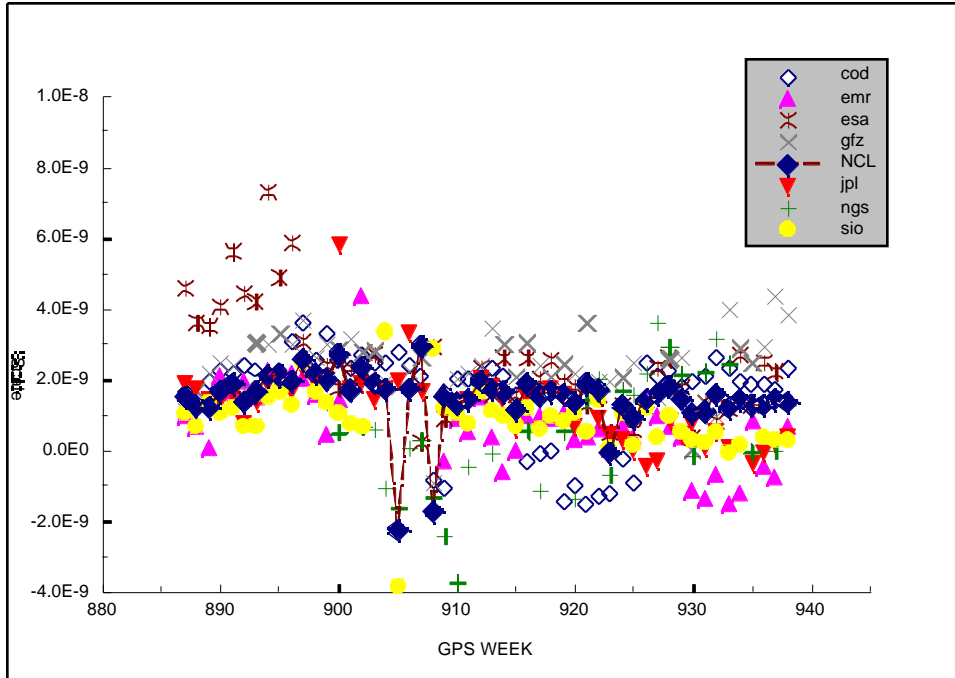


Figure 6: Time series of scaling parameters for the ACs and NCL GNAAC to ITRF.

4 RNAAC Results

In year 1997 we have also continued analyzing the RNAACs data to complete the full polyhedron. These analysis are based on the A-SINEXes input and the weekly input R-SINEXes from the RNAACs. In order to process an R-SINEX, the responsible RNAAC should submit at least three global stations in each weekly solution. However, this was not the case for most of the RNAACs and only few were analyzed on regular basis, see Figure 1.

As mentioned in the 1996 report that we use the “weight-space formulae for efficiency” to attach the R-Network to the polyhedron. This acts in turn as Helmert transformation for 3D rotation, 3D translation and scale. Figure 7 shows a time series for the Root Mean Square error of R-network transformation when attached to the global network.

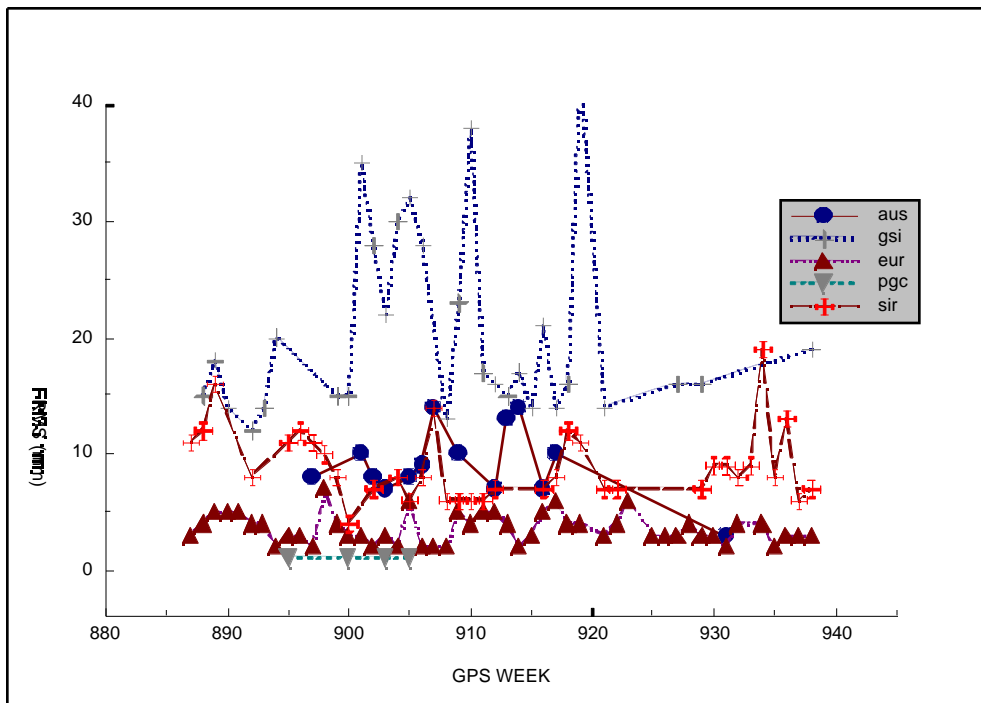


Figure 7: Time series of the RMS transformation of the RNAACs to NCL G-NET.

5 ITRF Realisation

As part of the Newcastle GNAAC contribution we submit our weekly G-SINEX and P-SINEX; which contain coordinate solution for Global and regional stations. The solution also shows better repeatability and smoother time series. Some examples of Time series of stations analyzed by NCL GNAAC are presented in figures 8 & 9.

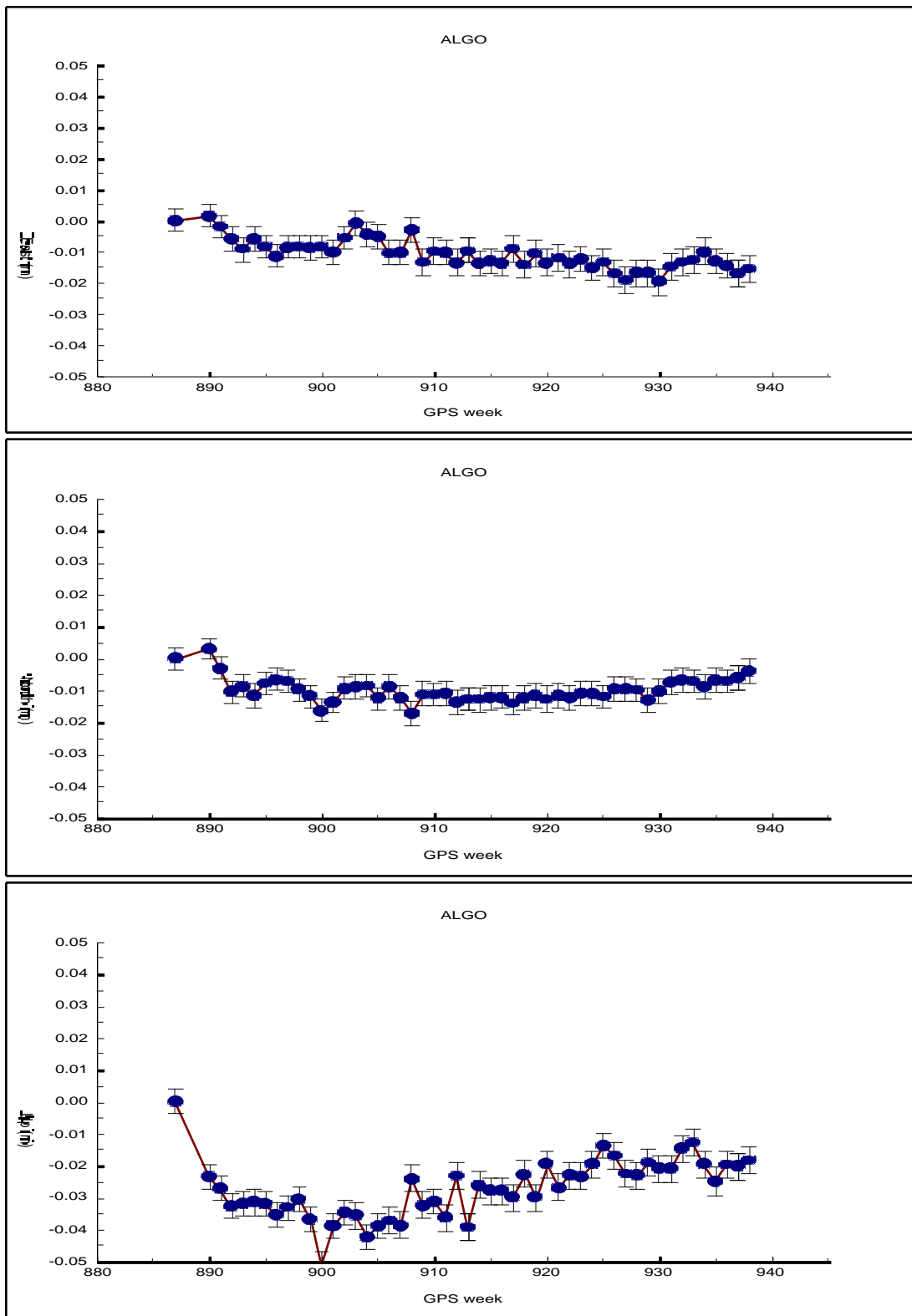


Figure 8 : ALGO Time series for East, North and Up components

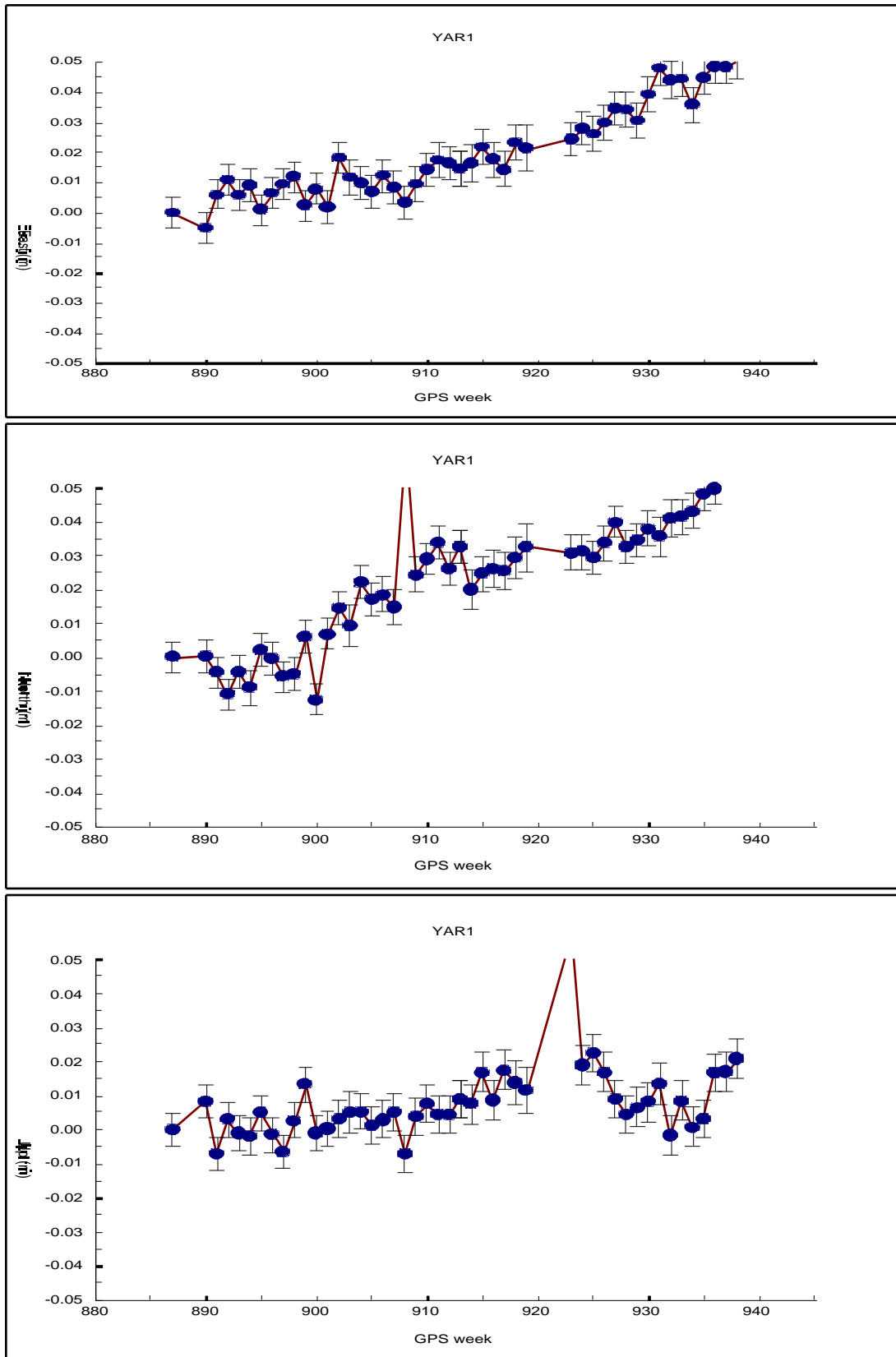


Figure 9 : YAR1 Time series for East, North and Up components

6 Conclusions

Based on the analysis and diagrams presented in this report; it became obvious that Newcastle GNAAC contributes a smooth and low rms error margin coordinate solution for the IGS and IERS, each week. This solution is also used for tectonic and geophysical studies, to understand the plate kinematics and boundary conditions.

7 References

International GPS Services for Geodynamics, 1996 Annual Report, edited by J.F. Zumberge, D.E. Fulton and R. E. Neilan. JPL Publication, Jet Propulsion Laboratory, Pasadena, California, 1997.

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MIT T2 Associate Analysis Center Report

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1 Abstract

We discuss the analysis of the 1997 combined solutions generated from the SINEX files submitted by the IGS analysis centers. We highlight the changes to the analysis procedures reported in previous annual reports. Analysis of our combined solutions shows mean fits to the (up to) 49 ITRF96 reference sites of 4.0 mm. For the G-SINEX combinations the median RMS repeatability in north, east, and height are 2.1, 2.6 and 6.7 mm, respectively for 124 sites. For the P-SINEX combinations, the RMS repeatabilities are 2.2, 3.0, and 7.6 mm, respectively for 181 sites.

2 Analysis Procedure Changes

As reported previously [Herring, 1996,1997], two analyses are performed each week. One of these uses the IGS Analysis Center (AC) weekly A-SINEX files to generate a combined G-SINEX file and the other uses the T1 Associate Analysis Center (AAC) R-SINEX files combined with the G-SINEX file to generate a weekly P-SINEX files. In 1997, the G-SINEX files contain 124 sites that were used more than 10 times during the year and 82 sites that were used every week. The corresponding values for the P-SINEX files are 181 and 114 sites, respectively. The G- and P-SINEX analyses are performed 3 and 7 weeks delays.

The basic procedures we use have not been changed and are documented in the weekly summary files submitted with the combined SINEX files. The three changes of note that have been are associated with (a) deconstraining SINEX files, (b) translation and scale estimation, and (c) generation of a weekly residual file for the G-SINEX combination.

2.1 Deconstraining AC SINEX files

The procedure we use to deconstrain SINEX files is to invert the covariance matrices for the estimates and apriori constrains, and to subtract the apriori constraints from the estimates. New weak constraints (± 5 meters for most centers) are applied to the station coordinates and the system re-inverted. For some analysis centers, this procedures leads to numerical stability problems which results in the deconstrained covariance matrices being non-positive definite. To diagnose and correct this problem, we now compute the eigenvalues of the deconstrained covariance matrix and, if negative

eigenvalues are found, scale the diagonal by increments of 1 part-per-million until all the eigenvalues are positive. Throughout 1997, the COD and NGS analysis centers generated negative eigenvalues when their SINEX files were deconstrained to ± 5 m. (After April 1998, COD SINEX files generate all positive eigenvalues).

Our analysis of the numerical stability problems indicates that it probably arises from large negative correlations in the deconstrained covariance matrices. The negative correlations arise from the implicitly determined center-of-mass origin for the GPS coordinate system. Sites that are located on opposite sides of the Earth have negatively correlated Cartesian coordinates so that if one coordinate increases, the other must decrease in order to keep the center of the coordinate system in the same location. These negative correlations (which unlike positive correlations that simply must always be less than unity) generally can not exceed specific negative values if the whole complete covariance matrix is to be positive definite.

2.2 Translation and Scale Estimation

We modified slightly the method used to estimate translations and scale of the SINEX files from individual analysis centers. As in the past, during variance rescaling and the combination solution we do not explicitly estimate translation and scale parameters. However, now when we compare each center individually to ITRF94 (during 1997 and now ITRF96) and to the combined solution, we explicitly estimate translations and scale parameters. The advantage of this approach is that generates more realistic standard deviations for the estimates of the translations and scale. The estimates of the center of mass position and the coordinates of the sites did not seem to be greatly effected by this change. The standard deviations of the translation and scale parameters were effected, and for most centers increased by generally at least a factor of three and became most consistent with the week-to-week scatter of the values. For some centers the standard deviations decreased when change was made.

At the end of 1997, we started using ITRF96 as the basic coordinate system in which our analysis is performed. We increased also from the 13-IGS core sites (which were reduced to less than 10 at the time of change) to 49-IGS reference sites defined in the ITRF96 coordinate system for variance rescaling and translation estimation. In our analyses presented here we used this new system to evaluate our 1997 combined SINEX files.

2.3 G-SINEX Residual file

Near the end of 1997, we introduced a new file in our submission that contains residuals by station for each of the seven IGS analysis centers. The files are named mitwwwg.res where www is the GPS week number. For the coordinate components (north, east and up) of each site the root-mean-square (RMS) scatter of the residuals for each center to the combined solution coordinate estimate, the square root of c^2 per degree of freedom of these residuals, and the individual center residuals and standard deviations

are given. At the bottom of the file the statistics for each center are given based on all the sites analyzed by the center.

3.0 Analysis of Combined Solutions

Our analysis of 1997 combined SINEX files examines the internal consistency of these combinations and their agreement with ITRF96. (At the time the combinations were made, the ITRF94 system was used). Figure 1 we show the RMS agreement between the 49 ITRF96 reference sites (list of sites given in weekly summary files) for each weekly combination in 1997 and the number of sites used in the realization. This RMS is computed from the combination of the north, east, and height differences after a translation, rotation, and scale are removed from the weekly combination. In computing the RMS, the height is down-weighted by a factor of 3, i.e., we construct a weight matrix with the heights given one-tenth the weight of the horizontal components. This weight matrix is used in the computing the RMS. In Figure 2, we show the values of the translations and scale factors estimated for each weekly G-SINEX file. As we have seen in the past, the Y- and Z-components of the translation appear to have significant annual signatures. The procedures used to determine the transformation between coordinate systems are discussed in *Dong et al.* [1997].

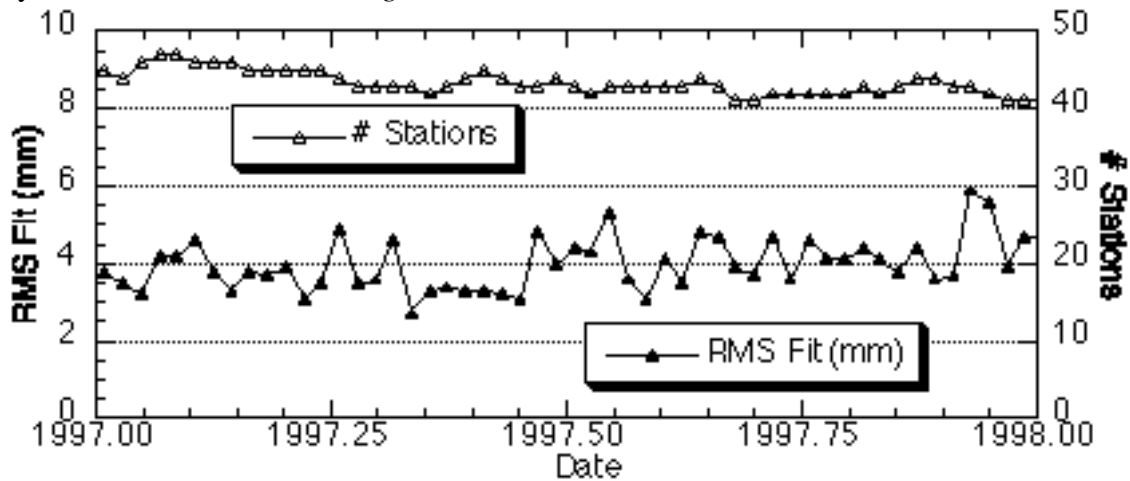


Figure 1: RMS fit of the weekly combinations to the (up to) 49 ITRF96 reference sites. The mean RMS fit is 4.0 mm with a median of 43 stations from the reference site list used.

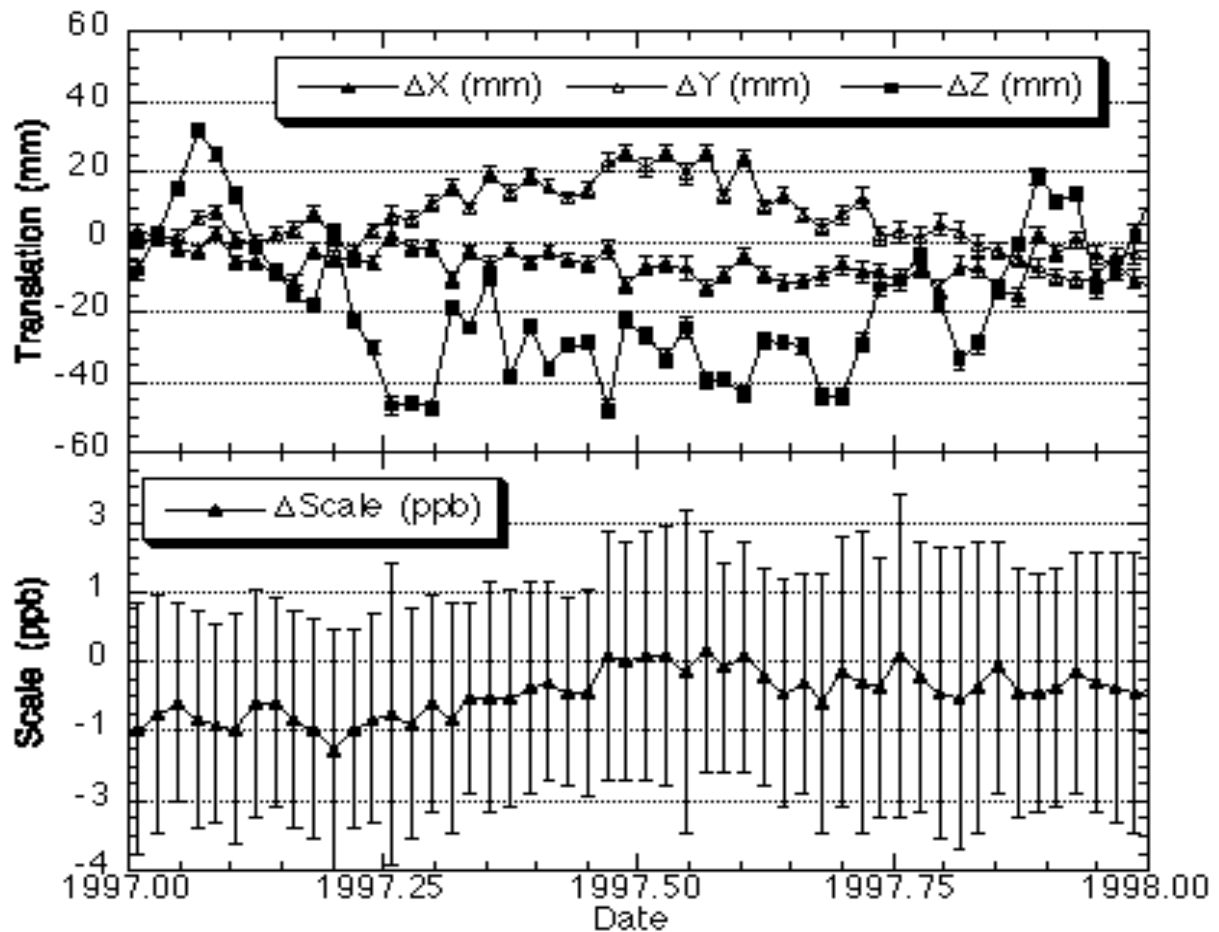


Figure 2: Estimated translation and scale factors to bring the weekly G-SINEX files into alignment with the ITRF96 reference sites. The error bars on the scale are inflated due to our down weighting the heights in the coordinate system realization.

In Figure 3, we show the histograms for the repeatabilities of the sites in the G- and P-combinations. Although the RMS scatters are small, they are typically three-times larger than the standard deviations of the estimates. The time series of the position estimates also show systematic variations as previously reported.

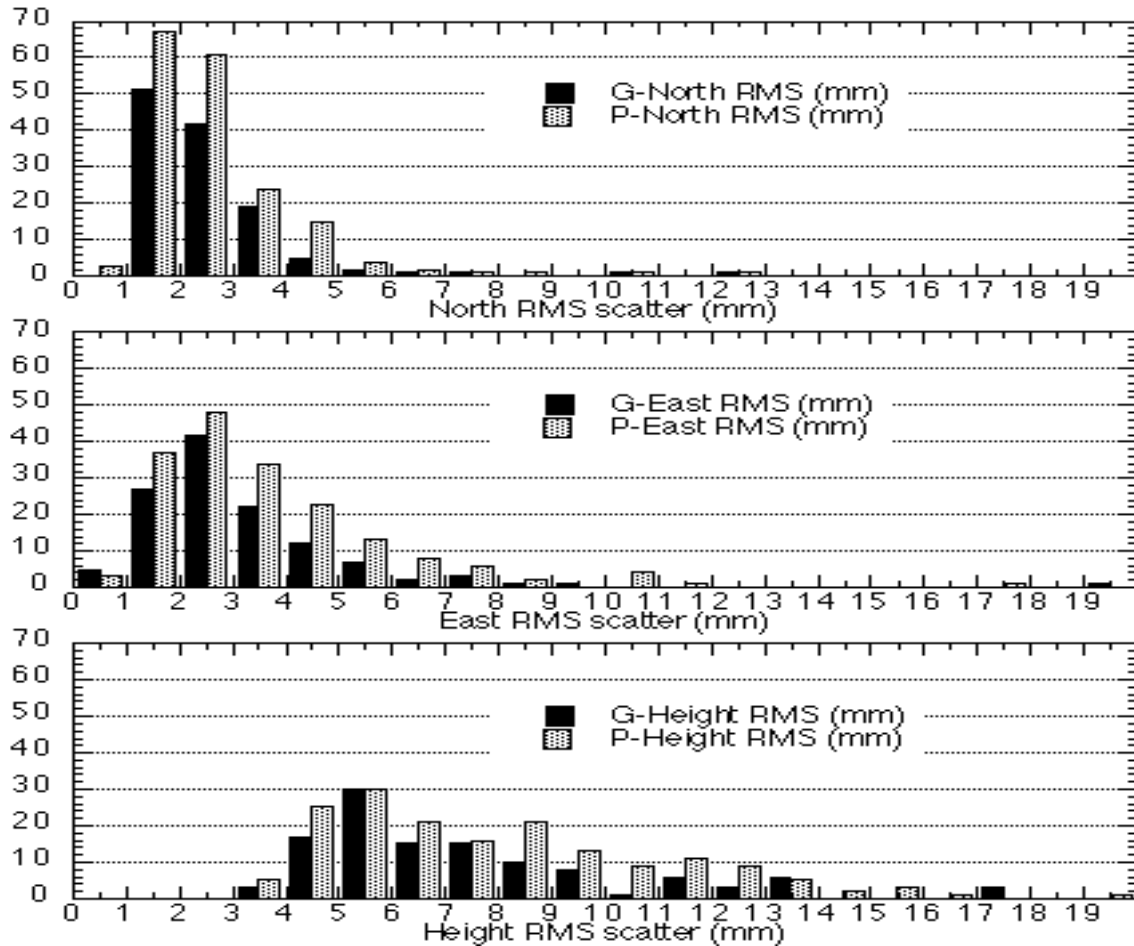


Figure 3: Histogram of the repeatabilities from the G- and P-SINEX combinations. For the height, six and eight sites are of the range for the G- and P-SINEX files. The median values are 2.0, 2.6, and 6.7 for the north, east and height in the G-SINEX combinations and 2.2, 3.0, and 7.6 mm in the P-SINEX combinations. The scatters are typically 3-times larger than the standard deviations for indicate.

4 References

Dong D., T. A. Herring, and R. W. King, Estimating Regional Deformation from a Combination of Space and Terrestrial Geodetic Data, *J. Geodesy*, 72, 200–214, 1997

Herring, T. A., MIT Global Network Associate Analysis Center Report, *International GPS Service for Geodynamics (IGS) 1995 Annual Report*, pp. 203–207, 1996.

Herring, T. A., MIT T2 Associate Analysis Center, *International GPS Service for Geodynamics (IGS) 1996 Annual Report*, pp. 255–267, 1997.

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GNAAC Coordinate Comparisons at JPL for GPS Weeks 813-964

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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. Sinex 1.0 format was implemented on week 890. A total of 152 weekly comparison reports have been produced to date.

Many improvements are either completed or in progress. Standard antenna heights are now provided by the IGS central bureau and incorporated into the weekly coordinate solutions. Each center will implement a weak or minimal constraint method for all products. Daily eop estimates and their full covariance information will be included with the coordinate solutions each week. These changes were implemented at JPL starting with GPS week 964. All parameters including orbits, clocks, tropospheres, coordinates, and eop are estimated daily with weak constraints of no more than 10 m on any coordinate. Orbits, coordinates, and eop are rotated into alignment with ITRF96. The geocenter and scale are left at their estimated values.

Solutions submitted from COD, EMR, ESA, GFZ, JPL, NGS, and SIO are obtained from the CDDIS each week. If necessary, a-priori constraints are removed to the level of about 10 m. Each pair of solutions is compared after application of internal constraints by estimating a 7-parameter Helmert transformation to minimize the least-squares coordinate residuals. All common sites are used. The errors from each solution are scaled to make CHI^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 is submitted to the CDDIS along with the summary report. 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.

Results for weeks 837-964 are summarized in Tables 1 and 2. Table 1 indicates the mean WRMS for weekly comparisons of each center with the combination rounded to the nearest mm. 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.

Table 1. Mean WRMS for GPS weeks 837-964.

Center	North mm	East mm	Vertical mm
COD	2	3	8
EMR	5	9	12
ESA	4	7	23
GFZ	3	7	11
JPL	2	2	7
NGS	11	15	14
SIO	3	4	8

Table 2. Mean geocenter and scale offsets with respect to JPL for GPS weeks 837-964.

Center	TX cm	TY cm	TZ cm	Scale ppb
COD	0.8	-0.3	0.3	0.5
EMR	0.4	-11.5	7.9	0.0
ESA	0.3	1.7	2.7	1.8
GFZ	-0.4	-6.0	2.4	0.3
NGS	0.4	-19.2	9.4	-1.7
SIO	-0.1	-0.2	6.4	-0.4

Mean geocenter offsets range from the mm level to more than 10 cm. Mean scale differences are less than 1 part per billion for all but two centers. Overall, weekly comparisons show agreement in horizontal coordinates at the mm level, agreement in vertical coordinates at the 1 cm level, agreement of geocenter estimates at the 1-10 cm level, and agreement of scale estimates at the level of a few parts per billion.

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

**Regional Network Associate
Analysis Centers**

The EUREF RNAAC: 1997 Annual Report

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1 Introduction

The IAG Subcommittee for the European Reference Frame (EUREF) continued in 1997 to monitor and process the European GPS tracking network. Ten European analysis centers process each a subnetwork and the individual subnetwork solutions are then combined into the official weekly EUREF solution. Coordinate time series for all the European stations are made available at the EUREF Permanent Network Web site :

<http://www.oma.be//KSB-ORB/EUREF/eurefhome.html>

2 The Proposed Network

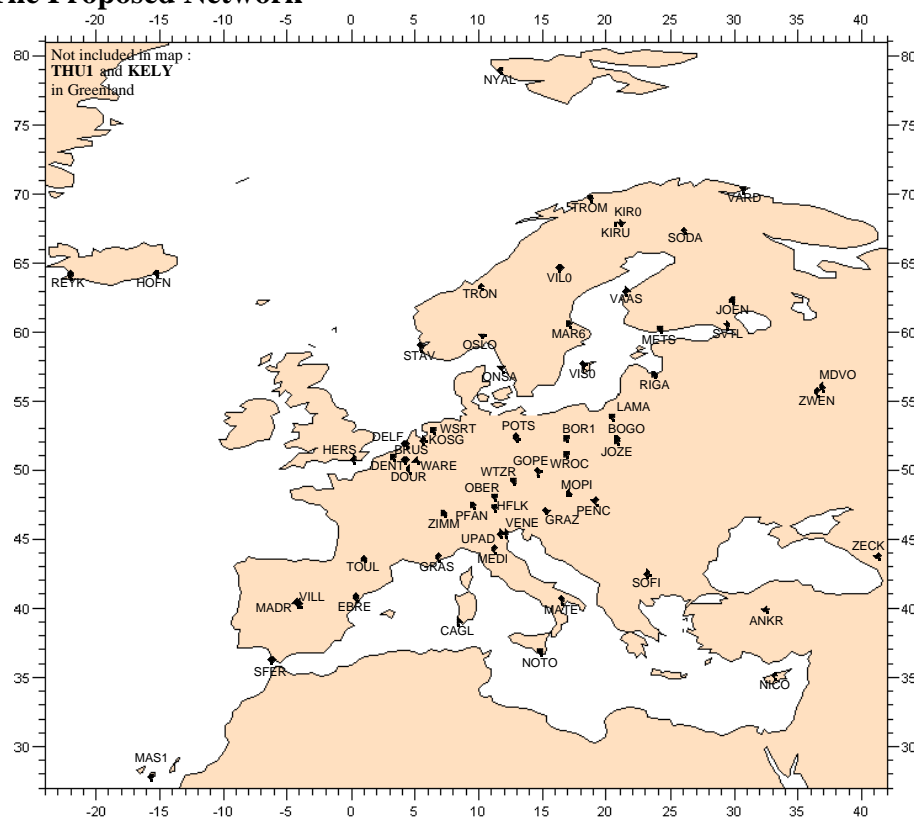


Figure 1. Network of EUREF Tracking Stations, as of January 1 1998.

The EUREF network, which consisted of 56 stations (January '97), was extended in 1997 with 9 new stations : Höfn (Iceland), Oberpfaffenhofen. (Germany), Nicosia (Cyprus), Pfänder (Austria), Sodankylä (Finland), Sofia (Bulgaria), Toulouse (France), Westerbork (Netherlands), Zelenchukskaya (Russia). The present network is shown in Figure 1.

3 The EUREF Local Analysis

Since mid 1996, weekly SINEX contributions from 10 European Local Analysis Centers are combined into one official weekly EUREF solution.

Since the summer of 1997, the EUREF local analysis centers follow all the analysis recommendations set up at the "EUREF Analysis Workshop" held in Brussels (April 1997) :

- common elevation cut-off angle of 15°
- use precise satellite orbits (IGS or CODE), all centers perform a fixed-orbit processing
- use consistent orbits and Earth Rotation Parameters
- adopt the IGS tables modeling the constant and elevation dependent antenna phase eccentricities
- adopt similar strategies for the modeling of the troposphere ; estimation of a tropospheric zenith path delay/2 hours

Also in the summer of 1997, a proposal for redistribution of the subnetworks was approved by the EUREF analysis centers and it has been effective since September 1997. Presently 18% of the EUREF stations have their data routinely analyzed by 2 EUREF analysis centers, 79% by 3 centers and 3% by 4 analysis centers.

Figure 2 shows, as an example, the RMS values derived from the Helmert residuals of the ASI/CGS analysis center with respect to the weekly combined EUREF solution. The results for the other EUREF Local Analysis Centers are similar.

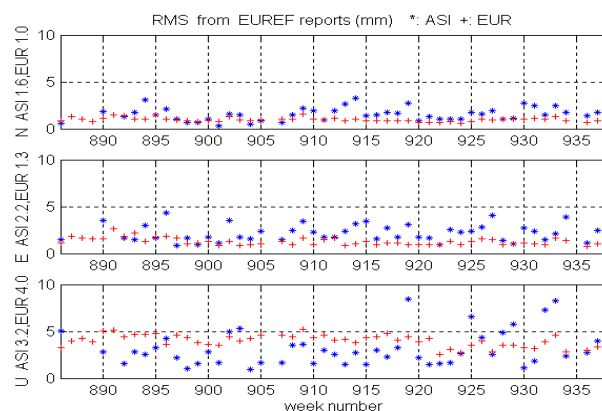


Fig. 2. RMS values derived from the Helmert residuals for ASI/CGS and EUR (combined solution) in 1997.

4 The EUREF Regional Analysis

4.1 The EUREF Combined Solution

In the combination scheme of the weekly SINEX solutions, delivered by the 10 local analysis centers, first all the applied constraints are removed and the covariance matrices are rescaled. In the final step new constraints are applied to tie the solution to the terrestrial reference frame, currently ITRF96.

Two different solutions are generated each week :

- a free network solution : well suited for the detection of problems within the combined solution and as a consistency check of the various subnetwork solutions ;
- a solution tightly constrained to the ITRF96 : the official weekly EUREF solution.

In addition, a combination of the most recent solution with the previous six weekly solutions is generated. This gives an insight into the behaviour of the sites over a period of almost two months and provides a measure of the inner consistency of the network. The RMS of this combination is below 2 mm horizontally and below 5 mm in height.

Since March 1, 1998 (GPS week 0947), the official EUREF combined solution is tied to the ITRF96. Before this time it was tied to the ITRF94. The following sites were selected for the realization of the new reference frame : BOR1, GRAZ, KOSG, MATE, ONSA, POTS, REYK, VILL, WTZR, ZIMM and ZWEN. These stations are tightly constrained (0.1 mm) to their ITRF96 coordinates.

The SINEX files of the combined EUREF solution is submitted every week to the CDDIS, BKG, ROB and CODE. More details about the combination scheme can be found in (Bruyninx et al, 1997).

4.2 Submission to the IERS (EUREF97)

As is the case for the ITRF96 realization, EUREF will contribute to the realization of the ITRF97 with a combined solution for the European permanent GPS network (EUREF97).

One of the major problems with regional solutions, like the EUREF solution, is that they are generated using the IGS (or CODE) orbits without orbit improvement. As a consequence, the reference frame changes of the orbits show up in the coordinate estimates of the regional solutions. Especially changes from ITRF92 to ITRF93 and subsequently from ITRF93 to ITRF94 led to a significant change in the reference frame, mainly caused by the ITRF93 being differently defined. These reference frame differences had to be removed before combining the weekly EUREF solutions.

The EUREF 97 contribution was done as follows :

- First, the reference frame change due to the transition from ITRF93 to ITRF94 (GPS week 860) was eliminated by estimating the values of a 7-parameter Helmert transformation between the two reference frames. No significant translations or rotations were found between ITRF94 and ITRF96 (GPS week 0947).
- Solutions for problematic sites had to be removed for some time periods, e.g. an 'old' receiver (MADR), snow on the antenna (SODA), and changes of the antenna/radome set-up (MOPI). More problems existed in the original EUREF solutions, but they were noticed and handled during the generation of the weekly EUREF solutions.
- If significant coordinate jumps were detected, then a new coordinate solution was set up, e.g. for the sites OSLO, STAV, TRON and VARD, due to equipment changes.
- The reference frame was defined by constraining the coordinates (1 mm) and the velocities (1 mm/y) of the following sites to their ITRF96 coordinates and velocities: BOR1, GRAZ, KOSG, MATE, ONSA, POTS, REYK, THU1, VILL, WTZR, ZIMM and ZWEN.
- All weekly EUREF solutions since GPS week 0834 to 0957 were used, and the coordinates and velocities of all stations were estimated.

The EUREF97 solution was compared to the ITRF96 and EUREF96 solutions by performing a 7-parameter Helmert transformation. The resulting RMS errors in position and velocity are given in Table 2. The agreement is excellent and is very consistent with the internal precision of the weekly solutions (1 mm and 5 mm for the horizontal and vertical component, respectively).

In Figure 3, the estimated EUREF97 velocities are plotted relative to the motion of the Eurasian plate as defined by the NUVEL-1A model. Plotting the relative velocities allows to detect easily sites with unexpected motions. The velocities for the sites STAV, TRON and OSLO differ significantly from their expected Eurasian motion. In these cases, the GPS velocity estimates are not reliable due to a change in GPS equipment, causing the short observation history to be split into two independent pieces. The site REYK shows a large (expected) relative velocity because it is located on the North-American plate. Many sites in the Mediterranean area show some movement, e.g. ANKR, NICO, MATE, and MEDI. This may be explained by the fact that the Mediterranean area is a tectonically active area where the African and Arabian plate are colliding with the Eurasian plate.

Table 2. Position and velocity RMS derived from the comparison of ITRF96, EUREF96 and EUREF97.

	# STA	POS RMS [mm]				VEL.RMS [mm/y]
		N	E	U	TO T	
EUREF96 - ITRF96	52	0.8	0.8	4.5	2.7	4.5
EUREF97 - ITRF96	53	1.3	1.7	4.2	2.8	4.7
EUREF97 - EUREF96	52	1.1	1.3	3.1	2.1	4.1

5 Outlook

A tentative list with about 20 future EUREF stations can be found at

<http://www.oma.be//KSB-ORB/EUREF/planned.html>.

In order to assess the velocity of the European plate with respect to neighbouring tectonic plates, EUREF will try to include permanent stations from outside Europe (North-Africa,

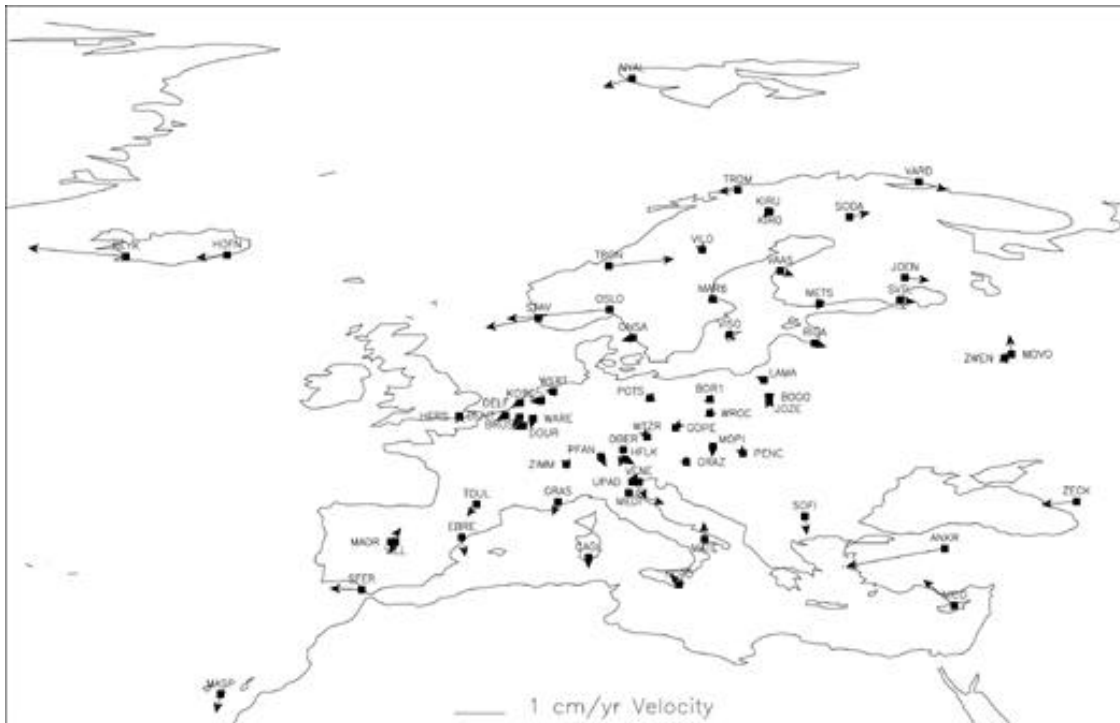


Fig. 3. : Map of the EUREF97 velocities relative to the motion of the Eurasian plate.

Middle-East) into its routine network processing. These stations will be considered as "Associated EUREF stations".

In the course of 1998, a supplementary local analysis center, located at IGN France, will be contributing to EUREF including the new permanent stations planned in France.

6 Acknowledgments

Without the labour and the commitment of the responsible agencies, their representatives at the observation sites, the data centers and the analysis centers, the EUREF network would not be the success that is it today. The authors would like to acknowledge especially the responsables of the EUREF analysis centers who have contributed to this report : J. Dousa (Geodetic Observatory Pecny, Czech Republic), W. Ehrnsperger (Bayerische Kommission für die Internationale Erdmessung, Germany), C. Ferraro, M. Fermi, A. Nardi, C. Sciarretta and F. Vespe, (ASI Space Geodesy Center, Italy), M. Figurski and J. Rogowski (Warsaw University of Technology, Poland).

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Report of the Regional Network Associate Analysis Center for Far-East Asia.

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1 Introduction

In early 1996, a pilot project aimed at analyzing the performance of Regional Network Associate Analysis Center (RNAACs) was initiated to prove the feasibility of the concept of distributed data processing in its operational services. In response to the International GPS Service for Geodynamics (IGS)'s call for participation, Geographical Survey Institute of Japan (GSI) started to process 7 sites from its dense network with other IGS global sites.

2 Outline of the Processing

7 sites are selected for the pilot project and have been processed with International GPS Service (IGS) global tracking station. (Figure 1a,1b). Daily coordinate solutions are generated using GAMIT version 9.45 and they are combined with GLOBK version 4.0 to generate weekly constraint solutions.

- Characterizing features of the performed solutions are
- Final IGS orbits and Earth orientation parameters are applied.
- Measurement elevation angle cut off 20 degrees, sampling rate 2 minutes for single-day adjustments.
- Tropospheric zenith delays are estimated every 3 hours.
- Orbit relaxation strategy is used.
- Station coordinates estimated in the International Terrestrial Reference Frame (ITRF), applying a priori sigma of $\sqrt{10}$.

3 Summary

Estimated parameters are obtained as Software/Solutions Independent Exchangeable (SINEX) format and submitted to Crustal Dynamics Data Information System (CDDIS). Densification of ITRF is important in Eastern Asia Region to construct a rigorous reference frame.



Figure 1. International GPS Service (IGS) global tracking station.

The PGC Regional Network Associate Analysis Centre: 1997 Annual Report

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1 Introduction

The Western Canada Deformation Array (WCDA) is a regional network of continuous GPS tracking stations in southwestern British Columbia established by the Geological Survey of Canada (GSC) beginning in 1991. This network currently consists of 8 sites (see Table 1) whose data, along with data from Whitehorse and Neah Bay, are analyzed at the Pacific Geoscience Centre (PGC) located in Sidney, British Columbia, 17 km north of Victoria. The purpose of the WCDA is to monitor crustal deformation along the northern Cascadia margin and thereby provide a better understanding of crustal dynamic processes and earthquake hazard in this region.

TABLE 1

Location:	Site ID:	Domes No.:	Latitude:	Longitude:	Start:
Whitehorse, Y.T.	WHIT	40136M001	60.7508	-135.2203	Jun-96
Williams Lk, B.C.	WILL	40134M001	52.2369	-122.1678	Oct-93
Holberg, B.C.	HOLB	40130M001	50.6403	-128.1350	Jul-92
Whistler, B.C.	WSLR	40141M001	50.1265	-122.9212	Sep-96
Penticton, B.C.	DRAO	40105M001	49.3225	-119.6250	Feb-91
NanOOSE, B.C.	NANO	40138M001	49.2948	-124.0865	May-95
Ucluelet, B.C.	UCLU	40140M001	48.9256	-125.5413	May-94
Sidney, B.C.	PGC1	40129M002	48.6486	-123.4511	Dec-89
Victoria, B.C.	ALBH	40129M003	48.3897	-123.4875	May-92
Neah Bay, WA	NEAH	40139M001	48.2978	-124.6249	Jul-95

Table 1: GPS sites included in the regional network analyses carried out at PGC. All sites except NEAH are operated by the Geological Survey of Canada; NEAH is operated by the University of Washington as part of the Pacific Northwest Geodetic Array (PANGA). All GSC sites use Rogue SNR-8000 receivers and Dorne-Margolin chokering antennas; NEAH currently uses an Ashtech Z12 receiver with an Ashtech Dorne-Margolin chokering antenna.

The GSC also operates two additional stations in central Canada (see Table 2). Data for all Canadian sites (except PGC1 which is a site for testing receivers) are available via anonymous ftp from our server sikanni.pgc.nrcan.gc.ca. Alternatively, the files can be accessed through the WCDA home page at:

<http://www.pgc.nrcan.gc.ca/geodyn/wcda.htm>.

The daily data files are also forwarded to the Geodetic Survey of Canada, Ottawa, and to NASA's CDDIS located at Goddard.

TABLE 2

Location:	Site	Domes No.:	Latitude:	Longitude	Start:
Flin Flon, Man.	FLIN	40135M001	54.7257	-101.9780	May-96
Lac Dubonnet, Man.	DUBO	40137M001	50.2588	-95.8662	Oct-96

Table 2: Continuous GPS sites in central Canada operated by the Geological Survey of Canada under a cooperative program with NASA to study glacial rebound. The Rogue SNR-8000 receivers at these sites have been provided by NASA and are supported by UNAVCO. Support for site operations is also provided in part by Manitoba Hydro.

2 Data Analysis

Daily station solutions are obtained using an L3 double-differencing strategy with IGS final orbits held fixed and a fixed reference station (DRAO). All other stations are loosely constrained (sigmas = 10 m). The variance-covariance matrix from this differential solution is scaled by a factor of 9 to facilitate a less rigid network integration of these regional results with global results and augmented to a full matrix by including the reference station position as a loosely (sigmas = 10 m) constrained observation. (To avoid a potential non-positive definite condition of the matrix arising from numerical precision of the computing platform, the nominal XX, YY, and ZZ variances for DRAO were set at $100 + 1\text{E-}08$.) Daily station solution files are combined into a weekly solution using the program "stacomb" from the Geodetic Survey Division, NRCan, Ottawa. The input files are the 7 daily station-solution Sinex files generated at PGC as well as a reduced version of the commensurate EMR weekly Sinex file which provides the coordinates and the covariances of sites common to both analyses as *a priori* constraints. The common sites are DRAO, ALBH, WILL, and WHIT. Currently, the *a priori* covariances introduced from the reduced version of the EMR weekly solution has been limited to the diagonal terms only; i.e. the *a priori* correlation between sites has been removed.

Other parameters used to characterize the WCDA regional network solution are summarized in the list below (for details see Dragert et al., 1995, and Chen, 1998):

<i>Solution Identifier:</i>	UT date and time stamp of combined weekly file
<i>Software Used:</i>	CGPS22 V1.0 (UNIX) (Kouba and Popelar, 1990)
<i>Reference Frame:</i>	Defined by IGS orbits (nominally ITRF94 during 1997)
<i>Reference Epoch:</i>	Current date
<i>GM:</i>	$398600.4415 \text{ km}^3/\text{s}^2$
<i>Gravity Model:</i>	GEMT3(8,8) + C21 + S21
<i>Tidal Corrections:</i>	Solid earth tide and pole tide corrections
<i>Ocean Loading:</i>	Pagiatakis, global_model Note: A new table of ocean loading corrections was generated and applied beginning with GPS Week 892. The Schwiderski 1 x 1 degree global modal was used to calculate the M2, S2, K1, O1, N2, & P1 constituents; beginning with Week 894, nine constituents were used by adding K2, Q1, and Mf.
<i>Tropospheric Model:</i>	Stochastic coloured noise with a correlation time of 10 hr
<i>Solution Type:</i>	L3 double-differenced phase (ionosphere-free linear combination of L1 and L2) with orbits held fixed & ambiguities not held fixed
<i>Solution Basis:</i>	120 sec intervals using all available satellites (max. 8) above 15° elevation

3 Results

The precision of the daily network solutions is gauged by the L3 double-difference phase range residuals averaged over all satellites and all stations. In general, the average of these residuals vary from 6 to 9 mm. Formal errors for the daily solutions of network station locations relative to the reference station (DRAO) are less than 1, 2, and 4 mm for relative latitude, longitude, and height respectively. More realistic estimates of errors are given by the day-to-day variations of relative positions which have sigmas that are double the values listed above.

Detailed analysis of temporal variations in the relative positions of network sites have resolved secular motions at the level of a few millimetres per year and also revealed significant transient signals of non-tectonic origin. For sites on southern Vancouver Island, velocity estimates based on linear trends in daily solutions of relative positions are in general agreement with current (pseudo) three-dimensional elastic models of a locked thrust fault. The margin-parallel motion of the GPS site on northern Vancouver Island (HOLB) is more consistent with shear-strain expected from Pacific Plate/North America Plate interaction across northwest trending strike-slip faults as opposed to elastic shortening across a locked convergent margin.

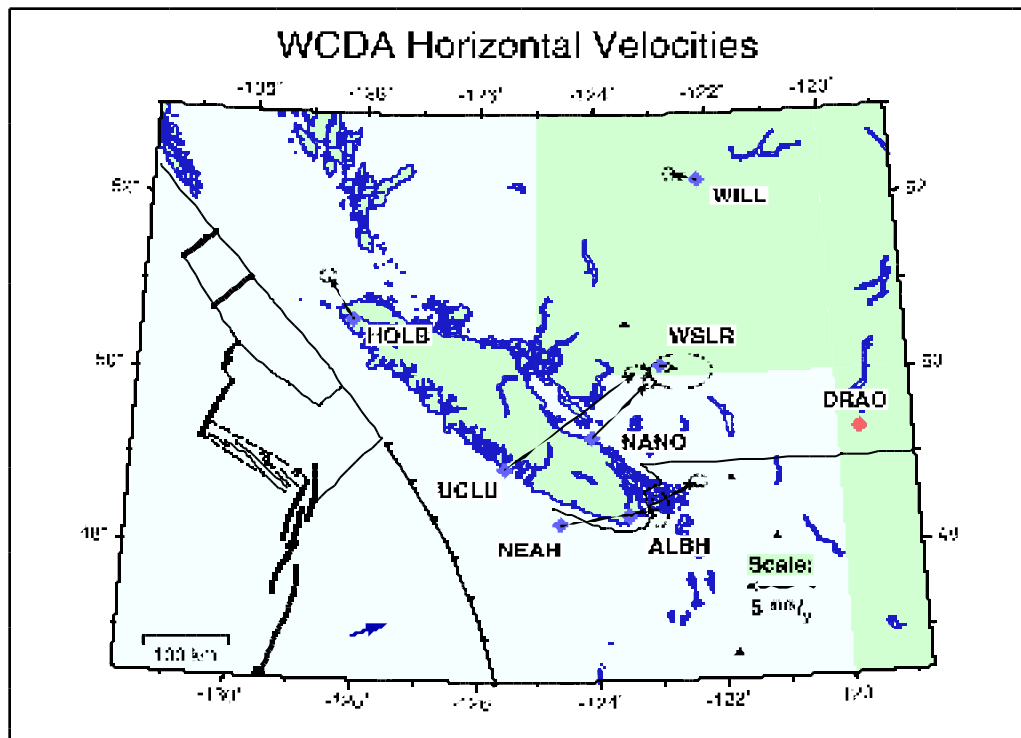


Figure 1: Horizontal motions of WCDA network sites relative to DRAO estimated from linear trends in the daily solutions. Length of observations at each site vary from over 4 yr to less than 2 yr.

The linear trends obtained from regressions on daily GPS solutions of relative site positions which form the basis of the crustal velocity estimates are made more uncertain by instrumental effects and by transient signals of non-tectonic origin. For example, changes in the position of the antenna phase centres as large as 3 mm in the horizontal and 19 mm in the vertical have been observed to accompany changes in the physical mounting of the antennas. Annual and semi-annual signals with amplitudes of several millimetres have been observed predominantly in the relative vertical components for almost all network sites. Non-stationary spectral peaks with amplitudes as large as 7 mm also appear in the relative vertical components in the period range of 10 to 20 days. The exact causes of these non-linear temporal variations are not known. However, the amplitudes of some of these signals appear to vary with elevation cut-off used in the analyses, indicating a near-field multipathing effect as a possible factor in these phase-centre changes.

Large sudden offsets in the phase centres of antennas are the most detrimental to unbiased estimates of linear trends in a station's time series. Table 3 provides a chronology for all WCDA sites of when physical changes were made in the set-up of the antennas which resulted in an apparently significant (2 to 3 mm in the horizontal; 5 to 20 mm in the vertical) change of relative position. The magnitudes of these changes are strongly

dependent on the nature of the GPS data analysis (L3 solution; double differencing; elevation cut-off; etc.); consequently, no absolute calibration of these steps can be provided. If data from WCDA sites are being used to estimate absolute or relative crustal motions, Table 3 can be used to flag times when discontinuities may have occurred.

Table 3

Date	Site	Description of Changes
94:041	DRAO	New antenna; New antenna mount;
94:124	HOLB	New antenna;
94:173	WILL	Added acrylic dome & mounting ring;
95:011	ALBH	New antenna mount;
95:103	DRAO	New antenna mount;
95:158	ALBH	New antenna;
95:189	WILL	New antenna mount; Added RF screening skirt;
95:202	ALBH	Added RF screening skirt;
95:223	UCLU	Added RF screening skirt;
96:010	DRAO	Added RF screening skirt;
96:046	NANO	Added RF screening skirt;
96:089	HOLB	New antenna mount;
97:033	NEAH	New antenna; New Ashtech cone dome;

Table 3: Listing of changes in the antenna set-up at WCDA sites which affected the mean phase-centre positions. Dates give year followed by the Julian day.

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Annual Report 1997 of the RNAAC SIRGAS

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1 Introductions

The IGS Regional Network Associate Analysis Center for the South American Reference System (RNAAC SIRGAS) is processing, on a weekly basis, all available data of permanently observing GPS stations in the mainland of South America and the surrounding areas. The resulting station coordinates solutions are routinely forwarded as SINEX files to the IGS Global Data Centers, and then combined within the polyhedron solutions of the Global Network Associate Analysis Centers (GNAAC). In early 1998, there are 22 stations included in these solutions.

2 Station Network

The RNAAC SIRGAS configuration has been extended in 1997 by including four new stations in Brazil (Cuiaba, Imperatriz, Manaus, Vicos), and one in Venezuela (Maracaibo). Instead of the two global IGS stations Bermuda and Richmond, the new station Barbados was included as a reference station. The complete actual network is shown in Figure 1.



Figure 1: Network processed by the IGS RNAAC SIRGAS

3 Processing and Results

The processing is continuously done using the automated Bernese Software Version 4.0 (Rothacher and Mervart 1996). The results are controlled by daily and weekly time series comparisons (see also Seemueller and Drewes 1998). A typical example is shown for the new station Vicosa in figure 2. We clearly see the broad variations of the diurnal solutions (only weakly constrained in the IGS orbits reference frame) and the smooth behaviour in the GNAAC's weekly global polyhedron solutions (constrained by IGS stations in the ITRF). The deviations between both solutions, RNAAC and GNAAC, are typically in the sub-centimeter level for horizontal components and one to two centimeters in the vertical.

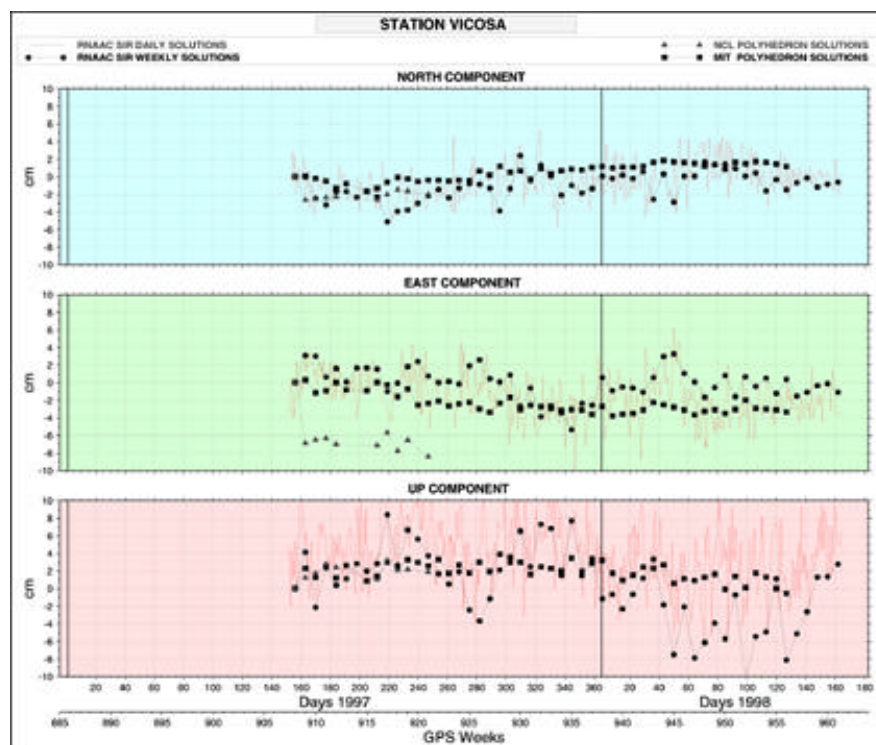


Figure 2: Variations of coordinate solutions for station Vicosa (Brazil)

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Rapid Service and Prediction

U.S. Naval Observatory Center for Rapid Service and Predictions

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1 Introduction

The mission of the U.S. Naval Observatory (USNO) includes determining the positions and motions of the Earth, Sun, Moon, planets, stars and other celestial objects, providing precise time, measuring the Earth's rotation, and maintaining the master clock for the U.S. The Earth Orientation (EO) Department contributes to this mission by collecting suitable observations and performing data analyses to determine and predict the time-varying orientation of the terrestrial reference frame within the celestial reference frame. The key parameters determined and disseminated are polar motion coordinates, universal time (UT1), precession, and nutation. The user community includes the U.S. Department of Defense, other U.S. government agencies, scientific researchers, and the general public. The primary applications are for high-accuracy navigation and positioning with an emphasis on real-time uses.

In order to accomplish these objectives, USNO collaborates closely with a large number of other groups and organizations, and relies on a combination of results from a variety of techniques. Very long baseline interferometry (VLBI) is essential in order to maintain accurate knowledge of UT1, the celestial pole, and the celestial reference frame, which is realized by the positions of about 600 extragalactic radio sources. Increasingly, however, GPS is being used to satisfy important aspects of the USNO mission. This report summarizes the current status of USNO participation with the IGS and GPS, together with some recent results.

2 IERS Sub-Bureau for Rapid Service and Predictions

The IERS Sub-bureau for Rapid Service and Predictions of Earth orientation parameters (EOPs) is hosted by the EO Dept. at USNO. EOP results contributed by many analysis centers derived from observations by VLBI, satellite laser ranging (SLR) to LAGEOS, lunar laser ranging (LLR), or GPS are combined into a homogeneous daily time series which is updated and distributed twice each week as *IERS Bulletin A*. Combined EOP values for the recent past are published together with predictions extending a year into the future.

In recent years, the *Bulletin A* polar motion results have been dominated by the precise, daily determinations of the IGS combined Final products, with the Rapid series being used for the most recent measurements. The Rapid determinations are quite important for *Bulletin A* by providing timely (delivered within 22 hours after each UTC

midnight), high-quality results which are most significant for the polar motion predictions needed by real-time users. The accuracy of these series during 1997 is estimated to be about 0.1 mas (per component) for the Finals and 0.2-0.3 mas for the Rapids. Implementation on 01 March 1998 of the much more robust and improved terrestrial reference frame realization proposed by Kouba *et al.* (1998), where the coordinates and velocities of 47 sites are constrained to their ITRF96 values, will surely produce significantly more stable polar motion results. Early indications are that the accuracy of the Rapid polar motion values has been improved to about 0.1 mas (Ray, 1998a). This, in turn, should improve the quality and reliability of near-term polar motion predictions.

In addition to polar motion, *IERS Bulletin A* has become increasingly reliant on IGS estimates of length of day (LOD). The IGS started producing an official LOD product on 02 March 1997 using a weighted combination of LOD results submitted by each IGS Analysis Center (AC). To calibrate for LOD biases, each series is compared with the most recent 21 days of non-predicted UT1 values from *Bulletin A* (Kouba and Mireault, 1997; Ray, 1996). Shortly after its advent, the IGS combined LOD results were introduced into the *Bulletin A* combination to extend the UT1 value of the most recent VLBI determination forward by integration. A few months later an independent set of GPS-based estimates of universal time, derived at USNO and described below, were also included in *Bulletin A*. About two weeks of the most recent estimates are used, after calibration in offset and rate compared to overlapping UT1 results from VLBI. In April 1998, an analogous universal time series from the EMR AC (Natural Resources Canada) was added in a similar manner. The EMR analysis strategy differs from the other IGS groups in applying *a priori* orbit constraints that allow both universal time and LOD to be estimated simultaneously. These three series together have proven very successful in extending UT1 results forward from the latest VLBI determinations, which can have a latency of up to about a week. As a consequence, the last non-predicted UT1 value in *Bulletin A* is now generally more accurate than 100 :s, usually considerably more so.

Errors in predicted EOP values are a significant source of systematic error in the IGS Predicted orbits, although they rarely dominate the overall error budget. MartRn Mur *et al.* (1998) have stressed the need for improved EOP predictions for use in computing the IGS Predicted orbits. Partly to address this concern, refinements already under development were implemented in *Bulletin A* on 03 March 1998 (Ray and Luzum, 1998). The improvement is most significant for the shortest prediction intervals (53% for 1 day) with diminishing effect over longer spans. Research is continuing into further improvements, which are likely to be implemented later in 1998.

For real-time users, given two updates of *Bulletin A* each week, the longest prediction interval is 7 days (for Tuesday updates compared with the previous Thursday issue which normally contains most recent data from 2 days earlier). This means that real-time users can experience polar motion prediction errors up to ~2.4 mas (in an RMS sense per component) and UT1 errors as large as ~1 ms (15 mas). Predictions of UT1 variation are more problematic because the geophysical excitation is about an order of magnitude larger than for polar motion. To reduce these prediction errors significantly

will require more frequent *Bulletin A* updates, preferably done daily shortly after the IGS Rapid products are released. Such a process is expected to be implemented during 1998 and will reduce the longest prediction interval from 7 days to ~58 hours, under normal circumstances. In that case, the maximum errors for real-time users should be less than ~0.7 mas (RMS per component) for polar motion and less than ~0.3 ms for UT1.

As part of its contribution to the IGS, USNO prepares regular reports and plots of the performance of each IGS Analysis Center compared with *Bulletin A*, which are available at <http://maia.usno.navy.mil/bulletin-a.html>. Additional analysis reports are prepared occasionally to assess changes in IGS performance (*e.g.*, Ray, 1998a) or to evaluate the geophysical implications (*e.g.*, Eubanks *et al.*, 1998).

3 IGS Rapid Service Associate Analysis Center

Given the significance of the IGS results and our increasing reliance upon them, it is natural for USNO also to contribute actively as a data analysis center. Beginning 23 April 1997 USNO officially became a contributor to the IGS Rapid products. Originally we intended to eventually begin submitting Final and other products to become a full IGS AC. Since that time, however, other GPS-related activities have developed, particularly the IGS/BIPM timing project (Ray, 1998b), which are more closely tied to the USNO mission and therefore take higher priority. Given limited resources, USNO would, for the time being, prefer not to assume the additional responsibilities of a full AC and plan instead to maintain the status of a Rapid Service Associate Analysis Center (RSAAC) contributing to the IGS Rapid and (eventually) Prediction products. We hope to begin producing and contributing predicted GPS orbits by late 1998.

Basic features of the USNO Rapid analysis strategy are summarized in Table 1. The software used is GIPSY/OASIS II, developed and maintained by JPL.

Table 1. USNO Analysis Strategy.

Software	GIPSY/OASIS II (vers. 4.8)
Observables	carrier phase & pseudo-range at 7.5 min.
Arc length	3 + 24 hr.
Network	30 global sites (usually)
Elevation cutoff	15 deg.
Sat. parameters	initial position & velocity, rad. pressure scale & Y-bias as constants, X,Z rad. pressure scales as stochastic
Attitude	yaw rates for eclipsing sats.

An emerging interest at USNO is improved GPS orbits for a variety of real-time applications, including precise time transfer. This requires the highest quality Rapid and Predicted orbits and EOPs. These interests mesh naturally with full participation in the IGS/BIPM timing project. In support of this effort, USNO deployed a TurboRogue

SNR12 receiver in Washington, DC connected to the USNO Master Clock (MC) as its frequency reference. Data were released to the IGS starting 01 May 1997. A second receiver was deployed at Falcon (recently renamed Schriever) Air Force Base in Colorado Springs on 25 March 1998. This is the site of the USNO Alternate Master Clock (AMC) and the operations center for GPS. The MC and AMC are kept closely synchronized by hourly two-way satellite time transfer (TWSTT) observations. These IGS sites can therefore serve as important comparison sites in the IGS/BIPM project.

A "timing solution" strategy is currently under development for the IGS/BIPM timing project. The approach is to adopt the IGS combined orbits (either Rapid or Final, as appropriate) without adjustment and to determine all the station and satellite clocks in a fully consistent way, relative to a reference station clock (normally, USNO). It is essential to use a global network of stations, preferably equipped with highly stable frequency standards, and to resolve as many phase cycle ambiguities as possible. Computational constraints limit the size of the tracking network to about 30 stations. In order to densify the clock network it will be necessary to supplement such an analysis with an adaptation of the precise point positioning technique (Zumberge *et al.*, 1997).

4 GPS Determinations of Universal Time

Elsewhere Kammeyer (1998) has described his method to determine UT1-like variations from an analysis of GPS orbit planes as estimated for IGS Rapid submissions. Briefly, the Earth-fixed GPS ephemerides determined operationally at USNO are compared to orbit planes propagated using a modeled radiation pressure acceleration normal to each orbit plane. For each satellite, the modeled acceleration is expressed relative to the projection of the Sun direction on the orbit plane and depends only on the angle from the orbital angular momentum to the Sun. The models being used were obtained empirically from observed experience when this angle was greater than 90° during 1994-1995. For each satellite, there is a unique axial rotation angle which brings the observed Earth-fixed positions into alignment with the propagated orbit plane. Since the propagated orbit plane of each satellite is different from its osculating orbit plane in an inertial frame, offsets are added to the rotation angles to form single-satellite estimates of GPS-based universal time. The median of these values for the 13 satellites modeled gives the UT estimate reported to *IERS Bulletin A*.

Kammeyer's results show quite encouraging short-term performance. The relatively slow drifts allow sliding segments of these data to be included in the *Bulletin A* combination after calibration only for an offset and a rate. The residual scatter is about 75 :s over 3-week intervals. The procedure is described above and has proven very successful in extending more accurate but less timely VLBI measurements of UT1 to near real-time. Over longer spans these GPS-based determinations drift systematically, up to about 600 :s in six months.

Several improvements can be made and are being pursued. The long-term drifts reflect deficiencies in empirical models for the orbit plane motions. With the longer series of orbits now available, better models should be feasible. In particular, the present

models are based on data collected before the current yaw bias was implemented. Models can be constructed for all satellites, not just the 13 currently being used. The procedure could be applied to the more precise and reliable IGS combined orbits rather using the USNO orbits.

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IERS Contributions

IERS References

Contribution of the Central Bureau of IERS

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1 The International Terrestrial Reference Frame

The main ITRF event in 1997 of interest to IGS is the generation of a new solution, namely the ITRF96, which is used as reference by IGS starting on March 1, 1998.

1.1 ITRF96

The ITRF96 solution represents a new generation of realization of the International Terrestrial Reference System (ITRS). It is achieved by combining simultaneously positions and velocities using full variance- covariance information provided, in SINEX format, by the IERS analysis centers. Moreover, a rigorous weighting scheme is used, based on the analysis and estimation of the variance components using Helmert method.

A brief description of the ITRF96 solution could be found in the 1997 IGS Annual Report, Volume 1. For more details about the results and analysis of the ITRF96, see (Boucher et al, 1988). Moreover, in Volume 1, we also provided some information about the selection of 47 ITRF96 reference stations to be used by IGS. For more details, see also (Altamimi, 1998). All the ITRF96 related files are available via the Web at:

<http://lareg.ensg.ign.fr/ITRF/ITRF96.html>

Here, we will provide more information on ITRF96 of interest to IGS.

The ITRF96 global combination is achieved using the following properties:

- 17 selected space geodetic solutions provided by the IERS analysis centers and 70 SINEX files, containing positions and covariances computed from local ties.
- The reference frame definition (origin, scale, orientation and time evolution) of the combination is achieved in such a way that ITRF96 is in the same system as the ITRF94.

- Velocities are constrained to be the same for all points within each site.
- Matrix Scaling Factors have been rigorously estimated during this combined adjustment, which was then iterated.

1.2. IGS Contribution to ITRF96

6 global IGS/GPS solutions were included in the ITRF96 adjustment. Moreover, two European GPS solutions, computed by CODE, were also included as part of EUREF contribution to the ITRF. These GPS solutions contain about 194 stations. Table 1 lists these solutions together with solutions coming from the other IERS techniques. Figure 1 shows the coverage of the 4 IERS technique sites implied in the ITRF96.

To have an idea about the quality of the individual solutions used to generate the ITRF96, Table 1 lists the global 3D Weighted RMS in position as well as in velocity. In position, the best level reached in 3D precision is greater than 1 cm for VLBI and GPS, around 1 cm for SLR, and 3 cm for DORIS. In velocity, the best 3D precision is about 2 mm/year for SLR and VLBI, 4 mm/year for GPS, and 8 mm/year for DORIS.

Conversely, the largest discrepancies (excepting 2 outliers) between the origins and scales of the individual solutions are respectively 4 cm and 4×10^{-9} .

Table 1. ITRF96: Used data and global residuals per solution.

Solution		Number of points	Data Span yy-yy	Position RMS mm	Epoch yy:day	Velocity RMS mm/y
VLBI						
SSC(GSFC)	97 R 01	120	79-97	5.80	93:001	1.90
SSC(GIUB)	97 R 01	43	84-96	13.60	93:001	.50
SSC(NOAA)	95 R 01	111	79-94	14.70	93:001	1.90
SSC(JPL)	97 R 01	8	91-96	20.70	93:001	
SLR						
SSC(CSR)	96 L 01	89	76-96	11.10	93:001	3.80
SSC(GSFC)	97 L 01	38	80-96	10.90	86:182	1.70
GPS						
SSC(EMR)	97 P 01	36	95-97	10.00	96:001	3.50
SSC(GFZ)	97 P 02	66	93-96	16.80	94:365	3.30
SSC(CODE)	97 P 02	100	93-97	7.10	95:076	1.90
SSC(EUR)	97 P 04	39	95-96	2.40	96:090	.30
SSC(EUR)	97 P 03	58	96-97	2.90	96:339	.30
SSC(MIT)	97 P 01	132	94-97	8.50	97:151	9.20
SSC(NCL)	97 P 01	114	95-97	5.40	96:001	6.30
SSC(JPL)	97 P 02	113	91-96	9.40	96:001	3.80
DORIS						
SSC(GRGS)	97 D 01	48	93-96	26.90	93:001	8.00
SSC(CSR)	96 D 01	54	93-96	26.10	93:001	10.60
SSC(IGN)	97 D 04	62	90-97	28.30	95:100	12.80

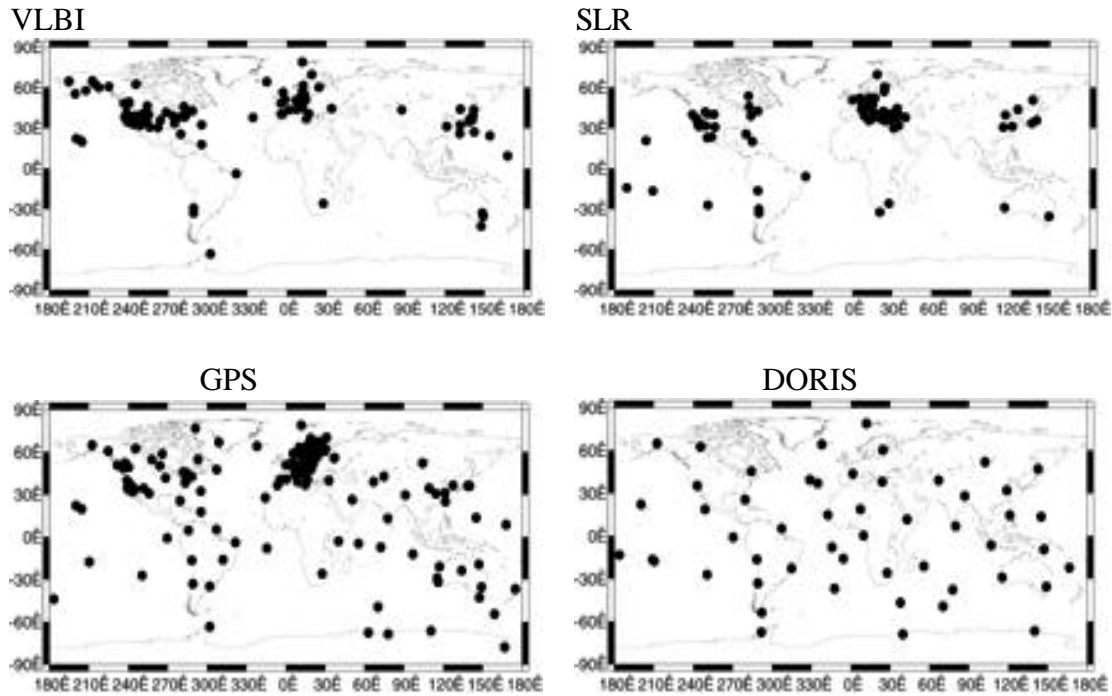


Figure 1. ITRF96 Sites

2. Earth Orientation

2-1 Contribution of GPS to Polar Motion and LOD

GPS EOP solutions (polar motion and LOD) have a significant contribution in the multi-technique combined solutions derived by the IERS. Since 1994, a combined solution of the various GPS series is performed and is used in our current analyses. Table 2 shows the mean differences and the unbiased RMS agreements of the various series GPS which contributed to this combined solution, and of different solutions derived from other techniques to (IERS) C04. These statistics reflect the accuracy reached by the different techniques. Note the significant improvement (shown in brackets) in the consistency between the various solutions due to the adoption of the ITRF96 in the GPS data analysis after March 1998. The relative weighting of GPS in the IERS C04 solution is now about 70 %.

Table 2 - biases and unbiased RMS of the differences of various solutions to (IERS) C04

Differences to (IERS) C04 ms	X- bias mas	RMS mas	Y-bias mas	RMS mas	lod-bias .1 ms	RMS .1
GPS solutions						
CODE 98 P 01	.33	.16 (11)	-.10	.19 (11)	.15	.31 (16)
EMR 96 P 03	.12	.21 (20)	.40	.22 (17)	.09	.45 (34)
ESOC 96 P 01	.13	.22 (14)	.21	.27 (14)	-.10	.37 (28)
GFZ 96 P 02	.24	.13 (09)	.14	.18 (14)	-.06	.37 (24)
JPL 96 P 03	.12	.14 (10)	.03	.17 (10)	.11	.67 (34)
NOAA 96 P 01	.54	.49 (26)	.22	.54 (26)	.06	.57 (39)
SIO 96 P 01	.20	.19 (16)	.04	.19 (16)	.00	.61 (37)
IGS 96 P 02	.32	.18 (17)	.17	.25 (13)	.00	.31 (24)
IERS 97 P 01	.00	.08 (06)	-.01	.11 (05)	-.02	.28 (20)
Other individual series						
USNO 97 R 08	.04	.20 (18)	.02	.15 (12)	-.13	.39 (28)
CGS 98 L 01	.38	.43	.03	.40 (11)		
CSR 95 L 01	-.34	.21 (21)	-.04	.23 (12)		
DUT 98 L 01	.64	.38 (47)	.50	.39 (41)		
GZ 98 L 02	.53	.25	.55	.28		
IAA 98 L 01	.06	.14 (16)	-.11	.15 (13)	.04	.14 (14)
Combined series						
USNO 98 C 01	-.07	.10 (09)	-.10	.12 (07)		
SPACE 98 C 01	-.05	.19 (11)	-.02	.14 (11)		

Figures 2a, 2b and 2c show for x-pole, y-pole and LOD, the plots of the differences of the seven individual GPS series, and other series with the combined IERS C04.

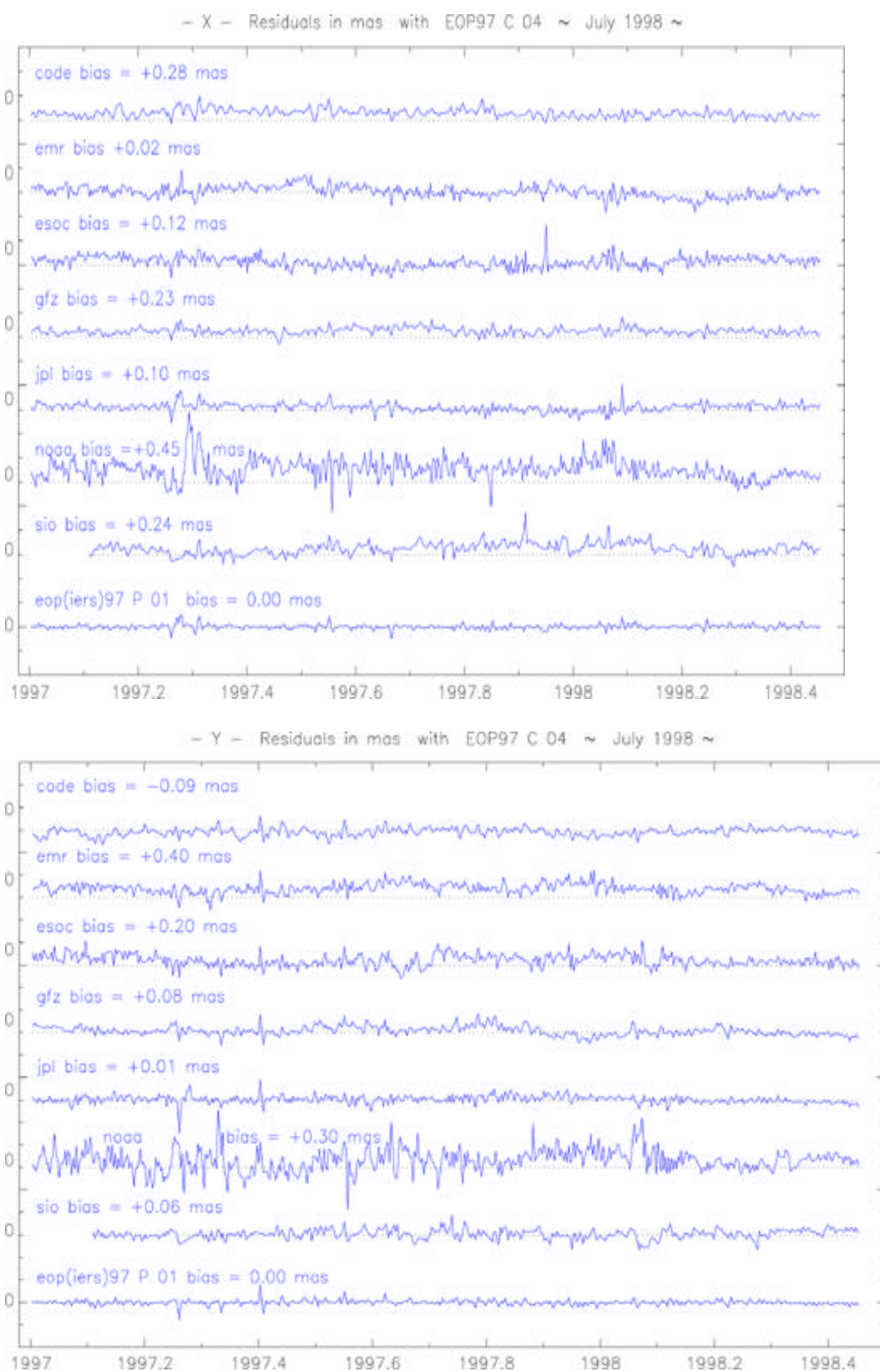


Figure 2a and 2b - x and y-pole coordinates in 1997/1998. Daily differences of individual GPS series with IERS C04.

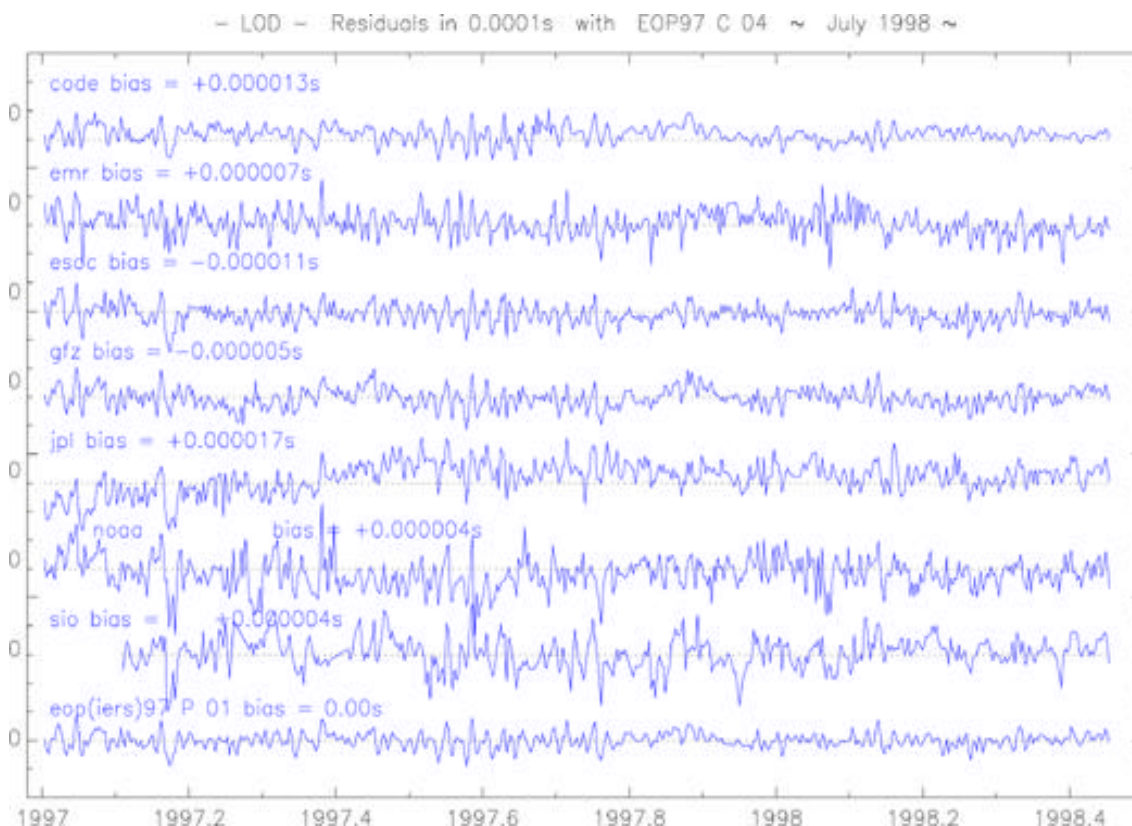


Figure 2c - LOD in 1997/1998. Daily differences of individual GPS series with IERS C04.

2-2 Use of GPS LOD Estimates for Near-real Time Universal Time Determination

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 satellite techniques but only from inertial methods like VLBI. On the other hand, these techniques can determine the length of day variations (lod), derivative of Universal Time together with the orbital parameters; of course their spectrum show similar systematic errors than those of Universal Time directly estimated. Various studies (Gambis et al 1993, Gambis 1996) have shown that the high-frequency signal contained in the lod estimates on time scales limited to a couple of months derived from SLR and GPS can be used to densify the series obtained by the VLBI technique and also for near-real time earth orientation monitoring.

The published near-real Universal Time was so far extrapolated from VLBI determinations. The present rapid availability of the GPS LOD solutions allows to significantly improve it when VLBI UT1 determination is available and consequently it gives a much better UT prediction. The following table represents the results obtained by this procedure over one year of operational analysis (1997.5 to 1998.5). The C04 solution

is now permanently computed. On tuesdays, 5 GPS LOD estimates are available whereas no VLBI UT1 solution is. Table 3 shows the accuracy reached using these GPS LOD estimates compared to regular predictions from the last available VLBI value. This corresponds to a near-real time service. The improvement is significantly of one order of magnitude for a 5-day time lag.

Table 3 - RMS errors (in microseconde) of the Universal Time solution based on GPS and compared to the current prediction based on an auto-regressive process.

UNIT: 1 ms	5 days

Pure Prediction	1000
GPS estimates	100

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Data Centers

Global Centers

CDDIS Global Data Center Report

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1 Introduction

The Crustal Dynamics Data Information System (CDDIS) has supported the International GPS Service for Geodynamics (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 1997 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* (Noll, 1995) as well as the subsequent updates (Noll, 1996 and Noll, 1997).

2 System Description

The CDDIS archive of IGS data and products are accessible worldwide by way of a password-protected user account. New users can contact the CDDIS staff to obtain the required username and password, as well as general instructions on the host computer, directory structure, and data availability.

2.1 Computer Architecture

During 1997, the CDDIS was 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) and through dial-in service.

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 120 station network, only three days of GPS tracking data can be stored on a single side of one of these platters. The older data continues to be stored on these optical disks and can easily be requested for mounting and downloading remotely by the user. Alternatively, if the request 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 both GPS data from the global IGS network as well as the products derived from the analyses 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
- European Space Agency (ESA) in Darmstadt, Germany
- Geoforschungszentrum (GFZ) in Potsdam, Germany
- Geographical Survey Institute (GSI) in Tsukuba, Japan
- NOAA's Geosciences Laboratory (GL/NOAA) Operational Data Center (GODC) in Rockville, Maryland
- Korean Astronomy Observatory in Taejeon, Korea
- Jet Propulsion Laboratory (JPL) in Pasadena, California
- National Geography Institute in Suwon-shi, Korea
- National Imagery and Mapping Agency (NIMA), formerly Defense Mapping Agency (DMA), in St. Louis, Missouri
- Natural Resources of Canada (NRCan) in Ottawa, Canada
- 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 Géographique 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 1997. Nearly 42K station days from 146 distinct GPS receivers were archived at the CDDIS during 1997; a complete list of all archived sites can be found on the web site (http://cddis.gsfc.nasa.gov/reports/gpsdata/cddis_summary.1997).

Table 1: Sources of GPS data transferred to the CDDIS in 1997

Source	Sites								No. Sites
AUSLIG	CAS1	COCO	DAV1	HOB2	MAC1				5
NOAA/GL	<i>AOML</i>	<i>BARB</i>	BRMU	FORT	HNPT	KELY	RCM6	SOL1	12
	USNA	<i>USNO</i>	WES2	WUHN					
NRCan	ALBH	ALGO	CHUR	DRAO	DUBO	FLIN	<i>NRC1</i>	<i>PRDS</i>	12
	<i>SCH2</i>	STJO	WHIT	YELL					
ESA	KIRU	KOUR	MALI	MAS1	PERT	VILL			6
GFZ	KIT3	<i>KSTU</i>	LPGS	OBER	POTS	ZWEN			6
GSI	TAIW	TSKB							2
IGN	ANKR	BOR1	BRUS	EBRE	GRAS	GRAZ	<i>HARK</i>	HART	32
	HERS	<i>HOFN</i>	IRKT	JOZE	KERG	(KIRU)	(KIT3)	KOSG	(39)
	(<i>KSTU</i>)	LHAS	(LPGS)	(MAS1	MATE	MDVO	METS	<i>NTUS</i>	
)						
	NYAL	OHIG	ONSA	PAMA	(POTS)	REYK	<i>TAHI</i>	TROM	
	WETT	<i>WSRT</i>	WTZR	<i>ZECK</i>	ZIMM	(ZWEN			
)				
JPL	AOA1	AREQ	ASC1	AUCK	AZU1	BOGT	BRAZ	CARR	60
	CASA	CAT1	CHAT	CICE	CIT1	CRO1	CSN1	DGAR	
	EISL	FAIR	GALA	GODE	GOL2	GOLD	GUAM	HARV	
	HRAO	IISC	JPLM	KOKB	KRAK	KWJ1	LBCH	<i>MAD2</i>	
	MADR	MCM4	MDO1	MKEA	MOIN	NLIB	OAT2	PIE1	
	POL2	<i>PPYN</i>	QUIN	SANT	<i>SELE</i>	SEY1	SHAO	SNI1	
	SPK1	THU1	TID2	TIDB	UCLP	USC1	USUD	WHC1	
	WHI1	WLSN	XIAN	YAR1					
KAO	TAEJ								1
NGI	<i>SUWN</i>								1
NIMA	BAHR								1
SIO	<i>MAG0</i>	MONP	<i>PETR</i>	PIN1	PVEP	SIO3	VNDP	YAKA	9
	<i>YAKZ</i>								
UNAVCO	POL2								1
Totals:	146 sites from 13 data centers								

Note: Sites in () indicate backup delivery route

Sites in *italics* indicate sites new to the CDDIS in 1997

Once they arrive at the CDDIS, these data are quality-checked, 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 and to ensure timely arrival in the CDDIS public disk areas. In general, the procedures for archiving the GPS tracking data are fully automated, requiring occasional monitoring only, for replacement data sets or re-execution because of system or network problems.

The CDDIS GPS tracking archive consists of observation, navigation, and meteorological data, all in compressed (UNIX compression) RINEX format. Furthermore, summaries of the observation files are generated by the UNAVCO quality-checking (QC) program and are used for data inventory and quality reporting purposes. During 1997, the CDDIS archived data on a daily basis from an average of 115 stations; toward the end of the year, this number increased to nearly 125 stations. Under the current 125 station network configuration, about 100 days worth of GPS data are available on-line to users at one time. Each site produces approximately 0.8 Mbytes of data per day; thus, one day's worth of GPS tracking data, including the summary and meteorological data files, totals nearly 100 Mbytes. For 1997, the CDDIS GPS data archive totaled over 35 Gbytes in volume; this figure represents data from nearly 42K observation days. Of the 125 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.

During 1997, tests were conducted to incorporate a "compact RINEX" into the IGS data flow. This software, developed by Hatanaka Yuki (GSI) and Werner Gurtner (AIUB), when used with UNIX compression, reduces the size of the RINEX data by approximately a factor of eight (as compared to approximately 2.5 with using UNIX compression alone). Tests were performed at various data center levels within the IGS, with the intent to use files in this format as the in exchange between data centers and analysis centers. The CDDIS continues, however, to archive and make data available in the compressed RINEX format for the greater user community.

The majority of the data delivered to and archived in the CDDIS during 1997 was available to the user community within 24 hours after the observation day. As shown in Figure 1, over forty percent of the data from all sites delivered to the CDDIS were available within six hours of the end of the observation day; over fifty percent were available within eight hours. 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.

The CDDIS staff often receives requests from users for the daily broadcast ephemeris file (denoted BRDCddd0.yyN_Z). To reduce the amount of time spent on these requests by the CDDIS staff, a new disk area has been established (GPS3:[GPSDATA.BRDC.yyyy]) to store the historic BRDC files.

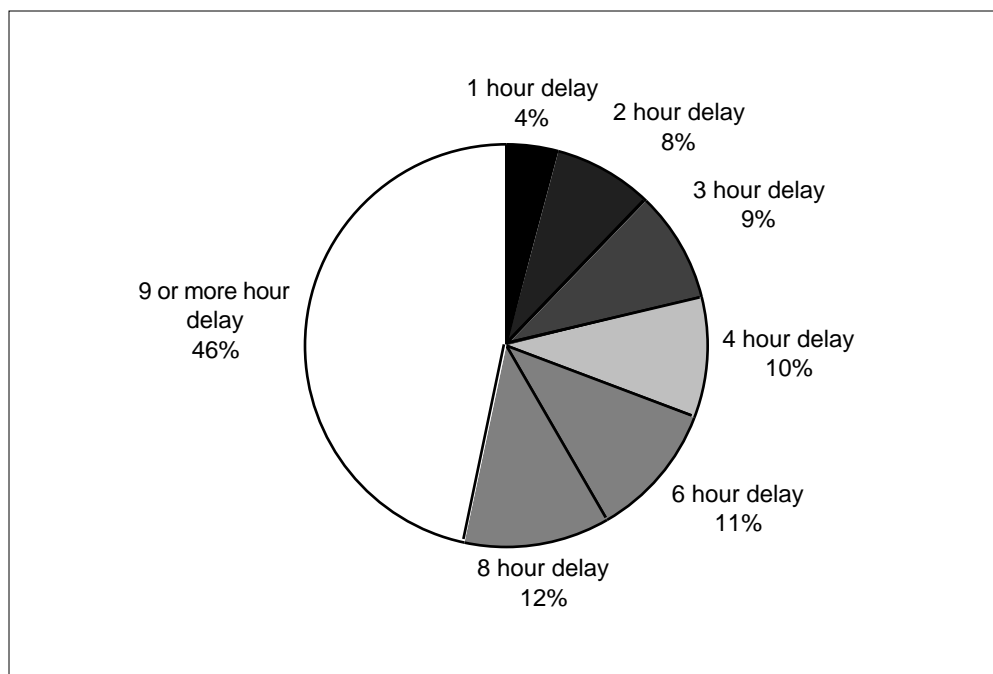


Figure 1: Median delay in GPS data delivery (all sites) to the CDDIS in 1997

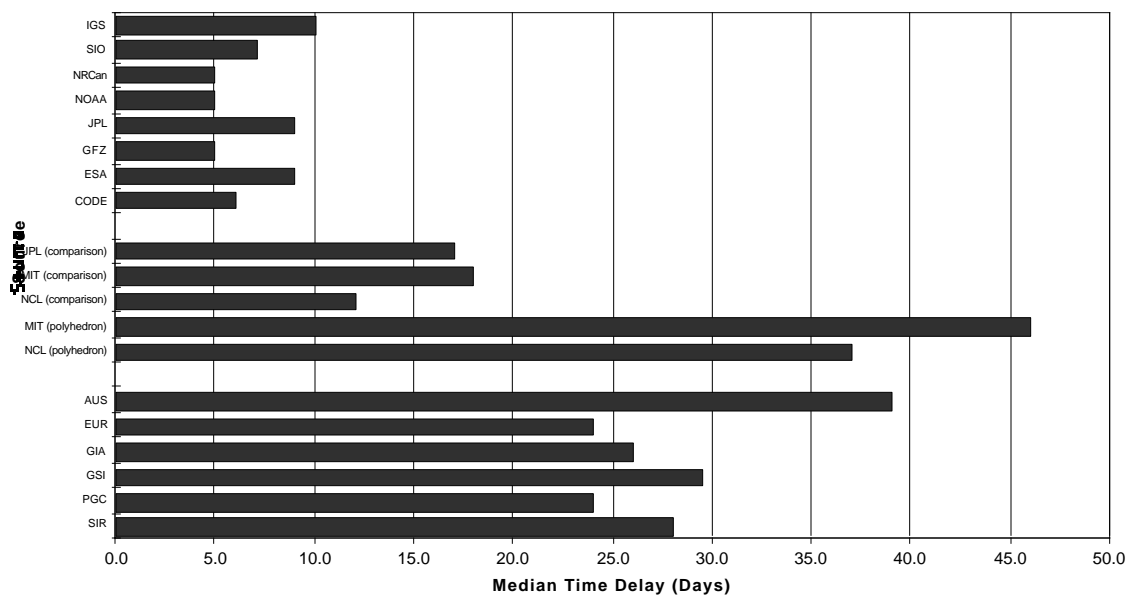


Figure 2: Median delay in GPS product delivery to the CDDIS (by source) in 1997

3.2 IGS Products

The 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 (ERPs) and station position solutions; the nine IGS associate analysis centers (AACs) also retrieve IGS data and products to produce station position solutions. The CDDIS archives the products generated by both types of IGS analysis centers. These files are delivered to the CDDIS by the IGS analysis centers to individual user accounts, copied to a central disk archive, and made available in ASCII format (generally uncompressed) 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 and derive the combined IGS orbits, clock corrections, and Earth rotation parameters as well as to generate reports on data quality and statistics on product comparisons. 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. As of 1996, access to the on-line archive of CDDIS products can also be performed through the World Wide Web (WWW) as well as through ftp.

During 1996, Regional Network Associate Analysis Centers (RNAACs) began the generation and submission of station position solutions for regional networks in Software INdependent EXchange (SINEX) format. The three Global Network AACs (GNAACs) continued their comparison of these files during 1997 and submitted the resulting SINEX files to the CDDIS. The GNAACs accessed the SINEX files from the IGS ACs and RNAACs and produced comparison and combined, polyhedron station position solutions.

The derived products from the IGS ACs are typically delivered to the CDDIS within seven days of the end of the observation week; delivery times for AAC products vary, but average 25 days for regional solutions. Figure 4 presents the median delay during 1997, in days and by source, of AC and AAC products delivered to the CDDIS. The statistics were computed based upon the arrival date of the solution summary file for the week. The time delay of the IGS 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 one to two days of receipt of data from all analysis centers and is typically available to the user community within ten days.

The rapid orbit and ERP products generated by the IGS Analysis Coordinator were also made available to the IGS global data centers starting in June 1996. These products are produced daily, within 24 hours UTC; automated procedures at the CDDIS download these files from NRCan in a timely fashion. Starting in early 1997, the IGS Analysis Center Coordinator began generating predicted orbit, clock, and Earth rotation parameter combinations based upon the individual ACs' predicted solutions. These solutions, designated IGP, are available within 0.5 hours of the beginning of the observation day.

3.3 Meteorological Data

The CDDIS currently receives meteorological data from approximately twenty sites. In 1997, additional IGS sites began providing meteorological data from collocated sensors; these stations are: Albert Head, Ottawa, Priddis, St. John's, and Yellowknife Canada, Colorado Springs CO, McDonald TX, USNO Washington D.C., Zimmerwald Switzerland, and Zwenigorod Russia. The meteorological data provided are dry temperature, relative humidity, and barometric pressure at thirty minute sampling intervals. These data are stored on CDDIS with the daily GPS observation and navigation data files in parallel subdirectories.

3.4 Supporting Information

Daily status files of GPS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath continue to be generated by the CDDIS. By accessing these files, the user community can receive a quick look at a day's data availability and quality by downloading a single file. Furthermore, monthly summaries of the data quality for the IGS sites are also generated. Both the daily and monthly status files are available through the WWW at URL <http://cddisa.gsfc.nasa.gov/gpsstatus/>. The daily status files are also archived in the daily GPS data directories.

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 WWW at URL http://cddisa.gsfc.nasa.gov/gpsdata/gpsdata_list.html. The CDDIS also maintains an archive of and indices to IGS Mail, Report, and Network messages.

4 System Usage

Figures 3 through 5 summarize the monthly usage of the CDDIS for the deposit and retrieval of GPS data during 1997. These figures were produced daily by automated routines that peruse the log files created by each network access of the CDDIS. Figure 3 illustrates the amount of data retrieved by the user community during 1997. Over one million files were transferred in 1997, totaling approximately 360 Gbytes in volume. Averaging these figures, users transferred 90K files per month, totaling nearly 30 Gbytes in size. The chart in Figure 4 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 an ftp session; this session may transfer a single file, or many files. Figure 5 illustrates the profile of users accessing the system during 1997; these figures represent the number of distinct hosts in a particular country or organization. Nearly two-thirds of the users of GPS data available from the CDDIS come from U.S. government agencies, universities, or corporations.

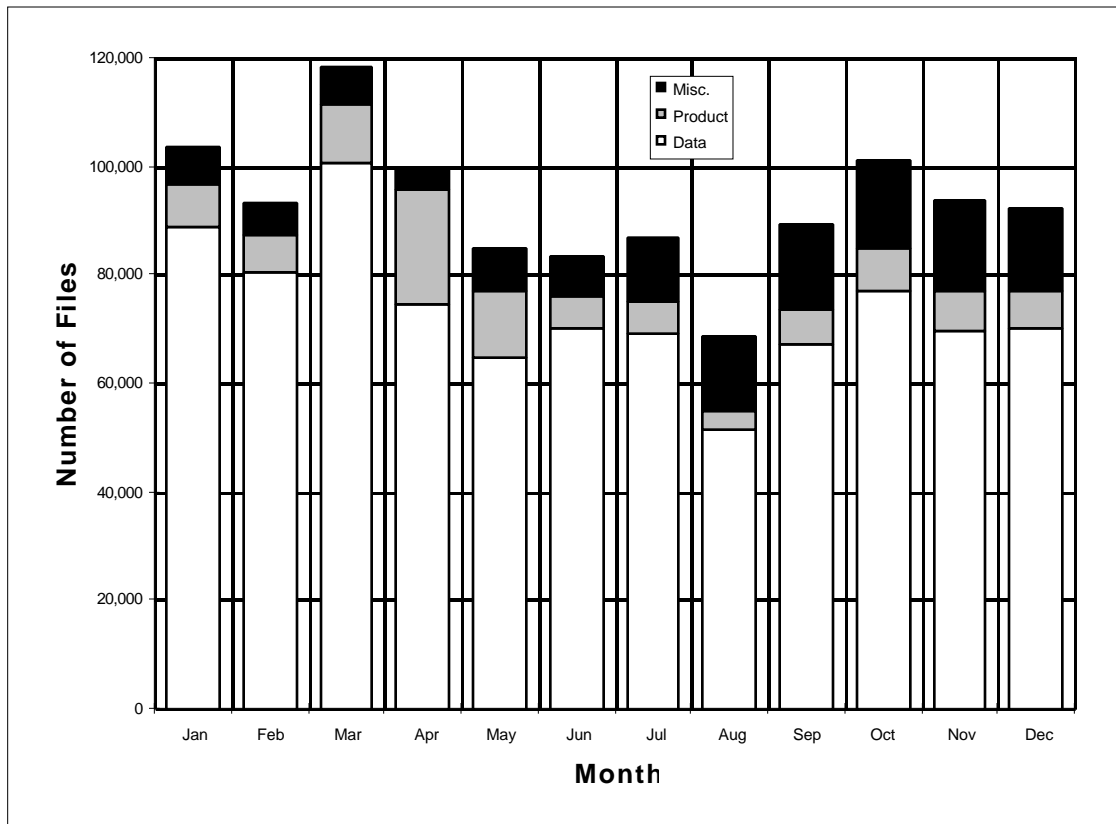


Figure 3: Number of GPS related files transferred to/from the CDDIS in 1997

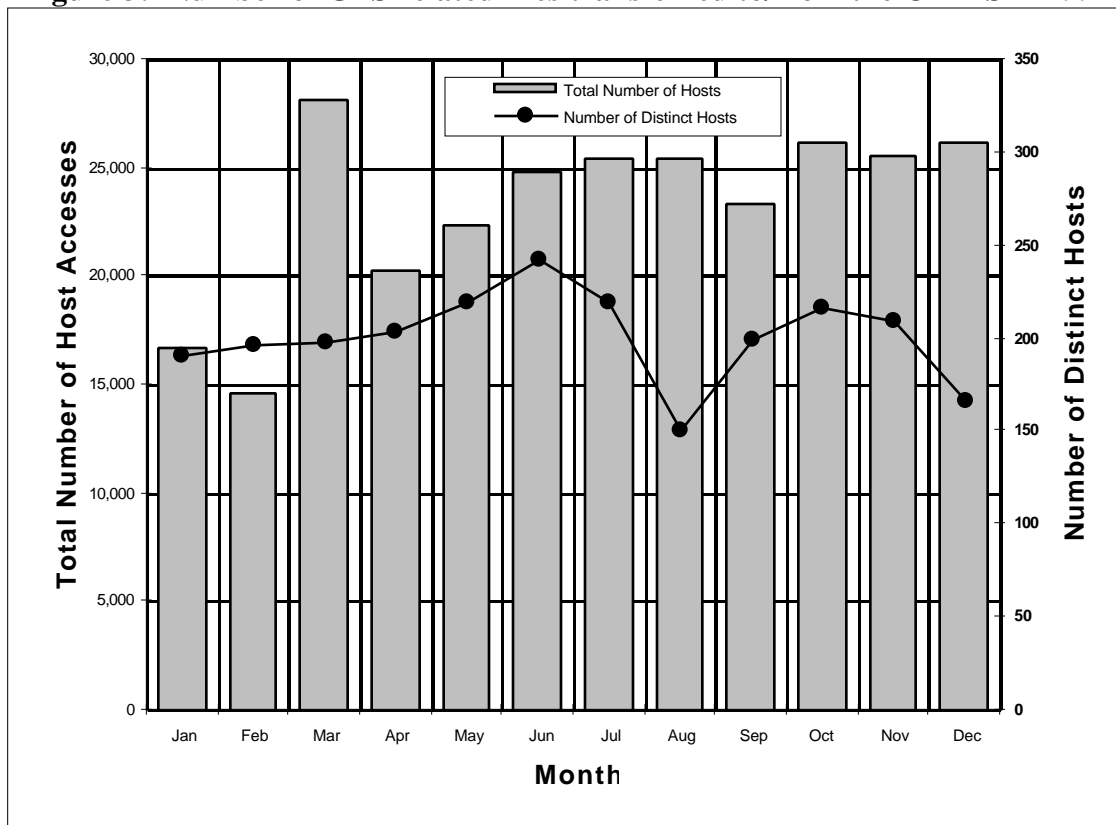


Figure 4: Number of hosts accessing GPS data and products on the CDDIS in 1997

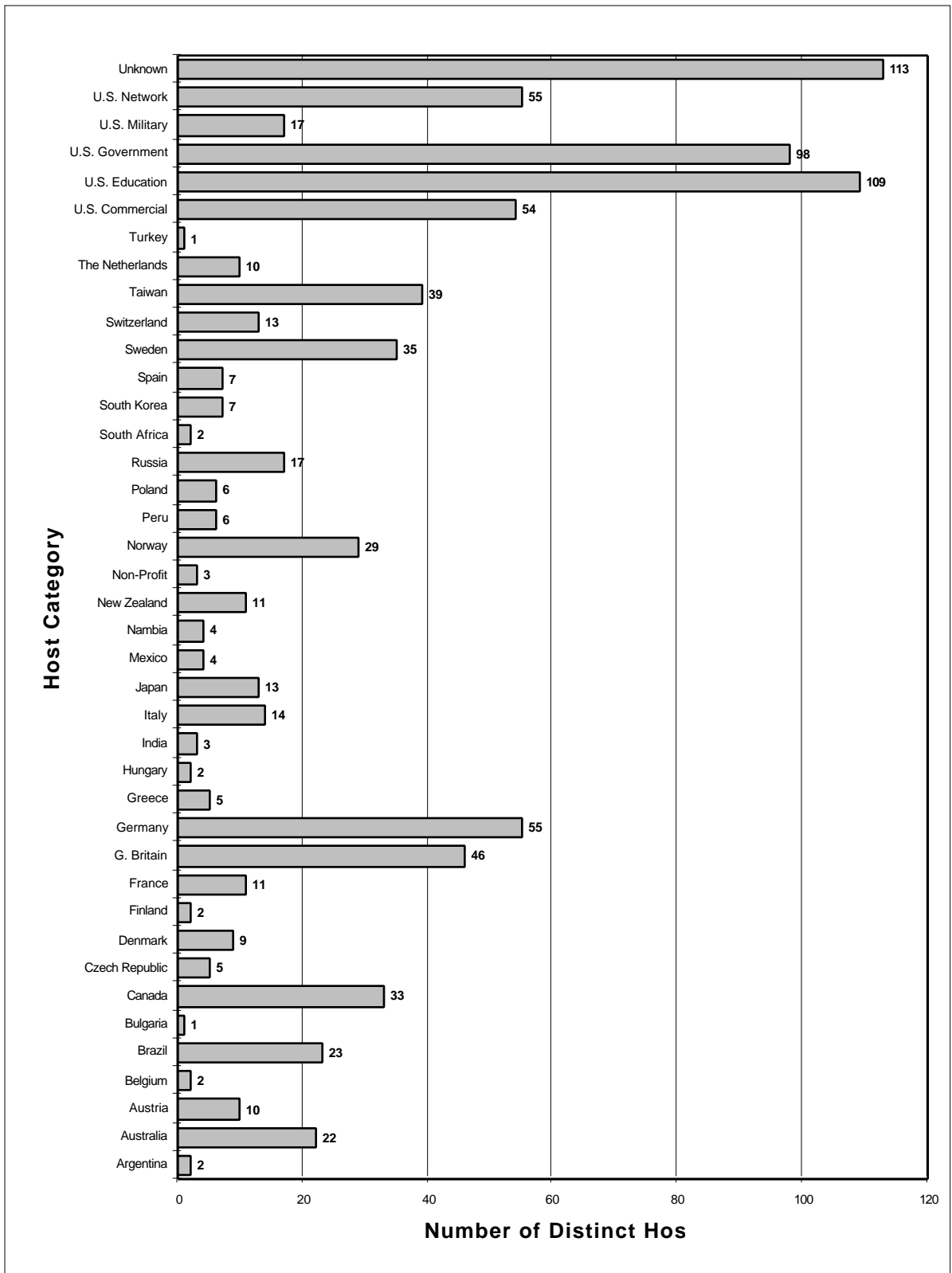


Figure 5: Distribution of IGS users of the CDDIS in 1997

Figures 3, 4, and 5 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 2 summarizes the type and amount of special requests directed to the CDDIS staff during 1997. 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.

Table 2: Summary of special requests for GPS data and information in 1997

Type of Request	Totals
General IGS/CDDIS information	~215 requests (phone, fax, e-mail)
Off-line GPS data	~130 requests (phone, fax, e-mail)
Amount of off-line data requested	~40,650 station days [†]
Volume of off-line data requested	~35 Gbytes

Notes: [†]In this context, a station day is defined as one day's worth of GPS data (observation and navigation file in RINEX format)

5 Publications

The CDDIS staff attended several conferences during 1997 and presented papers on or conducted demos of their activities within the IGS, including:

- “Flow of GPS Data and Products for the IGS” (Carey E. Noll) was presented at the Workshop on Methods for Monitoring Sea Level in March 1997
- “GIS and GPS Applications at the National Aeronautics and Space Administration” (Lola Olsen and Carey E. Noll) was presented at the Georesearch GPS/GIS '97 conference in May 1997

Hypertext versions of this and other publications can be accessed through the CDDIS on-line documentation page on the WWW at URL

<http://cddisa.gsfc.nasa.gov/documents.html>.

6 Future Plans

6.1 Computer System Enhancements

Procurement of a replacement hardware platform for the CDDIS VAX system was undertaken in early 1997. This system will be a DEC AlphaServer 4000 running the UNIX operating system; the system will have over 120 Gbytes of on-line magnetic disk storage. A significant amount of the CDDIS staff time was spent during 1997 developing data processing and archiving routines for this new system. The staff hopes to have all GPS data activities transferred to the UNIX platform by mid-1998; the host name for this computer is cddisa.gsfc.nasa.gov. The CDDIS anonymous ftp and WWW sites, however, will be operational on the UNIX platform in early 1998 (in fact, all URLs in this document reflect the web site on the new CDDIS computer).

An area of ongoing 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 in VAX VMS file format and the CDDIS VAX system is equipped with only two optical disk drives. The future CDDIS AlphaServer system under UNIX will not be equipped with these magneto-optical drives; therefore, a new medium for long-term storage of the historic GPS archive must be identified. The CDDIS staff has decided to utilize CD-ROMs for this archive. A CD recordable system and 600 platter jukebox were purchased during 1997. The CD recordable system consists of a Macintosh computer and a CD-ROM tower with the capability of recording up to five copies of a CD. The existing GPS archive on magneto-optical disks (in VAX/VMS format) will be migrated to CD-ROM during 1998. The data will most likely be written to CD-ROM by GPS week.

6.2 Changes in the Data Archive

The CDDIS data and product archive directories will be consolidated in mid-1998 once the system is operational on the new UNIX computer. This change will simplify data access for the user community since all data will be under one directory path.

Tests are underway in mid-1998 to provide hourly data to the IGS user community. During the tests, hourly data will be transmitted to CDDIS from JPL for several NASA sites. The hourly data will be archived to a public disk area on CDDIS in a timely fashion and retained there for three days. After three days, the hourly data will be deleted; the daily file, transmitted through normal channels with typically a one to two hour delay, will have been received and archived already and thus the hourly data are of little use.

In early 1998, a Call for Participation in the International GLONASS EXperiment (IGEX-98) was issued. IGEX-98 is sponsored by several organizations, including the IGS, and requests participation by stations, data centers, and analysis centers. The CDDIS responded to this call and hopes to make GLONASS data available to the IGS

user community. The CDDIS plans to establish on-line directories for these data and to incorporate GLONASS data in normal data processing procedures.

6.3 Changes in the Product Archive

Starting in early 1998, the IGS Analysis Center Coordinator began generating predicted orbit, clock, and Earth rotation parameter combinations based upon the individual ACs' predicted solutions. These solutions, designated IGP, will be available within 0.5 hours of the beginning 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.

Also early in 1998, the IGS Analysis Center Coordinator began generating accumulated IGR and IGS ERP files on a daily and weekly basis; these data are used with either the final or the rapid orbits. These files will be produced at the same time as the IGS rapid and final products are generated and downloaded by the IGS Global Data Centers. The files are designated IGS95P02.ERP (to be used with the IGS final orbits) and IGS96P02.ERP (to be used with IGS rapid orbits).

The CDDIS began generating "short-SINEX" files, designated with an .SSC extension in early 1998. These files contain the site information from the SINEX file but no matrices. The files are stored in the weekly IGS product subdirectories.

Since January 1997, the IGS has conducted a pilot experiment on the combination of troposphere estimates. Using a sampling rate of two hours, the zenith path delay (ZPD) estimates generated by the IGS analysis centers were combined by GFZ to form weekly ZPD files for approximately 100 IGS sites. These troposphere products will be available at all IGS Global Data Centers, including the CDDIS starting in early 1998.

As of June 1, 1998, several IGS Analysis Centers will be supplying daily, global ionosphere maps of total electron content (TEC) in the form of IONEX (an official format for the exchange of ionosphere maps) files. These products will also be available from the IGS Global Data Centers. At the CDDIS, the IONEX files will be located in subdirectories of the main product area, rather than under the weekly subdirectory structure, since the files are produced daily.

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 922
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://cddisa.gsfc.nasa.gov/cddis_welcome.html

8 Acknowledgments

The author would once again like to thank members of the CDDIS staff, Dr. Maurice Dube and Ms. Ruth Kennard (Raytheon-STX). Their continued, consistently outstanding support of the CDDIS has helped to make this system a success in the user community.

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September 1995.

Noll, C. E. "CDDIS Global Data Center Report" in *IGS 1995 Annual Report*.
September 1996.

Noll, C. E. "CDDIS Global Data Center Report" in *IGS 1996 Annual Report*.
November 1997.

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Scripps Orbit and Permanent Array Center 1997 Global Data Center Report

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1 Introduction

The Scripps Orbit and Permanent Array Center at the Scripps Institution of Oceanography (SIO) has served as an IGS Global Data Center since 1994. SIO is committed to collecting, archiving, and publishing high-quality continuous GPS data in a timely manner to support the global GPS research community. This report describes SIO's archiving operations, data access procedures and user statistics. The annual report of the SOPAC Analysis Center is in a separate document.

2 Archive Content

SIO's IGS archiving responsibilities include collection, storage, and distribution of IGS tracking data in RINEX format and IGS products. SIO also archives RINEX files from a variety of worldwide regional GPS networks. In particular, SIO is the data archive for the Southern California Integrated GPS Network (SCIGN) and a continuous GPS data archive for the University NAVSTAR Consortium (UNAVCO). Presently SIO collects and archives data from over 350 permanent GPS stations.

SIO collects and archives GPS products from all IGS analysis centers, including combined, rapid and predicted orbits, and Earth orientation parameters (EOP). In addition to products and tracking data, SIO archives tropospheric estimates, meteorological and navigation files in RINEX format, SINEX solutions, raw receiver data for some arrays, and site log files. SIO also archives and maintains data for users of the GAMIT/GLOBK software [King and Bock, 1998; Herring, 1998].

3 Computer Facilities

SIO's archiving facilities are made up of a distributed network of Sun Ultra Sparc workstations and one SGI data server. Data are collected, quality checked and stored on 250GB of primary on-line magnetic disk storage. Older data are stored on an 8-drive magneto-optical removable cartridge library, providing over 500GB of on-line secondary storage. With over 750GB of data storage, SIO can maintain all of its data holdings on-line. Figure 1 depicts SIO's archiving computer network.

4 Archiving Operations

Data collection and archiving are entirely automated. At set intervals all predetermined data archives are probed for new or re-submitted data. Any data that are needed are collected via ftp to a holding area and quality checked (QC'd). Upon successful QC, the data are catalogued, archived, mirrored, and immediately made available for anonymous ftp. All of the data collection software is written in PERL with command line

and Web-based interfaces. The cataloging is currently flat file based, but is being migrated to an Object Relational Database Management System (ORDBMS), Oracle 8.

**High Availability "GARNER" Data Archive
at SOPAC**

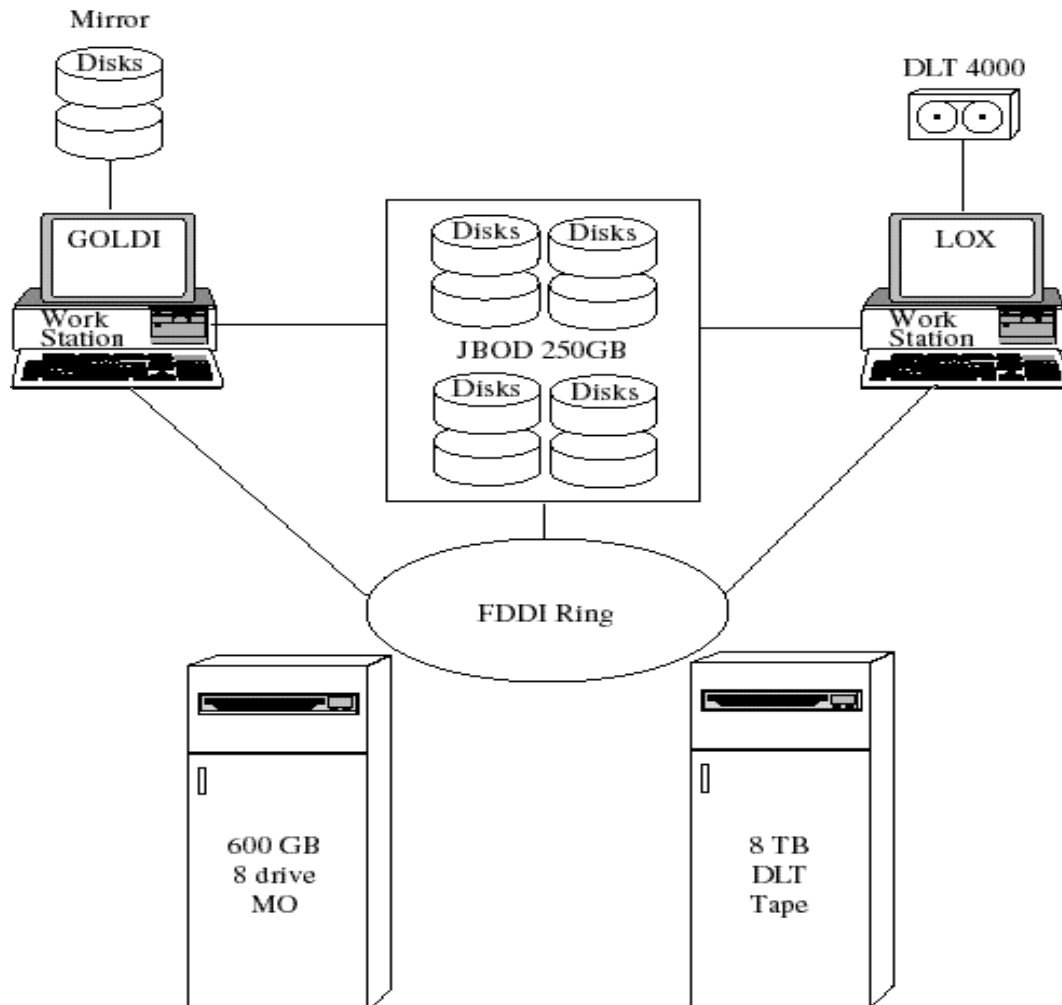


Figure 1

5 Tracking Data

On average, data were collected from 250 sites in 1997. Table 1 shows the breakdown of sites by array and the number of sites collected from each. The table reflects the current network breakdown (*circa* July 1998).

Table 1. GPS arrays archived at SIO

Array Code	Array Name	Number
IGS	IGS Global Network	110
SCIGN	Southern California Integrated GPS Network	53
ARGN	Australian Regional GPS Network	10
BARD	Bay Area Regional Deformation Array, California	24
CORS	U.S. Continuous Operating Reference Stations	91

EUREF	European Reference Network	45
INEGI	Instituto Nacional de Estadística, Geografía e Informática, Mexico	1
PANGA	Pacific Northwest Geodetic Array	9
SOI	Survey of Israel	3
WCDA	Western Canada Deformation Array	7
MISC	Miscellaneous sites	14
	Total	367

The following GPS data archives were accessed to complete our RINEX file data holdings. Some are publicly available, others are password protected.

Table 2. GPS Archives used to complete SIO's RINEX file data holdings.

Source	Address
Agenzia Spaziale Italiana	geodaf.mt.asi.it
Australian Surveying and Land Information Group	ftp.auslig.gov.au
Crustal Dynamics Data Information System	cddisa.gsfc.nasa.gov
Institut Geographique National	mozart.ensg.ign.fr
Bundsumt fur Kartographische und Geodasie	igs.ifag.de
Geosciences Operational Data Center	gracie.grdl.noaa.gov
Central Washington University	panga.cwu.edu
Canadian Active Control System	macs.geod.emr.ca
Forecast Systems Laboratory	spruce.fsl.noaa.gov
Australian Academy of Science, Institute of Space Research – Dept of Satellite Geodesy	flubiw01.tu-graz.ac.at
University of Washington	ftp.geophys.washington.edu
Jet Propulsion Laboratory	bodhi.jpl.nasa.gov
Survey of Israel	ftp1.netvision.net.il
Rensselaer Polytechnic Institute	inusa.geo.rpi.edu
Royal Observatory of Belgium	ftpserver.oma.be
Regional GPS Data Acquisition/Analysis Center on Northern Eurasia	ria.ipmnet.r
United States Geological Survey	dixie.gps.caltech.edu

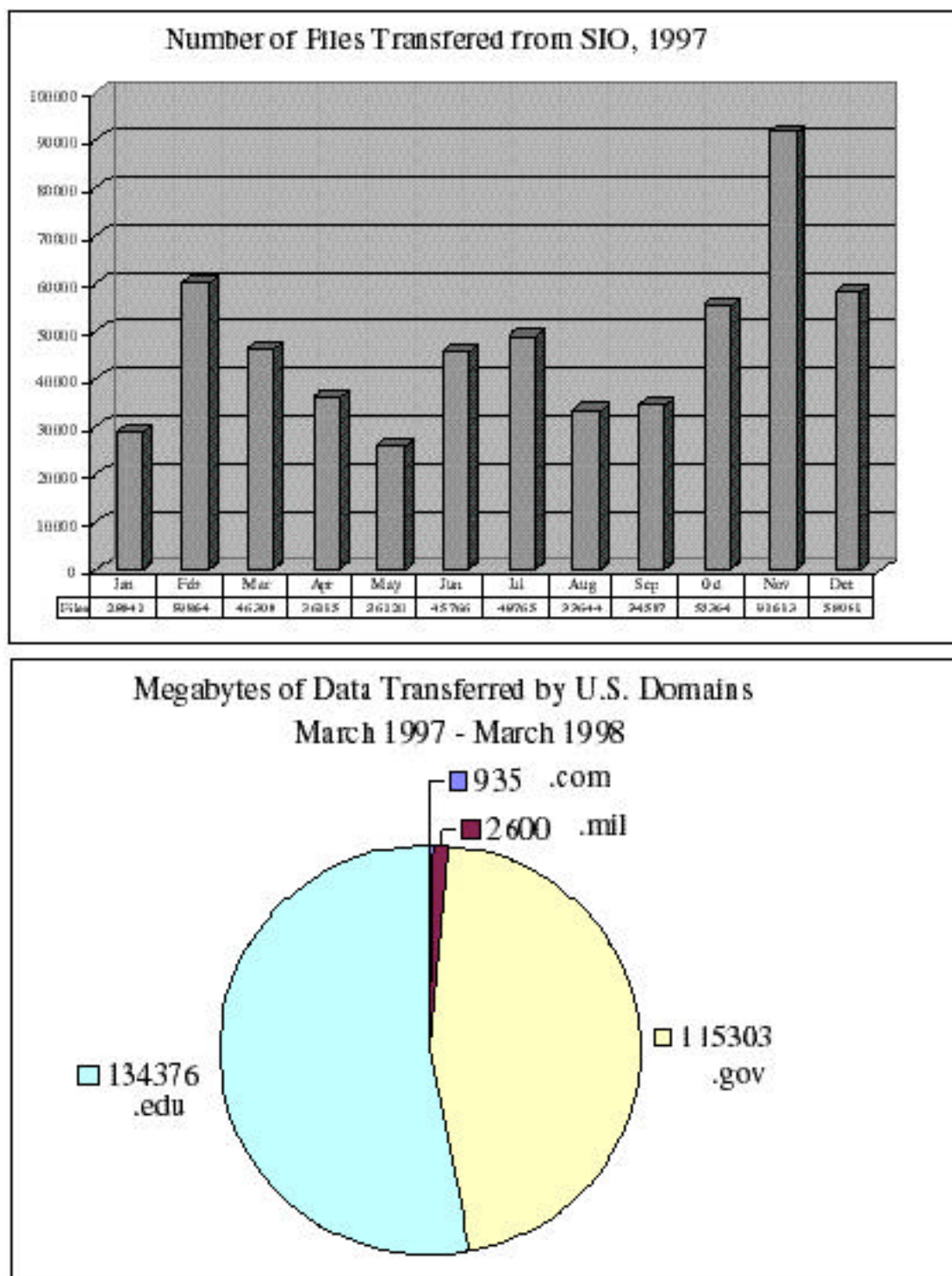


Figure 2. Some statistics of use of SOPAC GARNER archive. **Upper panel** indicates total number of files transferred from lox.ucsd.edu per month in 1997. Graph represents only April 17-30, March 7-31, all other months complete. **Lower panel** indicates amount of data (MB) transferred by U.S. domains only in the period March 1997 to March 1998, sorted by commercial, educational, government and military users.

6 IGS Products

IGS products are collected from the IGS analysis and associate analysis centers including SIO's own rapid and predicted ephemeris. Weekly products have a latency of 4 days. SIO's predicted and rapid ephemerides are available within 18 hours from the end of the previous observation (UTC) day in UTC. The IGS combined, rapid, and predicted orbits are available with a 20-22 hour latency from the end of previous observation day.

7 User Activity

The number of files extracted from our archive via ftp in 1997 totaled over 580,000 (~348GB), averaging approximately 48,000 (~30GB) transfers per month. An average of 300 different hosts accessed SIO each month. Figure 2 depicts the file transfers per month from SIO's archive in 1997, and a breakdown of U.S. domain users from March '97 to March '98.

The increase in on-line storage capacity has made it possible for SIO to put all data on-line, eliminating the need for data requests. User activity has increased over 100% since the end of 1997, and we are projecting an average of over 100,000 file transfers per month in 1998.

8 Data Policy

SIO maintains an open data policy without any restrictions. All data are made available as soon as they are collected. The open data policy eliminates the need for formal request procedures, thus reducing the time it takes to gain access to data. SIO encourages this policy wherever possible.

9 Archive Access

SIO's archive is accessible via ftp (<ftp://lox.ucsd.edu/pub/DATATYPE>). Users can ftp to the archive, navigate the data tree for data they are interested in, and collect any data they wish. SIO also provides a data interface on the WWW (<http://lox.ucsd.edu>). The Web page design is dynamic, but there will always be links to data availability.

10 Future Developments

SIO has increased the data archive capacity by at least 100% during 1998, allowing for on-line storage of 1 TB of data. SIO is implementing a high-availability computer network, which will greatly minimize system and archive downtime and improve disaster recovery situations.

The plans to migrate from flat files to an object relational database (Oracle 8) are well underway and should be implemented by late 1998.

SIO is also involved with the Seamless GPS Archive effort with many other data centers organized by the University NAVSTAR Consortium (UNAVCO); prototype applications and seamless data access will hopefully be available by the end of 1998.

11 User Information

To learn more about SIO's archiving facilities please contact:

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12 Acknowledgments

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- Herring, T. A., GLOBK: Global Kalman filter VLBI and GPS analysis program Version 4.17, Internal Memorandum, Massachusetts Institute of Technology, Cambridge, 1998.
- King, R. W., and Y. Bock, Documentation of the GAMIT GPS Analysis Software version 9.72, Massachusetts Institute of Technology, Cambridge, 1998.

Regional/Operational Centers

BKG Regional IGS Data Center Report

Heinz Habrich

Federal Agency for Cartography and Geodesy
D-60598 Frankfurt at Main, Germany

1 Introduction

The Federal Agency for Cartography and Geodesy (BKG) operates the Regional IGS Data Center for Europe since the beginning of the IGS Test Campaign in June 21, 1992. GPS tracking data from permanent GPS sites in Europe are obtained from Operational Data Centers (ODC's), Local Data Centers (LDC's) or directly from the stations. Also tracking data from stations outside of Europe are transferred to BKG, if these stations are operated by an European institution. The received data are uploaded to the Global Data Center (GDC) at the Institut Géographique National (IGN) in Paris and the Center for Orbit Determination in Europe (CODE) in Berne, and are also made available to other users and archived.

The IGS products as computed by the IGS Analysis Centers are downloaded from the GDC to BKG in order to provide these information to European users. The IGS tracking data and products together with the series of ITRF-solutions, which is also available at BKG, allow the users to get comprehensive information for various GPS applications using the Internet capability.

2 Computer Architecture

The Regional IGS Data Center at BKG operates on an HP-9000/J210 workstation running the HP-UX operating system. This workstation is connected to the Internet with a maximum transfer rate of 128 kbit/s and two harddiscs (each of 4 Gbyte capacity) store the on-line data. Data are archived on CD-ROM discs. If users connect to the computer using the anonymous ftp account, the directory structure given in Table 1 is available.

3 GPS Tracking Data

All institutions sending GPS data to BKG store these files in the "indata" directory. Only this directory has a "write permission" for the anonymous ftp user. The GPS tracking data received in the "indata" directory are uploaded to IGN and CODE, and available in the "outdata", "gpsdata" and "IGS" directory.

The outdata" directory stores the observation, summary and meteorological files of all stations for a period of *one month*. Daily GPS navigation files are concatenated to a file with the station abbreviation "IFAG" (e.g. IFAG1750.97N.Z). Because the number of files in this directory may grow up to about 8,000 it is recommended to use this directory *not for manual access* to the data but for automated procedures.

Table1. Directory Structure on *igs.ifag.de*

/indata			
/outdata	/ssssddd0.yyD.Z		
	/ssssddd0.yyO.Z		
	/ssssddd0.yyS.Z		
	/ssssddd0.yyM.Z		
	/IFAGddd0.yyN.Z		
/gpsdata	/ssss	/ssssddd0.yyD.Z	
		/ssssddd0.yyS.Z	
		/ssssddd0.yyM.Z	
	/NAV	/IFAGddd0.yyN.Z	
/IGS	/yyyy	/ddd	/ssssddd0.yyD.Z
			/ssssddd0.yyS.Z
			/ssssddd0.yyM.Z
			/IFAGddd0.yyN.Z
	/station	/ssssyymm.log	
/ORBITS	/www	/CODwwwwi.EPH	
		/CODwww7.ERP	
		/IGRwwwwi.SP3	
		/IGRwwwwi.ERP	
		/IGSwwwwi.SP3	
		/IGSwww7.ERP	
/COOR	/ITRFyy	/xxx	
/IGSMAIL	/IGSMESS.nnnn		
	/IGSMESS.INDEX		
	ssss = Station Abr.	ddd = Day of year	yyyy = year in 4 digit
	yy = year in 2 digit	www = GPS week	mm = month
	i = day of week	xxx = ITRF-solution	nnnn = Message no.

The "gpsdata" directory shows *station separated* subdirectories and can be used for manual data access. The GPS tracking data are available in these subdirectories for a period of *2 months*. For the same period the navigation files are on-line in the "NAV" subdirectory.

The "IGS" directory includes the GPS data in daily subdirectories which are created with a delay of 5 days after the end of observation and the data are on-line for a period of *6 months*.

The GPS tracking data are archived on CD-ROM and old data will be made on-line available on special request. In this case a complete CD-ROM is mounted on the anonymous ftp account point or a subset of files is copied to the daily subdirectories for a limited time period.

Table 2. Contact Information

Contact Address

Heinz Habrich	Tel: +49-69-6333267
Bundesamt fuer Kartographie und Geodaesie	Fax: +49-69-6333425
Richard-Strauss-Allee 11	E-Mail: habrich@ifag.de
D-60598 Frankfurt am Main	
Germany	

Data Center Access

hostname: igs.ifag.de (141.74.240.26)
account: anonymous ftp
URL: <http://www.ifag.de>

4 IGS Products

IGS precise orbits and earth rotation parameters are on-line available at BKG starting with GPS week 729 corresponding to the official start of the IGS at the beginning of 1994. Now the IGS rapid orbits, the IGS final orbits and the CODE orbits are stored in subdirectories for every GPS week. IGS final orbits are also archived on CD-ROM and CD-ROM copies can be delivered on special request.

5 User Activity

In 1997 the tracking data of 59 permanent GPS sites were collected and archived on daily basis at the BKG Data Center. Approximately 50 distinct users (institutions) contact the Data Center on regular basis with about 400 connections every day.

6 Future Activity

In order to start with tests for an hourly upload of RINEX files a new subdirectory *"/IGS/nrt"* was already created. It is planned to store the hourly files for a period of 3 days. BKG acts also as a data center for the IGEX-98 GLONASS experiment. For this purpose the directory *"/IGEX"* was created. GLONASS tracking data will be stored in this directory. BKG will participate in the IGEX campaign as an Analysis Center and make the products available in the *"/IGEX"* directory.

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Networks and Stations

Global, Regional, and Local Networks

AUSLIG 1997 IGS Annual Report Networks & Stations

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1 Australian Regional GPS Ground Station (ARGN)

The ARGN is a network of 15 GPS permanent ground stations extending from Antarctica to Cocos Island.

It consists of:

- Eleven AUSLIG sites
- One DSTO site, Salisbury South Australia
- ESOC site at Perth (IGS site)
- Tidbinbilla DSN/JPL site (IGS site)
- Yaragadee JPL (IGS site)

Of the eleven AUSLIG sites, five currently provide data to the IGS:

- Casey
- Davis
- Maquarie Island,
- Cocos Island
- Hobart

AUSLIG has also installed backup receivers at Tidbinbilla and Yaragadee sites. Data from all sites is processed by the AUSLIG Space Geodesy Analysis Centre as an IGS regional associate analysis centre.

2. GPS Data Center

The configuration of the GPS receivers and antennae at the sites are:

SITE	GPS Rx	GPS Vers.	ANTENNA	MONUMENT	DOME Hemi Sph
Casey	TurboRogue / Ashtech Z12	3.2.33.1 1F60	Dorne Margolin T	Concrete pedestal on rock	Yes
Cocos Island	TurboRogue	2.8.33.2	Dorne Margolin T	Concrete pillar	Yes
Davis	TurboRogue	3.2.33.1	Dorne	Steel rods in rock	Yes

SITE	GPS Rx	GPS Vers.	ANTENNA	MONUMENT	DOVE Hemi Sph
	/ Ashtech Z12	1F60	Margolin T		
Hobart	TurboRogue	3.2.33.1	Dorne Margolin T	Concrete pillar	No
Macquarie Island	TurboRogue / Ashtech Z12	3.2.33.1 1F60	Dorne Margolin T	Concrete pillar	Yes

A new acrylic dome was placed on the Casey monument during December.

Improvements to the GPS data system at AUSLIG have resulted in complete redundancy in the system for conversion of receiver data files to RINEX. A RAID system is now in place on the AUSLIG ftp server.

3 Station Reports

3.1 CAS1

During 1997 the data logging system was partially upgraded, and an Ashtech Z12 GPS receiver was installed as backup to the TurboRogue and to support DGPS during the Antarctic summer. The receiver operates on the external rubidium oscillator.

3.2 DAV1

During 1997 the data logging system was completely upgraded, and an Ashtech Z12 GPS receiver was installed as backup to the TurboRogue and to support DGPS during the Antarctic summer. The receiver operates on the internal quartz oscillator.

3.3 MAC1

During 1997 the data logging system was completely upgraded, and an Ashtech Z12 GPS receiver was installed as backup to the TurboRogue and to support DGPS during the Antarctic summer. The receiver operates on the internal quartz oscillator.

3.4 HOB2

No changes were made to this site during 1997.

3.5 COC1

No changes were made to this site during 1997. The receiver operated on the internal quartz oscillator.

4. Plans for 1998

The network will be developed to meet full IGS specifications and all sites made available to IGS. A new IGS site will be established during 1998 colocated with SLR, Absolute gravity and DORIS at Mt. Stromlo near Canberra.

5. Contract Details

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The GPS Receiver Network of ESOC: Malindi, Maspalomas, Kourou, Kiruna, Perth and Villafranca

C.Garcia-Martinez (1), J.M. Dow,
T.Martin-Mur, J.Feltens (2), P.Bernedo (1).

(1) GMV at ESOC ; (2) mbp at ESOC.

1 Introduction

ESOC is currently involved in the establishment of a network of high precision geodetic receivers on ESA 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.

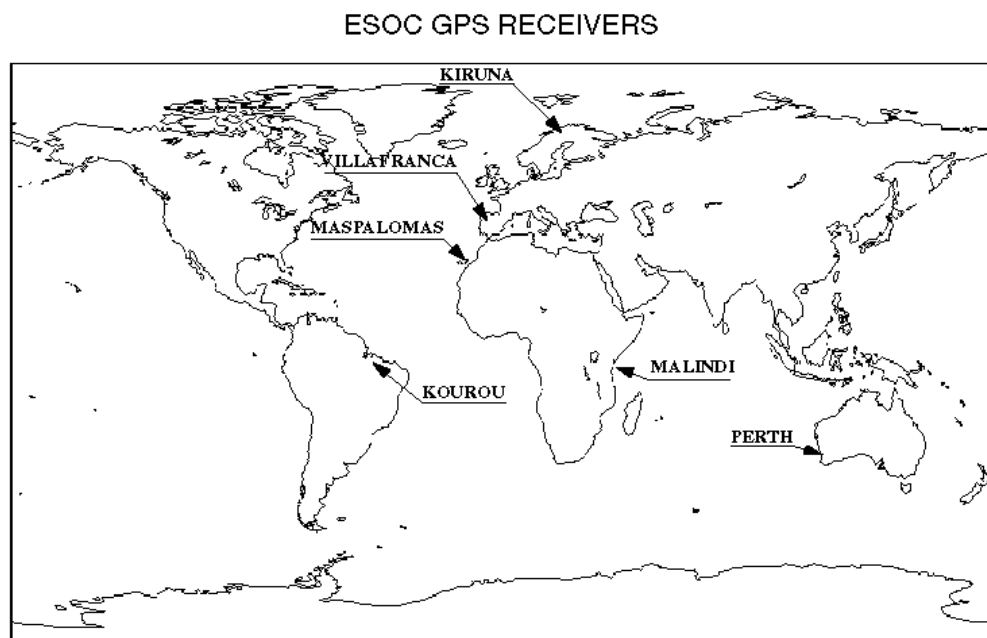


FIGURE 1

2 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 provide, along with the rest of the GPS-TDAF, also several services. Examples are the monitoring of the behaviour of the timing system, the 1PPS output and the ionosphere monitoring over the station.

2.1 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.

2.2 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.

2.3 Kourou

The GPS receiver is installed at the ESA Kourou Diane station that is located about 27 km from the town of Kourou, in French Guyana.

2.4 Kiruna

The GPS receiver is installed in the ESA Kiruna ground station, that is at Salmijarvi, 38 km east of Kiruna in northern Sweden.

2.5 Perth

The receiver is located at the ESA Perth station, that is approximately 20km 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.

2.6 Villafranca

The receiver is situated in the Villafranca (VILSPA) ground station, located in Villafranca del Castillo, 30 km west of Madrid, Spain.

3 History and Evolution

The development of the network started at the beginning of 1992 when two MiniRogues SNR-8C, the most advanced receiver then, were ordered from AOA. After a period of testing in ESOC, the first installation was completed in the week before the start of the IGS campaign at Maspalomas. Data was 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 Guyana were very irregular. The data was obtained for a period of 10 days in August, and sporadically thereafter. Attempts made from Pasadena to dial up the Kourou modem were also unsuccessful. The low transfer rates and the irregular quality of the telephone lines made very problematic the completion of the file transfers using XMODEM. A new solution had to be implemented. It was based on the permanent links between the station and the control 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 was operated permanently without hardware problems for more than five years. In October 1997 the MiniRogue was replaced by an eight channels TurboRogue with the corresponding Dorne Margolin T antenna.

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 despatched 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 earthing 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 set-up 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. At the beginning of 1998 this configuration presented several signal level problems and the receiver was moved to a portable station avoiding the necessity of the large cable.

The last installation has been Malindi. A MiniRogue SNR-8C was deployed at the station and started the 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 Bit/s digital circuit. This facilities depend 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. In October 1997 a 12 channels TurboRogue replaced the old MiniRogue.

4 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.

Three iron bolts are used to fix the antenna mounting in a horizontal position. The antenna is screwed to the mounting.

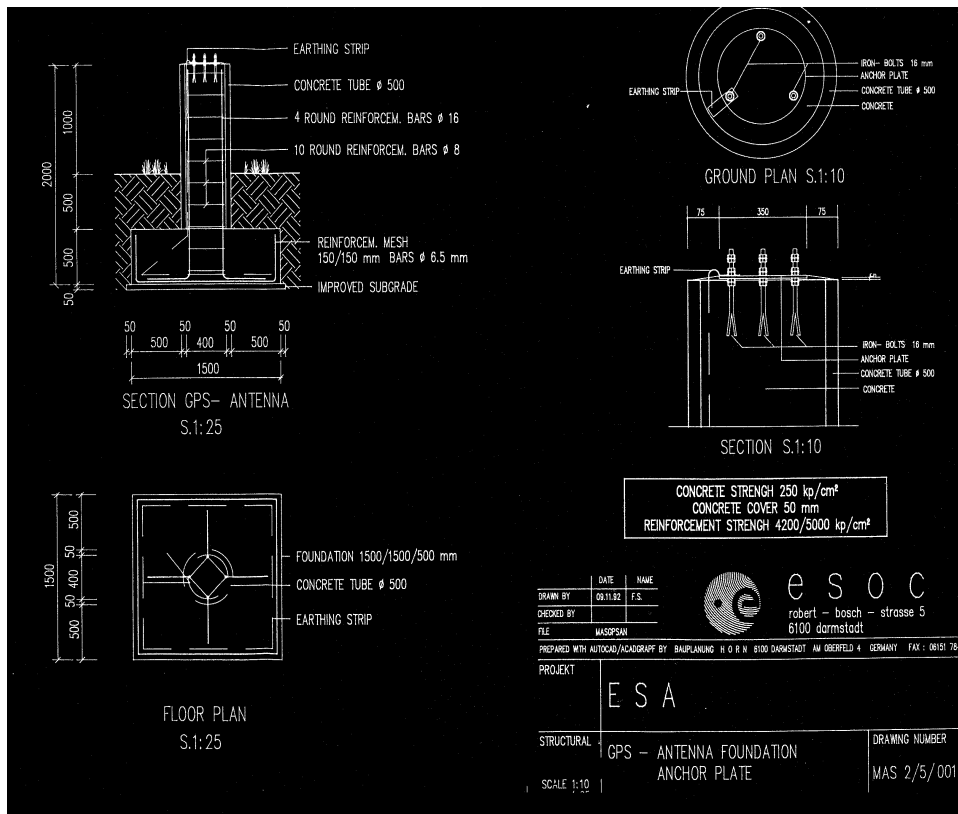


Figure 2

5 Equipment

The physical configuration of all the equipment involved in the remote stations part of the GPS TDAF is summarized in Figure 3.

The remote stations are continuously tracking the GPS satellites. The antenna is connected to the receiver normally with a standard 300 ft RG-214 coaxial cable. Only Villafranca has a cable 450 ft long, as remarked in the last section.

The timing system of the stations are used as 5 MHz reference frequency. They are cesiums manufactures by OSCILLOQUARTZ with long term drift controlled by timing GPS system.

All ESA stations are equipped with TurboRogues. In 1997 the last MiniRogues in Kourou and Malindi have been upgraded to TurboRogues.

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.

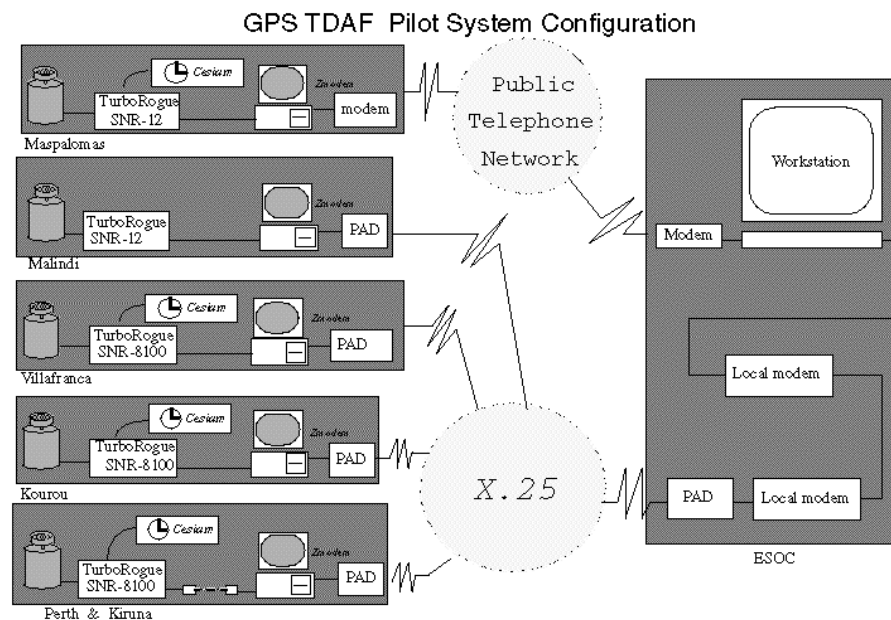


FIGURE 3

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 comm port to the one connected to the receiver, sends them, waits the answer and stores it. The active port is swap 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 TurboRogue SNR 12 RM. The antenna is Dorne Margolin T with a height of 0.1347 m and is located at the centre of the station. Data have been retrieved by means of a permanent digital circuit and since the end of 1996 we are making use of the very improved PSTN at Malindi station for data downloading using OCTOCOM dial-up modems.

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 Bit/s line has been used in the past.

Kourou is equipped with a TurboRogue SNR-8100. The antenna is Dorne Margolin T with a height of 0.045 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.

6 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 baseline of the plans for the future, concerning IGS, is more than new installations, the improvements of the current ones with the last hardware and software available and provide for an even more robust communications tending to the real time data availability at ESOC.

We are working on a Real Time Infrastructure project that will replace the software that currently is running in the remote stations PC's to a more versatile one that will provide for continuous data downloading to the control centre at ESOC and will enhance the data analysis capabilities.

In 1998 communications between ESOC and the Ground Stations will be reviewed and the GPS TDAF will have to look for new connectivity solutions for several stations.

7 References

- GPS TDAF Stations Configuration Manual. Version 1.1, December 1995, ESOC.
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GPS Global Network Operations at JPL and the UNAVCO Facility

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1 Transfer of Station Engineering and Maintenance Activities to UNAVCO

A proposal to collaboratively operate the NASA GPS Global Network (GGN) was developed jointly by JPL and the UNAVCO Facility and was submitted to NASA in April 1997. Arrangements were formalized in June, upon notification by NASA that the combined effort would be funded, and part of the responsibility for operating the GGN was transferred from JPL to the UNAVCO Facility during the last half of the year. Under this new arrangement, JPL is providing overall management of the GGN effort and is providing most of the data management system development and operations. The UNAVCO Facility is handling most of the station-level engineering and maintenance, including performing the new station installations and establishing data flow; enhancing the capabilities of existing GPS stations and data return; sharing the network monitoring responsibilities; supporting station-level troubleshooting and repairs; maintaining station configuration information, including the IGS logs; retrieving data from some of the more problematic stations; and supporting improvements to data retrieval, verification, management and reporting systems.

2 GPS Station Installations and Maintenance

Working in close cooperation with various international partners, JPL and the UNAVCO Facility have supported the installation of eight new GPS tracking stations in 1997 on behalf of NASA, including two new stations in Russia, three in Kyrgyzstan, one in Colombia, one in South Africa, and one in Turkey. Five of these already regularly provide data to the IGS, as will the others once they are capable of reliably returning data. Significant planning and preparations were also accomplished for several new stations to be installed during 1998 at locations including Brazil, China, Cote D'Ivoire, Morocco, and the Philippines.

Of the approximately 60 stations comprising the NASA Global Network (excluding the dense array stations in California and other locations), fifteen required the replacement of faulty receivers or antennas during 1997; four required the replacement of on-site computers; two required replacement of faulty telecommunications equipment;

two required establishment of new telecommunications services; and four required engineering staff visits for on-site troubleshooting, repair or re-configuration.

3 Improvements to Data Retrieval, Verification and Management Systems

Improvements made to data retrieval, verification and management systems have focused on enhancing overall data return and timelines of data deliveries to users, and on improving the quality and reliability of GPS data and associated descriptive information.

JPL's GNRT (Generalized Near-Real Time) software, which provides rapid-turnaround, data-driven, queued processing of any type of data, was tested in a configuration which produces daily RINEX files for NASA's Global Network stations. This set of Perl scripts is able to complete the RINEX production within minutes of receipt of raw GPS data and it is envisioned that this scheme may provide the IGS with a "Rapid Service" RINEX function in the future.

The JPL GNEX software, a PC/Linux based software package, which performs unattended data retrievals at remote GPS stations, was improved to include a prototype module for controlling Trimble receivers, based on the UNAVCO LAPDOGS (Local Automated Process for Downloading of Global Sites) software tool, which is currently being used at a number of installations. Capability was also added to support a broader set of commonly available modem types.

The UNAVCO software tool TEQC (Translate/Edit/Quality Check) was modified to include translation capability for ConanBinary and TurboBinary data types. For TurboBinary, this includes translation capability for normal-rate data, high-rate data (up to 50 Hz sampling rate), and the mixed "30-1" format contained LC observables. The raw data can contain any mixture of these types, and TEQC allows the user to easily extract the desired portion, e.g. extraction of just normal-rate (30 second sampling) from the "30-1" format. This code was also adapted for TurboBinary from the Allen Osborne Associates Benchmark receiver, to store the C/A-derived phase value for the RINEX L1 observable. The ConanBinary translator currently handles ConanBinary from the TurboRogue/TurboStar series and Benchmark receivers, though not for the original Rogue receiver. The TEQC software is used by several IGS participants, including UNAVCO, JPL and the CDDIS (Crustal Dynamics Data Information System) Global Data Center, for GPS data file conversion and validation/verification. UNIX and DOS versions are available on-line at the UNAVCO Facility web site (<http://www.unavco.ucar.edu/software/>).

Scripts to automatically compare descriptive information from the Central Bureau Information System (CBIS) and the CDDIS station log summary files and RINEX files were developed and are run daily to identify any discrepancies, with results posted at the CBIS. This information has been used extensively by JPL and the UNAVCO Facility to verify the GGN station log and RINEX header metadata and correct inconsistencies.

4 Plans for 1998

Up to seven new permanently operating GPS stations will be installed at global locations in 1998 in support of NASA activities and all will provide data to the IGS. Funding has been secured to improve data flow at several existing GPS stations by upgrading some with new PC/LINUX download systems running GNEX and improving Internet connectivity at another subset. At least four new automated meteorological data recording packages, funded by the US National Science Foundation, will be placed at GGN stations during 1998, with possibilities for additional units becoming available from other sources later in the year.

GNEX software functionality will be expanded to support Ashtech receivers and a new module to automatically establish dial-up PPP (Point-to-Point Protocol) connections will be added. Other modifications are also planned, including integrating data from automated meteorological recording instruments into the data flow, and rewriting sections of the code to improve operability and maintainability of the software.

The lightweight GNRT system for producing RINEX products is self-contained and portable among UNIX systems, making it appropriate for use as a backup to the JPL data retrieval and management operations in the event of a large-scale failure. The GNRT system will be installed at the UNAVCO Facility during 1998, and operational procedures will be developed and regularly exercised to assure adequate and maintainable back-up coverage. The Pacific Geosciences Center also hosts a minimal additional back-up system and a GNRT installation is planned there, as well.

A 24-station near-real time subnetwork of the GGN, which has provided hourly data since late 1996, is the springboard for the development of a subnetwork of high-rate, low-latency sites for ground support to CHAMP, GRACE, and other Low-Earth Orbiters (LEOs) being pursued cooperatively by several agencies. Utilizing existing GPS tracking stations is envisioned, with communications and receiver systems upgrades where appropriate. Highly capable, yet economical LINUX computers at the stations would host the "Smart Sites" software, currently being developed based on the GNEX package, allowing on-the-fly data verification/validation, active notification of error conditions, and other sophisticated new modes of reliable, automated site operations. GNRT processing would provide the required rapid turnaround of the LEO ground GPS network data to users. Detailed GPS ground network segment requirements are currently emerging and NASA and other funding is being pursued to support the LEO efforts.

The value of hourly data to applications such as rapid orbit prediction and atmospheric monitoring is clear, and JPL/UNAVCO will strive to increase the coverage of the hourly subnetwork and make these products broadly available. In addition to the GGN sites with sufficient communications capability for hourly data retrievals, several other partners such as SK, BKG, GFZ, and OSO, also make hourly data available from some stations and it is hoped that the IGS will endorse and promote the acceptance of hourly data in the future.

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The lightweight GNRT system for producing RINEX products is self-contained and portable among UNIX systems, making it appropriate for use as a backup to the JPL data retrieval and management operations in the event of a large-scale failure. The GNRT system will be installed at the UNAVCO Facility during 1998, and operational procedures will be developed and regularly exercised to assure adequate and maintainable back-up coverage. The Pacific Geosciences Center also hosts a minimal additional back-up system and a GNRT installation is planned there, as well.

A 24-station near-real time subnetwork of the GGN, which has provided hourly data since late 1996, is the springboard for the development of a subnetwork of high-rate, low-latency sites for ground support to CHAMP, GRACE, and other Low-Earth Orbiters (LEOs) being pursued cooperatively by several agencies. Utilizing existing GPS tracking stations is envisioned, with communications and receiver systems upgrades where appropriate. Highly capable, yet economical LINUX computers at the stations would host the "Smart Sites" software, currently being developed based on the GNEX package, allowing on-the-fly data verification/validation, active notification of error conditions, and other sophisticated new modes of reliable, automated site operations. GNRT processing would provide the required rapid turnaround of the LEO ground GPS network data to users. Detailed GPS ground network segment requirements are currently emerging and NASA and other funding is being pursued to support the LEO efforts.

The value of hourly data to applications such as rapid orbit prediction and atmospheric monitoring is clear, and JPL/UNAVCO will strive to increase the coverage of the hourly subnetwork and make these products broadly available. In addition to the GGN sites with sufficient communications capability for hourly data retrievals, several other partners such as SK, BKG, GFZ, and OSO, also make hourly data available from some stations and it is hoped that the IGS will endorse and promote the acceptance of hourly data in the future.

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Individual Stations

Status of the IGS Stations Provided by the Norwegian Mapping Authority in 1997

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1 Introduction

In 1997, the Norwegian Mapping Authority (NMA) provided data from two continuously operating stations in Norway, namely Ny-Ålesund and Tromsø, to IGS. In addition, NMA gathered and distributed data from the Scandinavian stations Onsala, Metsahovi and Thule.

2 Operation and Changes at the Sites

During the year, we experienced considerable problems with old Rogue SNR-8 receivers at Ny-Ålesund and Tromsø. However, with extensive support from JPL, we were able to get them operational again.

For several reasons, we could not guarantee the stability of our antenna pillars in Tromsø and Ny-Ålesund. Therefore, new antenna pillars were built at both sites. On these new pillars, a Rogue SNR-800 was installed in Tromsø, and a Rogue RM-12 at Ny-Ålesund. The old Rogue SNR-8 receivers and their antennas will be kept working on their old antenna pillars as long as possible for investigation of imaging.

At Høfn, Iceland, a new station has been established with NMA equipment. However, due to environmental problems, it was not possible to get our equipment operational in 1997 and to download data reliably.

We decided to operate our antennas without radomes. In order to avoid problems with snow, the antennas are mounted on steel towers of 3 to 5 m height. The plates at the top have minimal sizes thus reducing multi path.

3 Data

As a result of the problems with the Rogue SNR-8 receivers the stations did not provide data reliably over the complete year. In particular, Tromsø did not produce data for several months.

The download software has been modified. It now handles data from different receivers, and data are download every hour. At Ny-Ålesund and Tromsø, the computers used for down-loading are parts of NMA-LAN and connected to Internet. At Høfn, the computer is connected to a ISDN line.

Within a JPL project related to low orbiting satellites, JPL collects the data direct from the stations operated by NMA every hour. NMA collects data from the stations

once a day, concatenates the hourly files to one daily file, RINEXes the data and FTPs these files to IGS.

4 Outlook

In 1998, NMA will incorporate a quality check of all data as a part of the RINEXing program.

This quality check will aim at increasing the data coverage and the reliability and consistency of the data. Furthermore, it is planned to create a data archive for our IGS, as well as other continuously operating stations, where authorized users will get access to current and past RINEX files.

UPAD Status Report for 1997

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1 Introduction

The GPS station UPAD of the University of Padova has been operating since 1994 as a permanent installation in support of the International GPS Service for Geodynamics (IGS), and of the European initiatives EUREF and CERGOP. In 1997, our University joined UNAVCO. The UPAD station serves the scientific and tutorial needs of the Department of Geology, Palaeontology and Geophysics for the application of GPS data to Earth Sciences, and of the Interdepartmental Center for Space Activities (CISAS) for the application of GPS techniques to Space Engineering, Space Communication and Navigation. The station is located in downtown Padova, on the roof of the University Main Building, near a Geodetic Dome formerly used for astrolabe observations.

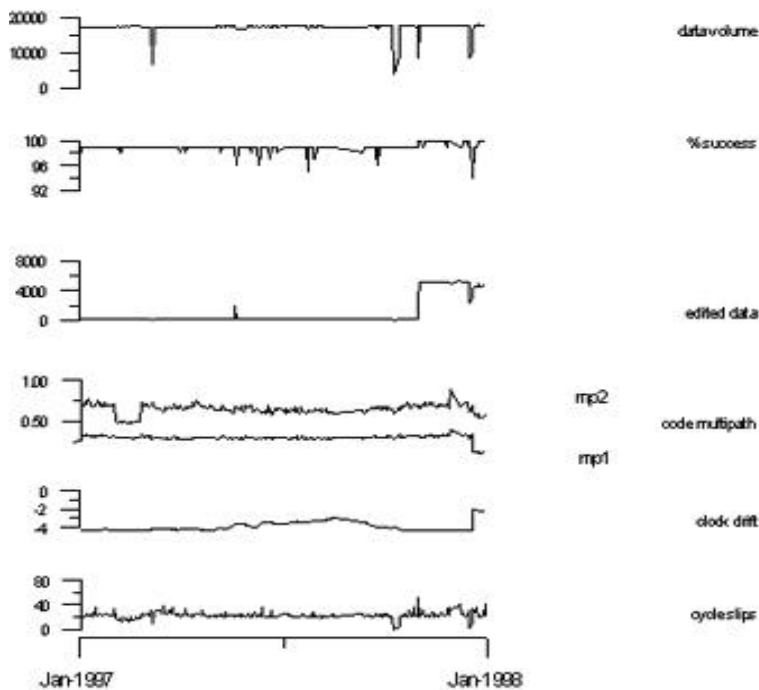


Figure 1: daily statistics of the UPAD data computed with QC. All unitless except clock drift (msec/hour)

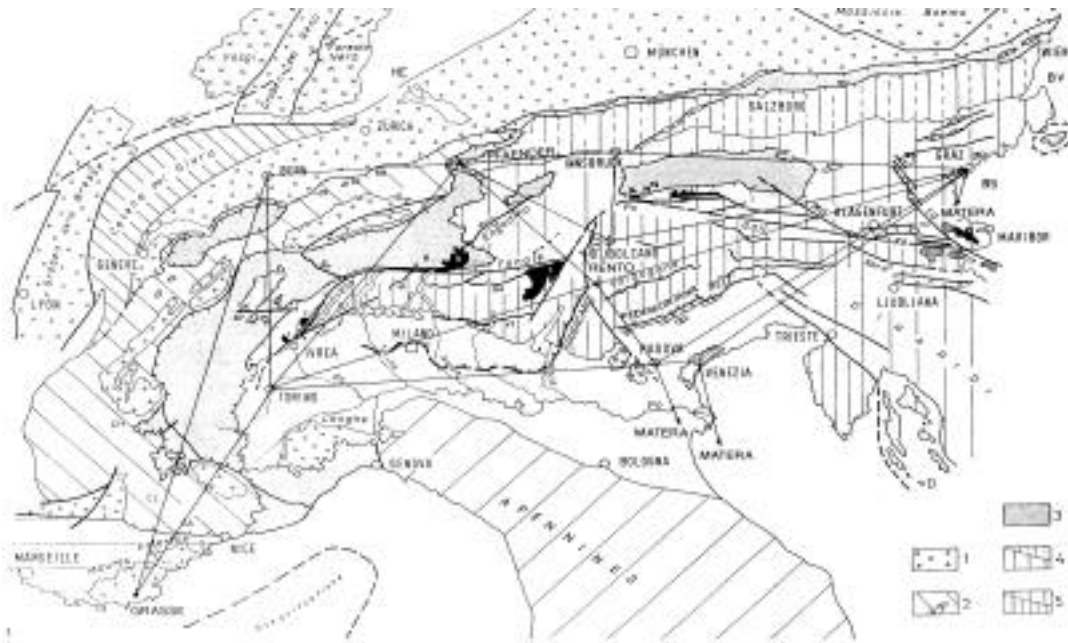


Figure 2: Network of permanent stations processed at UPAD. Units shown are Molasse(1), External units (2), Penninic- oceanic (3), Austroalpine (4) and Southalpine and Dinaric (5).

2 Instrumentation

As in the previous years, the station operated throughout 1997 with the TRIMBLE 4000SSE receiver and geodetic antenna with groundplane,. In September, new equipment was tested off-line. This included a TRIMBLE 4000 Ssi, choke ring antenna and the control software URS, under OS2. The tests occasionally implied a period of down-time for the 4000 SSE receiver. Before the new system went to regular operation, an increase of edited data, as reported by the QC program (Figure 1), was noticed. This was probably due to a transmitter nearby, but the final computation of the baselines seems unaffected. The receiver clock also showed a decrease in drift this summer, caused by temperature gradients in the room housing the receiver. Multipath was at nominal values and dropped sensibly after Dec. 21 with the new system, indicating a higher immunity of the choke ring antenna. A new modem was installed to support the local BBS. The local PC is configured as a FTP server to provide both by phone and Internet/FTP access.

3 Analysis Software

Bernese 4.0 was installed on a dedicated PC Pentium 266MHz in April. Systematic, semiautomatic analysis started in July 1997, with data from 11 stations being processed with analysis strategies recommended for regional networks (Figure 2).

Report on IGS Global Station Jozefoslaw (JOZE)

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The IGS permanent GPS station Jozefoslaw (JOZE) is located at the Astrogeodetic Observatory of the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology, 14 km southwards from the Warsaw city center. The Observatory was established in 1959 and at present, the following permanent services are maintained:

- GPS permanent service has been maintained since August 1993. Earlier, the station participated in the IGS Epoch'92 Campaign. As a basic GPS equipment the Trimble 4000SSE receiver serial No. 3249A02090 and antenna Trimble Geodetic L1/L2 No. 3247A66429 are used. Three rubidium frequency standards are available at the station; one of them is used as an external standard for IGS service. On January 1, 1995 the second GPS receiver, a TurboRogue SNR8000, serial No. 339 with the antenna type Dorne Margolin T No. 442, was installed at the station. The permanent GPS IGS service is maintained by both receivers (Trimble 4000SSE and TurboRogue SNR8000). The Trimble 4000SSE serves as the main receiver and the observations collected by this receiver are transmitted to the international data centers. The observations from Jozefoslaw are used for both IGS service and for maintenance of the EUREF system. The observations of the TurboRogue SNR receiver are available upon request for all interested centers for scientific research. Additionally, in some periods of 1996 and 1997, other types of GPS receivers were temporary installed at the station Jozefoslaw. They were: Ashtech ZXII-3, Leica SR9500 and Zeiss RM24. The observations were performed to study some instrumental effects, multipath and atmospheric (ionosphere and troposphere) influences.
- The station JOZE takes part in the works of the IGS Ionosphere Working Group.
- Gravimetric permanent tidal observations are carried out using LaCoste & Romberg, mod. G gravity meter. This service has been maintained since November 1993. The Observatory is incorporated to the international network of tidal observatories of the International Center for Earth Tides (ICET) of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS) as station No. 0909. The Observatory Jozefoslaw is one of the fundamental points of the Polish national gravimetric network; many absolute gravity determinations

have been performed by Polish and international observing groups. The Polish absolute gravity meter is installed at the station. A meridional gravimetric baseline, 26 km long, was established at the Observatory in 1976; periodic observations are made four times a year. The observations are used jointly with classical astrometric determinations for monitoring the changes of the vertical.

- Astrometric latitude observations have been carried out since 1959 in the international cooperation with BIH and IPMS and now the observations are used by Shanghai Observatory (international coordinator of the optical astrometry) and GOSTSTANDARD, Moscow. These observations are still used as complementary ones for the analyses of the time variations of the plumb line.
- Meteorologic service maintained at the station can be supported by nearby permanent meteo service of the Warsaw airport (Warszawa-Okęcie). The station Jozefoslaw is located in a distance of a few kilometer from the Warsaw airport.
- In some periods the observations of atmospheric electricity are made at the Observatory by the team of the Polish Academy of Sciences.

The monumentation of the reference point for IGS GPS observations was made according to the IGS standards. The network of control points is available. Due to the geological situation the pillar could not be monumented on the bedrock. Station Jozefoslaw is the reference point of several international GPS networks, e.g. EUREF (European Reference Frame), EXTENDED SAGET (Satellite Geodetic Traverses), CEGRN (Central Europe GPS Reference Network realized in the frame of the project CEI CERGOP (Central European Initiative Central Europe Regional Geodynamics Project) and BSL (Baltic Sea Level Project). The eccentricity of the EUREF point with respect to that of other campaigns is $X = 0.079$ m, $Y = 0.030$ m, $Z = 0.108$ m. In the 1960ties, 1970ties and 1980ties the Observatory also participated in other astrometric as well as satellite Doppler and GPS campaigns.

The Institute's Processing Center acts as IGS Regional Network Associate Analysis Center, EUREF Local Analysis Center and as CEI CERGOP Processing Center. The routine permanent GPS data processing and transmission are made for IGS and EUREF; also other GPS campaigns organized in Central Europe for geodynamic studies of the Teisseyre-Tornquist Contact Zone, the Carpathians Belt and Subalpine Regions are processed in the Center.

The BOR1 IGS Station

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Stability of the Borowiec Local Network

The geodetic network at Astrogeodynamical Observatory in Borowiec consists of few points which are using for different applications.

Most important from them are:

- 12205M002 Borowiec – SLR 7811 marker (BORL),
- 12205S002 BOR1 – permanent IGS marker with ROGUE SNR–8000 receiver,
- 12205S001 BORO – EUREF marker (0216 BOROWIEC) used in GPS campaigns in Poland,

Vectors between these three points were measured with GPS and classic techniques for comparison and stability analysis.

Below, in Table 1, we present values for height differences and distances for 6 years period from selected campaigns.

Mean values of differences of geodetic and cartesian coordinates for vector BOR1–BORO are presented in Table 2.

Table: 1 Results obtained from selected campaigns

BOR1- BORL		BOR1 - BORO		BORO - BORL		observations	
h	s	h	s	h	s	period	campaign
1.723	77.318	7.535	134.497			14 days	epoch'92
		7.532	134.497	5.811	98.604	2 days	LASER1'93
		7.536	134.496	5.819	98.603	4 days	LASER3'94
		7.533	134.499	5.811	98.607		classic
		7.533	134.499			3 days	Jaworski '97
		7.533	134.500			19 days	Jaworski '98

Table 2. The eccentricity values in geodetic and cartesian components for vector **BOR1 -BORO**

B [°]	L [°]	h [m.]
+0° 00' 03.03712"	- 0° 00' 05.06454"	7.533
X [m]	Y [m]	Z [m.]
-38.382	-112.239	63.397

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Peculiarity of POL2, SELE GPS Stations Operations

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The POL2 station operates in Kyrgyzstan (TIEN SHAN) from the 10th of May 1995 and SELE - from the 08 of May 1997. TurboRogue SNR 8000 receivers have been installed at both stations. Short Haul Modems are used for data downloading.

Some of SVs (or each of SVs) disappearing during TurboRogue operation without any reason is the one usual problem of the stations and of course, pauses in data flow. Sometimes TurboRogue hangs up for no reason whatever (owing to TR firmware bugs, probably), so it doesn't allow to download the data and simply doesn't react on **'bang'** command. The TurboRogue dispower/power process can only fix this problem. So, the necessity in frequent visits to the station is obvious.

The TurboRogue doesn't operate properly sometimes, when the computer used for downloading process is restarted. We can also get the same result after sending any disorder message to TurboRogue. In this case the reply would be as follows:

"User unknown" or "Data not found"

and the data would stay not downloaded.

TurboRogue operates better, when FreeWave modems are used, because the computer connects to TurboRogue only close to the downloading process and after the data is downloaded, this communication line becomes disconnected.

To avoid such troubles we decided to undertake the below solution. One commutator was installed between Short Haul Modem and TurboRogue to increase the TurboRogue operation reliability of POL2 and SELE. The commutator is controlled by two special sequences of 3 bytes. One sequence provides connection of the Short Haul Modem and TurboRogue and another - disconnection of them. Before the start of data downloading computer sends one sequence of bytes to commutator and the commutator switches SHM to TR. After the downloading, computer sends to commutator another sequence of bytes and the commutator switches SHM from TR. So, all the time between downloading process, the TurboRogue is not connected to computer serial port and SHM too. This solution decreases the quantity of pauses in data flow.

If the TurboRogue is hung up, the third and forth control sequences of bytes are used. The third sequence disconnects the power supply from TurboRogue and the forth connects the power supply to TR. The tracking is stopped at first by the **'terminate'** command, then the power supply becomes disconnected from TurboRogue by the third sequence of bytes, then the power supply becomes connected to TurboRogue by the

forth sequence of bytes after a short delay. The TurboRogue starts automatically and writes data on the Flash Card.

All control sequences are sent automatically by XTalk program according to the TurboRogue messages within the downloading process.

For more information, please email matix@gdirc.ru.

Pilot Projects/Committees

GLONASS IGEX-98 Campaign IGS 1997 Annual Report

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The GLONASS system is a Russian navigation satellite system, very similar in its principle to the GPS system. Even if the GLONASS constellation of satellite is not yet operational, this system may have some geodetic applications in geodesy and geophysics that need to be studied, specially combined use of GLONASS/GPS receivers.

At the 1997 IAG Scientific Assembly in Rio de Janeiro in Brazil, it was decided that the CSTG Subcommittee for Precise Microwave Satellite System should organize an international campaign of observation for the GLONASS satellites. This action was done jointly with the IGS as the IGS Directing Board also decided at its Rio de Janeiro meeting to organize such a campaign.

Several scientific goals were foreseen: precise GLONASS orbits using GLONASS data from a worldwide international tracking network, terrestrial reference frame issues, possible use of GLONASS and GPS data.

A Steering Committee was appointed in Rio de Janeiro to organize such a campaign, called IGEX-98 (International GLONASS Experiment): G. Beutler, W. Gurtner, G. Hein, R. Neilan, J. Slater, Pascal Willis (chair). This campaign was supported by several associations or services: the International Association of Geodesy (IAG), the International GPS Service (IGS), the International Earth Rotation Service (IERS) and the ION (US Institute of Navigation).

In order to organize such a campaign, the Steering Committee met at the AGU Fall Meeting in December 1997 and decided to send out in early 1998 an International Call for Participation for stations (combined GPS and GLONASS measurements), Data Centers, Data Analysis Groups for GLONASS and SLR data. A Web site has been created (<http://lareg.ensg.ign.fr/IGEX>) in order to give information to submit the proposal of participation.

Several institutions have answered positively to the International for Participation (the list is accessible at this Web site). The Steering Committee met in Marne-la-Vallee, France on June 29, in order to validate and analyse these answers. On June 26, 47 proposals were received, leading to a possible network of 30 to 50 GLONASS/GPS receivers collocated at existing IERS sites (mainly IGS sites).

An IGEX mail facility (equivalent to the IGS mail) has been started in order to regularly exchange information between the different participants. The campaign is planned for 3 months starting from September 20, 1998 to December 20, 1998.

More information can be found on the Web at the following address:

<http://lareg.ensg.ign.fr>

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IGS/BIPM Time Transfer Pilot Project

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1 Introduction

The “IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements” was authorized in December 1997 jointly by the International GPS Service for Geodynamics (IGS) and the Bureau International des Poids et Mesures (BIPM). A Call for Participation was issued shortly afterwards with responses received from about 35 groups. The respondents have formed a working group co-chaired by C. Thomas, BIPM, and J. Ray, U.S. Naval Observatory (USNO).

A number of groups have been working for several years to develop the capability of using geodetic GPS techniques for accurate time and frequency transfer. A variety of convincing demonstrations has already been performed showing the potential for determining clock differences at the level of a few hundred picoseconds. The current state of maturity of both the global tracking network and data analysis techniques now allows practical applications to be considered. The central goal of this Pilot Project is to investigate and develop operational strategies to exploit GPS measurements for improved availability of accurate time and frequency comparisons worldwide. This will become especially significant for maintaining the international UTC timescale as a new generation of frequency standards emerges with accuracies of 10^{-15} or better.

The Project is expected to run until January 2000. By that time, those aspects which are suitable for integration into the operational activities and official products of the IGS or BIPM should be underway. To the extent that some functions may not be suitable for the existing structure of the IGS, a new coordinator for this might be appropriate. The progress of the Project and other related information is maintained at the Web site <http://maia.usno.navy.mil/gpst.mil>.

2 Areas of Participation

2.1 Deployment of GPS Receivers

In addition to the GPS receivers already installed as part of the IGS global tracking network, other receivers at laboratories having accurate time standards are sought. These should be high-quality geodetic receivers capable of recording and rapidly transmitting dual-frequency pseudorange and carrier phase observations. The station configuration and data distribution should conform to IGS standards and appropriate documentation

must be filed with the IGS Central Bureau. A log file should be completed and sent to the IGS Central Bureau for each IGS station. For this Project, due consideration should be given to electronic stability, environmental control, and other factors which might affect the timing results. Upgrading of existing tracking stations for better timing performance is also encouraged. Deployment of dual-frequency GLONASS receivers, especially collocated at IGS sites, would provide an additional data source of interest.

2.2 GPS Data Analysis

Strategies for analyzing GPS phase and pseudorange observations must be developed, consistent with other IGS products, to allow the routine, accurate characterization of time standards at a large number of independent GPS receiver sites and onboard the GPS satellites. This work will be done in close cooperation with the IGS Analysis Center Coordinator. It is expected that regular reports will be issued by participating analysis centers, analogous to those distributed by the IGS for other activities, and filed in the IGS Electronic Reports series.

The precise relationship between the analysis activities that are needed for this Pilot Project and those required for the official products of the IGS is not entirely clear at this point. Certainly, the Project should build and rely upon the existing IGS structure. There may, however, exist a need for clock analysis and related products beyond the charter of the IGS. Also, some changes in the current analysis procedures of the IGS may be advantageous for enhanced timing performance. For these reasons it is essential that the Analysis Coordinator be actively involved.

2.3 Analysis of Instrumental Delays

In order to relate clock estimates derived from GPS data analysis to external timing standards it is necessary to understand the instrumental electronic delays introduced by the associated hardware. Studies are sought to characterize the short-term and long-term sensitivities to environmental changes and to develop suitable calibration methods. Differences for the L1 and L2 frequencies must be considered. Studies of both GPS ground sites as well as the GPS satellites are sought.

2.4 Time Transfer Comparisons

Simultaneous, independent time and frequency comparison data are needed to compare with the GPS-derived estimates. Collaborations are sought with groups performing time transfer experiments using a variety of techniques. Close cooperation is expected with the Consultative Committee for Time and Frequency (CCTF) of the Comit  International des Poids et Mesures (CIPM).

3 Objectives

To accomplish the overall goal of improved global accessibility to accurate time and frequency using GPS, several specific objectives can be set.

3.1 Accurate and Consistent Satellite Clocks

Satellite clock estimates are among the “core” products of the IGS (Kouba *et al.*, 1998). The IGS combined solutions for satellite clocks are distributed together with the IGS combined orbits in the sp3 product files. It is essential that the clock information be as accurate as possible and also that it be fully consistent with the other IGS products. Kouba *et al.* (1998) describe the importance of global consistency to ensure that the point positioning technique (Zumberge *et al.*, 1997) can be applied without degradation.

A type of point positioning likely to become increasingly important is for tracking low Earth-orbiting satellites equipped with onboard GPS receivers. For this application the 15-minute tabulation interval of the sp3 orbit files is not adequate because the SA corruption of the broadcast clocks does not allow accurate interpolation over intervals longer than about 30 s (Zumberge *et al.*, 1998a). For this and other applications, the IGS ACs have been asked to provide satellite clock products with 30-s sampling rates and the IGS will probably begin producing a corresponding combined product (Springer *et al.*, 1998). Methods for efficiently computing high-rate satellite clocks have been presented by Zumberge *et al.* (1998b) and Soehne *et al.* (1998). A new exchange format will be needed to permit easy distribution of the new high-rate results.

3.2 Accurate and Consistent Station Clocks

Presently, the IGS does not produce clock information for the GPS ground stations although doing so is mentioned in the IGS Terms of Reference. There is a clear interest in the user community for this information. Apart from time transfer uses, it could be used to characterize and monitor the performance of station frequency standards. Clock solutions from stations equipped with very stable frequency standards (especially H-masers) are needed to apply the method of Zumberge *et al.* (1998a) to estimate high-rate satellite clocks. For this purpose, station clock determinations at intervals of about 5 minutes can be accurately interpolated to the 30-s intervals needed to solve for the satellite clocks provided that the ground stations are referenced to stable clocks.

For time transfer applications, such as envisioned for this Pilot Project, accurate analysis results for the station clocks are mandatory. As with high-rate satellite clocks, a suitable exchange format must be developed. Regular summary reports to describe the analysis results characterizing satellite and station clocks will be encouraged. These should be publicly distributed in the IGS Electronic Reports series. Some IGS ACs, particularly JPL and EMR, already include valuable clock information in the weekly analysis summary reports that accompany their Final product submissions.

From geodetic analyses of the GPS data, the effective “clock” of each station is determined for the ionosphere-corrected L3 phase center of the antenna displaced by the electronic delay to the point in the receiver where the time tags are assigned to the phase measurements. These clock determinations are relative measurements in the sense that usually a single station is chosen as a time reference and not adjusted. From the viewpoint of geodetic applications, the precise reference point of the analysis clocks is irrelevant. As a result, manufacturers of geodetic receivers have generally not taken care to provide easy or accurate access to the time reference points. However, for timing applications, such as time transfer comparisons with other techniques, the precise location of the clock reference and accurate access to it are essential. Consequently, the investigation of instrumental path delays and access points is critical to the success of the Pilot Project.

Even if one imagines a shift in the timing paradigm so that the GPS receivers are eventually regarded as a part of the outer “electronics package” of stable frequency standards, it is nonetheless vital to establish accurate access to the clock reference points. The effects of environmental influences will be even more important in that case and must be minimized. Doing so will require new approaches for isolating GPS receiver equipment, such as efforts by Overney *et al.* (1997).

3.3 Accurate and Stable Reference Timescale

Ultimately, it is necessary that all clock information, for satellites and stations, be referenced to a common, consistent timescale. Individual sets of results from different ACs generally refer to different reference clocks. Thus, in the IGS combination process, the AC submissions must be realigned. This is currently done by choosing one submission as a reference solution, realigning its satellite clock estimates to GPS time based on the broadcast clocks for all the satellites (using only daily offset and rate terms), and then realigning all the other AC submissions to the reference solution (Springer *et al.*, 1998). Corrections are applied to each solution set to account for radial orbit differences compared to the IGS combined orbits. The IGS combined satellite clock estimates are then formed from the weighted average of the realigned, corrected submissions.

It has been suggested that the clock realignment and combination process would be improved if a common set of “fiducial” station clocks were used in all analyses and included in the IGS submissions (Springer *et al.*, 1998). Naturally, only stations equipped with very stable frequency standards (preferably geometrically well distributed) should be considered as candidate fiducials. Recommendations for this station set will likely be made during 1998.

Likewise, it is questionable whether GPS time is an appropriate choice for the underlying IGS timescale. The ideal choice should be accurate, accessible, and stable over all relevant time intervals (namely, 30 s and longer). GPS time is readily accessible but not with an accuracy comparable to other IGS products due to SA effects. Nor is GPS time particularly stable. The clocks of the GPS constellation are monitored from USNO

and this information is provided to GPS operations with the goal of maintaining GPS time within 28 ns (RMS) of UTC(USNO), allowing for accumulated leap second differences. In practice, the two timescales have been kept within about 6.5 ns (modulo 1 s) over the last two years (for 24-hour averages). However, the GPS time steering algorithm has a "bang-bang" character resulting in a saw-tooth variation with a typical cycle of about 25 days. This is equivalent to a frequency error greater than 10^{-14} over days to weeks, which changes periodically in an abrupt, nearly step-like fashion.

Almost certainly, an internal ensemble of the frequency standards used in the IGS network can be formed which would possess better stability than GPS time (Young *et al.*, 1996). There are currently about 27 IGS stations using H-masers, and about 40 with Cesium or Rubidium standards. Addition of new IGS sites located at primary timing laboratories would only improve this situation. A purely internal IGS timescale would probably not be stable against long-term drifts so some linkage to external laboratory timescales is required. Indeed, tracability to UTC(BIPM) is most desirable. In principle, this could be accomplished using the instrumental calibration data mentioned above, especially for the fiducial clock sites. It will be technically difficult, however, to achieve comparable accuracies for the calibration measurements to the few hundred picosecond level possible for the data analysis clocks. This will be one of the greatest challenges for this Pilot Project.

An alternative approach to provide external linkage that can be readily implemented uses monitor data for the GPS constellation that are collected and compared at the timing labs. USNO collects such data using pseudorange timing observations and makes the results publicly available. Using the observed offsets of GPS time relative to UTC(USNO), the corresponding IGS clock estimates can be related to UTC(USNO). Because of the effects of SA such comparisons would only be useful to remove long-term differences. This is probably sufficient, at least for an initial realization. Other timing laboratories would be encouraged to provide similar monitor data for a more robust tie to UTC(BIPM). A potential problem with this approach is possible biases between the effective clocks transmitted by the satellites as measured from the pseudorange and carrier phase observables.

Apart from the issues discussed above concerning calibration and external referencing for an IGS timescale, there are other practical questions that must be resolved. In particular, it may be difficult to form and maintain a timescale within the IGS product delivery schedule. This is likely to be especially true for the Rapid products even though that is probably also where the greatest user interest lies. Fundamentally, this does not seem overwhelming although it will require entirely new and highly automated IGS processes. Other practical concerns are minimizing discontinuities at day boundaries, dealing with clock discontinuities and drop-outs in the ensembling process, and finding an appropriate robust ensembling algorithm. These subjects, together with those mentioned above, should be studied during this Pilot Project.

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IGS Combination of Tropospheric Estimates -- The Pilot Experiment

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1 Introduction

The existing global and regional networks of permanent GPS receivers installed for geodetic and navigational applications can be used with marginal additional cost for determination of atmospheric water vapor with high temporal and spatial resolution. In different countries projects are under way in which the impact of GPS derived water vapor on the improvement of weather forecast are studied. Within the IGS a network of more than 100 globally distributed sites is analyzed on a daily basis. The zenith path delay (ZPD) values obtained should be converted into precipitable water vapor (PWV) and should be made available to the scientific community.

This IGS product could meet the demands for climatological studies. Here a time resolution of 2 hours (this is what IGS will provide) is sufficient, because long-term characteristics are of interest only, and a time delay of a few weeks for product delivery is acceptable.

Since the beginning of the Pilot Experiment six of the global IGS Analysis Centers (ACs) have regularly contributed (Table 1). Different mapping functions and elevation cutoff angles of 10, 15 or 20 degrees are implemented. The number of sites per AC varies from 30 to 85, and their were 100 sites in total. The product from the combination is a weekly file for each site containing the ZPD estimates and precipitable water vapor if conversion is possible. Additionally, a combination report will summarize some statistics on the differences to the IGS Mean (bias, standard deviation), for the global mean of each AC and separately for all sites.

Table 1. Contributing Analysis Centers with some relevant parameters

	ZPD[min]	Cutoff[deg]	No.Sites	Mapping Function
CODE	120	20, 10(wk 926)	85	Saastmoinen; Niell (week 926)
EMR	60	15	30	Lanyi
ESA	120	20	50	Saastmoinen
GFZ	60	20	55	Saastmoinen; Niell (week 929)
JPL	5	15	37	Lanyi; Niell (week 920)
NGS	120	15	55	Niell

2 Comparisons, Results

For comparisons the differences between individual AC estimates and the IGS can be used. More than 60 sites are used by at least three ACs, so that sufficient statistical information about the quality of the tropospheric estimates can be gained. For most sites and ACs the stddev is ± 6 mm ZPD (which corresponds to ± 1 mm PWV) and it approaches in many cases the ± 3 mm level. The magnitude of the stddev is of course highly correlated with the magnitude in the repeatability of the estimated station coordinates. Looking into the geographical distribution of the magnitude for the stddev the largest stddevs can be found in the equatorial region. The bias for most sites is below ± 3 mm. Even for sites with a larger bias its repeatability is very high.

The global mean stddev (mean over all sites) of the best ACs is at the 4 mm level (Figure1). Only a small global bias at the 1 mm ZPD level can be stated. However, significant effects of ± 1 -2mm from AC to AC exist. ACs having changed their parameters (cmp. Table 1) show larger jumps correlated with those changes.

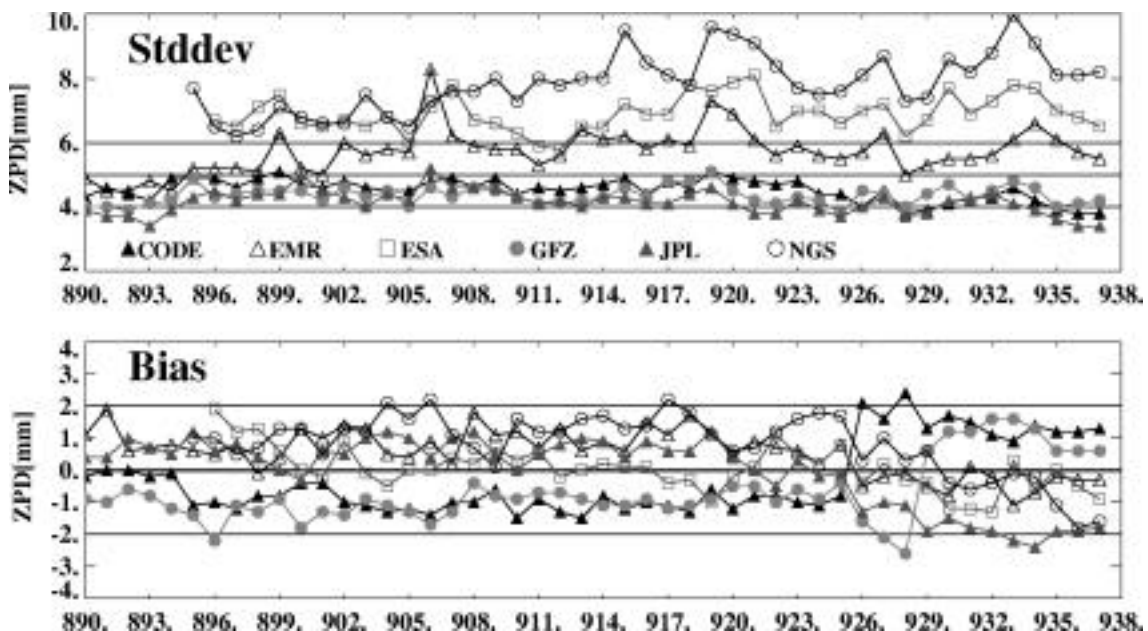


Fig. 1. Difference between AC ZPD and IGS Combined ZPD. Mean values (mean over all sites) per week and Analysis Center

The biases for fiducial (or other well determined) sites are very small, and the repeatability is at the 2 mm ZPD level. However, larger systematic effects can be found for some sites too, especially in the equatorial region. Here systematic effects of about ± 6 mm exist with single peak to peak differences in the weekly biases of 20 mm. The bias differences could be reduced by taking into account the well-known correlation between the station height and the ZPD estimates. This works rather well for some sites, but not for all. However, such a procedure will not be recommended because any corrections to

the estimates are dangerous. It is better to reduce the scattering in the determined station heights. One step in this direction will be the enlarged set of 52 fiducials, which will be constrained to a certain extent by all the ACs. The introduction of a smaller elevation cutoff angle may also help to reduce the bias.

3 Conversion into Precipitable Water Vapor

For the conversion meteorological surface measurements are needed. At the moment 19 sites report regularly their met data to the global data centers. Ten further sites have announced the installation of met packages, but the data are not yet available. The met data must be of high precision (1 mbar corresponds to 0.35 mm in PWV) and reliability (continuous time series). For some sites too many missing days or larger gaps must be stated. In those cases no meaningful series of PWV could be produced. Unfortunately, only 10 to 15 reliable sites with met sensors exist at the moment (a small percentage of all analyzed sites).

The GPS derived PWV estimates can be compared with WVR measurements to get a measure for the absolute accuracy. Only at POTS measurements of a collocated WVR were available. A WVR-1100 of Radiometrics Corporation is operated by Meteorological Observatory Potsdam of the German Weather Service, and is located 400m apart from the GPS receiver. The agreement of the GPS results (both CODE and GFZ) with the WVR is at the 1 mm level (Figure 2). The stddev of the difference approaches ± 0.5 mm, the bias has a level of ± 1 mm and shows some long-periodic behavior for both GPS results. The difference between the two GPS solutions is smaller than their differences to the WVR measurements.

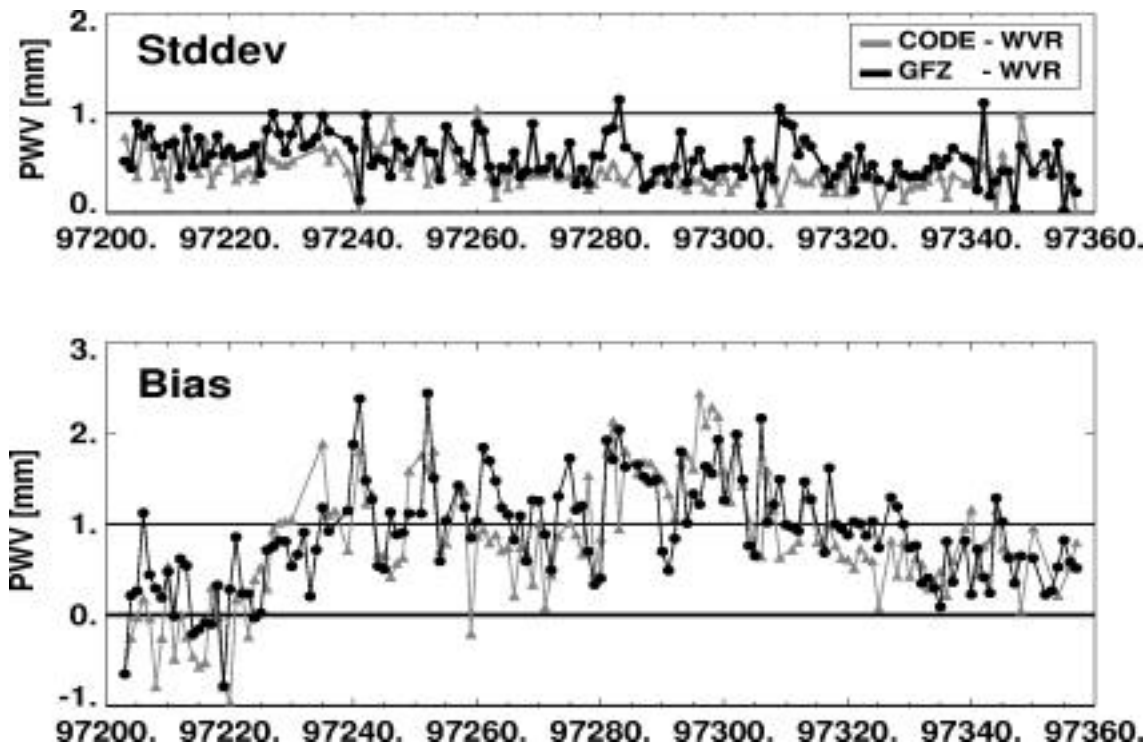


Fig. 2. Comparison of PWV estimates from GPS and WVR at POTS. WVR data are from Meteorological Observatory Potsdam, 400 apart from GPS receiver.

4 Summary

During the one year experiment all components involved in the combination have performed well and timely. The ZPD estimates have a high quality for all the weeks. The consistency is at the 4 to 5 mm level both for the bias and for the stddev.

The importance of the IGS contribution to climate research will not only depend on the quality of the ZPD estimates but also on the number of sites which could be equipped with met packages. The number of instruments available now is not sufficient.

To get a better insight into the behavior of the bias more collocated WVR should be made available, either at existing IGS sites or at non-IGS sites which then should be analyzed by all IGS ACs for some test periods.

The pilot phase for the IGS Combined Tropospheric Product is finished and the combined zenith path delay (ZPD) estimates are an official product now. The conversion into precipitable water vapor will be postponed until a sufficient number of surface met packages is available. At the moment it is to the customer to convert the ZPD by relying both on the existing RINEX met files as well as on interpolation within global or regional meteorological fields. The product will be archived at the global Data Centers.

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1997 IGS Activities in the Area of the Ionosphere

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A subsession was dedicated to the ionosphere at the IGS workshop in Potsdam in May 1995 and again at the IGS workshop held in Silver Spring in March 1996. In preparation for the latter, an intercomparison of ionosphere TEC maps and satellite differential code biases was initiated. Five Analysis Centers (ACs) contributed to this intercomparison, for which TEC data over a time span of five weeks had been used. The intent of this intercomparison was to get an idea of the accuracies that can be achieved. Additionally it could be identified which ACs were interested in contributing to an IGS ionosphere product.

However in 1996, most of the ACs were still in a development stage with their modeling and software, and at this time they were not in a position to produce ionosphere products for the IGS on routine basis. During the year 1997, the ionosphere activities at the ACs were thus concentrated in the background rather than in the foreground, and some of the ACs modeling capabilities were significantly improved during that time. These improvements include the successful prediction of ionosphere model parameters as well as first attempts to model the ionosphere's electron content 3-dimensionally.

Another important thing that was achieved in 1997 was the development of the so-called IONosphere Map EXchange Format (IONEX) (Schaer et al., 1997), defining for the first time which and how ionosphere products should be exchanged. The IONEX became in the meantime the mandatory ionosphere format within the IGS.

At the Darmstadt IGS workshop in February 1998 it was then decided to start a coordinated routine processing and a combination of IGS ionosphere products. Based on a Position Paper (Feltens and Schaer, 1998) and a Terms of Reference (Schaer and Feltens, 1998) an IGS Ionosphere Working Group has been established at 28 May 1998, which started immediately with its pilot phase in June 1998.

The importance of an IGS engagement within the area of ionosphere science is obvious, and representatives of the ionosphere community have indicated a great interest in a continuous series of global IGS ionosphere models. Since mid 1996 we are approaching the next solar maximum. Therefore good and rapidly available information about the ionosphere's actual state becomes increasingly important. Users of satellite navigation systems need accurate corrections to remove signal degradation caused by the ionosphere, information on the ionosphere's behavior is of great importance for radio signal propagation applications, and scientists will benefit from up-to-date and long-term ionosphere information.

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IGS Infrastructure Committee Report

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1 Introduction

The IGS Infrastructure Committee was established by the IGS Governing Board at its meeting in Rio de Janeiro in September, 1997. The primary motivations for the formation of this committee was to assist the IGS Central Bureau in:

1. eliminating existing discrepancies that impact the accuracy, reliability, and timeliness of IGS products (e.g., incorrect or ambiguous antenna heights, incorrect or ambiguous RINEX data file headers),
2. identifying weaknesses in station infrastructure and recommending actions (e.g., replacing aging and obsolete equipment, evaluation of monumentation and long-term site stability, evaluation of data flow), and
3. re-evaluating and promoting adherence to IGS standards within the IGS organization (e.g., site standards, station reporting, data quality and reliability, data archiving and dissemination).

The committee identified several actions that could improve the IGS infrastructure:

1. Preparation of a network “road map” to chart data collection and data flow
2. Preparation of a station performance table
3. Preparation of an automated site log preparation scheme to solve the persistent problem of contradicting or missing information about sites
4. Development of guidelines for IGS tracking stations and operational centers
5. Promotion of improved communications between operation centers
6. Recommendation of courses of action to the Governing Board and Central Bureau

2 Progress

The committee in consultation with the IGS Central Bureau prepared two documents (initially drafted by Werner Gurtner) which were adopted as IGS policy by the Governing Board at its meeting in Boston in May, 1998:

1. Joining the IGS
2. Guidelines for IGS Stations and Operational Centers

The first document describes the procedures to be followed when establishing a new IGS station. The second document gives guidelines for operating IGS tracking stations and Operational Centers.

The documents can be found in Appendices A and B. The latest version of these documents is being maintained by the IGS Central Bureau (<http://igscb.jpl.nasa.gov/>)

Committee members have been active in planning for the IGS Network Workshop planned for November, 1998 in Annapolis, Maryland. An organizational meeting of the network planning committee was held at Scripps Institution of Oceanography in August, 1998. At the meeting the following actions were adopted in preparation of the November workshop and to meet the objectives of the infrastructure committee:

1. Preparation of a network “road map” to chart data collection and data flow (led by UNAVCO Boulder Facility).
2. Preparation of an automated site log preparation scheme to solve the persistent problem of contradicting or missing information about sites (led by Scripps Orbit and Permanent Array Center).

APPENDIX A: Joining the IGS

Version 1.1 ((reformatted for IGS Report, August 31, 1998))
(prepared by IGS Infrastructure Committee and Central Bureau)

A.1 Introduction: Procedures for Becoming an IGS Station

This document describes the procedures to be followed when establishing a new IGS station. It is applicable to stations of global and regional interest, and includes detailed steps to be taken by the responsible agency, in consultation with the IGS Central Bureau (CB). Also described in this document are maintenance of the public station log files and procedures related to data flow, archiving, and analysis.

Note: The IGS recommends that these procedures also be applied to stations of local interest, as well. However, the IGS does not take any responsibility for completeness, correctness, nor for data processing and data archiving for "Local" stations.

For more detailed descriptions of station requirements with respect to monumentation, receiver, antenna, data handling, documentation, and data formats please refer to "Guidelines for IGS Stations and Operational Centers."

All electronic messages, unless otherwise specified, should be sent to the CB at igsch@igsch.jpl.nasa.gov.

A.2 Initial Steps

Contact the CB concerning the intent to install the station(s). Include a statement of desire for the station to be considered as part of the IGS network. Clearly identify the schedule for implementation, the responsible installation agency, the responsible operational agency once the site is established, and the funding agency (including prospects for long-term funding support).

A proposed four character station identifier should also be included for confirmation by the CB. The CB will assist in the designation of the identifier to prevent duplication.

The CB will announce the new station on its schedule of future or proposed stations.

A.3 Site Installation

IGS standards need to be followed when installing the station. (see "Guidelines for IGS Stations and Operational Centers").

Once the station is installed and operational, a communication should be addressed to the CB indicating the data availability.

A.4 Station Log

If the new station is part of an existing network, the responsible Operational Center has to update the center description form (download [/igsch/center/oper/'center'.ocn](#) from igsch.jpl.nasa.gov, modify, and send an electronic notification to the CB).

If the station is part of a new network, the new Operational Center has to create a center description form (download [/igsch/center/oper/BLNKFORM.OCN](#) from igsch.jpl.nasa.gov, modify, and send electronic notification to the CB).

A station log must be prepared (download /igscb/station/general/BLNKFORM.LOG from igscb.jpl.nasa.gov); many examples are available in /igscb/station/log.

Forward the station log to the IERS with a request for a DOMES number; this is the numbering system that is used by the International Earth Rotation Service (IERS) to keep track of all space geodetic stations. Instructions on obtaining a DOMES number is available from the Laboratoire de Recherche en Géodésie (LAREG) (<http://lareg.ensg.ign.fr/ITRF/domesreq.html>). The IERS will assign a DOMES number for the station and any other monument or reference marker located at the same site location.

Forward completed station log (updated with DOMES number) to the CB to be included into the Central Bureau Information System (CBIS). E-mail files to the CB.

Mandatory items include: Station name, 4-character site code, DOMES number, approximate coordinates (X/Y/Z and/or lat/lon/elev), antenna height and description, receiver and antenna types, antenna diagram (see files rcvr_ant.gra, antenna.gra available at <ftp://igscb.jpl.nasa.gov/igscb/station/general> for correct names), eccentricity elements (if any) to nearby geodetic markers at the same site location, contact addresses.

Important Note: Station log files with missing or incorrectly entered information will not be accepted by the CB.

When all the information is available on the CBIS an announcement should be prepared by the implementing agency for distribution through IGSMail. (It is not necessary to distribute the log file itself through IGSMail).

A.5 Station Log Updates

Whenever there is an update or change to the information contained in the station log file, the current log file should be downloaded from the CBIS (/igscb/station/log) and modified by adding the new information and the modification date. This file should be sent back to the CB and an announcement of the modification should be made through an IGSMail message. This procedure ensures that modifications of the station log done by the CB will be preserved.

Important Note: Any changes at the site must be relayed promptly (preferably in advance) to the CB and posted via IGS Mail. In particular, these include but are not limited to changes in monument, GPS equipment, and antenna height.

A.6 Data Format

It is the responsibility of the Operational Agency to provide GPS data to the IGS in Receiver Independent Exchange (RINEX) format. The RINEX files must be prepared following the guidelines for IGS stations and Operational Centers (“Guidelines for IGS Stations and Operational Centers”, “rinex2.txt”).

To ensure compatibility, send an extract of a sample daily RINEX file (header, first and last few epochs of data records, ASCII) per e-mail to the CB.

A.7 Data Flow and Archive

The long-term archiving of the data falls within the responsibility of the Operational Center.

If the station is part of a local, regional or special network (e.g. SCIGN, EUREF, CIGNET, JPL FLINN) the daily data files have to be sent to the respective data centers from where they will be forwarded, if appropriate, to other IGS Data Centers.

The operational agency needs to inform the CB to which IGS Data Center it is planning to send its data.

The data from regional networks that will not be processed by more than one IGS Analysis Center can be kept in the Regional Data Center and not forwarded to an IGS Global Data Center.

The data of sites of local networks not to be processed by an IGS Analysis Center should be kept in their respective Local Data Center, or forwarded to a Regional Data Center.

Important Notes:

Daily data may not be accepted by the IGS Data Centers if station log files are missing or incomplete, if the RINEX data files are not correctly formatted or incomplete, or if the station log files and RINEX file headers are inconsistent.

Individual data files may not be accepted by the IGS Data Centers if the files contain less than 10 percent of the nominal amount of data.

A.8 Data Analysis

“Global sites” are those sites of global interest that are processed by at least three Analysis Centers located on more than one continent. That is, data from these sites contribute significantly to the production of IGS global products (e.g., satellite orbits, EOP). New sites which contribute significantly to regional densification of the IGS polyhedron are classified as “Regional sites.” Otherwise, a site is classified as a “Local site.” Analysis of Local sites will be performed by a local analysis center and will not be the responsibility of the IGS.

For densification purposes the results (especially coordinates and velocities) may be forwarded as SINEX files to Associate Analysis Centers to be included into combined solutions (SINEX: see <ftp://igsjb.jpl.nasa.gov/igsjb/data/format/sinex.txt>).

Important Note: IGS Analysis and Associate Analysis Centers may not process data and submit results to the IGS of those sites not meeting all of the requirements outlined in this document.

APPENDIX B: Guidelines for IGS Stations and Operational Centers

Version 1.2 (reformatted for IGS Report, August 31, 1998)

(prepared by IGS Infrastructure Committee and Central Bureau)

B.1 Introduction

This document gives guidelines for operating IGS tracking stations and Operational Centers. For potential or new IGS participants, please refer to the document “Joining the IGS” (Appendix A).

B.1.1 Organization of the IGS Data Flow

En route to Analysis Centers and other users, the tracking data collected by permanent GPS receivers flow through the following components of the IGS network:

- Tracking Stations (TS): They set up and operate the permanent GPS tracking receivers and antennae on suitable geodetic markers.
- Operational Centers (OC): They perform data validation, conversion of raw data to Receiver Independent Exchange Format (RINEX), data compression, and data upload to a data center through the Internet. For some sites the OC is identical with the institution responsible for the respective site (i.e., the OC is identical with the TS).
- Local Data Center (LDC): They collect the data of all stations of a local network and distribute them to the (local) users. One or more of these stations are part of the IGS network. For many of the local networks the LDC will be identical with their Operational Center.

The LDC will forward the data (of a selection) of the local sites to the Regional Data Center.

If there is not a LDC for particular data, data will flow directly from the OC to the designated Regional Data Center.

Note: These guidelines do not pertain to local networks which are not part of the IGS network, nor to any actions of Local Data Centers related to non-IGS stations.

- Regional Data Centers (RDC): They collect all the data of a certain region (e.g., Europe) or special network (e.g., JPL) and make it available to the users, especially to those of the respective region. They forward the data of the sites of global interest to one of the three Global Data Centers.
- Global Data Center (GDC): They collect the data of global interest from the Regional Data Centers. They equalize their data holdings among themselves and make the data available through anonymous ftp to the users, especially to the IGS Analysis Centers.

B.1.2. Requirements for Permanent Stations

Because the user of the network will be mainly interested in the data and the necessary auxiliary information about the tracking sites, we do not make a clear distinction between the activities and responsibilities of the Tracking Stations and the Operational Centers.

Very strict rules are inconsistent with the nature of the IGS. However for a station to be included in the IGS Network, the following guidelines will be used to judge the merits of a candidate station. Please consult also the check list of how to become an IGS station.

Instrument

The GPS receivers should

- track both codes and phases on both frequencies under non-AS- (anti spoofing) as well as AS-conditions
- track at least 8 satellites, simultaneously
- track at least with 30 seconds sampling rate. If the sampling rate is faster, the data should be decimated to 30 seconds prior to upload to the Regional Data Center
- synchronize the actual instant of observation with true GPS time within +- 1 millisecond of the full second
- be protected from power failures wherever feasible. If the data are downloaded in real time to an external PC without being stored in the receiver for a certain time, the same protection should include the PC as well

Antenna

- The antenna should include a Dorne-Margolin element and a choke ring
- The antenna should be oriented in the manner proposed by the manufacturer.
- The antenna should be protected against a heavy snow load, other meteorological factors, and vandalism by use of an antenna cover (“radome”). The effect of the radome on the antenna phase center should be determined. Various radome designs are available from the IGS Central Bureau.

Marker

The marker should fulfill standard requirements for a first order geodetic monument with respect to stability, durability, long-term maintenance, documentation, and access. The marker description should be fully documented in the IGS site log file (see *Documentation* below).

Obstruction should be minimal above 15 degrees elevation, but visibility to lower elevations is encouraged whenever possible.

Signal reception quality has to be verified, especially with respect to interference of external signal sources like radars, and with respect to multipath.

The antenna height corresponds to the vertical distance of the agreed-upon physical reference point (see antenna diagrams) on the antenna above the marker.

Local ties to other markers on the sites should be determined in the ITRF coordinate system to guarantee 1-mm precision in all three dimensions. Offsets are given in delta-X, delta-Y, delta-Z, X,Y,Z being the geocentric Cartesian coordinates (ITRF).

Documentation

A standard IGS site description file (log file) should be filled out and sent to the IGS Central Bureau at e-mail:

igsbc@igsbc.jpl.nasa.gov

Blank forms are available through anonymous ftp at the IGS Central Bureau Information System (CBIS):

<ftp://igsbc.jpl.nasa.gov/igsbc/station/general/blank.log>

Consistency in both format and content is strongly encouraged. Additional site descriptions (photos, maps, etc) should be sent to the Central Bureau.

B.1.3 Operational Centers

Responsibilities

The Operational Centers control the sites of a particular (local) network from the operational point of view.

They form a link between the sites and the Data Center. The Data Center then makes available the data to the Analysis Centers, other Data Centers, and individual users.

The Operational Centers are responsible for

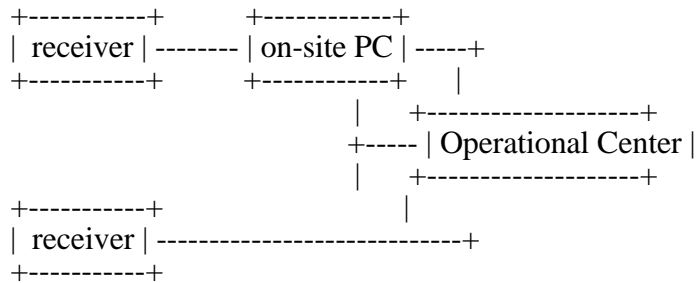
- the download of the raw data from the receivers of the local network
- the archiving of the raw data
- the reformatting of the data into the agreed-upon exchange format (RINEX)
- the quality check of the data on a station by station basis

- the generation of status messages (abnormal conditions)
- the alert/engagement of on-site personnel (abnormal conditions)
- the upload of the data to the Data Center at agreed-upon times

Within the International GPS Service for Geodynamics there are many independent tracking sites (e.g. Zimmerwald, Herstmonceux) that are not part of a local or special network. As such they are not connected to an actual Operational Center. In this case the organization operating the site also performs the tasks outlined above.

Data Download From the Stations

The downloading from the receiver to the Operational Center's computer system can either be done directly or indirectly through a small on-site computer, e.g. a PC:



The PC could download the data from the receiver continually, using e.g. some manufacturer-provided download software.

The communication between the Operational Center and the stations can be achieved through any one of several means, including dialup modem, Internet, special-purpose data links, Inmarsat, etc. Station communication configuration information should be included in documentation provided to the CB.

Data Archive

As the exchange data format does not conserve all information found in the raw data it should not be used for the primary data archiving. The Operational Center is responsible for the long-term data archiving unless this task has been delegated to the Tracking Stations. The original raw data files or compressed (e.g. zipped) raw data files are usually archived.

The IGS Data Centers archive the RINEX files for the general benefit of the IGS.

Data Format

The data are to be prepared in daily (24 hours) RINEX files, both for observations and broadcast navigation messages. This is the current standard. For emerging applications (e.g., atmospheric sensing, Low-Earth-Orbiters -- LEO's) more frequent data collection and preparation may be considered by the IGS.

The daily observation files contain the observations collected between 00:00:00 and 23:59:59 GPS time. The sampling rate (observation interval) must be the adopted standard,

currently 30 sec. In case of a higher original observation rate a decimation of the data to the adopted standard is mandatory.

The header information, especially the station name, receiver and antenna information, and antenna height, must be up-to-date and has to strictly follow the agreed-upon conventions (see blank log forms for the stations). Consistency in both format and content is strongly encouraged.

The navigation message file contains all messages with TOC/TOE (time of clock, time of ephemeris) between 00:00 and 23:59 GPS time of the respective day.

It is recommended to generate a combined daily RINEX navigation file containing non-redundantly all navigation messages collected by all sites of a local network. The filename (part "ssss", see below) should then contain a 4-character code of the Operational Center.

The RINEX navigation files are prepared in a compressed form using the standard UNIX compress program. The RINEX observation files are additionally compressed using the Hatanaka compression scheme. Compress and decompress programs for other platforms (PC/DOS, VAX and Alpha VMS) are available at the IGS CBIS:

<ftp://igscb.jpl.nasa.gov/igscb/software/compress> (for the UNIX Compression)

<ftp://igscb.jpl.nasa.gov/igscb/software/rnxcmp> (for the Hatanaka Compression)

File Type	ASCII File	Compressed Files		
	UNIX	UNIX	VMS	DOS
Observation	ssssdddf.yyO	ssssdddf.yyD.Z	ssssdddf.yyD_Z	ssssdddf.yyE
Navigation	ssssdddf.yyN	ssssdddf.yyN.Z	ssssdddf.yyN_Z	ssssdddf.yyN
Meteorological	ssssdddf.yyM	ssssdddf.yyM.Z	ssssdddf.yyM_Z	ssssdddf.yyM

ssss: 4-character station code

ddd : day of the year of the first record

f : file sequence number within the day

0: containing all data of the day

yy : year

The extension yyD (or yyE in DOS) indicates Hatanaka-compressed files. More information about the Hatanaka compression can be found in

<ftp://igscb.jpl.nasa.gov/igscb/software/rnxcmp/docs/README>

Files sent to another host must be named on the target system in accordance with the target operating system:

Example: Put a file from a UNIX to a VMS system:

binary

put zimm1230.94D.Z ZIMM1230.94D_Z

Data Validation

Data should be checked before being sent to a Data Center. A minimum verification should consist of a check of

- the total number of observations
- the total number of observed satellites
- the date of the first observation record in the file

- the station name, receiver/antenna types, antenna height

The use of a true quality check program is highly recommended, e.g. UNAVCO's QC program (available through the IGS Central Bureau Information System, directory /igsb/software/qc).

Files which do not meet the minimum verification should not be sent to a Data Center.

Data Handling

It is highly recommended that all steps in the data handling -- download from the receiver, reformatting, data validations, generation of statistics, data archiving and transmissions -- be fully automated. Data failing to pass the validation step should be kept back for manual treatment and then posted.

Data Upload

The data must be sent daily to a designated IGS Data Center, via a Local Data Center if appropriate.

The IGS Data Center to be used is assigned by the Central Bureau. Alternate and back-up routing will also be assigned in case of emergency and should be fully tested.

Timeliness of the Data Transfer

In order to allow for rapid analysis of the data and to avoid the times of heavy network traffic on the international data lines the data should arrive at the Regional Data Center not later than 2 hours after midnight Universal Time, to be forwarded to one of the Global Data Centers not later than 03:00 UT.

Documentation

The IGS Central Bureau Information System makes available a blank form for an Operational Center description file (blankform.ocn in /igsb/center/oper). This form should be filled out by the Operational Center or by the agency operating an independent permanent GPS station and sent to the Central Bureau.

B.1.4 Local Data Centers

General

Depending on the policy of the respective agencies, the tracking data and the auxiliary station information of the local network can be made available through computer networks or bulletin boards etc. This task would be the responsibility of a Local Data Center.

Stations not part of a local network send their data directly to the designated IGS Data Center.

Data Access

It is recommended to allow access to (all or part of) the data through Internet's anonymous ftp, currently being the most effective and easy to use access method, especially for automated data download. Another access procedure on Internet is through World Wide Web (WWW) servers with easy to use browsers such as Mosaic or Lynx.

Available Information

It is recommended to make available at least the following information:

- Station information (site log files, requested)
- Data Center Information (blank forms and examples can be found in the IGS CBIS (<ftp://igsb.jpl.nasa.gov/igsb/center/data>)).
- Other network information: Data flow, Operational Center description, reference and access to other networks (EUREF, IGS, ...)
- Daily tracking data (RINEX files), including results of quality checks
- Data holding information (i.e. a machine-readable summary of the available tracking data). Examples can be found in directory <ftp://igsb.jpl.nasa.gov/igsb/data/holding>. A program to generate such a data holding file can be obtained through the IGS Central Bureau.
- Status information about the network and GPS in general and cross-references to other information systems

Sites for which there is incomplete, incorrect, or contradictory documentation will be identified automatically at the Central Bureau. A notification will be made to users by the CBIS. Users of data may use this information as they see fit. However, the expectation is for these discrepancies to be eliminated.

Data Organization

It is recommended to organize at least the tracking data in a hierarchical directory structure. From the user's point of view it is usually preferable to combine all the data of one day (or one week) into one directory than to have station-dependent directories. Examples of directory organizations can be found in the IGS Data Center description files (<ftp://igsb.jpl.nasa.gov/igsb/center/data>).

All the other information can be made available either through ASCII files in a directory tree or through more advanced means like data bases of hypertext documents or, preferably, through both.

The Local Data Center description file and the daily updated data holding file should be made available to the IGS Central Bureau Information System.

Data Transfer to the Regional Data Center

The tracking data of stations that are also part of an upper level network (EUREF, IGS) have to be forwarded through Internet to the respective Regional Data Center by anonymous ftp, or other reliable electronic means. It is recommended that a binary (image) "put" be used.

B.1.5 Data Analysis

- Although the IGS Analysis Centers are free regarding which sites to process they should not report results (such as coordinates and velocities) for sites for which there are no correctly filled out log files available at the IGS CBIS. In principle the corresponding RINEX data files should also be available at least one IGS Regional Data Center. Data available only from Local Data Centers should be used by special arrangement only.
- The Analysis Centers are requested to use the primary site information (DOMES numbers, receiver and antenna names, antenna heights, antenna phase center information) provided in master files available at the CBIS.
- The Analysis Centers and Associate Analysis Centers are requested to ensure that their SINEX files are consistent with the site information provided in master files available at the CBIS.

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Continuous GPS Positioning of Tide Gauges: Some Preliminary Considerations

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1 Introduction

The IGS is working with the oceanographic community to begin implementation of the long-considered step of adding continuous GPS (CGPS) stations to tens of tide gauges around the world so as to reference sea level at this set of points to the ITRF. A technical committee formed under the auspices of the IGS and the PSMSL was established at the 1997 JPL Workshop in order to write a set of standards for groups constructing these CGPS stations. During its discussions the committee has come to realize that the oceanographic community is pursuing several different agendas, and that these efforts have distinct accuracy requirements and are impacted in different ways by various geotechnical considerations and local environmental factors. There are two main agendas:

- (i) The ‘centimeter’ agenda. The idea is to establish the absolute vertical position of the tide gauge and its benchmarks (and ultimately the local sea level history) with an accuracy of 2 - 3 cm, for the purpose of calibrating and/or validating modern satellite altimeter measurements (e.g. TOPEX). The oceanographers engaged in this activity typically place little importance on providing tectonic corrections for historical sea level data obtained at their calibration stations.
- (ii) The ‘millimeter’ agenda. Tide gauge measurements reflect vertical motions of both the land (to which the gauge is attached) and the sea surface. The intra-annual, annual and even decadal fluctuations recorded by a tide gauge are usually totally dominated by absolute sea level changes. But when averaged over much longer periods of time (~100 years) the rates of vertical motion of the land and the sea surface are often similar in magnitude (~ 1 mm/yr). In order to obtain an absolute sea level history from a long historical record of relative sea level change, it is necessary to estimate the rate of vertical motion of the land or structure supporting the tide gauge. The goal is to use CGPS to measure the vertical velocities of tide gauge stations with an accuracy of better than 1 mm/year within ten years, and with considerably better velocity accuracy over longer periods

of time. This more ambitious agenda was the main focus of the well-known Carter reports.

The second agenda is much more challenging and will lead to quite severe requirements for the selection of 'suitable' tide gauge sites, the CGPS installations and data analysis. Tide gauges that can be instrumented with CGPS for the purposes of the centimeter agenda may often be unsuitable for pursuing the millimeter agenda. As such the technical committee is now working on separate sets of recommendations for these distinct 'end case' applications. A key realization is that these recommendations need to be considered as tide gauges are being selected, and not just during the implementation stage.

2 The Impact of Geodetic Requirements on Site Selection

Some requirements are common to any positioning agenda and would apply to any tide gauge. For example, one should always 'tie', by precise leveling, the GPS antenna to the system of tide gauge benchmarks (TGBMs) as well as to a reference point on the tide gauge itself. This is especially important when one is working at a tide gauge with a long history and this history is a major focus of the effort. This is because over many decades the tide gauge is likely to have been modified, moved and even replaced on several and perhaps many occasions. It is the TGBMs and the associated program of precise leveling measurements that provide the temporal continuity of the vertical datum at such stations. In this sense one could argue that when the focus is on a very long sea level time series, the system of TGBMs is even more important than the specific tide gauge that is operating today. Nevertheless, the need to tie the GPS antenna to the TGBMs as well as to the tide gauge is clear no matter what application we are pursuing or where we are working. Not all requirements are this straightforward, however.

The technical requirements for geodetic positioning of tide gauges need to be considered during the selection of gauges for GPS augmentation, and not just subsequently. Only a small fraction of all available tide gauges will be retrofitted with a CGPS station. It would be short-sighted to base the selection of these tide gauges purely on oceanographic criteria, without regard to the relative geodetic suitability of the candidate tide gauges. The ease with which a given tide gauge can be positioned geodetically depends both on the positioning accuracy required and the local environmental conditions. Consider the standard issue of sky view, for example. It is unlikely that one could ever obtain subcentimeter vertical accuracy by making GPS measurements at a tide gauge located at the base of a 200 meter cliff. This raises the question of how far the CGPS station can be removed from the tide gauge. In many cases the existence of walls or buildings besides the tide gauge will require the GPS antenna to be moved at least several meters from the gauge itself. This will rarely matter as long as the GPS antenna mount is connected to the same structure as the gauge, making significant relative motion of the tide gauge and GPS antenna impossible. But could it ever be acceptable to install a CGPS station hundreds of meters or even kilometers away from the

tide gauge in order to optimize conditions for the GPS measurements (e.g. an improved sky view) or for other purposes such as security of the GPS equipment?

There are a number of factors that must be addressed before one can answer this question. What positioning agenda are we pursuing? How often would the GPS antenna be referenced to the tide gauge using precise leveling? What is the nature of the ground beneath and between the tide gauge and the GPS antenna? I do not have space to discuss here all the relevant issues in a comprehensive manner, but the following points may illustrate the nature of the problems and trade-offs involved.

Some tide gauges are attached to seawalls or piers that were constructed on sediments or, worse still, engineering fill. The well-known tide gauge at Valparaiso (Chile) is an example of the latter situation. These structures typically subside as the underlying material compacts. Oceanographers have long been aware that tide gauges may be subject to purely local vertical motions of this kind, and this is one of the reasons why they have referenced their tide gauges to TGBMs. Some oceanographers have concluded that a CGPS station serves a similar role to a TGBM, and so there is no particular need to place the CGPS station very close to the tide gauge. However, a CGPS station is being positioned in a global reference frame on a daily basis. If a somewhat remote CGPS station is moving by an unknown amount relative to its tide gauge, then the absolute position of the tide gauge is being determined only as frequently as the levelling tie is being made. This may be just once a year. This represents a massive dilution of the positioning power of CGPS.

The negative impact of losing the temporal continuity of CGPS measurements is further illustrated by the following example. Some tide gauges are tied to large standing structures such as piers that may be undergoing thermoelastic displacements with amplitudes of millimeters and sometimes even centimeters. Suppose one such tide gauge is being tied by precise leveling to a CGPS station built on a rock outcrop 1 km away. If the leveling survey happens roughly annually and always takes place around the same time of year, even large annual thermoelastic motions of the gauge might never be observed at all!

If a tide gauge and a non-colocated CGPS station are not constructed on a coherent outcrop of solid rock, the possibility of subsurface displacements changing the relative level of the tide gauge and the GPS antenna is present even when near-surface ‘engineering’ instability of a pier or a harbor wall can be ruled out. An analysis of all releveled data obtained in the USA prior to 1980 showed that most of the largest vertical displacements occurred in and near cities built on sediments such as those underlying the coastal planes of the Atlantic and Gulf Coasts. Most of these signals manifest differential subsidence associated with water withdrawal. Many tide gauges are based in this kind of setting.

One also needs to keep in mind that in many parts of the world precise leveling surveys do not take place at reasonable intervals (except on paper). In this case there will be no strong constraints on possible relative motions of the tide gauge and the GPS antenna.

If one is pursuing the centimeter agenda it will usually be acceptable to offset the GPS station from the tide gauge by distances as great as 1 km, provided that frequent first-order leveling ties are performed. In some settings the leveling ties should be performed several times during the first year to ensure that annual cycles of deformation affecting any large structures supporting the gauge (or the GPS antenna) are not going undetected or being misunderstood due to aliasing. Additionally these surveys should be performed throughout the lifetime of the observation program to ensure that slower (but not necessarily steady) secular movements will be adequately characterized. The larger the separation of the GPS station and the tide gauge, the more difficult and expensive the leveling program will be, and the more likely it will not be executed properly throughout the lifetime of the program. The inconvenience of frequent leveling should be contemplated very carefully before one abandons the idea of putting the GPS station very close to the tide gauge.

It will rarely be acceptable to separate the tide gauge and the GPS antenna by more than a few meters when one is pursuing the millimeter agenda. The only exception to this would be when both the tide gauge and the GPS station were being installed in a single massive outcrop of competent and locally rigid rock. Under these circumstances one could separate the tide gauge and the GPS antenna by a few tens of meters.

Suppose the oceanographic agenda in a given region could be satisfied by adding a CGPS station either to tide gauge A or tide gauge B. Suppose gauge A is built on a solid rock outcrop in an area with minimal human impact, and it will be possible to build a monument that couples the GPS antenna to the rock substrate just a few meters from the tide gauge. Suppose that tide gauge B is located on a harbor wall at the base of a large building. The nearest place with a good sky view is over a kilometer away and this place, the tide gauge, and the road between them overlie a sedimentary basin, which includes a heavily pumped aquifer. It would be unreasonable to select B over A even if the location of B made it slightly preferable for purely oceanographic reasons.

The selection of tide gauges for GPS augmentation must involve some sort of compromise between oceanographic and geodetic requirements. The higher the positioning accuracy required, the more weight must be placed on the environmental and geodetic suitability of the site. We must be very careful when we determine whether we are pursuing the centimeter or the millimeter agenda at a given site. If the geodesists hear one or two oceanographers say that their primary interest is the centimeter agenda then it is naturally tempting to settle on that goal, since it makes it much more likely that the proposed site can be considered suitable, and because the standards for installation will be more lax and therefore easier to achieve. However, in many cases, stations built to this standard will not be suitable for pursuing the millimeter agenda. So if the oceanographers change their minds about the precision levels they seek to attain, then much of early work on CGPS positioning of tide gauges will subsequently be viewed as substandard. This prospect is particularly worrying given the history of upwards creeping accuracy requirements in almost every application of GPS geodesy.

3 The Writing of Standards for CGPS Installations at Tide Gauges

The above discussion should make clear that the writing of standards for CGPS installations at tide gauges is more involved than most members of our technical committee first realized. Nevertheless we are working on a document which is based both on multidisciplinary discussions, and on experience gained during past installations.

The University of Hawaii is one of several groups working in this area. Our effort is a collaboration between the Pacific GPS Facility led by the author, and by the UH Sea Level Center led by Mark Merrifield, another member of the technical committee. Our first project, begun last year, was the installation of a CGPS station at the Honolulu Tide Gauge. This dataset is freely available on a daily basis. We are presently engaged in selecting another six tide gauges for GPS augmentation. Early site selection studies indicate that almost every station will be a special case! We will be documenting each project as it occurs, and will make this information available on the web. We hope that other groups will be doing this too. Hopefully we will be able to refer to these websites in the IGS/PSMSL standards document, so that specific cases can be made to serve as illustrations of the general requirements associated with CGPS positioning of tide gauges.

4 Data Processing and the Role of the IGS

By the beginning of the year 2000 we expect that 15 - 25 tide gauges around the world will have been retrofitted with CGPS stations. These data will be made available to the IGS via one or more data centers. The IGS needs to consider now what mechanisms need to be established to ensure that these data are processed in an optimum manner. We must keep in mind that, initially at least, most of these stations will not be reporting within a few days of real-time. Thus the processing streams associated with IGS orbit production are not relevant to this agenda. Additionally, because many tide gauges are built on relatively unstable structures, these new CGPS stations may not be of much interest to geodetic groups already engaged in ITRF densification efforts if their primary motivation is crustal motion research. Who is going to be responsible for this new processing effort? And who is going to pay for it?

5 Getting Involved

Anyone wishing to join the IGS/PSMSL technical committee on CGPS positioning of tide gauges, and/or participate in our email discussions, should send an email message to bevis@soest.hawaii.edu.

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