IGS

INTERNATIONAL GPS SERVICE FOR GEODYNAMICS

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IGS Central Bureau

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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 third annual report of the IGS.

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Preface

Reiner Rummel

President of Section II, *Advanced Space Technology*,
of the International Association of Geodesy (IAG)

The 1996 volume is the third Annual Report of the International GPS Service for Geodynamics (IGS). Again it provides the participating parties and the users with all-important information on the structure of IGS and on the current status and prospects of the work of IGS. It is also the record of a success story. In operation since 1994, IGS is the youngest of the services of the International Association of Geodesy (IAG). It is certainly one of its most successful and, considering the wide range of applications and the large number of users, it is by far the most popular. With its successful work, IGS has placed itself in the center of all current and future scientific uses of GPS.

The 145 stations of the IGS form one global, rather dense polyhedron spanning the entire globe. Its extreme precision allows us to see plates moving; crusts subsiding, rising, and deforming; glaciers moving; and Earth as a whole pulsating under the tidal forces of Sun, Moon, and planets. Connection with tide gauges reveals sea-level changes in their global context and permits separation of sea-level rise from crustal movements. In other words, the IGS network constitutes a unique global geodynamic observatory. An equally important second element are the ephemerides of the GPS satellites, provided almost in real time and with incredible precision (and now even in *real time*, albeit with somewhat reduced precision). The satellites form a second geometric configuration, tied to the terrestrial frame (ITRF) as well as to the celestial frame (ICRF). This connection results in an important temporal densification of the Earth rotation time series, which serves meanwhile as a standard part of the Earth rotation parameters distributed by the International Earth Rotation Service (IERS). Thirdly, the vertices of the two geometric configurations, the GPS satellites on the one hand and ground stations on the other, are uninterruptedly connected by thousands and thousands of rays, densely and almost evenly probing both in space and time the atmospheric layer between them. This makes a perfect laboratory for monitoring and research of the troposphere, atmosphere, and ionosphere. The same web of connections also permits ultraprecise time-of-frequency transfer. Finally, all of the three projected gravity field mapping missions—a Challenging Micro-Satellite Payload for Geophysical Research and

Applications (CHAMP), Gravity Recovery and Climate Experiment (GRACE), and gravity field and steady-state ocean circulation (GOCE)—will rely on IGS for the implementation of the high-precision satellite-to-satellite range-rate determination between the low-orbiting spacecraft and the GPS satellites. One should be aware that this high–low link is the backbone of future precise long-wavelength gravity-field modeling.

There seems no end to the uninterrupted flow of new ideas concerning further applications of GPS to Earth sciences, and IGS will have to guard against an overload of obligations. Already it seems almost a miracle that on a purely voluntary basis, so many parties (the network of stations, Governing Board, global data centers, analysis centers, associated analysis centers, analysis center coordinator and Central Bureau) continue to cooperate so smoothly, so productively, and so successfully.

On behalf of IAG, sincere thanks and congratulations go to all who contribute to this success.

IGS

GENERAL ASPECTS OF THE IGS

International GPS Service for Geodynamics: Terms of Reference

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

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

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

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

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

- realization of global accessibility to and the improvement of the International 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.

The IGS accomplishes its mission through the following components:

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

1 Networks of Tracking Stations

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

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

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

2 Data Centers

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

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

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

The Global Data Centers are the main interfaces to the Analysis Centers and the outside user community. Their primary tasks include the following:

- receive/retrieve, archive and provide on line access to tracking data received from the Operational/Regional Data Centers
- provide on-line access to ancillary information, such as site information, occupation histories, etc.,
- receive/retrieve, archive and provide on-line access to IGS products received from the Analysis Centers
- backup and secure IGS data and products.

3 Analysis Centers

The analysis centers fall into two categories: Analysis Centers and Associate Analysis Centers.

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

The Analysis Centers provide as a minimum, ephemeris information and earth rotation parameters on a weekly basis, as well as other products, such as coordinates, on a quarterly basis. The Analysis Centers forward their products to the Global Data Centers.

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

4 Analysis Coordinator

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

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

5 Central Bureau

The Central Bureau (CB) is responsible for the general management of the IGS consistent with the directives and policies set by the Governing Board. The primary functions of the CB are to facilitate communications, coordinate IGS activities, establish and promote compliance to IGS network standards, monitor network operations and quality assurance of data, maintain documentation, and organize reports, meetings and workshops, and insure the 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.

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

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

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

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

6 Governing Board

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

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

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

The election for each position is by the number of nominations received from the relevant IGS component, i.e., from the networks (for this purpose organizations operating two or more Global Stations are considered a network), from the Analysis Centers and from the Data Centers. In case of a tie, the election is by the members of the Governing Board and the IGS Associate Members (see below) by a simple majority of votes received. The election will be conducted by a nominating committee of three members, the chair of which will be appointed by the Chair of the IGS Governing Board.

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

The IAG/FAGS representative is appointed by the IAG Bureau (or by FAGS) for a maximum of two four-year terms. Members of the GB become IAG Fellows with the appropriate rights and privileges after an initial two-year period.

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

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

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

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

7 IGS Associate Members

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

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

IGS Associate Members are considered IAG Affiliates with the appropriate rights and privileges.

8 IGS Correspondents

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

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

The Year 1996 in Retrospect as Seen From the IGS Governing Board

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1 IGS Events in 1996 in Overview

1996 was the third year of official IGS operations; consequently, this short overview is part of the third IGS Annual Report. After all the rapid developments that took place since June 21, 1992 (the start of the 1992 IGS Test Campaign), one would expect business as usual in the IGS, at last! In a certain sense, the answer is yes indeed, business as usual: The IGS is, as it has been since 1992, in rapid evolution. It seems that more and more information of the greatest value to Earth sciences can be extracted from the IGS network.

Let us quickly browse through the IGS events in 1996 in this introductory section and address three aspects in some detail in the subsequent sections. The essential IGS-related events in 1996 are summarized in Table 1.

Table 1: IGS Events in 1996

Date	Event
January 11	Call for Participation for RNAACs in the IGS Mail Message No. 1178
March 19	IGS Analysis Center Workshop in Silver Spring
June 30	Essential Changes in IGS Processing
June 30	IGS Pilot Project on the Densification of the ITRF using Regional GPS Networks includes RNAAC results
July 23	Western Pacific Geophysics Meeting
September 1	1995 IGS Annual Report available!
October 16	Sixth IGS Governing Board Meeting in Paris
December 17	Business Meeting of the IGS Governing Board Meeting in San Francisco

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

- IGS message No. 1178 (dated January 11, 1996) brought a Call for Participation for Regional Network Associate Analysis Centers (RNAACs).

- IGS message No. 1266 (dated March 29, 1996) contains a report about the 1996 IGS Analysis Center Workshop in Silver Spring, Maryland, and a summary of the associated Business Meeting of the IGS Governing Board. The same report was also included as “Executive Summary” in Reference [1].

- IGS message No. 1475 (dated November 12, 1996) is a summary of the Sixth Governing Board Meeting of the IGS in Paris on October 16, 1996.

The present report covering the year 1996 is based on the above IGS messages, on the Proceedings of the 1996 IGS Analysis Center Workshop [1], on a contribution prepared for the U.S. National Research Council Workshop on Improving the DGPS Infrastructure for Earth and Atmospheric Science Applications in Boulder, March 1996, and on the IGS presentations given at the Western Pacific Geophysical Meeting in Brisbane in July 1996.

Let us start the overview with the remark that the IGS network was again growing considerably in 1996. We mention in particular the stations Ascension Island, Cocos Island, Diego Garcia, Kwajalein Atoll, Lintong (XIAN), and Mauna Kea that became available in the equatorial region and in the Southern Hemisphere; this led to a much better global distribution of stations in the IGS network.

On January 11, the *Call for Participation* for RNAACs was sent through IGS mail. This was done after a successful initial phase of the IGS Pilot Project Densification of the ITRF using GPS, where only the IGS Analysis Centers delivered their coordinates in the required format [2,3].

The 1996 Analysis Center Workshop was extremely fruitful and interesting, but it also created a lot of work for the IGS Analysis Centers in spring 1996. Many changes in processing making IGS analyses more coherent were agreed upon at the workshop and had to be implemented by the Analysis Centers by Sunday, June 30, 1996, the first day of GPS week 860. If we look at the IGS products, we learn from the Analysis Center Coordinator Report that the data and product quality stayed in 1996 on the same high level as that in 1995 (or was even slightly better) and that the consistency between Analysis Centers could again be improved. The essential progress in 1996 in the analysis, however, may be seen in the earlier availability of products of highest quality and reliability, i.e., in the redefinition of Rapid and Final IGS Products. Final Products are now available with a delay of only 11 days (previously a few months) and Rapid Products within 23 hours (previously within 11 days)—quantum jumps indeed. These aspects are dealt with in detail in [4], but they are outstanding and must be mentioned here. More aspects of the 1996 IGS Analysis Center Workshop will be reviewed in Section 3.

The IGS was invited to participate in the Western Pacific Geophysical Meeting, which took place in Brisbane in 1996. A delegation of the IGS Governing Board consisting of Ruth Neilan, Director of the IGS Central Bureau; Bill Melbourne, IGS Coordinator for the IERS; and Gerhard Beutler, Chairman of the IGS, accepted this invitation with greatest pleasure. As one may see from Table 2, there was also a meeting organized in Canberra by John Manning from AUSLIG, IGS Governing Board Member since January 1, 1996. IGS-related topics, in particular those concerning Australia and Southeast Asia, were discussed at this meeting. The IGS delegation thanked AUSLIG for making openly available many of the Australian sites to the IGS. They contribute in a very significant way to the quality of the IGS products.

Table 2: Presentations/Events in 1996 on behalf of the IGS

Month	Presentation/Event	Presenter/Organizer
March	National Academy of Sciences, Colorado; DGPS Infrastructure	G. Beutler, J. Kouba, R. E. Neilan, C. Noll
April	American Congress on Surveying and Mapping	R. E. Neilan, J. Zumberge, M. Watkins, M. Heflin
May	Asian Pacific Space Geodynamics Workshop, Shanghai, China	R. E. Neilan
May	IGS Booth at AGU Spring Meeting, Baltimore	R. E. Neilan, P. Van Scoy
July	Delegation of the IGS Governing Board at AUSLIG, Canberra, Australia	G. Beutler, R. E. Neilan, B. Melbourne
July	Western Pacific Geophysical Meeting; Invited Presentation and Splinter Meeting; IGS Exhibit Booth, Brisbane, Australia	G. Beutler, J. Kouba, R. E. Neilan, P. Van Scoy
October	Invited Presentation about IGS Densification Project at CSTG Workshop in Paris	G. Blewitt
November	NASA Concluding Dynamics of Solid Earth	R. Neilan
December	IGS Booth at AGU Fall Meeting	R. E. Neilan, P. Van Scoy

The IGS Annual Report for 1995 became available in September 1996 (three months earlier in the year than the preceding Annual Report). The format slightly differed from that of the Annual Report for 1994, but again the result was most satisfactory. The IGS Governing Board at its October meeting in Paris in asked the Chairman and Ruth Neilan to congratulate Jim Zumberge and his team from the IGS Central Bureau for the excellent editorial work.

The Sixth Meeting of the IGS Governing Board was attached to the 1996 IERS Workshop in Paris. It will be discussed together with the Business Meeting of the IGS in San Francisco in Section 4.

2 Densification of the ITRF

Let us briefly recall the development of the IGS Pilot Project Densification of the ITRF using the GPS. The theoretical foundations for this project were developed at the IGS Workshop in Pasadena, in December 1994 [5]. The project was introduced in the 1994 IGS Annual Report [6], and the state of the project at the end of 1995 was discussed in the 1995 IGS Annual Report by Kouba [2]. The topic is again addressed by the same author in this Annual Report [3]. Therefore, we only give a short summary here.

- The project officially started on September 3, 1995, the first day of GPS week 817. The project was originally planned to last for one calendar year. Several delays required a continuation at least until mid-1997.

- In the first phase of the project, which lasted until mid-1996, the seven IGS Analysis Centers (ACs)—COD, EMR, ESA, GFZ, JPL, NGS, and SIO—produced so-called free network solutions, which may subsequently be combined into a unified IGS coordinate solution. The AC contributions are in the SINEX format and are delivered at weekly intervals.

- Three IGS Global Network Associate Analysis Centers (GNAACs) combine the individual contributions every week:

  Jet Propulsion Laboratory (JPL) with Mike Heflin.

  Massachusetts Institute of Technology (MIT) with Tom Herring.

  University of Newcastle (NCL) with Geoff Blewitt and Phil Davies.

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

- The response to the *Call for Participation* was most encouraging. Today the following institutions are contributing solutions as RNAACs on a weekly basis:

—AUS: Australian Surveying and Land Information Group (AUSLIG)

—EUR: EUREF–Solution (EUREF Subcommission of IAG) with the following contributors:

ASI: Nuova Telespazio S.p.A., Space Geodesy Center.

BEK: International Commission for Global Geodesy of the Bavarian Academy of Sciences (BEK).

COE: European solution created at Center for Orbit Determination in Europe (CODE).

GOP: Geodetic Observatory Pecny, Czech Republic.

IFG: Institute for Applied Geodesy in Germany (IfAG).

LPT: Bundesamt für Landestopographie (L+T), Switzerland.

NKG: Nordic Geodetic Commission (NKG).

OLG: Observatory Lustbuehel Graz (OLG).

ROB: Royal Observatory of Belgium (ROB).

WUT: Warsaw University of Technology (WUT).

—GIA: Geophysical Institute / University of Alaska, Fairbanks.

—GSI: Geographical Survey Institute, Japan.

—PGC: Natural Resources Canada / Pacific Geoscience Centre, Canada.

—SIR: SIRGAS Solution prepared by the Deutsches Geodaetisches Forschungsinstitut, Abt.I (DGFI/I).

- The solutions prepared by these RNAACs are combined into weekly solutions by the above mentioned GNAACs, the result being weekly coordinate sets in the best possible IGS realization of the ITRF.

- The results of the three GNAACs are in turn analyzed by the IGS Analysis Center Coordinator (for more information, refer to [3]).

3 The IGS Analysis Center Workshop in Silver Spring

The 1996 IGS Analysis Center Workshop took place on March 19–21, 1996, in Silver Spring, Maryland. Gerry Mader and Jan Kouba who organized this meeting arranged it as a real workshop. The setup was perfect to focus the discussion and everybody enjoyed a very fruitful three days at the NOAA facilities. On Friday, March 22, a business meeting of the IGS Governing Board with the session chairs as guests was organized with the goal of producing the appropriate action items.

Each topic was introduced by a position paper prepared by the session chair persons. The following topics were addressed:

- Orbit/clock combination (chair Kouba/Beutler).
- Earth orientation (chair Ray/McCarthy).
- Antenna calibration (chair Mader/Rothacher).
- SINEX, densification of the ITRF using the GPS (chair Blewitt).
- Receiver standards and performance (chair Zumberge/Gurtner).
- Atmospheric topics (chair Feltens/Gendt).

The position papers were available before the beginning of the workshop. The proceedings of the workshop, including an executive summary, all position papers, all resolutions, and many interesting individual contributions are available through the IGS Central Bureau [1]. Therefore, we confine ourselves to a few remarks concerning the resolutions (pages xxiii–xxvi of the proceedings).

Even in retrospect, it is amazing to see how well the workshop did focus on IGS Analysis Center issues and what impact it had on the IGS. Most of the recommendations were actually followed by the IGS Analysis Centers. It should be mentioned that the Analysis Center Coordinator could not participate personally in the workshop; at times I had the impression that this fact made it easier for the workshop participants to go for the grand design without thinking too much about the work involved because they exactly knew that Jan Kouba would supervise the implementation process after the workshop and raise the flag if unhealthy developments had to be avoided—which is exactly what happened between the workshop and Sunday, June 30, 1996 (first day of GPS week 860).

- ***Orbit-related resolutions:*** Five recommendations emerged from the orbit session. The ACs were, e.g., urged to improve their orbit modeling (using stochastic or once per revolution techniques). It was decided to use the latest realization of the ITRF made available by the IERS, and that the deadlines for the final and the rapid products be shifted to 11 days and 23 hours, respectively. The new mode of operations were intended to start on June 30, 1996, which is what actually happened.

- ***Resolutions related to Earth orientation parameters (EOPs):*** All in all, six resolutions emerged from very fruitful discussions of IERS and IGS "exponents." The Analysis Centers were urged to adopt (to the extent possible) the IERS Conventions 1996 [7], to meticulously describe their models, to estimate EOP drifts, and to apply the subdaily EOP model as developed by Richard Ray. The users of IGS products were recommended to use the IGS combined EOP series, and, last but not least, the IGS AC Coordinator was asked to devise a method to combine submitted LOD/UT1 results to perform a preliminary UT1–UTC estimate.

- ***Phase-center-related resolutions:*** It was recommended that a small group consisting of Gerry Mader, Markus Rothacher, and Chuck Meertens put together two sets of phase center calibration corrections for all available receiver/antenna combinations (a "mean" offset file and an elevation-dependent phase center correction file relative to the Dorne Margolin T antenna). These files were made available and have been in use since June 30, 1996, not only by the IGS Analysis centers, but also by the IGS and other users.

- ***Resolutions related to the Pilot Project on the Densification of the ITRF:*** The resolutions were mostly related to modifications of the SINEX format and to preparations for the second phase of the project including RNAACs.

- ***Network-related resolutions:*** In view of the shifting IGS product deadlines, data delivery deadlines had to be adapted. It also seemed advisable to prepare a list of stations, which should be made available as quickly as possible. The need to implement a network monitoring tool was emphasized and declared a Central Bureau Activity. A new compression algorithm developed by Dr. Hatanaka was recognized as extremely interesting for the IGS and extensive tests were recommended. These tests actually were successful and will hopefully lead to the implementation of this new compression procedure some time in 1997.

- ***Atmosphere-related resolutions:*** The IGS sites were urged to install high-accuracy MET stations with given specifications. Starting by the end of 1996, the Analysis Centers should make available total zenith path delays with a resolution of at least 2 hours. GFZ–Potsdam volunteered to act as an Associate Analysis Center comparing and combining these files.

Ionosphere activities focused on a 5-week test campaign. A data format called IONEX is under development. This activity includes also institutions newly contributing to the IGS, e.g., University of New Brunswick, Canada, and DLR Germany.

The Governing Board considered the IGS AC Workshop in Silver Spring as extremely fruitful and recommends the format for future IGS AC Workshops.

4 The Sixth IGS Governing Board Meeting in Paris

The sixth meeting of the IGS Governing Board took place on Wednesday, October 16, 1996 at the Observatoire de Paris, France. The meeting was attached to the 1996 IERS Workshop. A full report covering this event was distributed through IGS mail (IGS message No. 1475, dated November 12, 1996). This allows us to focus in this overview on a few important aspects, only.

4.1 IGS as a FAGS Service

Some time ago, the IGS applied to become an official FAGS Service (Federation of Astronomical and Geophysical Data Analysis Services). In a letter dated May 10, 1996, the IGS was informed that the FAGS Council, at its meeting on April 22, 1996, in London, had decided to give FAGS recognition to the IGS beginning with January 1, 1996.

In the same letter we were informed that Dr. David Pugh of the Southampton Oceanographic Centre was designated as the FAGS representative to the IGS Governing Board. This created a minor problem, because, according to the IGS Terms of Reference, there is just one slot for an IAG/FAGS representative on the IGS Governing Board. It is well known that Prof. Ivan I. Mueller was appointed by IAG at the IUGG General Assembly in Boulder, Colorado, 1995, to fill this position for the time period 1995–1999. The problem was solved with a motion by the Board to consider both Ivan I. Mueller and David Pugh as Governing Board members until 1999, when IAG/FAGS will delegate only one person to the IGS Governing Board. The IGS Governing Board unanimously approved this motion, increasing the number of Board members for this period by one. The Governing Board thanked Ivan I. Mueller for being willing to continue serving on the IGS Governing Board.

4.2 Elections in 1997

In order to have a good blend of both continuity and new ideas, the elected IGS Board members were given staggered terms, which is why elections must be organized every 2 years. The next elections will be organized in 1997 for those members whose terms start on January 1, 1998. In addition, the Chairman reminded the Board that his term will elapse on December 31, 1997, and that (due to other commitments) he is not available for a second term.

According to the IGS Terms of Reference, the elections of the Governing Board members and of the Chairperson will be conducted by a nominating committee of three members, the chair of which is appointed by the Chair of the IGS Governing Board. This appointment took place at the IGS Business Meeting on December 17, 1996, in San Francisco. The Chairman asked Ivan I. Mueller to organize the elections in 1997.

4.3 IGS Involvement in LEO Tracking

With a letter dated July 2, 1996 John Labrecque from NASA Headquarters asked the IGS Governing Board to review and identify its position with respect to supporting GPS receivers on low Earth orbiters.

The request was passed on in July from the Governing Board to the (already existing) working group consisting of Bill Melbourne, John Dow and Chris Reigber, asking it to come up with a position paper for the sixth Governing Board Meeting. This team, together with Mike Watkins and John Labrecque, came up with a document called *IGS White Paper on Low Earth Orbiting GPS*. When reading this paper it becomes crystal clear that spaceborne applications of the GPS will become rather common in future and that the scientific implications, within and outside the scope of Space Geodesy, are remarkable.

The white paper concluded by asking the IGS to consider:

- Broadening participation within the IGS and its Governing Board to include atmospheric and navigation agencies and institutions.
- Encouraging enhancement of the IGS constituent facilities, including the IGS Global Network, the Analysis Centers, and the Data Centers, to provide optimum support to space-based applications.
- Encouraging participants of the various groups developing satellites to carry the appropriate GPS receiver hardware.
- Encouraging development of GPS occultation science through such activities as workshops, and the development of standards, data exchange formats, and data policy.

The IGS white paper was discussed at length at the GB Meeting. Short statements by those Analysis Center representatives present at the Board Meeting revealed that there indeed is great interest in spaceborne applications. The general opinion within the Board clearly favors at least some of the developments recommended above.

On the other hand, it was recognized that such developments are a major undertaking and that there is a lot of work involved for the existing IGS structures, which are under considerable pressure already. It was therefore decided that the paper should first be made available to the key IGS components (such as Data Centers and Analysis Centers) and that specific questions should be asked (e.g., the level of anticipated involvement, etc.). The topic should then be brought on the agenda (perhaps within one or two sessions) at the next IGS Analysis Center Workshop (spring 1997). Based on the feedback from the IGS components and on the outcome of the next IGS workshop the Governing Board should be in a position to get a clearer picture, of not only the policy to follow, but also of the next concrete steps to be taken in this field of GPS applications.

Epilogue: At the IGS Business meeting on December 17, 1996, in San Francisco, it was decided to devote a major part of the 1997 IGS Workshop in Pasadena to this topic. The outcome of this workshop will be discussed in the next IGS Annual Report!

5 Acknowledgments

The IGS Governing Board was extremely pleased by the progress made during the year 1996. This statement implies that in essence all components of our service are in good shape. This is probably also due to the presentations given and the meetings organized (Table 2) with the goal of making the scientific world aware of the existence and the achievements of the IGS.

Unanimously, the IGS Central Bureau was congratulated for the preparation of the IGS Annual Report 1995, which became available in September 1996. It is considered an extremely informative document about the IGS and deserves a wide distribution.

The permanent friendly competition between IGS Analysis Centers continued in 1996 and provided the basis for the very successful work of IGS Analysis Center Coordinator Jan Kouba and his team, which provided every week highly accurate, reliable, and, since June 30, 1996, very timely official IGS products.

The Governing Board wishes to express its gratitude to the operators of the IGS network, to the IGS data centers on all levels, and to all individuals and institutions sacrificing considerable parts of their working power to the IGS. The strength of the IGS relies on these voluntary contributions. Let us conclude by expressing the hope that the same kind of support will be given in future, too.

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IGS Organization and the International Tracking Network

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1 Overview

With the close of 1996, the IGS successfully completed its third year of full operation as an international service; this does not mean, however, that all business is routine—quite the contrary. While many people expect the IGS to reach steady-state activity, this was certainly not the case in 1996. This was another busy year for the IGS, which added new activities as just outlined in Beutler's contribution to this volume. These activities include the improvement of the analysis techniques as described by Kouba and Mireault (also in this volume), particularly the changes implemented in June 1996 for the rapid orbits and orbit improvement; the densification of the ITRF through combination of GPS solutions (see the Associate Analysis Centers section in this volume); the question of IGS role or involvement in low Earth-orbiting (LEO) satellite missions; and IGS support for monitoring sea level rise at coastal margins; these were some areas of expanding effort in 1996.

A key achievement of the IGS was its designation as a service of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS).

2 Description of the IGS Organization

The organization of the IGS[1] is depicted in Figure 1. The GPS stations shown below the GPS satellites in this figure are permanently installed and operate

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[1] The 1994 Annual Report of the IGS, available from the Central Bureau, describes in greater detail the fundamental organization of the IGS and describes the evolution of the GPS tracking network into the current IGS network.

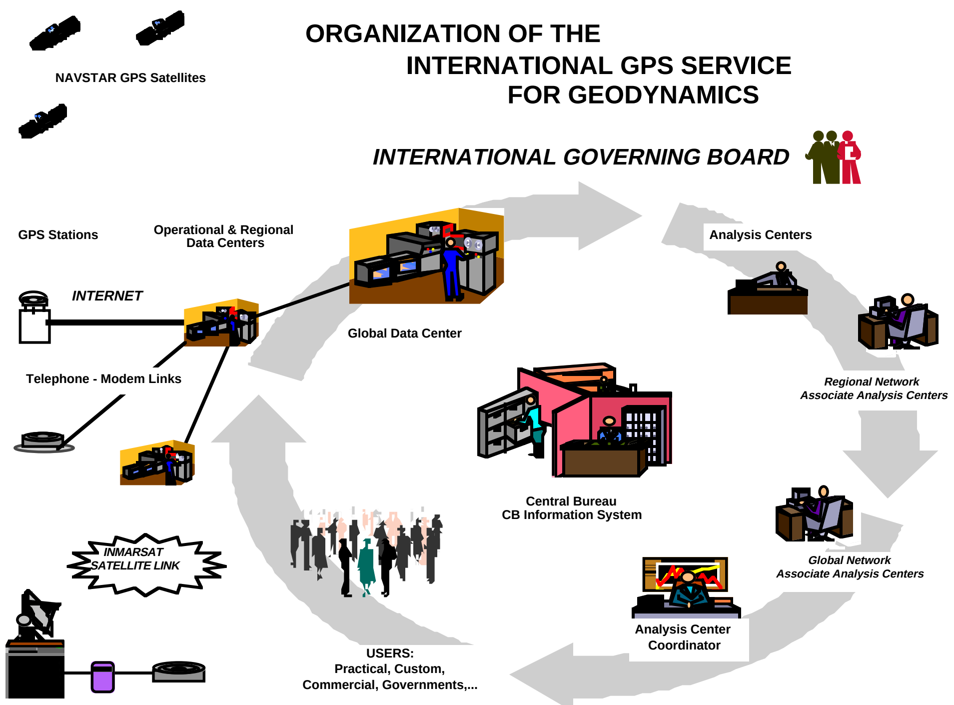


Figure 1: An organizational diagram of the IGS

continuously, receiving and recording the L-band, dual-frequency signals transmitted by the satellites. The map of the IGS network of tracking stations is shown in Figure 2. The station data are accessed by Operational Data Centers through various communication schemes, including Internet, telephone, INMARSAT, radio modem, and V-SAT.

The Operational Data Centers, such as those listed in Table 1, operate subnetworks of the IGS. These Operational Centers monitor and validate the data, format the data according to standards, and forward the data sets to the Regional (Table 2) or Global Data Centers (Table 3). Details on the IGS data flow can be found in Noll and Daniel in the Data Center Reports section of this volume. The IGS Analysis Centers (Table 4) retrieve the data sets from the Global Data Centers. Each center then performs analysis to produce GPS ephemerides, station coordinates, and Earth rotation parameters. These products are then sent to the Analysis Center Coordinator who uses an orbit combination technique to produce the official IGS orbits (the rapid orbit is available on a daily basis, and the final orbit is available with a delay of approximately 8 to 10 days and based on weekly inputs). The Analysis Center coordinator since 1993 is Dr. Jan Kouba at NRCan in Canada. The products generated are sent back to the Global Data Centers and to the Central Bureau Information System (CBIS), where they are archived and accessible to users. The Central Bureau is responsible for the overall coordination and management of the service and is located at NASA's Jet Propulsion Laboratory, which is operated for NASA by the California

Institute of Technology. The International Governing Board is the oversight body that determines the activities and directions of the IGS.

GPS TRACKING NETWORK
International GPS Service for Geodynamics

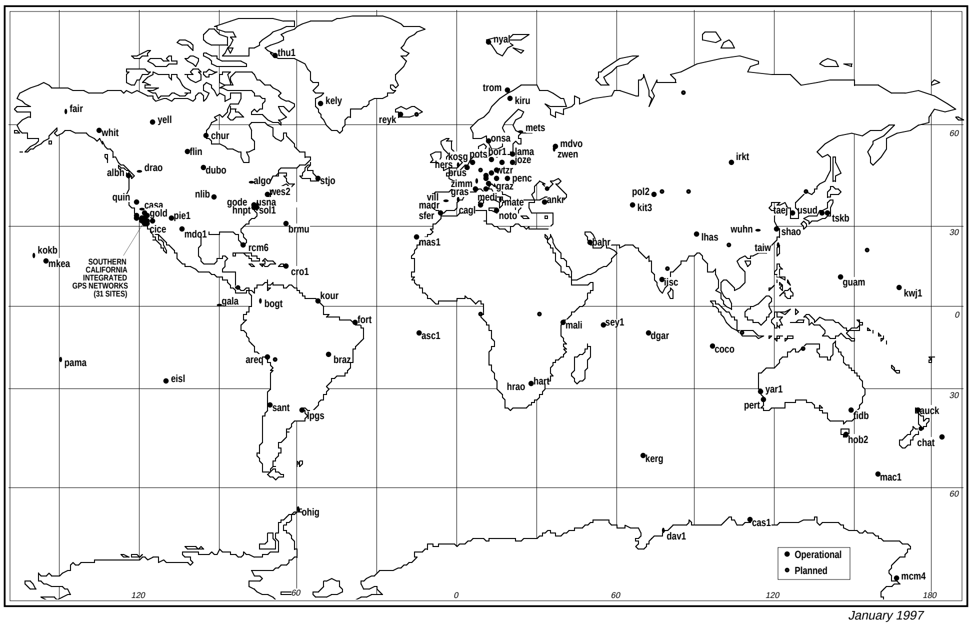


Figure 2: Operational Stations of the IGS GPS Tracking Network at the end of 1996

Table 1: IGS Operational Data Centers

Operational Data Center	Location	Country
Australian Land Information Group	Canberra	Australia
Centre National d'Etudes Spatiales	Toulouse	France
Delft University of Technology	Delft	Netherlands
European Space Operations Center	Darmstadt	Germany
GeoForschungZentrum	Potsdam	Germany
Geographical Survey Institute	Tsukuba	Japan
Geosciences Research Lab /NOAA	Silver Spring	USA
Institute for Space Research	Graz	Austria
Italian Space Agency	Matera	Italy
Jet Propulsion Laboratory	Pasadena	USA
Korean Astronomical Observatory	Taejon	Korea
National Imaging and Mapping Agency	Washington D.C.	USA
Natural Resources Canada	Ottawa and Sidney	Canada
Scripps Institution of Oceanography	San Diego	USA
Norwegian Mapping Authority	Honefoss	Norway
University NAVSTAR Consortium	Boulder	USA

Table 2: IGS Regional Data Centers

Regional Data Center	Location	Country
Australian Land Information Group	Canberra	Australia
Jet Propulsion Laboratory	Pasadena	USA
Institut für Angewandte Geodäsie	Frankfurt	Germany
Natural Resources Canada	Ottawa	Canada
Geosciences Research Lab/NOAA	Silver Spring	USA

Table 3: IGS Global Data Centers

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

Table 4: The Seven Analysis Centers of the IGS

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

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

Associate Analysis Centers produce unique products within the IGS. The highly successful Pilot Project for the Densification of the ITRF reference frame using the IGS network officially began in September of 1995 (see the Associate Analysis Center Reports in this volume for activity reports). This project is designed as a proof of concept for distributed processing of GPS data from many stations and relies on the Global Network Associate Analysis Centers (GNAACs, Table 5) for a rigorous combination of results submitted by IGS Analysis Centers and the Regional Network Associate Analysis Centers (RNAACs). This combination of solutions produces precise station locations and velocities in a consistent reference frame. The Call for Participation at the regional level was announced in January 1996, and Table 6 lists those groups participating in this project. It is of interest to note that EUREF, the Subcommission for Europe within the

International Association of Geodesy (IAG), Commission X on Global and Regional Geodetic Networks, is an RNAAC combining a number of solutions from various RNAACs within Europe and then passing this regionally combined solution on to the GNAACs. Additional detailed information can also be found in the IGS Reports series on the CBIS.

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

Table 5: GNAACs for the Densification of the Global Reference Frame

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

Table 6: RNAACs for the Densification of the Terrestrial Reference Frame

RNAAC	Country
Geographical Survey Institute of Japan	Japan
Geophysical Institute of the University of Alaska	USA
EUREF - IAG Commission X - Global and Regional Geodetic Networks, Subcommission for Europe (European Coordinating RNAAC):	Europe
Bundesamt für Landestopographie (L+T)	Switzerland
Center for Orbit Determination in Europe	Switzerland
Geodetic Observatory Pecny	Czech Republic
Institute for Applied Geodesy (IfAG)	Germany
International Commission for Global Geodesy of the Bavarian Academy of Sciences	Germany
Nordic Geodetic Commission	Scandinavia
Nuova Telespazio S.p.A., Space Geodesy Center	Italy
Observatory Lustbuehel Graz	Austria
Royal Observatory of Belgium	Belgium
Warsaw University of Technology	Poland
SIRGAS, Deutsches Geodätisches Forschungsinstitut	Germany
Onsala Space Observatory	Sweden
Pacific Geosciences Centre	Canada

4 Governing Board Changes in 1996

A few key changes occurred in the membership of the Governing Board (Table 7). In May 1996 at the IERS Directing Board meeting, a decision was made for Claude Boucher to replace Martine Feissel as the IERS representative to the IGS as reflection of the major role that terrestrial frame issues have in the cooperation of the two services. Martine's influence and contribution within the Governing Board is noted with appreciation. Claude will assume service on the Governing Board as representative of the IERS/ITRF.

As mentioned above, the IGS was approved as a service of the Federation of Astronomical and Geophysical Data Analysis Services (FAGS). When a service is selected to become a FAGS service, the FAGS council appoints a designated representative to sit on the service's governing board. The FAGS council appointed David Pugh from the Southampton Oceanography Center to the IGS Governing Board. David Pugh has much experience working with the International Association for the Physical Sciences of the Ocean (IAPSO), the Permanent Service for Mean Sea Level, and the Global Sea Level Observing Systems (GLOSS), and is warmly welcomed onto the Governing Board.

Within the Terms of Reference of the IGS—the bylaws that govern the organization of the IGS—there is to be one representative appointed to the Governing Board from either FAGS or the IAG. In this case, the IAG had already appointed Ivan Mueller as its representative in 1995 for a 4-year term. When David Pugh was then appointed by FAGS in 1996, this created a situation outside the scope of the Terms of Reference. In this instance, the Governing Board unanimously approved a motion at the October meeting to increase its membership by one, through 1999, and thus permit Ivan Mueller to complete his term of representation on behalf of the IAG.

Table 7: The IGS Governing Board Members, current and former

Name	Country Institution	Functions	Term
Gerhard Beutler	Switzerland University of Bern	Chair, Appointed (IAG/CSTG)	4 years[a]
Geoff Blewitt	UK University of NewCastle upon Tyne	Analysis Center Rep.	2 years[a]
Yehuda Bock	USA Scripps Institution of Oceanography	Analysis Center Rep.	4 years[a]
John Dow	Germany ESA/European Operations Center	Network Rep.	4 years[a]
Bjorn Engen	Norway Statens Kartverk	Network Rep.	4 years[b]
Claude Boucher	France Institut Geographique National	IERS Rep.	—
Jan Kouba	Canada Natural Resources Canada	Analysis Coordinator	4 years[a]
Gerry Mader	USA GRDL, National Oceanic and Atmospheric Administration	Appointed (IGS)	2 years[a]

Table 7: (continued)

Name	Country Institution	Functions	Term
John Manning	Australia Australian Survey and Land Information Group	Appointed (IGS)	4 years[a]
Bill Melbourne	USA Jet Propulsion Laboratory	IGS Rep. to IERS	—
Ivan Mueller	USA Ohio State University	IAG Rep.	
Ruth Neilan	USA Jet Propulsion Laboratory	Director, Central Bureau	—
Carey Noll	USA Goddard Space Flight Center	Data Center Rep.	4 years[b]
David Pugh	UK Southampton Oceanography Center	Appointed (FAGS)	—
Christoph Reigber	Germany GeoForschungsZentrum	Appointed (IGS)	4 years[a]
Bob Schutz	USA CSR, University of Texas-Austin	Appointed (IGS)	2 years[a]
Martine Feissel	France International Earth Rotation Service	Former Member	'94-'95
Teruyuki Kato	Japan ERI, University of Tokyo	Former Member	'94-'95

[a]Terms beginning in January 1, 1996
[b]Terms beginning January 1, 1994

5 Associate Membership

"Persons representing organizations which participate in any of the IGS components and who are not members of the Governing Board are considered IGS Associate Members," according to the IGS Terms of Reference. The Associate Members along with the Governing Board Members are responsible for the nomination and election of the incoming Governing Board members every 2 years. The Associate Members also become IAG Affiliate Members. The list of present Associate Members is shown in Table 8, and will be revised in 1997. More information on the formal relations can be found in the IGS Terms of Reference.

Table 8: Associate Members of the IGS, 1996

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

6 Contributing Agencies of the IGS

Increasing interest in the IGS, expanding GPS applications, and—especially in 1996—the Pilot Project for the Densification of the IGS have increased the number of agencies that contribute to the IGS on a regular basis. The agencies listed in Table 9 are jointly responsible for contributing to the international success of the IGS, and it is only through their dedication, resources, and participation that the IGS continues to thrive.

Table 9: Contributing Agencies of the IGS

Acronym	Agency
AIUB	Astronomical Institute, University of Bern, Switzerland
ALO	Astronomical Latitude Observatory, Poland
ASI	Italian Space Agency, Matera, Italy
AUSLIG	Australian Survey and Land Information Group, Australia
BfL	Bundesamt für Landestopographie (Federal Topography), Switzerland
CAS	Chinese Academy of Sciences, China
CDDIS	Crustal Dynamics Data Information System, GSFC/NASA, USA
CEE	Centro de Estudios Espaciales, Chile
CICESE	Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico
CMMACS	CSIR Centre for Mathematical Modeling and Computer Simulation, Bangalore, India
CNES	Centre National d'Etudes Spatiales, Toulouse, France
CSR	Center for Space Research, University of Texas at Austin, USA
CU	University of Colorado at Boulder, Boulder, CO, USA
DLR/DFD	Deutsche Forschungsanstalt für Luft-und Raumfahrt e.V., Neustrelitz, Germany
DUT	Delft University of Technology, Netherlands
ERI	Earthquake Research Institute, University of Tokyo, Japan
ESA	European Space Agency, Germany
ESOC	European Space Operations Center, Germany
FGI	Finnish Geodetic Institute, Finland
FOMI	FOMI Satellite Geodetic Observatory, Budapest, Hungary
GFZ	GeoForschungsZentrum Institute, Potsdam, Germany
GIUA	Geophysical Institute, University of Alaska, Fairbanks, AK, USA
GOPE	Geodetic Observatory Pecny, Ondrejov, Czech Republic
GRDL	Geosciences Research and Development Laboratory, NOAA, USA
GSC	Pacific Geoscience Centre, Geological Survey of Canada, NRCan, Canada
GSD	Geodetic Survey Division, NRCan, Canada
GSFC	Goddard Space Flight Center/NASA, USA
GSI	Geographical Survey Institute, Tsukuba, Japan
HRAO	Hartebeesthoek Radio Astronomy Observatory, South Africa
IAA	Institute of Applied Astronomy, St. Petersburg , Russia
IBGE	Instituto Brasileiro de Geografia de Estatistica, Brazil
ICC	Institut Cartografic de Catalunya, Barcelona, Spain
IDA	International Deployment of Accelerometers, Scripps Institution of Oceanography, USA
IERS	Paris Observatory, International Earth Rotation Service, Paris, France
IESAS	Institute of Earth Sciences, Academia Sinica, Taiwan
IfAG	Institut für Angewandte Geodasie, Frankfurt, Germany
IGN	Institut Géographique National, Paris, France
IGNS	Institute of Geological and Nuclear Sciences, New Zealand
IMVP	Institute for Metrology of Time and Space, GP VNIIFTRI, Mendeleevo, Russia

Table 9: (continued)

Acronym	Agency
INASAN	Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia
INGM	National Institute in Geosciences, Mining and Chemistry (INGEOMINAS), Colombia
INPE	Instituto Nacional de Pesquisas Espaciais, Brazil
IRIS	Incorporated Research Institutions for Seismology, USA
ISAS	Institute for Space and Astronautic Science, Sagamihara, Japan
ISRO	Institute for Space Research Observatory, Graz, Austria
JPL	Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA
KAO	Korean Astronomy Observatory, Taejon, Korea
KMS	Kort & Matrikelstyrelsen, National Survey and Cadastre, Denmark
LINZ	Land Information New Zealand, Wellington
MIT	Massachusetts Institute of Technology, USA
NASA	National Aeronautics and Space Administration, USA
NBSM	National Bureau of Surveying and Mapping, China
NGRI	National Geophysical Research Institute, Hyderabad, India
NIMA	National Imagery and Mapping Agency, USA
NOAA	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada, Ottawa, Canada
OSO	Onsala Space Observatory, Sweden
OUAT	Olsztyn University of Agriculture and Technology, Poland
POL	Proudman Oceanographic Laboratory, UK
RGO	Royal Greenwich Observatory, UK
ROA	Real Instituto y Observatorio de la Armada, Spain
ROB	Observatoire Royal de Belgium, Brussels, Belgium
SAO	Shanghai Astronomical Observatory, China
SCIGN	Southern California Integrated GPS Network, USA
SIO	Scripps Institution of Oceanography, San Diego, CA, USA
SK	Statens Kartverk, Norwegian Mapping Authority, Norway
UB	University of Bonn, Germany
UFPR	University Federal de Parana, Brazil
UNAVCO	University NAVSTAR Consortium, Boulder, CO, USA
UNT	University of Newcastle upon Tyne, United Kingdom
UPAD	University of Padova, Italy
USNO	US Naval Observatory, USA
VS NIIFTRI	East-Siberian Research Institute, Irkutsk, Russia
WING	Western Pacific Integrated Network of GPS, Japan
WTU	Wuhan Technical University, China
WUT	Warsaw University of Technology, Poland

7 IGS Network in 1996

The configuration of the IGS network as shown in Figure 2 demonstrates continued expansion again in 1996. At the close of 1995, 112 stations were included in the IGS station listing. This number has increased to 144 GPS stations, as listed in Table 10. While some of these are the result of regional densification, others have significantly improved the distribution of the global network. There is still a need for stations in Africa, Russia, and the ocean island areas of the world. The agencies that implement these stations and operate them are responsible for the backbone of the IGS, the GPS global network. The network centers are attempting to meet the increasing requirements of the analysis centers for new stations, timely communications, and rapid data retrieval. There are a number of improvements in the maintenance and performance of the overall network that the Central Bureau is pursuing (see Neilan's Central Bureau report and Zumberge's report on the IGSnet in this volume.)

Table 10: GPS Stations of the IGS Tracking Network (also at http://igscb.jpl.nasa.gov/network.html)

No.	Acro.	Location	Country	Long. (E)	Lat. (N)	Agency
1 *	albh	Victoria, British Columbia	Canada	-123.4870	48.3898	NRCan/GSC
2 *	algo	Algonquin Park, Ontario	Canada	-78.0714	45.9558	NRCan/GSD
3 *	ankr	Ankara	Turkey	32.7585	39.8874	IfAG
4	aoa1	Westlake, CA	USA	-118.8300	34.1574	NASA/JPL
5	areq	Arequipa	Peru	-71.4928	-16.4655	NASA/JPL
6 *	asc1	Ascension Island	Ascension Island	-14.4121	-7.9512	NASA/JPL
7 *	auck	Auckland	New Zealand	174.8344	-36.6028	IGNS-JPL
8	azu1	Azusa, CA	USA	-117.8960	34.1260	NASA/JPL
9 *	bahr	Manama	Bahrain	50.6081	26.2091	DMA
10	blyt	Blythe, CA	USA	-114.7150	33.6104	SIO
11 *	bogt	Bogota	Colombia	-74.0809	4.6401	INGM-JPL
12	bor1	Borowiec	Poland	17.0735	52.2770	SRC-PAS
13	bran	Burbank, CA	USA	-118.2770	34.1849	USGS-SIO
14 *	braz	Brasilia	Brazil	-47.8779	-15.9475	IBGE-JPL
15 *	brmu	Bermuda	Bermuda Islands	-64.6963	32.3704	NOAA
16	brus	Brussels	Belgium	4.3592	50.7978	ROB
17	cagl	Cagliari	Italy	8.9728	39.1359	ASI
18	carr	Parkfield, CA	USA	-120.4310	35.8883	NASA/JPL
19 *	cas1	Casey	Antarctica	110.5197	-66.2834	AUSLIG
20	casa	Mammoth Lakes, CA	USA	-118.8970	37.6446	NASA/JPL
21	cat1	Catalina, CA	USA	-118.4830	33.4458	NASA/JPL
22 *	chat	Waitangi	New Zealand	-176.5660	-43.9558	IGNS-JPL
23	chil	Chilao, CA	USA	-118.0260	34.3334	USGS-SIO

Table 10: (continued)

No.	Acro.	Location	Country	Long. (E)	Lat. (N)	Agency
24	chur	Churchill, Manitoba	Canada	-94.0887	58.7591	NRCan/GSD
25	cice	Ensenada	Mexico	-116.6670	31.8713	CICESE-JPL
26	cit1	Pasadena, CA	USA	-118.1270	34.1367	NASA/JPL
27 *	coco	Cocos Island	Australia	96.8340	-12.1884	AUSLIG
28	coso	Ridgecrest, CA	USA	-117.8090	35.9823	SIO
29	crfp	Yucaipa, CA	USA	-117.1000	34.0391	SIO
30 *	cro1	Christiansted	US Virgin Islands	-64.5843	17.7569	NRAO-JPL
31	csn1	Northridge, CA	USA	-118.5240	34.2535	NASA/JPL
32 *	dav1	Davis	Antarctica	77.9726	-68.5773	AUSLIG
33 *	dgar	Diego Garcia	Diego Garcia	72.3702	-7.2697	NASA/JPL
34	dhlg	Durmid Hill, CA	USA	-115.7880	33.3898	SIO
35 *	drao	Penticton	Canada	-119.6250	49.3226	NRCan/GSC
36	dubo	Lac du Bonnet, Manitoba	Canada	-95.8662	50.2588	NRCan/GSC
37	ebre	Roquetes	Spain	0.4924	40.8209	ICC
38	eisl	Easter Island	Chile	-109.3830	-27.1482	NASA/JPL
39 *	fair	Fairbanks, AK	USA	-147.4990	64.9780	JPL-GSFC
40	flin	Flin Flon, Manitoba	Canada	-101.9780	54.7256	NRCan/GSC
41 *	fort	Fortaleza	Brazil	-38.4256	-3.8774	NOAA
42	gala	Galapagos Island	Galapagos Islands	-90.3036	-0.7427	NASA/JPL
43	gode	Greenbelt, MD	USA	-76.8268	39.0217	NASA/GSFC
44 *	gold	Goldstone, CA	USA	-116.8890	35.4252	NASA/JPL
45	gope	Ondrejov	Czech Republic	14.7856	49.9137	RIG
46	gras	Caussols	France	6.9206	43.7547	CNES
47	graz	Graz	Austria	15.4935	47.0671	ISR
48 *	guam	Dededo	Guam	144.8684	13.5893	NASA/JPL
49 *	hart	Pretoria	South Africa	27.7078	-25.8871	CNES
50	harv	Harvest, CA	USA	-120.6820	34.4694	NASA/JPL
51	hers	Hailsham	United Kingdom	0.3363	50.8673	RGO
52	hflk	Innsbruck	Austria	11.3861	47.3129	ISR
53	hnpt	Cambridge, MD	USA	-76.1304	38.5888	NOAA
54 *	hob2	Hobart, Tasmania	Australia	147.4387	-42.8047	AUSLIG
55	holc	Pearblossom, CA	USA	-117.8450	34.4582	USGS-SIO
56	hrao	Krugersdorp	South Africa	27.6872	-25.8898	HRAO-JPL
57 *	iisc	Bangalore	India	77.5704	13.0212	CMMACS-JPL
58 *	irkt	Irkutsk	Russia	104.3162	52.2190	DUT
59	joze	Jozefoslaw	Poland	21.0315	52.0973	IGGA-WUT
60	jplm	Pasadena, CA	USA	-118.1730	34.2048	NASA/JPL
61 *	kely	Kangerlussuaq	Greenland	-50.9448	66.9874	NOAA
62 *	kerg	Port aux Francais	Kerguelen Islands	70.2555	-49.3515	CNES
63	kiru	Kiruna	Sweden	20.9684	67.8574	ESA

Table 10: (continued)

No.	Acro.	Location	Country	Long. (E)	Lat. (N)	Agency
64 *	kit3	Kitab	Uzbekistan	66.8854	39.1348	GFZ
65 *	kokb	Kokee Park, HI	USA	-159.6650	22.1263	NASA/JPL
66 *	kosg	Kootwijk	The Netherlands	5.8096	52.1784	DUT
67 *	kour	Kourou	French Guiana	-52.8060	5.2522	ESA
68 *	kwj1	Kwajalein Atoll	Kwajalein Atoll	167.7302	8.7222	NASA/JPL
69	lama	Olsztyn	Poland	20.6699	53.8924	OUAT
70	lbch	Long Beach, CA	USA	-118.2030	33.7878	NASA/JPL
71 *	lhas	Lhasa	China	91.1040	29.6573	IfAG
72	long	Irwindale, CA	USA	-118.0030	34.1119	USGS-SIO
73	lpgs	La Plata	Argentina	-57.9323	-34.9067	GFZ
74 *	mac1	MacQuarie Island	Australia	158.9358	-54.4995	AUSLIG
75 *	madr	Robledo	Spain	-4.2497	40.4292	NASA/JPL
76 *	mali	Malindi	Kenya	40.1944	-2.9959	ESA
77 *	mas1	Maspalomas	Spain	-15.6333	27.7637	ESA
78 *	mate	Matera	Italy	16.7045	40.6491	ASI
79	math	Lake Mathews, CA	USA	-117.4370	33.8567	SIO
80 *	mcm4	Ross Island	Antarctica	166.6693	-77.8383	NASA/JPL
81 *	mdo1	Fort Davis, TX	USA	-104.0150	30.6805	NASA/JPL
82 *	mdvo	Mendeleevo	Russia	37.2236	56.0275	IMVP-DUT
83	medi	Medicina	Italy	11.6468	44.5200	ASI
84 *	mets	Kirkkonummi	Finland	24.3953	60.2175	FGI
85 *	mkea	Mauna Kea	USA	-155.4560	19.8014	NASA/JPL
86	monp	Laguna Mountains, CA	USA	-116.4220	32.8919	SIO
87 *	nlib	North Liberty, IA	USA	-91.5749	41.7716	NASA/JPL
88	noto	Noto	Italy	14.9898	36.8761	ASI
89 *	nyal	Ny Alesund	Norway	11.8651	78.9296	NMA
90	oat2	Oat Mountain, CA	USA	-118.6010	34.3299	NASA/JPL
91	ober	Oberpfaffenhofen	Germany	11.2799	48.0862	GFZ
92 *	ohig	O'Higgins	Antarctica	-57.9003	-63.3207	IfAG
93 *	onsa	Onsala	Sweden	11.9255	57.3953	OSO
94	penc	Penc	Hungary	19.2815	47.7896	FOMI
95 *	pert	Perth	Australia	115.8852	-31.8020	ESA
96	pie1	Pie Town, NM	USA	-108.1190	34.3015	NASA/JPL
97	pin1	Pinyon Flat, CA	USA	-116.4580	33.6122	SIO
98	pin2	Pinyon Flat, CA	USA	-116.4576	33.6121	SIO
99	pol2	Bishkek	Kyrgyzstan	74.6943	42.6798	UNAVCO-MIT
100	pots	Potsdam	Germany	13.0661	52.3793	GFZ
101	pvep	Palos Verdes, CA	USA	-118.4040	33.7433	SIO
102	quin	Quincy, CA	USA	-120.9440	39.9746	NASA/JPL
103 *	rcm6	Perrine, FL	USA	-80.3839	25.6138	NOAA

Table 10: (continued)

No.	Acro.	Location	Country	Long. (E)	Lat. (N)	Agency
104 *	reyk	Reykjavik	Iceland	-21.9555	64.1388	IfAG
105	roch	Pinemeadow, CA	USA	-116.6090	33.6110	SIO
106 *	sant	Santiago	Chile	-70.6686	-33.1503	NASA/JPL
107	sey1	Mahe Island	Seychelles	55.4794	-4.6737	JPL-IDA
108	sfer	San Fernando	Spain	-6.5389	37.3106	ROA
109 *	shao	Sheshan	China	121.2004	31.0996	SAO-JPL
110	sio3	La Jolla, CA	USA	-117.2500	32.8647	SIO
111	sni1	Port Hueneme, CA	USA	-119.5240	33.2479	NASA/JPL
112	sol1	Solomons Island, MD	USA	-76.4539	38.3189	NOAA
113	spk1	Saddle Peak, CA	USA	-118.6460	34.0593	NASA/JPL
114 *	stjo	St John's, Newfoundland	Canada	-52.6777	47.5952	NRCan/GSD
115 *	taej	Taejon	Korea	127.3661	36.3744	KAO
116 *	tahi	Papeete	Tahiti	-149.6094	-17.5765	CNES
117 *	taiw	Taipei	Taiwan	121.5365	25.0213	IES-AS
118	thu1	Thule	Greenland	-68.7880	76.5373	KMS-JPL
119 *	tidb	Tidbinbilla	Australia	148.9800	-35.3992	NASA/JPL
120	toul	Toulouse	France	1.4808	43.5608	CNES
121	trak	Irvine, CA	USA	-117.8030	33.6179	SIO
122	trom	Tromsoe	Norway	18.9383	69.6627	NMA
123 *	tskb	Tsukuba	Japan	140.0875	36.1057	GSI
124	uclp	Los Angeles, CA	USA	-118.4420	34.0691	NASA/JPL
125	upad	Padova	Italy	11.8779	45.4067	UP
126	usc1	Los Angeles, CA	USA	-118.2850	34.0239	NASA/JPL
127	usna	Annapolis, MD	USA	-76.4794	38.9833	NOAA
128	usno	Washington DC	USA	-77.0662	38.9190	USNO/NOAA
129 *	usud	Usuda	Japan	138.3620	36.1331	NASA/JPL
130	vill	Villafranca	Spain	-3.9520	40.4436	ESA
131	vndp	Vandenberg AFB, CA	USA	-120.6160	34.5563	SIO-JPL
132 *	wes2	Westford, MA	USA	-71.4933	42.6133	NOAA
133	whc1	Whittier, CA	USA	-118.0310	33.9799	NASA/JPL
134	whi1	Whittier, CA	USA	-118.0340	33.9738	NASA/JPL
135 *	whit	Whitehorse, Yukon Territory	Canada	-135.2220	60.7505	NRCan/GSC
136	wlsn	Mt Wilson, CA	USA	-118.0560	34.2261	NASA/JPL
137 *	wtzr	Koetzting	Germany	12.8789	49.1442	IfAG
138	wtzt	Koetzting	Germany	12.8789	49.1442	IfAG
139 *	wuhn	Wuhan	China	114.3573	30.5317	NOAA-JPL
140	xian	Lintong, Xi'an	China	109.2215	34.3687	NASA/JPL
141 *	yar1	Yaragadee	Australia	115.3470	-29.0466	NASA/JPL
142 *	yell	Yellowknife, NW Territories	Canada	-114.4810	62.4809	NRCan/GSD
143	zimm	Zimmerwald	Switzerland	7.4653	46.8771	FOT

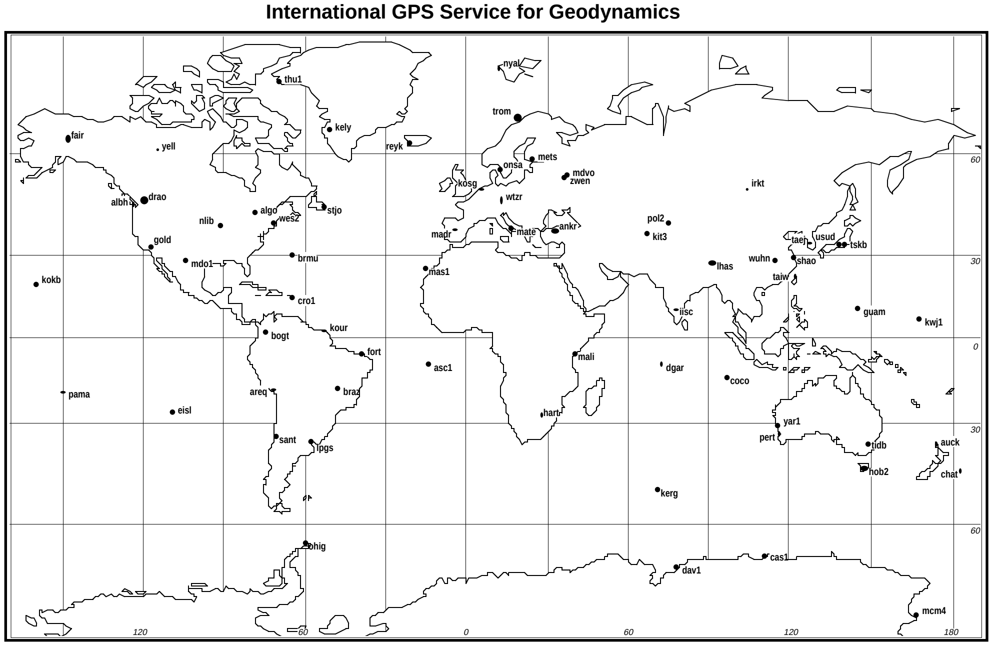
Table 10: (continued)

No.	Acro.	Location	Country	Long. (E)	Lat. (N)	Agency
144	* zwen	Zwenigorod	Russia	36.7586	55.6993	GFZ

* Global Station: analyzed by at least three IGS Analysis Centers, at least one of which is on a different continent.

Most of the IGS Analysis Centers rely on a well-distributed subset of the stations to produce the global rapid orbits and products. This subnetwork includes stations whose data are used by three or more Analysis Centers primarily for the purpose of orbit determination. These stations are called IGS Global Stations. The Central Bureau records the use of all IGS stations by noting which Analysis Centers access what stations. The map of these Global Stations is shown in Figure 3. Of the 32 stations implemented or upgraded in 1996, 12 are now designated as Global. These stations are Easter Island; Bogota, Colombia; Ascension Island; Ny Allesund, Spitzbergen Island; Bishkek, Khazahkstan; Lhasa, Tibet, China; Wuhan, China; Taejon, Korea; Diego Garcia; Davis, Antarctica; Auckland, New Zealand; and Kwajalein. Table 11 lists those stations that are installed, but for which the data flow is not yet established.

GLOBAL STATIONS †
International GPS Service for Geodynamics



† Processed by three or more IGS Analysis Centers, one of which is on another continent — January 1997

Figure 3: Global Stations of the IGS GPS Tracking Network at the end of 1996. These stations are processed by three or more IGS Analysis Centers, one of which is on another continent

Table 11: Operational stations resolving communications issues

Station	Country	Long (E)	Lat (N)	Agency
Hyderabad	India	79.2800	17.2900	UB-NGRI
Limón	Costa Rica	-83.0200	10.0000	JPL-UNAVCO
Krasnoyarsk	Russia	93.1200	56.1300	GFZ
Urumqi	China	87.7200	43.8200	GFZ-NBSM

IERS References
Contribution of the Central Bureau of IERS

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Following its Terms of Reference, IGS works in close cooperation with the International Earth Rotation Service (IERS). The Central Bureau of IERS is operated jointly by Institut Géographique National (IGN), in charge of the International Terrestrial Reference Frame (ITRF), and Paris Observatory, in charge of the International Celestial Reference Frame (ICRF) and the Earth's rotation determination. The other techniques used by IERS are very long baseline radio interferometry (VLBI), lunar and satellite laser ranging (LLR, SLR), and Doppler orbit determination and radiopositioning integrated on satellite (DORIS).

The IGS has adopted the ITRF as the reference for the orbit computations. The GPS contribution is important for the maintenance and extension of the ITRF as well as for the global consistency of the IERS results through the permanent high-resolution monitoring of polar motion. GPS also provides information on universal time (high-frequency variations and near-real-time estimation). The general analyses of GPS results appear in the 1996 IERS Annual Report together with those of the other techniques. We present hereafter detailed analyses of interest to IGS.

1 Terrestrial Reference Frame

Two main topics of interest to IGS were investigated in 1996:

- Analysis of global GPS/IGS solutions together with VLBI, SLR, and DORIS, leading to the assessment of the respective relative qualities of these global solutions.

- Analysis of the position time series of GPS/IGS weekly solutions together with DORIS monthly solutions.

1.1 Analysis of Global GPS/IGS Solutions

The ITRF94 solution is the current frame in use by the IGS analysis centers. Meanwhile, a new complete solution (called ITRF-C1) has been proposed to be the ITRF conventional frame for several years and to supersede ITRF94.

The analysis of the data collected in 1996 to obtain this solution revealed some inadequacy in ensuring the robustness and the quality required for ITRF-C1. Moreover, this fact led to the need for more refined specifications. The IERS Working Group on the ITRF Datum was established to develop specifications for ITRF and in particular ITRF-C1, for which a final conclusion is not yet reached.

In the meantime, a simultaneous combination of station positions and velocities (at epoch 1993.0) of the data collected in 1996 was performed. The solutions incorporated in this combination are listed in Table 1.

Table 1: Solutions used in the global combination

Technique	Solution	MSF[a]	Position Epoch	Data Span
Combination	ITRF94-TIES	1.00	93.0	
VLBI	SSC(GSFC) 96 R 01	3.92	93.0	80–96
	SSC(JPL) 96 R 01	3.05	93.0	78–96
GPS	SSC(JPL) 96 P 02	5.23	93.0	91–96
	SSC(CODE) 96 P 01	44.43	94.7	93–96
	SSC(GFZ) 96 P 01	22.91	95.0	93–96
SLR	SSC(CSR) 96 L 01	2.88	93.0	76–96
DORIS	SSC(CSR) 96 D 01	1.99	93.0	93–96

[a]MSF: Matrix scaling factor.

The ITRF94-TIES solution is obtained for collocation sites using

- ITRF94 positions and velocities for reference points.
- Local ties for the other points.

The combination was achieved in three steps:

- The matrix scaling factors were estimated from comparisons of the individual solutions to the ITRF94, restricted to class A and B stations.
- The individual solutions were orthogonally projected as follows:
  - The VLBI solutions were projected on the three translations and three rotations

  - The dynamical solutions (GPS, SLR, and DORIS) were projected on the three rotations only.
- Simultaneous combination of positions and velocities at epoch 1993.0.

The transformation parameters and their rates resulting from this combination are listed in Tables 2 and 3, respectively. The 3-D weighted rms per solution are listed in Table 4.

The analysis of this combination indicates that

- For the origin, there are still several centimeters of difference between GPS and SLR solutions. The Center for Space Research (CSR) DORIS solution is within 1 cm from the SLR solution. The rates of the three translations relative to ITRF94 are less than 1 cm/year for all solutions.
- For the scale, the difference between the VLBI GSFC and SLR CSR solutions is about 0.5×10^{-9}, with a rate of about 0.5×10^{-9}/year. On the other hand, with respect to the ITRF94, the scale differences of the GPS solutions are about 0.7×10^{-9}, with rates less than 0.2×10^{-9}/year.

Table 2: Transformation parameters derived from the combination of solutions received in 1996

Solution		T1 (cm)	T2 (cm)	T3 (cm)	D ($\times 10^{-8}$)	R1 (× .001")	R2 (× .001")	R3 (× .001")	Epoch (year—1900)
ITRF94-TIES		0	0	0	0	0	0	0	93.00
(GSFC) 96 R 01		–.61	.74	.38	–.119	1.264	.912	–.147	93.00
	±	.20	.21	.19	.031	.102	.099	.075	
(JPL) 96 R 01		–.57	–.23	–.87	–.240	–.913	–.326	–.839	93.00
	±	.30	.32	.30	.128	.154	.101	.126	
(JPL) 96 P 02		.45	2.11	–4.11	–.080	–.056	.014	–.073	93.00
	±	.18	.17	.16	.025	.063	.064	.066	
(GFZ) 96 P 02		6.07	3.76	–4.79	–.072	1.154	1.902	–.192	95.00
	±	.40	.41	1.64	.031	.079	.092	.073	
(CODE) 96 P 01		1.18	–1.07	–.53	–.057	–.552	–.442	–.343	94.69
	±	.22	.22	.23	.033	.075	.074	.073	
(CSR) 96 L 01		–.30	–.50	.78	–.168	–.825	.130	.008	93.00
	±	.19	.19	.22	.030	.109	.112	.104	
(CSR) 96 D 02		1.37	–.25	.71	.218	–.192	.137	–.105	93.00
	±	.57	.58	.45	.072	.179	.195	.29	

The solution definitions are D = DORIS; L = SLR; P = GPS; R = VLBI.

Table 3: Rates of the Transformation parameters derived from the combination of solutions received in 1996

Solution		$\dot{T}1$ (cm/year)	$\dot{T}2$ (cm/year)	$\dot{T}3$ (cm/year)	$\dot{D}$ ($\times 10^{-8}$/year)	$\dot{R}1$ (× .001"/year)	$\dot{R}2$ (× .001"/year)	$\dot{R}3$ (× .001"/year)
ITRF94-TIES		0	0	0	0	0	0	0
(GSFC) 96 R 01		.01	.19	.02	.016	–.013	.012	–.064
	±	.05	.06	.05	.007	.019	.019	.016
(JPL) 96 R 01		–.24	.16	.21	.013	–.035	–.192	.051
	±	.10	.18	.12	.022	.130	.093	.126
(JPL) 96 P 02		–.44	–.76	–.65	–.017	–.020	.004	–.006
	±	.06	.06	.04	.007	.020	.020	.021
(GFZ) 96 P 02		–.18	–.16	.12	.008	–.206	–.111	–.244
	±	.06	.05	.06	.007	.029	.025	.045
(CODE) 96 P 01		.04	–.05	.00	–.003	–.135	–.037	–.172
	±	.05	.05	.05	.006	.031	.023	.043
(CSR) 96 L 01		.03	–.03	.20	–.032	–.188	–.065	.031
	±	.04	.04	.05	.006	.022	.028	.023
(CSR) 96 D 02		–.83	–.36	.30	–.019	.036	–.014	–.017
	±	.38	.38	.30	.045	.131	.135	.192

Table 4: 3-D rms derived from the combination of solutions received in 1996

Solution	Positions (mm)	Epoch (year)	Velocities (mm/year)
ITRF94-TIES	8.0	93.00	1.1
(GSFC) 96 R 01	5.6	93.00	1.2
(JPL) 96 R 02	18.0	93.00	5.0
(JPL) 96 P 02	7.4	93.00	2.9
(GFZ) 96 P 02	23.6	95.00	2.2
(CODE) 96 P 02	10.6	94.69	0.9
(CSR) 96 L 01	10.3	93.00	3.4
(CSR) 96 D 02	23.7	93.00	10.1

As this was the first time positions and velocities were combined simultaneously, the velocity analysis revealed that

- 319 stations located in 136 sites (with only 44 collocated sites) have significant horizontal velocities (see Figure 1).
- Only 72 stations located in 28 sites (with only 14 collocated sites) have significant vertical velocities (see Figure 2).

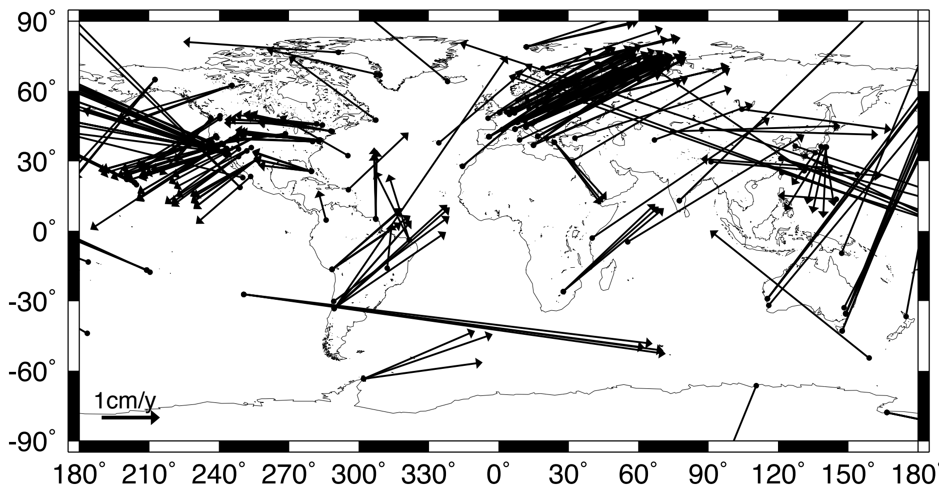


Figure 1: Combined VLBI, GPS, SLR, and DORIS horizontal velocities, excluding velocities smaller than 3 sigmas

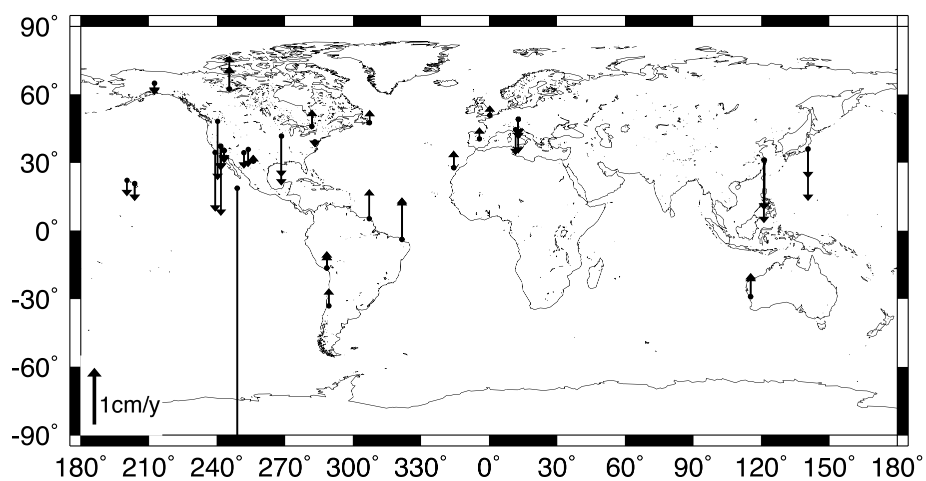


Figure 2: Combined VLBI, GPS, SLR, and DORIS vertical velocities, excluding velocities smaller than 3 sigmas

1.2 Analysis of GPS/IGS and DORIS Position Time Series

In the framework of the IERS analysis campaign to investigate motions of the geocenter, preliminary tests were made on IGS/JPL sets of coordinates and DORIS monthly solutions. In order to intercompare the two techniques, JPL weekly GPS solutions were accumulated to get monthly solutions. The comparisons were made from November 1995 to March 1996. The sets were globally combined with the ITRF94, and the computation underlying reference frame was the ITRF94. A Helmert estimation of variance factors was involved in the combination. It led to the following factors (square-root of the variance matrix scale factor): 0.8 for the ITRF94 set, 1.5 in the mean for DORIS, and 4.5 for the JPL GPS data.

Two types of computations were made: the first was a classical seven-parameter-per-set combination (no constraints between DORIS and GPS transformation parameters); in the second, GPS and DORIS translations and scale factors were constrained to be equal for the same months. Plots of the transformation parameters are shown in Figures 3 to 6. One can see that the combined determination is mainly influenced by the DORIS set, which could be a consequence of the fact that DORIS satellites are lower than GPS satellites and are therefore expected to lead to a better geocenter position. Nevertheless, this should be verified through a specific variance analysis (Helmert type), which will be investigated at IGN in 1997.

It can be observed that, at the moment, DORIS and JPL's GPS determinations are not statistically mutually consistent except for the Z parameter. Such combinations have to be extended to other IGS Analysis Center sets of coordinates. In 1997, DORIS analysis centers might be able to deal with weekly solutions, and then interest in the kind of analyses that have been made in 1996 concerning geocenter motion will become obvious.

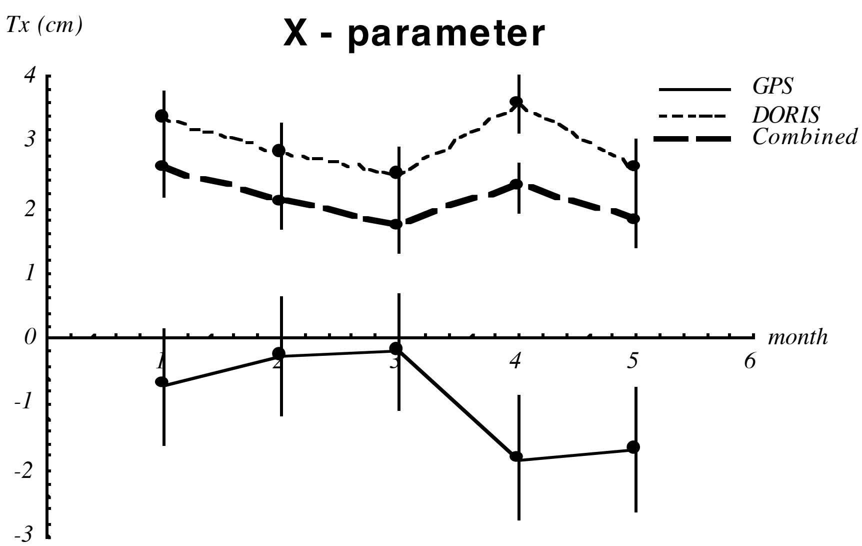


Figure 3: X-geocenter parameter with respect to ITRF94

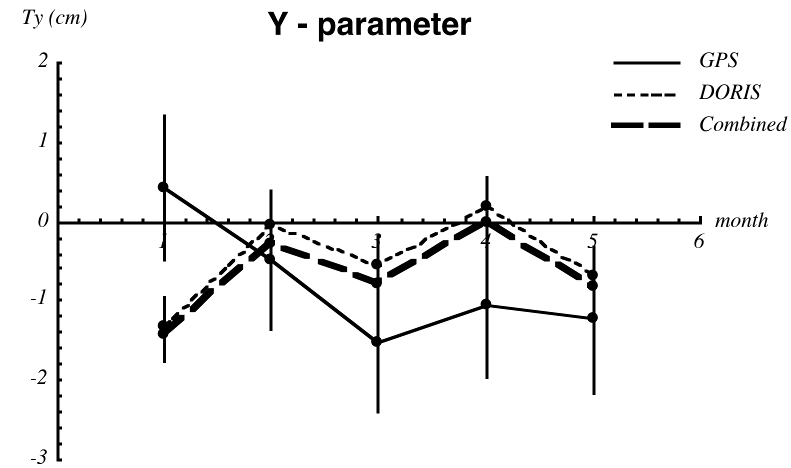


Figure 4: Y-geocenter parameter with respect to ITRF94

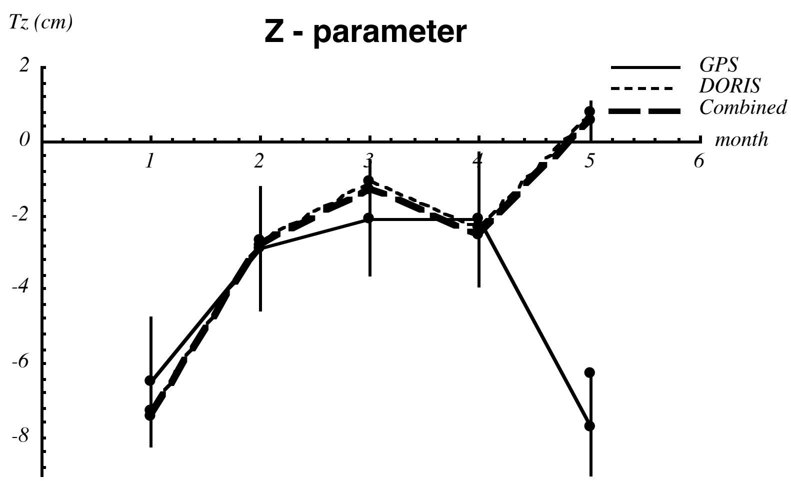


Figure 5: Z-geocenter parameter with respect to ITRF94

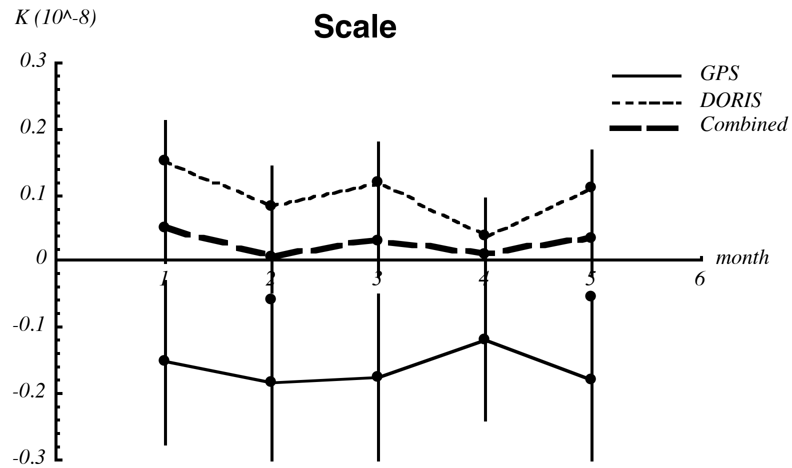


Figure 6: Scale time evolution with respect to ITRF94

2 Earth Orientation

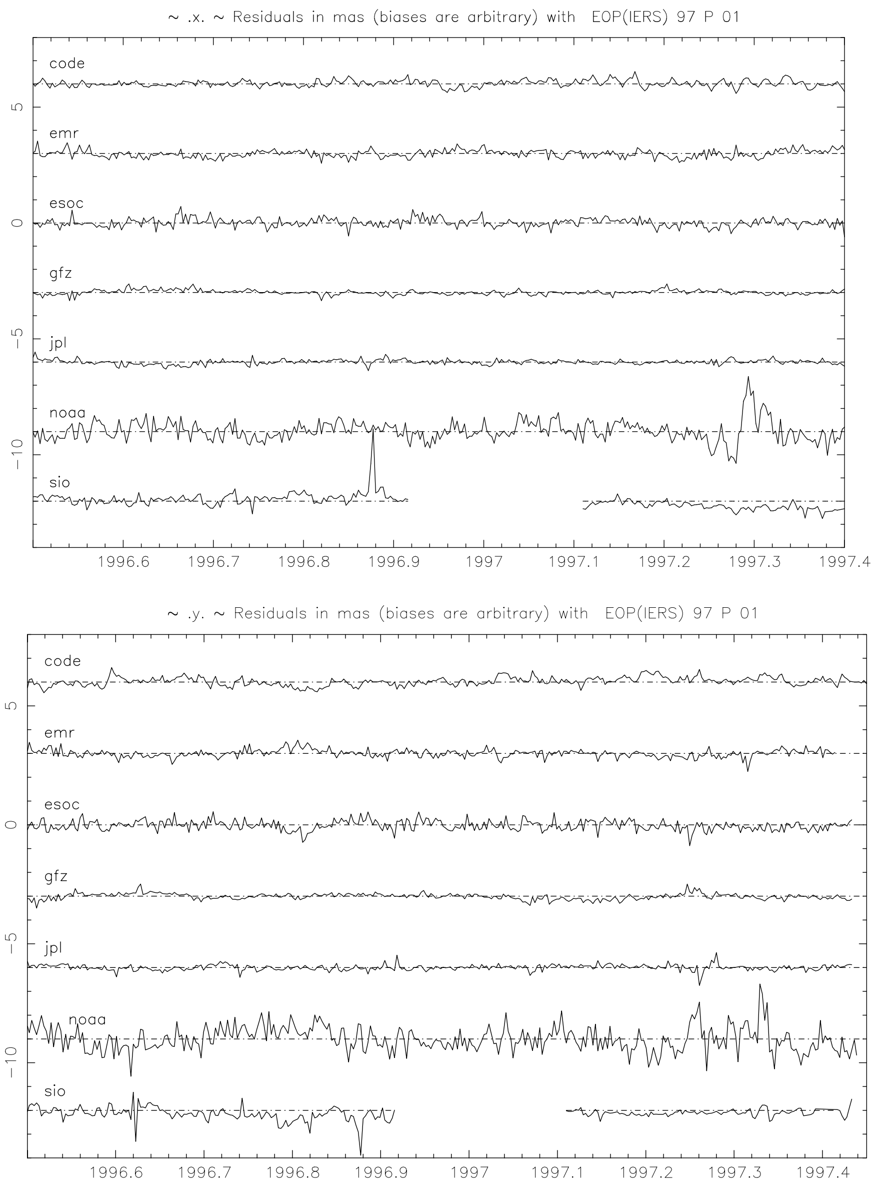
2.1 IERS GPS Combined Solution of Polar Motion and LOD

Since 1994, a combined solution of the various GPS series is performed and is used in our current analyses. All series are given at 1-day intervals and for the same date; the combination is made by a weighted average of the various series. The weighting reflects the qualities of the series, and long-term and short-term stability. Two different approaches are used for that purpose: the first, a pair variance analysis based on the mutual comparisons of the series [1]; the second, comparisons to other reference series. Both give results of approximately the same order of magnitude. The relative percentages of the series entering the pole and the length-of-day-variations (LOD) combination for 1996/1997 are listed in Table 5.

Table 5: Percentage over 1996.5–1997.4 of the various GPS series contributing to the EOP (IERS) 97 P 01 pole and LOD solutions

Station	X pole	Y pole	LOD
CODE	14	15	35
EMR	17	17	20
JPL	28	27	5
GFZ	28	27	25
ESOC	8	10	10
NOAA	2	2	2
SIO	3	2	3

Figures 7a, 7b, and 7c show for the pole and LOD the plot of the differences of individual series entering the combinations with (IERS) 97 P 01. Table 6 shows the mean differences and the unbiased rms agreements of the various series GPS that contributed to this combined solution and to different solutions derived from other techniques. These statistics reflect the accuracy reached by the different techniques.



Figures 7a and 7b: X- and Y-pole coordinates in 1996–1997. Daily differences of individual GPS series from IERS 97 P 01

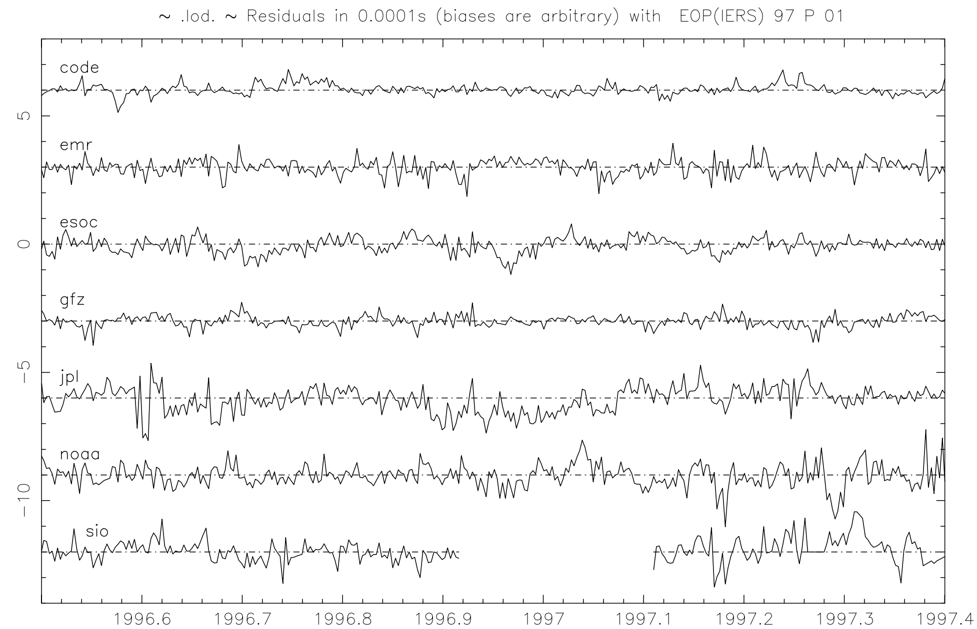


Figure 7c: LOD in 1996–1997. Daily differences of individual GPS series from IERS 97 P 01

Table 6: Biases and unbiased rms of the differences of various solutions from (IERS) 97 P 01

Differences from (IERS) 97 P 01	X-bias (mas)	Rms (mas)	Y-bias (mas)	Rms (mas)	LOD bias (× .1 ms)	Rms (× .1 ms)
GPS solutions						
(CODE) 96 P 03	.30	.15	-.03	.16	–.12	.27
(EMR) 96 P 03	.19	.18	.52	.18	–.06	.62
(ESOC) 96 P 01	.26	.19	.44	.24	–.08	.24
(GFZ) 96 P 02	.33	.14	.31	.13	–.05	.31
(JPL) 96 P 03	.22	.12	.15	.13	.13	.33
(NOAA) 96 P 01	.42	.44	.42	.51	–.06	.40
(SIO) 96 P 01	.37	.34	.26	.62	.06	.46
(IGS) 96 P 02	.34	.15	.25	.16	.06	.25
Other individual series						
USNO 97 R 08	.04	.18	.10	.16	–.49	.28
CLG 97L 01	.08	.48	.22	.42		
CSR 95 L 01	–.32	.32	.13	.32		
DUT 93 L 03	.40	.40	–.60	.41		
GZ 97 L 01	.10	.36	.49	.45	–.01	.65
IAA 96 L02	–.14	.22	–.97	.19	.00	.37
Combined series						
USNO 97 C 01	.00	.11	.09	.12		
IERS C 04	.00	.16	.02	.14	.01	.29
JPL 97 C 01	–.09	.13	.16	.07		

2.2 Universal Time Based on Both VLBI and GPS Techniques

Due to the difficulty of determining the long-term behavior of the nonrotating 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 LOD, i.e., the time derivative of Universal Time, together with the orbital parameters.

The various determinations made by the analysis of satellite data follow different strategies; some of them integrate their estimates of LOD to derive a "free-running" Universal Time series; some constrain their determination using a priori VLBI values in order to maintain consistency with the nonrotating inertial reference frame. Various studies [2,3] have shown that the high-frequency signal contained in the LOD derived from SLR and GPS data can be used as estimates on time scales limited to a couple of months to densify the series obtained by the VLBI technique and also for near-real-time Earth-orientation monitoring. For clarification, it was felt [4] that the acronym UT1 should be reserved for Universal Time derived from inertial techniques (astrometry and VLBI). We shall adopt in this paper the acronym UT for a series partially constructed from various techniques.

Since December 1995, the Central Bureau of IERS operationally publishes a mixed Universal Time solution based on a combined short-term GPS UT solution calibrated by the long-term VLBI UT1 series. The strategy has now evolved. Since spring 1997, a combined GPS LOD solution is calculated using the seven GPS Analysis Center estimates and integrated to give an "internal free-running" solution that is finally calibrated by VLBI and labelled (IERS) 97 P 01.

Figure 8 shows the difference of this solution and other individual solutions from EOP(IERS) 97 C 04, which is taken as a reference. The solution (IERS) 97 P 01 exhibits a significant tidal residual with a period of about 14 days and an amplitude of 20 microseconds; this term questions the procedure used by the GPS Analysis Centers. Table 7 gives the rms of the differences of various solutions from this solution.

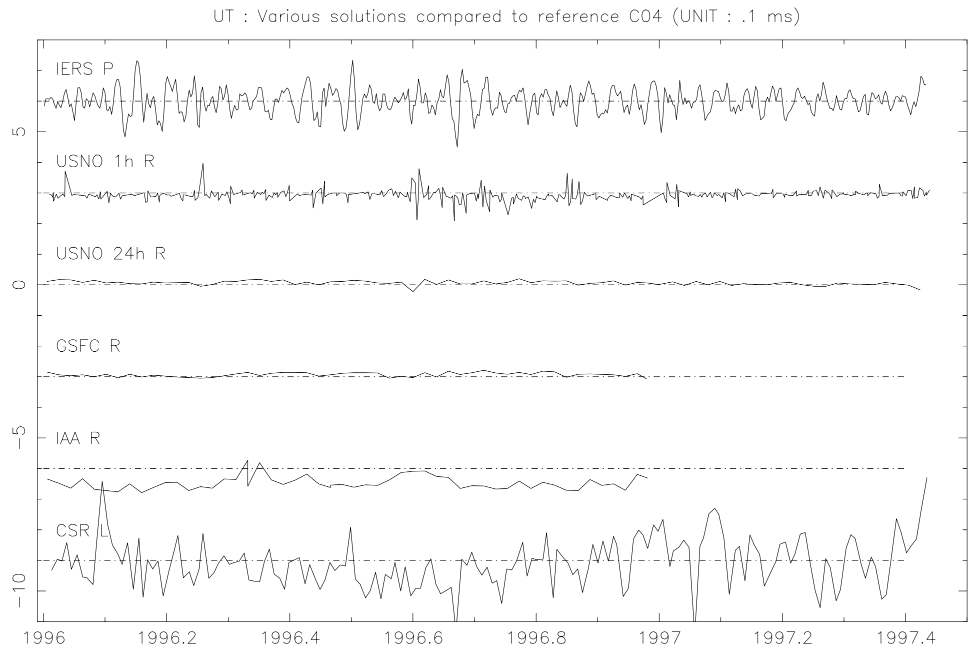


Figure 8: Differences of various UT individual series from C04

Table 7: Rms agreement of various solutions with respect to EOP(IERS) 97 P 01

Series	Rms agreement (μs)
(USNO) 97 R 09	37
(USNO) 97 R 08	30
(GSFC) 97 R 01	33
(IAA) 97 R 01	39
(CSR) 95 L 01	74
(IERS) 97 C 04	40
(USNO) 97 C 01	36
(JPL) 97 C 01	37

2.3 Use of UT1 GPS Estimates for Near-Real-Time Applications

2.3.1 Simulations

Another application of LOD (or UT1 integrated series) derived by GPS is the estimation of Universal Time from the last available VLBI estimation. This problem is now dramatic with the availability of rapid estimation of LOD estimates from the CODE Analysis Center. These LOD estimates are integrated to give a UT solution that extrapolates the last VLBI value. This procedure takes into account a model to correct long-term errors in the GPS UT series [5]. This model now consists of a linear term or an autoregressive process. A nonlinear approach to the modeling of these long-term errors is under investigation. Table 8 shows the results from a series of simulations performed over 1996–97 compared with the current predictions based on the VLBI technique. The improvement is significant: a 1- to 2.5-order of magnitude for 1 and 3 weeks.

Table 8: Rms errors (in μs) of the Universal Time solution based on GPS and compared to the current prediction, which is based on an autoregressive process

	1 week	2 weeks	3 weeks
Pure prediction	1150	4000	7000
GPS estimates	150	180	270

2.3.2 Operational Applications

The real situation is different. Since the beginning of 1997, CODE has implemented a rapid orbit determination including preliminary LOD estimates [6] and available twice a week (with intervals of 2 and 5 days). These estimates are integrated into a free-running UT series; this series, after long-term corrections are removed, is piped to the last available VLBI estimate or C04 solution. This extrapolation of UT1 is now calculated on a current basis and enters our current analyses since January 1997. Figure 9 shows the comparison of this solution relative to the updated C04. The rms of the differences is about 70 μs. The availability of these near-real-time estimates also enables a better UT1 prediction.

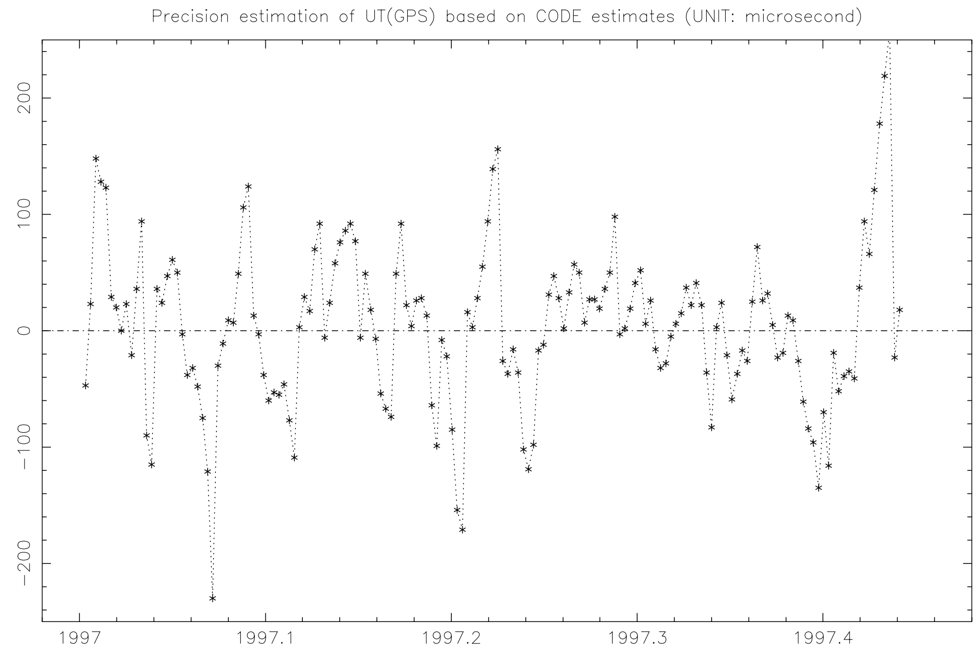


Figure 9: Estimation of the UT precision obtained when CODE GPS LOD rapid-solution estimates are integrated and piped to the last available VLBI UT1 value

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Analysis Coordinator Report

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1 Introduction

1996 has been another busy year for the IGS Analysis Centers (ACs). An ambitious agenda was initiated during the 1996 AC Workshop held in Silver Spring, Maryland. It included implementation of ITRF94, changes in generation and availability of the IGS Final and Rapid combination products (orbits, Earth orientation parameters (EOP), and clocks), as well as several improvements in modeling and estimations. As planned, all the above recommended changes have been implemented by all ACs by the GPS Week (Wk) 0860 (June 30, 1996). Moreover, the workshop resolutions also recommended generation of new combinations for LOD/UT1 and predicted orbits, which proved to be more difficult and were implemented only in early 1997. The details about the above changes and their effect on results and users are described below. In particular, possible discontinuities in the IGS Final orbit and EOP series on June 30, 1996 have been investigated.

As for the past years, comprehensive statistics and plots of all the IGS products (i.e., the submitted AC and IGS combined solutions) were compiled and are summarized in the Appendix. The statistics indicate significant improvements realized by all ACs during 1996.

2 IGS Product Reference Frame Changes During 1994–1996

In order for the IGS products to be consistent with the latest ITRF and to ensure the best possible reference frame realization, the IGS reference frame was changed twice since January 1, 1994, the start of the official IGS service. Namely, on January 1, 1995 (Wk 0782), the ITRF92 was superseded by ITRF93, and on June 30, 1996 (Wk 0860), the ITRF94 was introduced. In all cases, the IGS ITRF realization was based on the same set of 13 stations whose ITRF coordinates and velocities are relatively well determined by several space techniques. The respective ITRF92/93 station coordinates and velocities, which were fixed or constrained in all AC solutions up to June 29, 1996, were published in the 1994 IGS Annual Report [1, Tables 2 and 8]. The ITRF94 coordinate/velocity set adopted by IGS on June 30, 1996, is listed in Table 1.

Table 1: ITRF94 coordinates and velocities of the IGS 13 stations used for ITRF realization since June 30, 1996 (GPS Wk 0860) (ITRF94.SSCA-C, epoch 1993.0, sigmas 5 to 10 mm for X,Y,Z and 1 to 4 mm/y for VX,VY,VZ)

Dome Number	IGS Name	X (m)	Y (m)	Z (m)	VX (m/y)	VY (m/y)	VZ (m/y)
10302M003	TROM	2102940.420	721569.352	5958192.079	–.0193	.0107	.0051
13407S012	MADR	4849202.504	–360329.194	4114913.044	–.0062	.0199	.0127
13504M003	KOSG	3899225.315	396731.752	5015078.302	–.0146	.0173	.0089
14201M010	WTZR	4075580.763	931853.599	4801568.010	–.0169	.0173	.0065
30302M002	HART	5084625.454	2670366.541	–2768494.007	–.0015	.0164	.0180
40104M002	ALGO	918129.576	–4346071.229	4561977.811	–.0158	–.0051	.0035
40127M003	YELL	–1224452.405	–2689216.097	5633638.289	–.0204	–.0042	–.0027
40405S031	GOLD	–2353614.102	–4641385.423	3676976.478	–.0146	.0030	–.0057
40408M001	FAIR	–2281621.345	–1453595.784	5756961.969	–.0208	–.0031	–.0117
40424M004	KOKB	–5543838.079	–2054587.518	2387809.589	–.0079	.0600	.0305
41705M003	SANT	1769693.258	–5044574.114	–3468321.112	.0225	–.0066	.0147
50103M108	TIDB	–4460995.984	2682557.093	–3674443.881	–.0366	–.0030	.0442
50107M004	YAR1	–2389025.344	5043316.844	–3078530.925	–.0488	.0121	.0493

Note: WTZR(ITRF94)–WETT(ITRF94) used: DX/DY/DZ = 2.106m/.981m/–1.992m

Unlike the previous ITRF realizations, ITRF93 introduced additional small RX, RY rotations of about 1 mas, which were intended to align ITRF93 close to the orientation and time evolution of the IERS EOP series. For ITRF94, after some discussions, the IERS decided to revert to the original ITRF alignment and time evolution (consistent with the NNR NUVELL 1 plate motion model), which again resulted in small (~1 mas) RX, RY rotations with the opposite sign. The ITRF92/ITRF93 transformation and discontinuities were estimated for all the IGS products in [1, Table 9] and the ITRF93/ITRF94 transformation in [2, Table 5]. For completeness and convenience, all the transformations/discontinuities applicable to the IGS Final combinations are reproduced in Table 2. The original estimates of the ITRF93/ITRF94 change in Table 2 were derived simply from a weighted transformation between the ITRF93 and ITRF94 13-station position/velocity sets. They did not take into account small misalignments due to modeling and estimation changes introduced on June 30, 1996, and a small systematic offset between the EOP(IGS) 95P01 and the IERS Bulletin B. Note that the Bulletin B polar motion (PM), corrected for the ITRF-EOP misalignment was used to orient the IGS Final orbits up to June 29, 1996; after that date, the IGS Final orbits, based on the IGS EOP series (EOP(IGS) 95P02) are used. Both IGS (EOP) series (95P01 and 95P02) are based on weighted averages (using orbit weights) of AC PM solutions, combined with UT1–UTC from the current IERS Bulletin A. The 95P01 EOP series, based on ITRF93, starts on January 1, 1995, and ends on June 29, 1996. The 95P02 EOP series started on June 30, 1996.

Table 2: Estimated transformation parameters/discontinuities for IGS Final orbit/EOP products. Estimated sigmas are up to about 5 mm (transformation convention consistent with IERS Annual Reports is used)

Products	Epoch	ITRF Change	T1 (cm)	T2 (cm)	T3 (cm)	D (ppb)	RX (mas) PM y	RY (mas) PM x	RZ (mas)
IGS Final orbits	1995.0	ITRF92-ITRF93	2.0	.8	.3	–.1	1.66	.68	.55
Rates per year			.23	.04	–.08	.11	.12	.15	–.04
IGS Final orbits	1996.5	ITRF93-ITRF94	–2.1	–.1	.1	–.2	–1.27	–.87	–.54
EOP(IGS) (95P01–95P02)	1996.5	ITRF93-ITRF94					–1.51	–.97	
Rates per year			–.27	.0	.20	–.09	–.13	–.20	.04

The PM offsets between the 95P01 and 95P02 series was obtained from comparisons with the IERS Bulletin B and the offsets at 1996.5 were derived using the corresponding rates of Table 2. Consistent PM offset values were obtained when the IERS Bulletin A and the National Earth Orientation Service (NEOS) 24h VLBI PM were used. The PM offset in Table 2 is also compatible with all the individual AC (except for SIO) PM solution offsets, which should be expected since the EOP(IGS) is a weighted average of all AC PM solutions. All the PM offset estimates are summarized in Table 3. They are also based on the 1996.5 rates of Table 2. The different PM offset for SIO, seen in Table 3, is likely due to solution problems SIO AC experienced in the second half of 1996. Note that the difference between the expected ITRF93/94 PM offsets for the Final orbits at 1996.5 and the observed 1996.5 EOP(IGS) discontinuity is likely due to the modeling and estimation changes introduced on June 30, 1996. In the analysis reports for Wk 0860, CODE and EMR reported PM offsets determined independently from overlapping solutions at 1996.5 that were in close agreement with the above EOP(IGS) PM offset [3,4].

The IGS Final orbit discontinuities on June 30, 1996, are expected to be close to the values in Table 2, since, except for the RX and RY rotations, up to June 29, 1996, the IGS Rapid and Final orbits were virtually identical, mostly based on identical AC solutions, but differed in RX, RY orientations. The IGS Rapid orbits were consistent with EOP(IGS) 95 P01, whereas the Final orbits were rotated according the Bulletin B (ITRF93) PM, (i.e., the Bulletin B corrected for the

Table 3: PM offset estimates for June 30, 1996, based on IERS Bulletins A and B; the National Earth Orientation Service (NEOS) weekly, 24h VLBI EOP series, and the assumed rates of Table 2 (–.20; –.13 mas/year for PM x and PM y)

	EOP Ref.	PM Offset (at 6/30/96) (mas)			
PM Solutions	Series Used	PM x	Sig	PM y	Sig
EOP(IGS)95P01-P02	Bull. B	–.97	.01	–1.51	.01
EOP(IGS)95P01-P02	Bull. A	–1.00	.01	–1.54	.01
EOP(IGS)95P01-P02	NEOS VLBI	–.94	.05	–1.51	.05
EOP(COD)	Bull. B	–.95	.02	–1.40	.02
EOP(EMR)	Bull. B	–.97	.03	–1.48	.03
EOP(ESA)	Bull. B	–.82	.03	–1.73	.03
EOP(GFZ)	Bull. B	–.93	.02	–1.49	.02
EOP(JPL)	Bull. B	–.90	.02	–1.47	.02
EOP(NGS)	Bull. B	–.85	.04	–1.79	.05
EOP(SIO)	Bull. B	–1.42	.04	–1.48	.07

ITRF93-EOP misalignment shown in Table II-2 of [5]). Thus the EOP(IGS) offset in Table 2 and the average difference (during the first half of 1996) between EOP(IGS) 95P01 and the Bulletin B (ITRF93) can be used to estimate the effective RX, RY rotation changes for the IGS Final orbits on June 30, 1996. The average 95P01 Bulletin B (ITRF93) PM difference was 0.02 and –.24 mas for PM x and y, respectively (see Table 6), giving RX and RY rotation changes of –.99 and –1.27 mas, respectively, which agree quite well with the predicted values in Table 2. Since the values of Table 2 are close to the above best estimates, and since they were already published in the 1995 IGS Annual Report and have already been used, it is recommended that the original RX, RY estimates, as listed in Table 2 be retained.

Any reference frame change, even from one ITRF version to another, could produce discontinuities in orbits and EOP series. This is due to small errors and biases that can be present in both GPS solutions and ITRF coordinate/velocity sets even after seven-parameter transformations, such as those given in Table 2. This is significant for the modern precise point positioning utilizing precise orbits and clocks [6], which is affected by transformation errors or reference frame changes to the full extent. On the other hand, the traditional relative positioning (at least over separations up to 1000 km) is almost an order of magnitude less sensitive to orientation and scale transformation errors in comparison to the precise point positioning, and it is not at all affected by errors in translation parameters. Thus the precision of the transformation parameters in Table 2 assures submillimeter relative positioning errors for station separations up to 1000 km.

3 1996 IGS Orbit/EOP/Clock Product Changes and Enhancements

Apart from the new ITRF94 reference frame, a number of other significant changes were introduced by all ACs on June 30, 1996, to simplify product generation and improve quality. As mentioned earlier, the original IGS Rapid orbit/EOP/clock (IGR) combinations, based on EOP(IGS) and produced within 11 days from the last observation, became the IGS Final ones. The former IGS Final (Bulletin B (ITRF93)) combinations, produced with a delay of about 2 months, were discontinued. New IGR orbit/EOP/clock products, produced within 24 h and largely independent due to data and, for some ACs, processing differences, were introduced and replaced the IGS Preliminary combinations, which were run on a trial basis in the first half of 1996 (see the Appendix and [7,11]). On June 30, 1996, all ACs were required to implement the subdaily EOP model as well as to solve for PM x and y rates. Some ACs also took this opportunity to introduce other new models in agreement with the 1996 IERS Conventions [9]. This resulted in small precision improvements for most AC Final solutions, as can be seen from Tables 4 and 5 which show summaries of AC Final solutions for December 1995 and December 1996, respectively.

Table 4: Statistics for IGS Final orbit/clock combination in December 1995. Start: December 3, 1995, Wk 0830; end: December 30, 1995, Wk 0833; WRMS, LaRMS, and RMSc are weighted orbit, long arc, and clock rms, respectively

AC	Sta. No.	DX (m)	DY (m)	DZ (m)	RX (mas)	RY (mas)	RZ (mas)	SCL (ppb)	RMS (cm)	WRMS (cm)	LaRMS (cm)	RMSc (ns)	Days
COD	61	0.00	0.02	0.00	–0.19	0.05	–0.25	0.1	8	6	11	2.0	28
		0.01	0.01	0.01	0.13	0.20	0.21	0.1					
EMR	26	0.00	–0.03	–0.01	0.31	0.09	0.11	–0.1	11	11	15	1.0	28
		0.01	0.01	0.01	0.25	0.23	0.17	0.1					
ESA	44	0.01	–0.03	–0.04	0.13	0.03	0.17	0.1	16	14	18	5.0	28
		0.01	0.01	0.01	0.41	0.43	0.31	0.1					
GFZ	43	–0.03	–0.02	0.00	–0.03	0.11	–0.18	–0.4	13	12	17	5.6	28
		0.01	0.01	0.01	0.21	0.24	0.30	0.2					
JPL	37	0.01	0.03	0.00	–0.43	0.03	0.10	0.2	9	9	11	1.0	28
		0.01	0.01	0.01	0.19	0.26	0.15	0.1					
NGS	44	0.02	–0.03	0.02	–0.09	0.60	0.19	–0.1	14	14	18	3684.7	28
		0.01	0.01	0.01	0.30	0.32	0.22	0.1					
SIO	103	–0.01	0.03	0.02	–0.46	0.03	0.10	0.2	10	9	15	0.0	28
		0.01	0.01	0.01	0.23	0.26	0.24	0.1					

Table 5: Statistics for IGS Final orbit/clock combination in December 1996. Start: December 1, 1996, Wk 0882; end: December 28, 1996, Wk 0885; WRMS, LaRMS, and RMSc are weighted orbit, long arc, and clock rms, respectively

AC	Sta. No.	DX (m)	DY (m)	DZ (m)	RX (mas)	RY (mas)	RZ (mas)	SCL (ppb)	RMS (cm)	WRMS (cm)	LaRMS (cm)	RMSc (ns)	Days
COD	83	0.00	0.02	0.00	–0.37	–0.07	0.17	–0.2	8	6	9	1.2	28
		0.00	0.01	0.01	0.10	0.11	0.19	0.1					
EMR	31	–0.01	–0.01	0.00	0.24	0.00	0.18	–0.1	9	9	13	0.6	28
		0.01	0.01	0.01	0.12	0.14	0.32	0.1					
ESA	57	0.00	0.00	0.00	0.17	0.06	0.21	0.1	12	8	12	2.7	28
		0.01	0.01	0.01	0.18	0.16	0.28	0.1					
GFZ	48	0.00	–0.02	0.00	0.13	0.05	–0.20	–0.2	7	6	12	0.6	28
		0.01	0.01	0.00	0.08	0.09	0.13	0.1					
IGR	N/A	0.00	0.00	0.00	–0.04	0.05	–0.11	0.0	8	5	11	0.7	28
		0.01	0.01	0.00	0.15	0.11	0.22	0.1					
JPL	37	0.00	0.01	0.00	–0.17	–0.03	–0.06	0.5	8	8	11	0.6	28
		0.01	0.01	0.00	0.08	0.11	0.08	0.2					
NGS	50	0.01	–0.04	0.00	0.19	0.03	–0.19	–0.1	15	15	16	80.0	28
		0.01	0.01	0.01	0.23	0.23	0.22	0.2					
SIO	123	0.00	0.01	0.02	2.13	0.94	–0.41	0.6	12	9	13	0.0	28
		0.01	0.01	0.01	1.06	0.76	0.32	0.4					

As it can be seen from Tables 4 and 5, most ACs are now using more stations than they did at the end of 1995. It also shows small orbit rms improvements, which may be due to a larger number of stations used, a better station geometry, and perhaps receiver hardware improvements. However, the most significant precision improvements are seen for the RX, RY rotation (PM y, x) standard deviations. The best ACs now show PM precision at or below 0.1 mas! This is likely due to the new subdaily EOP modeling and the PM rate estimation rather than the increased number of stations and/or the improved IGS station network geometry. As it is now customary for IGS Final combination summary reports, the new IGR (IGS Rapid) orbit/clock combinations are also included in Table 5. It is surprising that, despite data delays and occasional lack of data, the IGR orbit/clock and PM (RX, RY rotation) precision is still comparable to the best AC Final solutions, which typically take at least 3 or more days to be produced.

To provide quality and consistency checks to IGS users, the new IGR orbit/clock combinations are compared to the IGS Final Products, and the corresponding statistics are included as IGR in the weekly summary reports for the IGS Final Products. Similar to the tests of precision, consistency, and the reference frame compatibility of the Broadcast orbits/clocks, a unique set of 24-h broadcast orbits/clocks are compared daily to the IGR orbit/clock combinations, and the corresponding statistics and transformation parameters are included as Broadcast (BRD) in the daily IGR summary reports. In this way, reference frame transformation parameters between ITRF94 and BRD orbits are available daily. Typically, BRD orbits are at the 3-m orbit rms level, and could be misaligned or shifted by as much as a meter on some days (see the Appendix, Figure A-13).

For more information on the June 30, 1996, changes, see the Appendix, and for a simple transformation program that transforms the sp3 orbit files from and to various IGS ITRF changes, see IGSMESSAGE # 1391 at the IGS Central Bureau Information System (CBIS) [10] at `http://igscb.nasa.gov//igscb/mail/igsmail/igsmess.1391`. For more information on individual AC processing approaches, see the ***center***.acn files available via WWW at `http://igscb.jpl.nasa.gov/center/analysis/center.acn`. The individual AC and combined IGS product statistics, evaluations, and performance are summarized in the Appendix.

4 1996 EOP Solutions and Orbit/EOP Consistency

In order to increase GPS orbit precision and the consistency with EOP, the AC final orbit solutions before June 29, 1996, were aligned to the ITRF corrected Bulletin B by means of respective AC PM solutions, whereas the IGS Rapid orbits were combined directly in ITRF without any prior PM alignment since May 28, 1995 (Wk 0803). Both combination approaches have been analyzed during 1995 (see [2, 7, and 11]) with no significant difference in precision or consistency, which indicates that all ACs used a consistent ITRF realization and that prior PM orbit alignment was no longer needed. That is why, since June 30, 1996 (Wk 0860), the new IGS Final orbit combinations as well as the new rapid combinations do not use PM alignment of AC orbit solutions. To confirm this for 1996, the RY and RX orbit combination rotations and the corresponding PM x and y differences are compiled in Tables 6 through 8. Tables 6 and 7 summarize the old IGS Final and Rapid orbit combinations for the first half of 1996, comparing the AC orbit RY,RX rotations with the AC PM differences with respect to ITRF corrected Bulletin B and IGS95 P01 PM, respectively. From Tables 6 and 7 it can be seen that, subject only to a small PM y offset, both combinations show virtually identical PM precision and consistency. For completeness, Table 6 also shows the mean RX, RY differences for IGR and EOP(IGS)95P01–Bulletin B (ITRF93), which were used to investigate possible discontinuity for the IGS Final orbits on June 30, 1996, as discussed in the first section dealing with reference frame changes. As expected, both the mean and IGR PM x, y differences in Table 6 are very small. The IGR orbit RY,RX are not available for this period in the IGS Final combination summary reports and thus they are not included in Table 6.

Table 6: IGS Final orbit RX, RY rotation and IERS (Bulletin B) PM differences for AC solutions between January 1–June 29, 1996. (Bulletin B is corrected for the IERS-ITRF93 misalignment; units: mas)

	IGS Final Orbits				IERS (Bulletin B)				Difference (Orb–IERS)			
Center	RY	sig	RX	sig	PM x	sig	PM y	sig	PM x	sig	PM y	sig
CODE	.01	.17	–.48	.23	–.03	.20	–.55	.25	.04		.07	
EMR	–.07	.25	.22	.21	–.10	.28	.08	.29	.03		.14	
ESA	.09	.25	–.23	.32	.08	.27	–.22	.33	.01		–.01	
GFZ	.00	.18	–.09	.15	.00	.24	–.15	.19	.00		.06	
JPL	.05	.18	–.34	.15	–.01	.20	–.31	.19	.06		–.03	
NGS	.19	.46	–.19	.33	.18	.46	–.31	.41	.01		.12	
SIO	–.20	.20	–.10	.27	–.21	.21	–.05	.27	.01		–.05	
MEAN	.01	.04	–.17	.07	.01	.04	–.21	.07	.02	.01	.05	.02
IGR (EOP(IGS)95P01)					.02	.15	–.24	.14				

Table 7: IGS Rapid orbit RX, RY rotation and EOP(IGS) 95 P01 PM differences for AC solutions between January 1–June 29, 1996 (units: mas)

	IGS Rapid Orbits				EOP(IGS) 95 P01				Difference (Orb–IERS)			
Center	RY	sig	RX	sig	PM x	sig	PM y	sig	PM x	sig	PM y	sig
CODE	.02	.13	–.27	.17	.00	.14	–.31	.18	.02		.04	
EMR	–.06	.21	.42	.21	–.07	.23	.32	.26	.01		.10	
ESA	.10	.20	–.02	.26	.11	.21	.02	.27	–.01		.04	
GFZ	.01	.18	.12	.12	.03	.19	.09	.14	–.02		.03	
JPL	.05	.11	–.12	.15	.02	.12	–.07	.15	.03		–.05	
NGS	.18	.41	.03	.30	.21	.42	–.07	.36	–.03		.10	
SIO	–.18	.18	.10	.28	–.19	.15	.19	.26	.01		–.09	
MEAN	.02	.04	–.04	.07	.02	.04	.02	.07	.00	.01	.02	.03

Table 8 shows the consistency of the new IGS Final orbits and the new EOP(IGS) 95P02 PM for the second half of 1996. The improvements in PM precision for most ACs are significant and are approaching 0.1 mas for the best ACs. They are mainly due to the EOP subdaily model and estimation enhancements introduced on June 30, 1996. The ITRF/EOP consistency, on the other hand, is about the same as that in Table 7, i.e., well below the 0.1-mas level for most ACs. Note that atypically large values for SIO were due to problems in SIO orbit/EOP solutions in the second half of 1996. For completeness, Table 8 also shows the current IGS Rapid orbit and the corresponding EOP(IGS) 96P02 combinations. Since these rapid combinations are completed within 24 h after the last observation, often without some crucial station data and/or even missing some AC solutions, it is not surprising that the current IGR orbits and EOP are consistent only at the 0.1-mas level. The results in Tables 6 through 8 show only the consistency of EOP and ITRF as realized by IGS combined and AC orbit solutions. A similar analysis of EOP and the ITRF, as realized by the IGS-combined and AC-station solutions should be done, but this is more appropriate within the scope of the IGS Pilot Project to densify the ITRF [8,12].

Table 8: IGS Final orbit RX, RY rotation and EOP(IGS)95 P02 PM differences for AC solutions between June 30–December 28, 1996 (units: mas)

	IGS Final Orbits				EOP(IGS) 95 P02				Difference (Orb–IERS)			
Center	RY	sig	RX	sig	PM x	sig	PM y	sig	PM x	sig	PM y	sig
CODE	–.02	.10	–.32	.16	–.04	.12	–.32	.18	.02		.00	
EMR	–.02	.19	.30	.24	–.07	.17	.28	.17	.05		.02	
ESA	–.04	.17	.16	.18	–.05	.19	.24	.20	.01		–.08	
GFZ	.04	.12	.12	.13	.07	.12	.10	.12	–.03		.02	
JPL	–.06	.11	–.09	.12	–.05	.12	–.12	.14	–.01		.03	
NGS	.04	.28	.20	.37	.07	.30	.20	.46	–.03		.00	
SIO	.33	.59	.21	1.11	.26	.90	.08	1.56	.07		.13	
MEAN	.04	.04	.08	.08	.03	.04	.06	.08	.01	.01	.02	.02
IGR (NEW)	–.07	.21	–.11	.23	.05	.19	.00	.20	–.12		–.11	

In Figures 1 and 2, the 1996 AC PM solutions are compared to the EOP(IGS). As the EOP(IGS) and all ACs implemented ITRF94 at the same time, their differences are not affected by the change. Any AC PM shifts at 1996.5 would simply indicate that the AC PM x, y offsets (on June 30, 1996) differ from those of the IGS combination. There are no noticeable PM shifts at 1996.5 for most ACs. Note that IGR took a few days to stabilize after the reference frame change, as for several days some ACs continued using ITRF93 for their rapid solutions before implementing ITRF94 in their automated processing. The SIO solution problems, experienced at the end of 1996, are apparent in both figures. The AC PM sigmas for the first and second half of 1996, corresponding to Figures 1 and 2, are listed in Tables 7 and 8, respectively. The new IGR series (EOP(IGS)96 P02) started on June 30, 1996, so, for the first half of 1996, compatible (EOP(IGS)96 P01) series were obtained from the IGS Preliminary combinations (see the Appendix). The IGS(EOP) series used as a reference are precise at the 0.1 mas level according to the IERS Bulletin-A and -B multitechnique EOP combinations and comparisons.

In Figures 3 and 4, the newly implemented PM rate solutions are compared to the IGS Final combination PM Rates, included in EOP(IGS)95P02. There is considerable variation in AC PM rate solutions, and some centers with good PM solutions show relatively poor and biased PM Rate solutions (see, e.g., EMR). This may be at least partly caused by differences in a priori constraints and

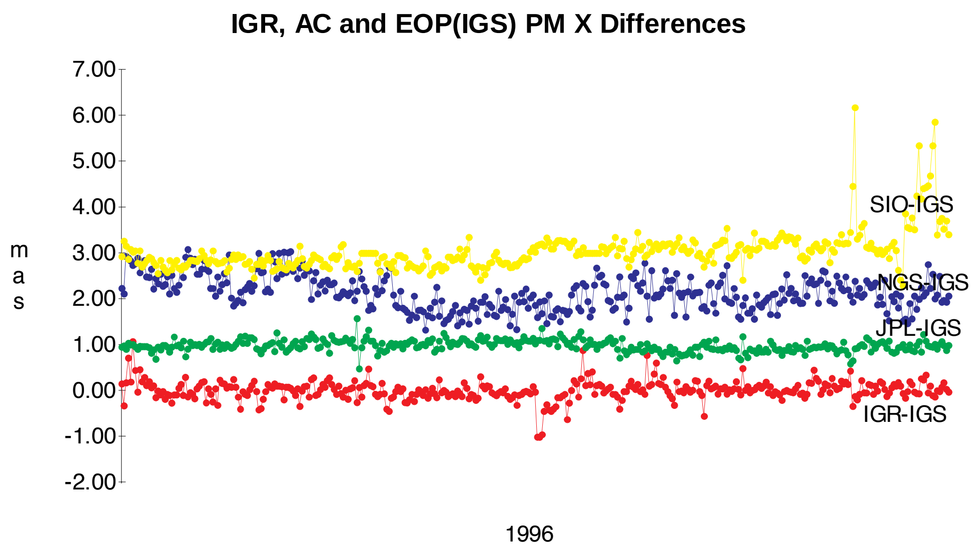

Figure 1a: Polar Motion (PM) X coordinate differences between the IGR (EOP(IGS)96 P02), JPL, NGS, and SIO (offset by 1, 2, 3 mas, respectively) and the EOP(IGS) (95P01 and 95P02) during 1996

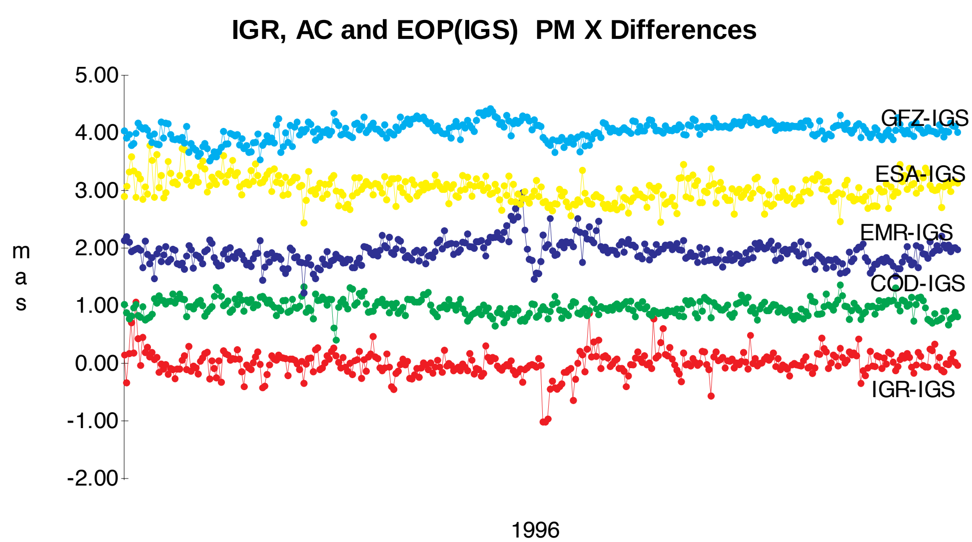

Figure 1b: Polar Motion (PM) X coordinate differences between the IGR (EOP(IGS)96 P02), COD, EMR, ESA, and GFZ (offset by 1, 2, 3, 4 mas, respectively) and the EOP(IGS) (95P01 and 95P02) during 1996

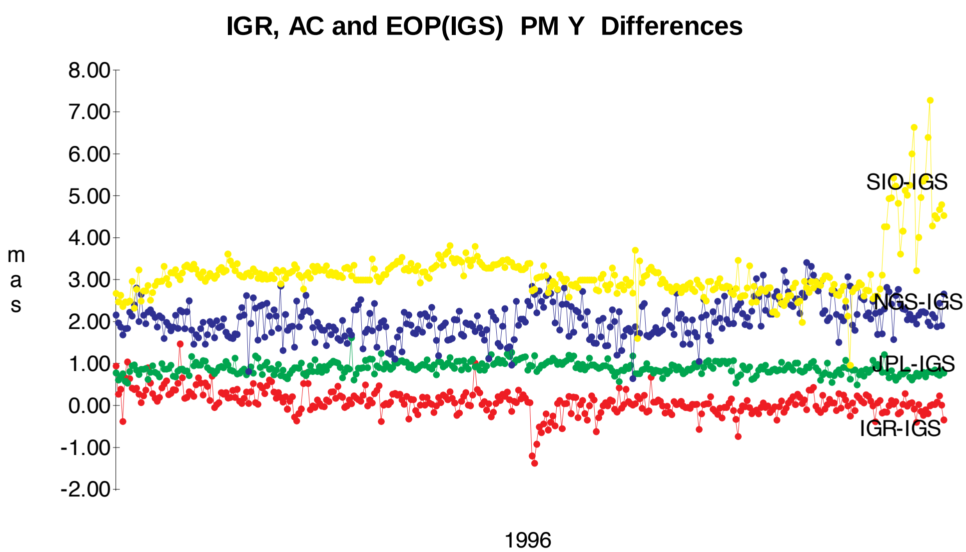

Figure 2a: Polar Motion (PM) Y coordinate differences between the IGR (EOP(IGS)96 P02), JPL, NGS, and SIO (offset by 1, 2, 3 mas, respectively) and the EOP(IGS) (95P01 and 95P02) during 1996

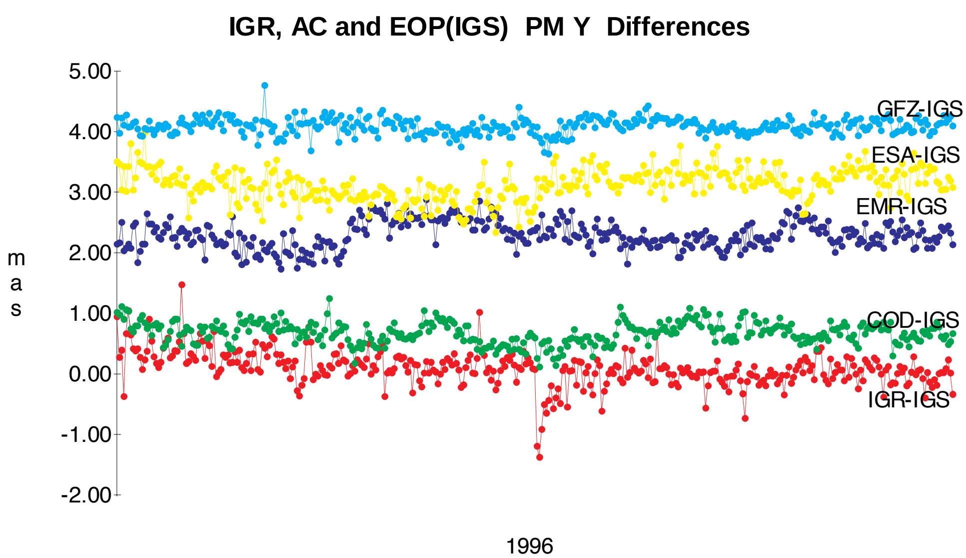

Figure 2b: Polar Motion (PM) Y coordinate differences between the IGR (EOP(IGS) 96 P02), COD, EMR, ESA, and GFZ (offset by 1, 2, 3, 4 mas, respectively) and the EOP(IGS) (95P01 and 95P02) during 1996

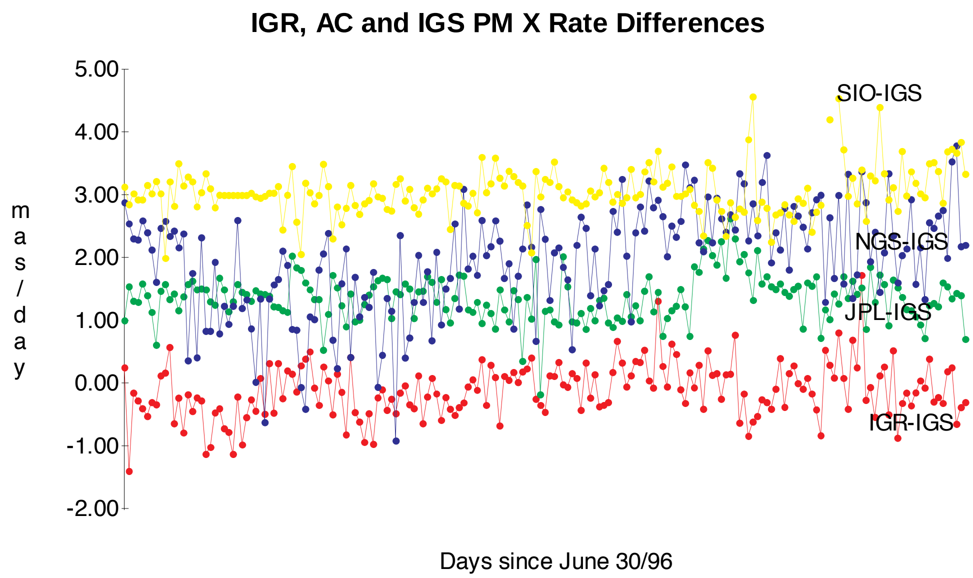

Figure 3a: Polar Motion (PM) X coordinate rate differences between the IGR (EOP(IGS)96 P02), JPL, NGS, and SIO (offset by 1, 2, 3 mas/day, respectively) and EOP(IGS) 95P02 PM X Rates during 1996

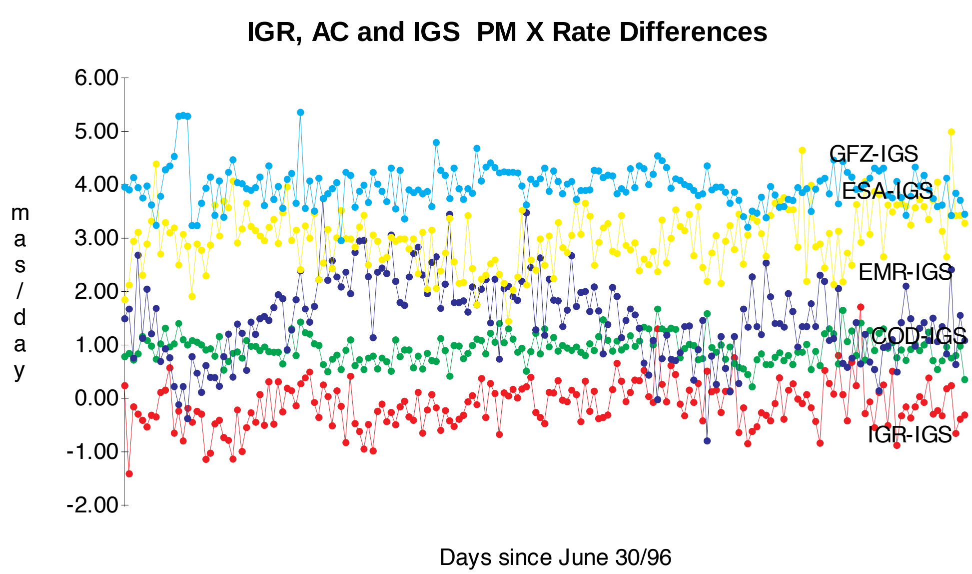

Figure 3b: Polar Motion (PM) X coordinate rate differences between the IGR (EOP(IGS)96 P02), COD, EMR, ESA, and GFZ (offset by 1, 2, 3, 4 mas/day, respectively) and the EOP(IGS) 95P02 PM X Rates during 1996

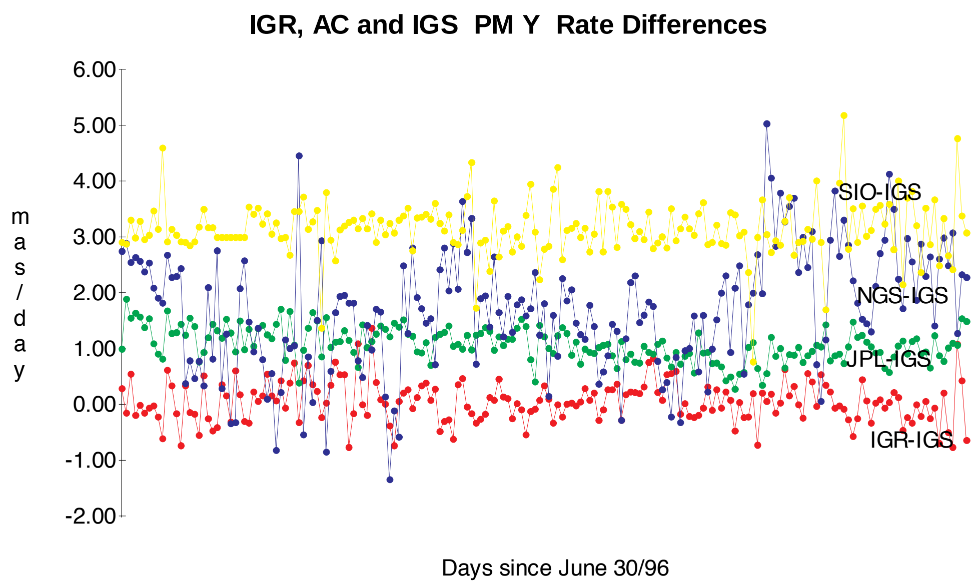

Figure 4a: Polar Motion (PM) Y coordinate rate differences between the IGR (EOP(IGS)96 P02), JPL, NGS, and SIO (offset by 1, 2, 3 mas/day, respectively) and the EOP(IGS) 95P02 PM Y Rates during 1996

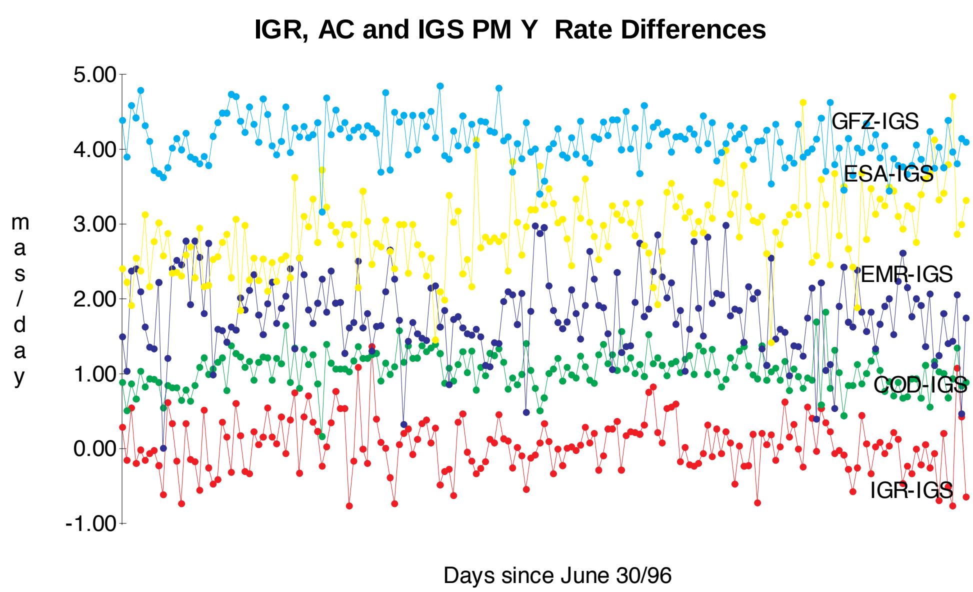

Figure 4b: Polar Motion (PM) Y coordinate rate differences between the IGR (EOP(IGS)96 P02), COD, EMR, ESA, and GFZ (offset by 1, 2, 3, 4 mas/day, respectively) and the EOP(IGS) 95P02 PM Y Rates during 1996

interval lengths (longer than 24 h), or even some continuity conditions used in respective AC PM and PM rate estimations. In fact, for some ACs, the PM rates are consistent with PM (e.g., GFZ after July 28, 1996), indicating that they are derived either from PM or strict PM, and PM rate continuity is enforced in the PM solutions. It should be noted here that the subdaily PM variations are properly modeled by all ACs. Neglecting the subdaily EOP significantly compromises the EOP rate estimation. It was shown that the significant LOD effects up to 100 μs, common to EMR and GFZ (see [13,14]) were in fact caused by the neglected subdaily UT1 variations (Gendt, and Ray, 1996, private communications). The statistics corresponding to Figures 3 and 4 are compiled in Table 9.

Also shown in Table 9 are the statistics for EOP/Rate consistency, which are based on the rates (centered at 0h UT) computed from respected EOP by subtracting the neighboring EOP and the rate solutions at 12 h UT linearly interpolated to 0 h UT. Since all ACs solve for LOD, the UT1 rates are also included for all ACs (except IGS and IGR) in the consistency tests. For statistically independent EOP and rate solutions, the consistency in Table 9 is more sensitive to the EOP sigmas (by a factor of 2) than to the EOP rate sigmas, while for positively correlated EOP rate errors the factor will approach $\sqrt{2}$. In Table 9 one can see the exact correspondence of JPL UT1 and LOD (the JPL UT1 is an integrated LOD), and similar correspondence of GFZ PM and PM rates. The large UT1 sigmas for some ACs (e.g., NGS) are due to a priori UT1 updates used in the AC solutions. Table 9 also shows the consistency for IGS PM and PM rates. Assuming statistical independence and the IGS PM sigma of about 0.1 mas, then the IGS consistency sigmas of 0.2 mas in Table 9 imply PM rate sigmas of about .2 mas/day for EOP(IGS)95 P02.

Table 9: PM rate solution differences with respect to the IGS combined PM rates and the rates computed from EOP (EOP/EOP Rate Consistency) for IGR and AC Final solutions between June 30–December 31, 1996

Center	AC-IGS PM Rate (mas/d)				EOP/Rate Consistency (mas/d)					
	PM x	sig	PM y	sig	PM x	sig	PM y	sig	UT1(μs/d)	sig
CODE	–.06	.24	.05	.24	–.04	.11	–.06	.14	–2	20
EMR	–.50	.77	–.19	.53	–.49	.78	–.30	.55	–1	33
ESA	.00	.56	–.08	.53	.00	.60	–.17	.64	4	90
GFZ	–.01	.36	.13	.29	.00	.09	.00	.07	0	50
JPL	.37	.36	.08	.30	.39	.43	–.04	.34	0	0
NGS	–.03	.86	–.29	1.09	–.03	.86	–.40	1.19	–15	147
SIO	.10	.53	.21	.69	.06	.56	.09	.71	–1	56
IGR(96 P02)	–.11	.44	.06	.36	–.11	.40	–.08	.36	-	-
IGS(95 P02)	0	0	0	0	–.02	.22	–.11	.21	-	-

5 1997 and Future Improvements

Two additional recommendations of the 1996 AC Workshop took much longer to implement. Both IGS predicted orbit and the IGS LOD/UT1 combinations took about a year to implement. The prediction and LOD/UT combination products were introduced on March 2, 1996 (Wk 0895), and are still being evaluated.

5.1 IGS Orbit Prediction Combination

The development of the IGS Predicted Orbits (IGP) started in the Summer of 1996. Originally, to minimize AC effort, it was planned that the IGP be based on a long arc fitting, performed at the time of IGR combinations. ACs were invited and encouraged to take part, develop, and test such a long-arc orbit-prediction scheme. COD and JPL, later joined by GFZ, took part in the initial stages, submitting their long-arc predictions (about 4-day orbit fits, extrapolated to 24 to 48 h). Detection, deletion, and orbit weight determination took a considerable effort at the initial stages. Each day, the AC predictions were compared to the current IGR orbits as soon as they became available. After a few months it became clear that the combination of AC predictions would be more reliable and in most cases more precise than the best individual AC orbit predictions. The AC orbit prediction combination was implemented at the end of 1996. After about 3 months of testing and improvements, the IGP combinations were officially introduced on March 2, 1997. Since then, daily AC orbit predictions, available by 23:00 UT, are combined and made available to the IGS DCs and IGS CB no later than 23:30 UT, so that the IGP orbits for the next day are available for real-time applications. For completeness and user convenience, the extrapolated broadcast clocks are included in IGP orbit files. Within 22 h after the end of the day, the IGP and the corresponding broadcast (BRD) orbits are compared to the IGR orbits. The statistics and transformation parameters are also included in the daily IGR report files to provide timely quality evaluation of IGP and BRD orbits. Typically, the IGP orbit precision is below 1 m, while the BRD orbit precision is at about the 3-m level. Both types of orbit may experience problems with some satellites at some times. All but one AC have chosen to contribute to IGP (some initial statistics are given in the Appendix). More details and performance statistics will be provided in the 1997 Annual Report.

5.2 IGS LOD/UT Combinations

The need for IGS LOD/UT combinations was discussed at the 1996 AC Workshop [7,13]. An approach proposed by Ray [14] was implemented with some modifications and improvements by the end of 1996. It is based on a weighted average of AC LOD solutions, which are calibrated with respect to the latest 21 days of nonpredicted IERS Bulletin A UT1 values. This LOD is then used to integrate IGS UT, starting from the last nonpredicted (observed) Bulletin A UT1 value. Tests over about half a year, from the end of 1996 to the beginning of 1997, indicated that during this period the IGR UT (i.e., 2- to 6-day Bulletin A UT1 predictions) sigmas of about 600 μs could be significantly reduced to about 170 μs using the LOD/UT combinations. The IGS LOD/UT combinations were implemented on March 2, 1997. Starting with Wk 0895 (MJD 50509), the IGS Rapid combinations EOP(IGS)96P02 and Wk 0894 (MJD 50502) the IGS Final combinations EOP(IGS)96P02 contain the LOD combination, and the UT is integrated from the latest observed Bulletin A UT1. Initially only the Bulletin A UT1 values, which included 24-h VLBI data, were used for the LOD calibration and the subsequent UT integration; but since Wk 0898 (MJD 50530), all the observed Bulletin A UT1s have been used for both IGR and IGS LOD/UT combinations. As in the IGS PM and PM rate combinations, the AC orbit weights are also used for the LOD combinations. Observed Bulletin A UT1 values are typically available at the time of the IGS Final combinations, thus the LOD combination is typically used to interpolate for only 0.5 day. But significant UT1 improvements are expected for IGR LOD/UT. As of Wk 0895, both EOP(IGS) series include consistent PM, LOD, and UT combinations.

5.3 Future Improvements of AC Solutions

As pointed out above, the ACs improved the precision of their solutions during 1996. The availability of IGR combination solutions within 24 h considerably enhances quality control because ACs can now use IGR to assess their final solutions. This eliminates the need for any resubmission of final AC solutions, and there is no provision for resubmission of either rapid or final AC solutions after June 30, 1996. Despite the fact that the best ACs and the IGS Final Combination orbits and PM are consistently near the 5-cm and 0.1-mas precision level, further improvements are possible based on the analysis of PM, PM rates, the ITRF/EOP consistency, and the IGS SINEX combination analysis [12]. Some AC still show small solution biases in EOP, EOP/ITRF consistency, and the implied geocenter, as well as small discontinuities between daily orbits. In particular, the orbit discontinuities and the geocenter offsets obtained from the unconstrained SINEX solutions can exceed 10 cm for some ACs, despite the concentrated effort by all ACs to eliminate such biases. Additional improvements will also be realized when station-related biases such as antenna-, atmospheric-, and ocean-loading effects are used consistently and further improved. The 1997 AC Workshop—held at JPL in Pasadena, California, in March 1997—concentrated on local site effects [15,16] and initiated a systematic effort to improve the quality and quantity of data. Precision could be increased by improved stability and consistency of IGS reference frame realization, e.g., by making use of the IGS GNAAC (Global Network Associated AC) SINEX combinations [12].

Another topic discussed during the 1997 AC Workshop relates to the IGS support of low Earth orbiting (LEO) satellites [17]. From the workshop presentations and discussions it became clear that most LEO requirements could be met by the IGS products currently available or under development, such as tropospheric/ionospheric delay combinations. However, higher data sampling

(≤ 10 s) and near-real-time availability of data from a subset of IGS stations and IGS clock combinations at much shorter intervals than the sp3 files (15 min) are not generated at present time. The inclusion of some LEO satellites may further improve AC global solutions and the IGS products.

6 Summary

A number of changes and enhancements of IGS products took place in 1996 and in early 1997; the new IGS Predicted (IGP) Orbits were introduced. The current IGS combinations, their precision, availability, and other characteristics are summarized in Table 10 and in the Appendix.

Other IGS products currently under developments by some AC/AACs, such as tropospheric, ionospheric delay, and SINEX combinations, are described by Gendt [18], Feltens [19], and Kouba [12].

Table 10: IGS combined Orbit/EOP/Clock product characteristics and precision. (All IGS products are in ITRF94; *WWWW* denotes the GPS Wk No.; *D* denotes day No. (0–6); delivery delays are as of April 1997 since the last observation)

Product Type	Effective Date	Product Files	Precision orbit/EOP	Clock precision	Delivery delays	EOP series in 1997
IGS Final	Jan 1/94	IGS*WWWWD*.SP3	5 cm	.5 ns	11 days	EOP(IGS) 95P02
		IGS*WWWW*7.ERP	.10 mas	.		
		IGS*WWWW*7.SUM				
IGS Rapid	Jan 1/94	IGR*WWWWD*.SP3	5–10 cm	.5–1.0 ns	22 h	EOP(IGS) 96P02
(IGR)		IGR*WWWWD*.ERP	.20 mas			
		IGR*WWWWD*.SUM				
IGS Predicted	Jun 30/96	IGP*WWWWD*.SP3	50–100 cm	80–100 ns	0 h	IERS Bull. A
(IGP)		IGP*WWWWD*.ERP	1_3 mas			(prediction)
		IGP*WWWWD*.SUM				

Note: Performance statistics for IGR and (BRD, IGP) orbits are included in the *IGSWWWW7.SUM* and *IGRWWWWD.SUM* files, respectively.

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Appendix

1996 IGS Orbit, Clock and EOP Combinations and Their Evaluation

A.1 Introduction

This Appendix will review the combination and evaluation procedures and statistics for 1996. Some changes and enhancements were discussed earlier and will not be fully described hereafter. The contributing ACs were listed in Table 7 of the IGS 1995 Annual Report [2]. As in 1995, two IGS combinations were routinely performed: the IGS Rapid and Final combinations; their definitions and submission deadlines changed after GPS Wk 860 (June 30, 1996). New IGS prediction combinations were introduced on GPS Wk 895 (March 2, 1997) and will also be briefly discussed.

A.2 Changes and Enhancements on GPS Wk 860

On GPS Wk 860 (June 30, 1996), the former IGS Rapid orbit/clock/EOP combination (IGR), based on EOP(IGS) and produced within 11 days after the last observation, became the IGS Final combination replacing the former IGS Final combination (Bulletin B (ITRF93)) produced about 2 months after the last observation. New IGR orbit/clock/EOP products, produced within 24 h from the last observation, were introduced on GPS Wk 860 (ITRF94) replacing the former IGS Preliminary combinations (ITRF93) run on a trial-basis only. The new IGR combination is generated daily as opposed to a weekly cycle for the Final products. All the changes that have occurred in the past three years of IGS Service are summarized in Table A-1, which includes names, orbit orientation, and submission delays.

Table A-1: History of the IGS Preliminary, Rapid and Final Products

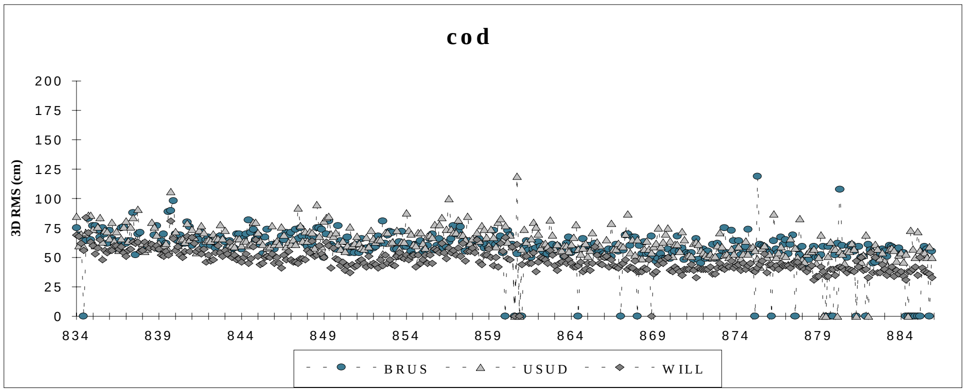
GPS Wks	Short Name	IGS Name	Orientation	Delays	Status	Cycle
734-802	IGS	IGS Final	Bulletin B	2 months	Official	Weekly
	IGR	IGS Rapid	Bulletin A	14 days	Official	Weekly
803-859	IGS	IGS Final	Bulletin B	2 months	Official	Weekly
	IGR	IGS Rapid	ITRF93	11 days	Official	Weekly
834-859	IGP	IGS Preliminary	ITRF93	38 hours	Pilot	Daily
860-...	IGS	IGS Final	ITRF94	11 days	Official	Weekly
860-901	IGR	IGS Rapid	ITRF94	24 hours	Official	Daily
902-...	IGR	IGS Rapid	ITRF94	22 hours	Official	Daily
895-...	IGP	IGS Prediction	Bulletin A	~30 min before start of new day	Official	Daily

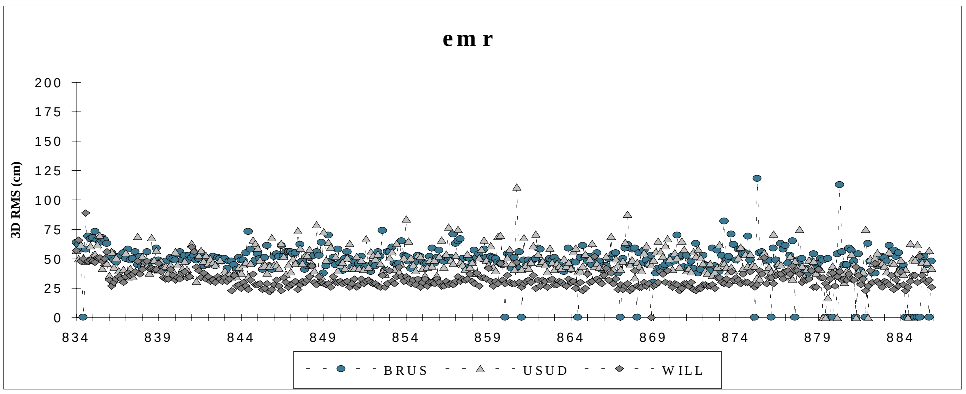
A.3 Orbit and Clock Evaluations

The long-arc orbit evaluation was implemented to detect problems that could affect the daily weighted average combinations and to assess the consistency of individual AC solutions, including IGS combined orbits, over a 1-week period. Ephemerides are analyzed for individual AC independently from the combination process. The long-arc (LA) orbit evaluation is described in more detail in the IGS 1994 Annual Report [20]. The IERS subdaily EOP (Ray model for diurnal and subdiurnal tides) was implemented in the LA evaluation procedure on GPS Wk 866 (August 11, 1996). This resulted in decreased LA rms of about 1 cm (7-day arc). Note also that LA evaluation is performed only for the orbit products generated on a weekly cycle, i.e., for the former IGS Rapid orbits (before GPS Wk 860) and for the IGS Final orbits. LA rms are presented in Figure A-10.

Starting with GPS Wk 834 (December 31, 1995), the IGS combined orbits/clocks as well as all AC solutions that contain both the orbit and clock data are further evaluated by an independent single point positioning program (navigation mode) developed at NRCan. This is done to verify clock solution precision and orbit/clock consistency. At first, only the former IGS Rapid (IGR and ACs— GPS Wks 834–859) orbits/clocks were evaluated using this technique. On GPS Wk 860, we also started evaluating the Final (IGS and ACs) orbits/clocks quality. Evaluation of the new Rapid (IGR and ACs) orbits/clocks began only on GPS Wk 878. However, the new IGR orbits/clocks evaluation has been performed weekly since GPS Wk 860, when the IGR has been included for comparison in the IGS Final summary reports. Note that this evaluation was never performed for the IGS Final combination before GPS Wk 860 (referenced to Bulletin B) since rms values were virtually the same as the old Rapid IGS unless ACs submitted new orbit/clock solutions, which rarely happened.

Pseudorange data from three stations are used daily and their corresponding position rms (with respect to ITRF93 prior to GPS Wk 860 and to ITRF94 from GPS Wk 860) are summarized in Tables 4 and 5 of the weekly/daily IGS Final/Rapid combination summary reports. The three stations are Brussels in Belgium (BRUS), Usuda in Japan (USUD), and Williams Lake in Canada (WILL). Table A-2 summarizes the point positioning results obtained from both the former IGS Rapid Combination (GPS Wks 834–859) and the new IGS Final combination (GPS Wks 860–885). These two series differ mainly by the ITRF reference frame used, i.e., ITRF93 versus ITRF94. Figures A-1a, A-1b, and A-1c show the daily 3D point positioning rms series for all ACs found in Table A-2. It is important to note that the IGR orbits/clocks are included in the Final IGS summary reports for performance comparison, i.e., they are compared to the IGS Final orbits/clocks.





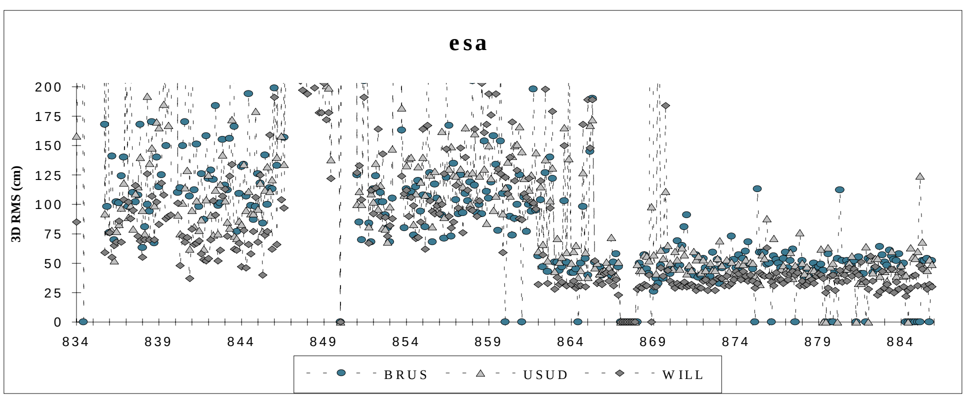


Figure A-1a: Final Combination—1996 Daily 3D Point Positioning rms (navigation mode) for COD, EMR, and ESA. Zero rms means that either the station data or the AC clock/orbit solutions were missing

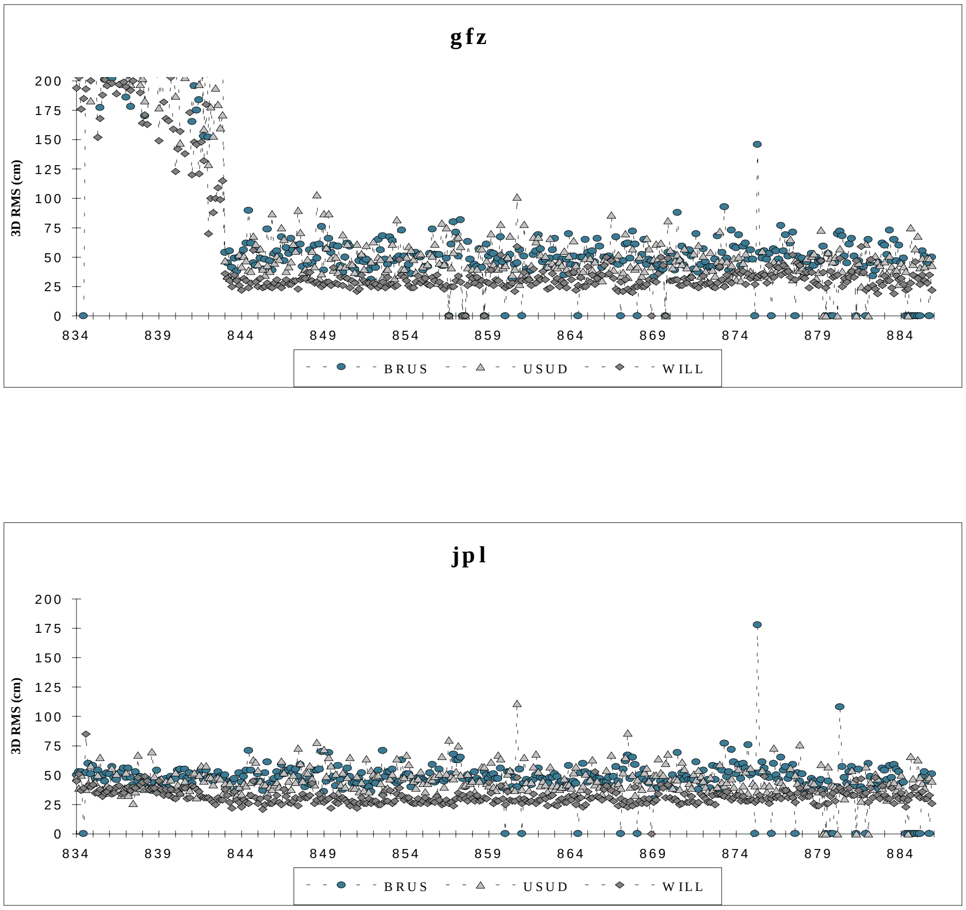
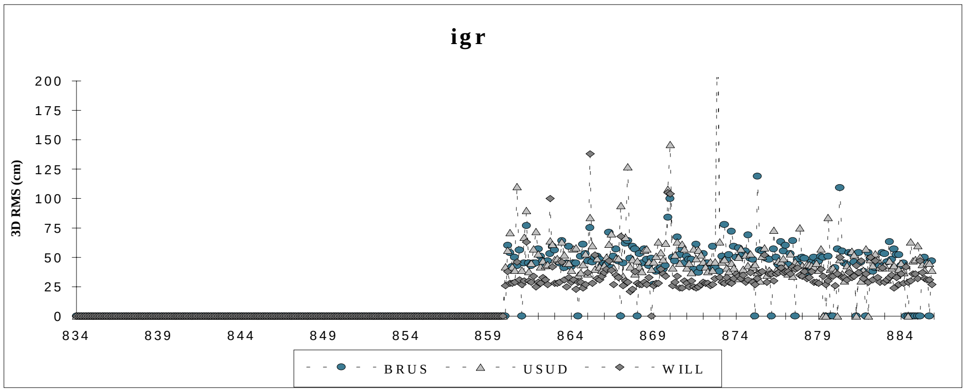


Figure A-1b: Rapid Combination—1996 Daily 3D Point Positioning rms (navigation mode) for GFZ and JPL. Zero rms means that either the station data or the AC clock/orbit solutions were missing



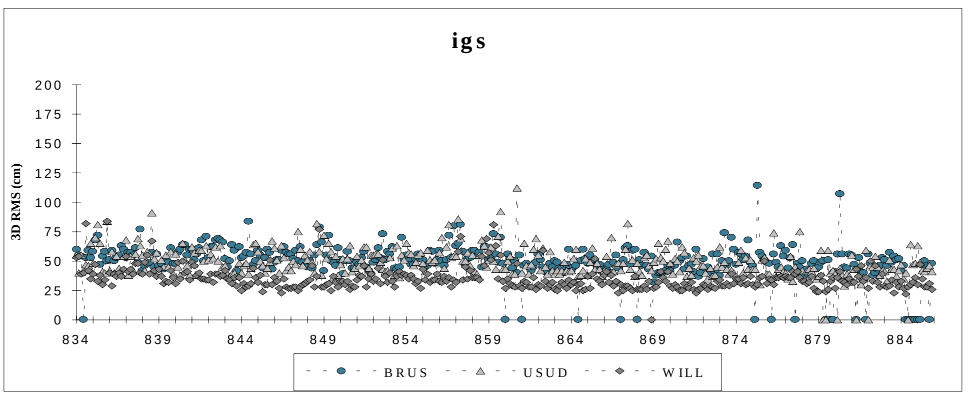


Figure A-1c. Final Combination—1996 Daily 3D Point Positioning rms (navigation mode) for IGR and IGS. Zero rms means that either the station data or the AC clock/orbit solutions were missing

Table A-2: 1996 IGS Rapid/Final combination point positioning rms (pseudorange data - navigation mode) for ACs providing orbit/clock solutions (GPS Wks 834–859/860–885[a], respectively)[b,c]

	BRUS				USUD				WILL			
ACs	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D	Lat	Lon	Ht	3D
COD	52	35	88	62	48	35	94	64	40	28	68	48
EMR	41	28	75	52	35	26	73	49	30	17	47	34
ESA	141	82	249	172	130	84	245	167	143	82	193	147
GFZ	99	61	179	123	94	54	170	117	90	54	114	90
IGR[d]	47	30	80	56	38	28	85	56	35	22	64	44
IGS[e]	43	29	76	53	36	27	75	51	31	18	51	36
JPL	42	27	72	51	33	25	69	47	28	16	46	32

[a] Period covered: GPS Wks 834–885 (December 31, 1995–December 28,1996).

[b] Units: cm.

[c] Rms ≥ 999 cm were excluded from the rms computations.

[d] Includes the new Rapid combination only (IGR–GPS Wks 860–885)

[e] Includes both the old Rapid (IGR–GPS Wks 834–859) and the new Final (IGS -GPS Wks 860–885).

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

Table A-3 summarizes step by step the Rapid and Final combination procedures for all three products during 1996: ephemerides, clocks, and EOP. It is divided into two parts: before GPS Wk 860 (Table A-3a) and from GPS Wk 860 until now (Table A-3b). A more detailed description including the formulas involved in the combination can be found in the IGS 1994 Annual Report [20].

Table A-3a: GPS Wks 834–859—Orbit, Clock, and EOP combination/evaluation procedures

Step	Procedure
1	Long-arc ephemerides evaluation for each AC: Rapid and Final combinations: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and rms residuals are examined.
2	Transformation to common reference: (a) Orbit Final combination: the difference between each AC EOP solution and Bulletin B values are applied to the respective ephemerides. Rapid Combination: performed directly in the ITRF93 reference frame without EOP alignment. (b) Clock Clock offset and drift with respect to broadcast GPS clock corrections are estimated for each AC using non-SA satellites and applied to the respective AC reference clocks.
3	Orbit and clock combinations: AC orbit weights are computed from absolute deviations with respect to unweighted mean orbits. AC clock weights are computed from absolute deviations from broadcast GPS clocks for non-SA satellites. Satellite ephemerides and clock corrections are combined as weighted averages of AC solutions.
4	EOP Combination: Final combination: none. Rapid combination: PM x and y EOP and, since GPS Wk 857, PM x and y rates are combined as weighted averages from available AC PM values using orbit weights.
5	Long-arc ephemerides evaluation for IGS/IGR combined orbits: Seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program, and rms residuals are examined.
6.	Independent point positioning evaluation (navigation mode): Final combination: none. Rapid combination: all AC solutions that contain orbits and clocks (including IGR combinations) are evaluated using the three IGS stations: BRUS, USUD, and WILL.

Table A-3b: GPS Wks 860 and after—Orbit, Clock, and EOP combination/evaluation procedures

Step	Procedure
1.	Long-arc ephemerides evaluation for each AC:
	Final combination: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and rms residuals are examined.
	Rapid Combination: none.
2.	Transformation to Common Reference:
	(a) Orbit Rapid and Final combinations: performed directly in the ITRF94 reference frame without EOP alignment.
	(b) Clock Clock offset and drift with respect to broadcast GPS clock corrections are estimated for each AC using non-SA satellites and applied to the respective AC reference clocks.
3.	Orbit and Clock Combinations:
	AC orbit weights are computed from absolute deviations with respect to unweighted mean orbits.
	AC clock weights are computed from absolute deviations from broadcast GPS clocks for non-SA satellites.
	Satellite ephemerides and clock corrections are combined as weighted averages of AC solutions.
4.	EOP Combination:
	Rapid and Final combinations: PM x and y and PM rates are combined as weighted averages from available AC EOP values using orbit weights.
5.	Long-arc ephemerides evaluation for the IGS Combined Orbits:
	Final combination: seven daily satellite ephemerides are used as pseudo-observations in an orbit adjustment program and rms residuals are examined.
	Rapid combination: none.
6.	Independent Point Positioning Evaluation (navigation mode):
	Rapid and Final combinations: all AC solutions that contain orbits and clocks (including IGS/IGR combinations) are evaluated using the three IGS stations: BRUS, USUD, and WILL.

A.5 IGS Rapid and Final Combination Results in 1996

In this section, results for the third year of IGS service, i.e., December 31, 1995, to December 28, 1996 (GPS Wks 834–885), are presented.

Tables A-4a, A-4b, A-4c, A-4d and A-4e show, for each AC, means and standard deviations for the translation, the rotation, and the scale parameters of the daily Helmert transformations with respect to the IGS Final, Rapid or Preliminary combinations for the period before and after GPS Wk 860. Splitting the results this way allows the reader to see more easily the differences (if any) when the reference frame, AC modeling, and/or the combination strategies were changed.

More specifically, Table A-4a shows the Helmert transformation statistics with respect to the IGS Final orbits for all seven ACs when the orbits were referenced to Bulletin B (GPS Wks 834–859). A complete series would have 182 days in the last column. Note that SIO's statistics on January 1, 1996, were not included in Table A-4a because they biased these statistics too much.

Table A-4a: IGS Final combination—GPS Wks 834–859 (referenced to Bulletin B); means (μ) and standard deviations (σ) of the daily Helmert transformation parameters

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(meters)			(mas)		(ppb)	
COD	μ	0.00	0.02	0.00	–0.48	0.01	–0.16	0.1	182
	σ	0.01	0.01	0.01	0.23	0.17	0.25	0.1	
EMR	μ	0.00	–0.01	–0.01	0.22	–0.07	0.41	–0.1	182
	σ	0.01	0.02	0.01	0.21	0.25	0.24	0.2	
ESA	μ	0.00	–0.01	–0.01	–0.23	0.09	–0.07	0.1	182
	σ	0.01	0.01	0.01	0.32	0.25	0.27	0.1	
GFZ	μ	–0.02	–0.03	0.00	–0.09	0.00	–0.22	–0.3	182
	σ	0.02	0.01	0.01	0.15	0.18	0.19	0.1	
JPL	μ	0.00	0.02	0.00	–0.34	0.05	0.11	0.1	182
	σ	0.01	0.01	0.01	0.15	0.18	0.15	0.1	
NGS	μ	0.01	–0.04	0.01	–0.19	0.19	–0.09	–0.2	182
	σ	0.01	0.02	0.02	0.33	0.46	0.30	0.2	
SIO	μ	–0.01	0.02	0.00	–0.10	–0.20	0.02	0.1	181
(*)	σ	0.01	0.01	0.01	0.27	0.20	0.38	0.2	

(*) 01 Jan., 1996 excluded from SIO's statistics because of a very large outlier.

Table A-4b shows the Helmert transformation statistics with respect to IGR for all seven ACs and the IGS Preliminary (IGP) combined orbits (GPS Wks 834–859). During this period, the IGR orbits were combined directly in the ITRF93 reference frame. Note that the IGP solutions were combined on a daily basis within 38 hours after the last observation, while all other ACs had delays up to 11 days. A complete series would have 182 days. IGP comparisons with IGR started only on GPS Wk 837, which is exactly 161 days. As in Table A-4a, SIO's statistics on January 1, 1996, were not included in Table A-4b.

Table A-4b: IGS Rapid Combination—GPS Wks 834–859 (performed directly in the ITRF93 reference frame); means (μ) and standard deviations (σ) of the daily Helmert transformation parameters

AC		DX	DY (meters)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
COD	μ	0.00	0.02	0.00	–0.27	0.02	–0.16	0.1	182
	σ	0.01	0.01	0.01	0.17	0.13	0.27	0.1	
EMR	μ	0.00	–0.01	–0.01	0.42	–0.06	0.41	–0.1	182
	σ	0.01	0.02	0.01	0.21	0.21	0.24	0.2	
ESA	μ	0.00	–0.01	–0.01	–0.02	0.10	–0.07	0.1	182
	σ	0.01	0.01	0.01	0.26	0.20	0.27	0.1	
GFZ	μ	–0.02	–0.03	0.00	0.12	0.01	–0.22	–0.3	182
	σ	0.02	0.02	0.01	0.12	0.18	0.19	0.1	
JPL	μ	0.00	0.02	0.00	–0.12	0.05	0.11	0.1	182
	σ	0.01	0.01	0.01	0.15	0.11	0.15	0.1	
NGS	μ	0.01	–0.04	0.01	0.03	0.18	–0.11	–0.2	175
	σ	0.01	0.02	0.02	0.30	0.41	0.30	0.2	
SIO	μ	–0.01	0.02	0.01	0.10	–0.18	–0.04	0.1	167
(*)	σ	0.01	0.01	0.01	0.28	0.18	0.76	0.2	
IGP	μ	0.01	–0.01	–0.01	0.21	–0.06	0.16	–0.1	161
	σ	0.01	0.01	0.01	0.28	0.23	0.20	0.2	

(*) 01 Jan., 1996 excluded from SIO's statistics because of a very large outlier.

Table A-4c shows the Helmert transformation statistics with respect to IGP for all six ACs that participated in this pilot project (GPS Wks 834–859). Again, during that period, orbits were combined directly in the ITRF93 reference frame with a 38-h delay. A complete series would have 181 days, since December 31, 1995, was excluded from the statistics due to insufficient number of ACs. Broadcast (BRD) orbit statistics are shown for comparison.

Table A-4c: IGS Preliminary Combination—GPS Wks 834–859 (performed directly in the ITRF93 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(meters)			(mas)		(ppb)	
COD	μ	–0.01	0.01	0.00	–0.25	0.10	–0.31	0.2	179
	σ	0.01	0.02	0.02	0.52	0.48	0.37	0.7	
EMR	μ	0.00	–0.01	0.00	0.22	–0.22	0.37	–0.1	166
	σ	0.01	0.02	0.02	0.41	0.44	0.48	0.3	
ESA	μ	0.02	–0.01	0.00	–0.15	0.05	–0.22	0.1	146
	σ	0.02	0.01	0.02	0.42	0.45	0.36	0.3	
GFZ	μ	0.00	–0.03	0.00	0.01	0.22	–0.16	–0.2	146
	σ	0.01	0.02	0.01	0.30	0.28	1.10	0.2	
JPL	μ	0.00	0.02	0.00	0.16	0.07	0.36	0.1	159
	σ	0.01	0.02	0.01	0.38	0.29	0.31	0.2	
SIO	μ	–0.01	0.02	–0.01	0.36	–0.08	0.01	0.1	159
	σ	0.02	0.02	0.03	1.37	1.92	1.88	0.4	
BRD	μ	0.05	0.04	0.20	0.70	0.67	8.07	6.5	181
	σ	0.14	0.10	0.42	2.19	2.94	6.22	5.0	

Note: December 31, 1995 excluded from statistics for all ACs.

Table A-4d shows the Helmert transformation statistics with respect to IGS Final orbits for all seven ACs and the new IGR (GPS Wks 860–885). During that period, orbits were combined directly in the ITRF94. Note that the IGR orbits are combined on a daily cycle within 24 h of the last observation, while other ACs have delays up to 11 days. A complete series would have 182 days.

Table A-4d: IGS Final Combination—GPS Wks 860–885 (performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY	DZ	RX	RY	RZ	SCL	DAYS
			(meters)			(mas)		(ppb)	
COD	μ	0.00	0.02	0.00	–0.32	–0.02	0.15	–0.1	182
	σ	0.01	0.01	0.01	0.16	0.10	0.21	0.1	
EMR	μ	0.00	0.00	0.00	0.30	–0.02	0.31	–0.1	182
	σ	0.01	0.01	0.01	0.24	0.19	0.29	0.1	
ESA	μ	0.00	0.00	0.00	0.16	–0.04	0.24	0.1	175
	σ	0.01	0.01	0.01	0.18	0.17	0.22	0.1	
GFZ	μ	0.00	–0.02	0.00	0.12	0.04	–0.24	–0.2	182
	σ	0.01	0.01	0.01	0.13	0.12	0.20	0.1	
JPL	μ	0.00	0.01	0.00	–0.09	–0.06	0.01	0.2	182
	σ	0.01	0.01	0.01	0.12	0.11	0.12	0.2	
NGS	μ	0.00	–0.05	0.00	0.20	0.04	–0.22	–0.1	182
	σ	0.01	0.01	0.01	0.37	0.28	0.27	0.2	
SIO	μ	–0.01	0.01	0.01	0.21	0.33	–0.75	0.2	147
	σ	0.01	0.01	0.01	1.11	0.59	1.86	0.3	
IGR	μ	0.01	0.00	0.00	–0.11	–0.07	–0.11	–0.1	182
	σ	0.01	0.01	0.01	0.23	0.21	0.22	0.1	

Finally, Table A-4e shows the Helmert transformation statistics with respect to IGR for all seven ACs and the broadcast orbits (GPS Wks 860–885). During that period, orbits were combined directly in the ITRF94. AC solutions were combined on a daily basis within 24 h of the last observation. A complete series would have 182 days except for NGS, which started on day 4 of GPS Wk 866 (total of 136 days).

Table A-4e: IGS Rapid Combination—GPS Wks 860–885(performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (meters)	DZ	RX	RY (mas)	RZ	SCL (ppb)	DAYS
COD	μ	–0.01	0.02	–0.01	–0.46	0.18	0.12	–0.1	181
	σ	0.01	0.01	0.01	0.24	0.24	0.25	0.2	
EMR	μ	0.00	0.00	–0.01	0.39	0.04	0.45	0.0	144
	σ	0.02	0.02	0.02	0.54	1.49	0.50	0.4	
ESA	μ	0.02	–0.01	0.00	0.31	0.05	0.26	0.2	166
	σ	0.01	0.01	0.02	0.38	0.29	0.34	0.3	
GFZ	μ	0.00	–0.02	0.00	0.22	0.15	–0.33	–0.1	150
	σ	0.01	0.02	0.01	0.47	0.37	0.61	0.2	
JPL	μ	0.00	0.02	0.00	0.01	–0.09	0.05	0.2	138
	σ	0.01	0.01	0.01	0.28	0.23	0.22	0.2	
NGS	μ	0.00	–0.04	0.04	0.56	0.20	–0.25	–0.1	103
	σ	0.02	0.04	0.04	1.11	0.52	0.55	0.3	
SIO	μ	–0.01	0.01	0.00	–0.71	–0.91	–0.81	0.2	151
	σ	0.02	0.02	0.03	0.71	0.80	1.30	0.4	
BRD	μ	0.01	0.04	–0.02	–2.26	0.40	4.94	1.3	182
	σ	0.13	0.10	0.53	2.83	3.52	5.51	5.7	

Figures A-2 through A-9 display, for each AC, the weekly averages and standard deviations of the translation, rotation, and scale of the X, Y, Z satellite coordinates with respect to the IGS Final orbits. Only the Final Helmert transformation statistics (for all ACs and IGR) are included in Figures A-2 through A-9. Note that the IGS orbits were aligned to Bulletin B before GPS Wk 860 and that orbits were combined directly in the ITRF94 reference frame starting on GPS Wk 860 (this remark is also valid for Figures A-10 and A-11). The impact of all changes that occurred on GPS Wk 860 can be seen in some of the AC results.

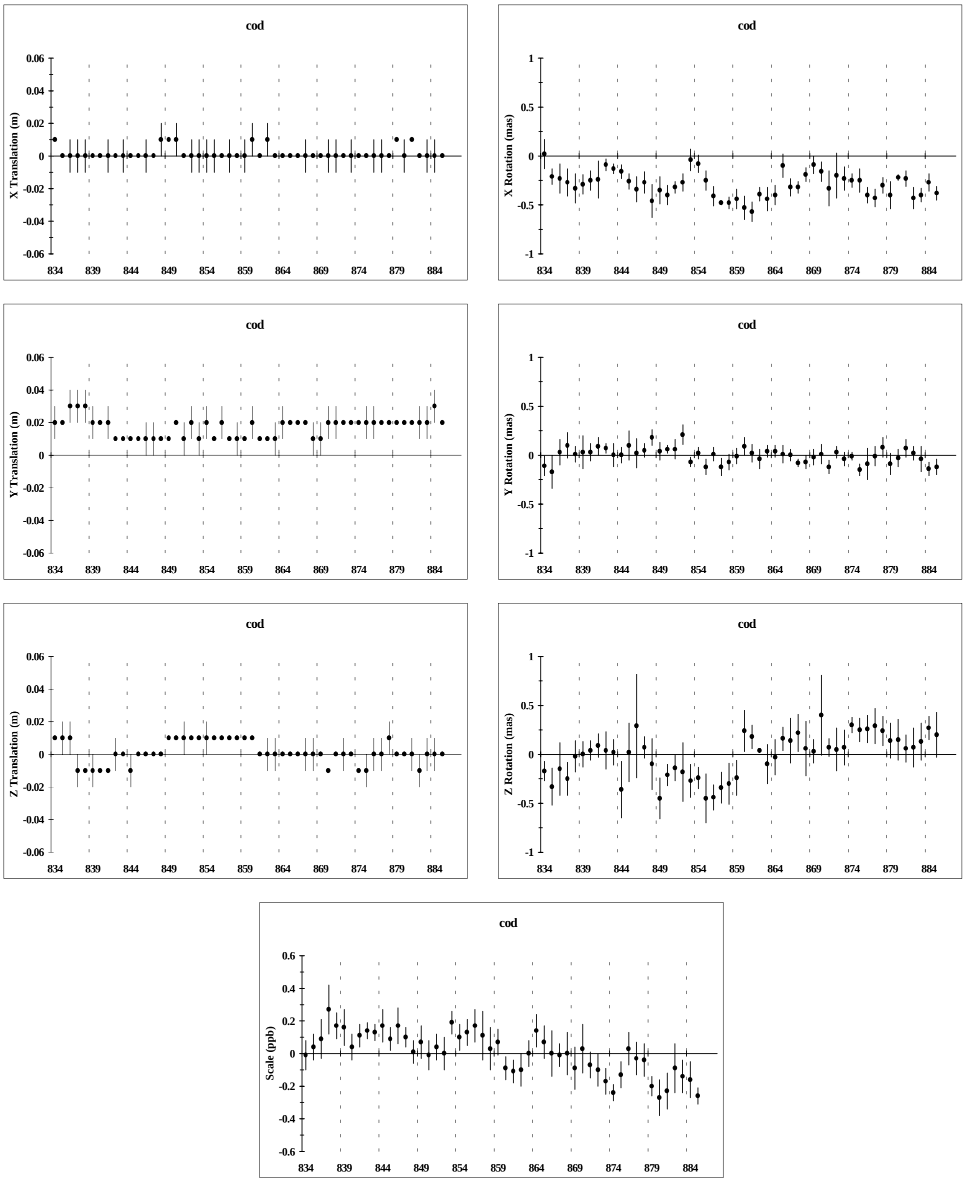


Figure A-2: COD 1996: Final weekly mean seven-parameter Helmert transformations

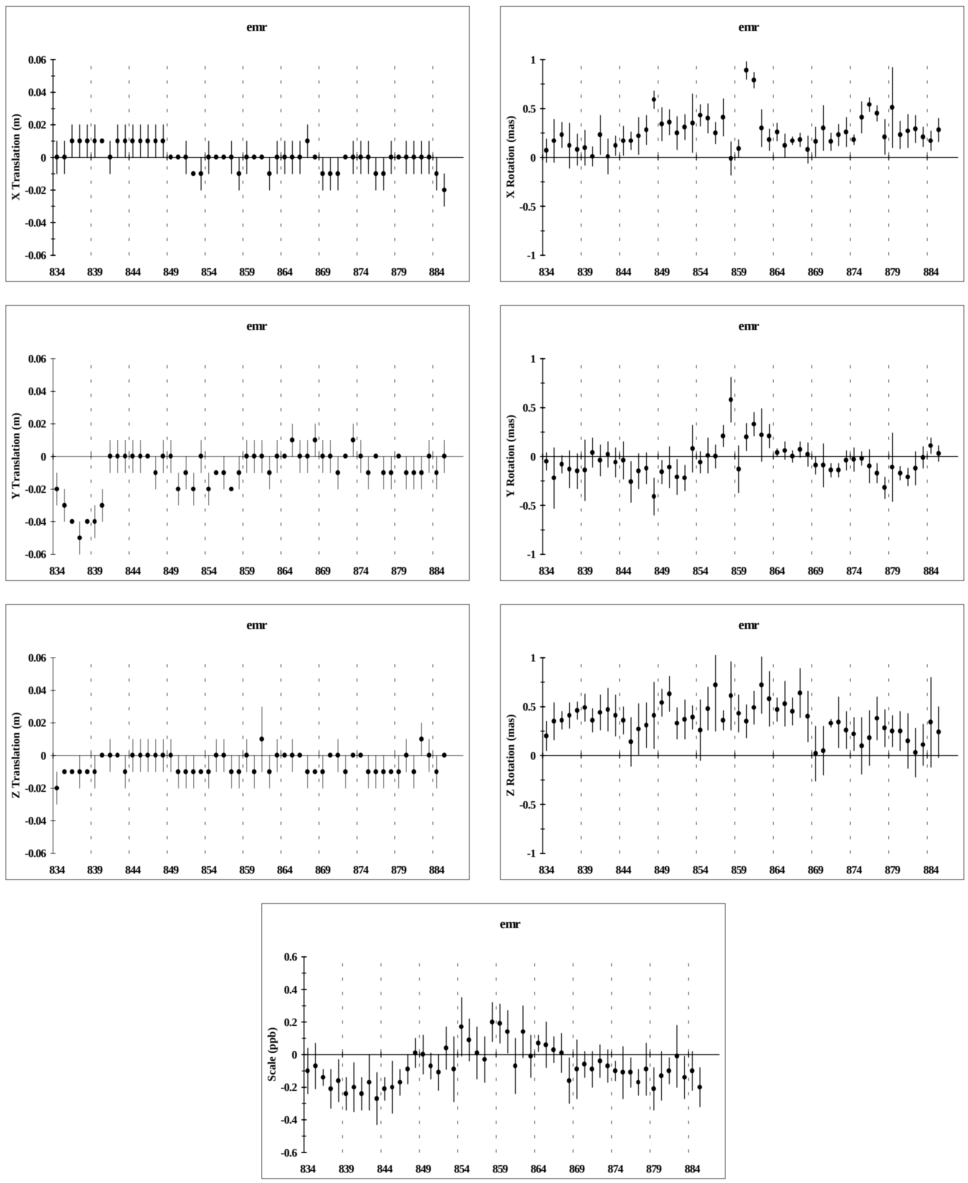


Figure A-3: EMR 1996: Final weekly mean seven-parameter Helmert transformations

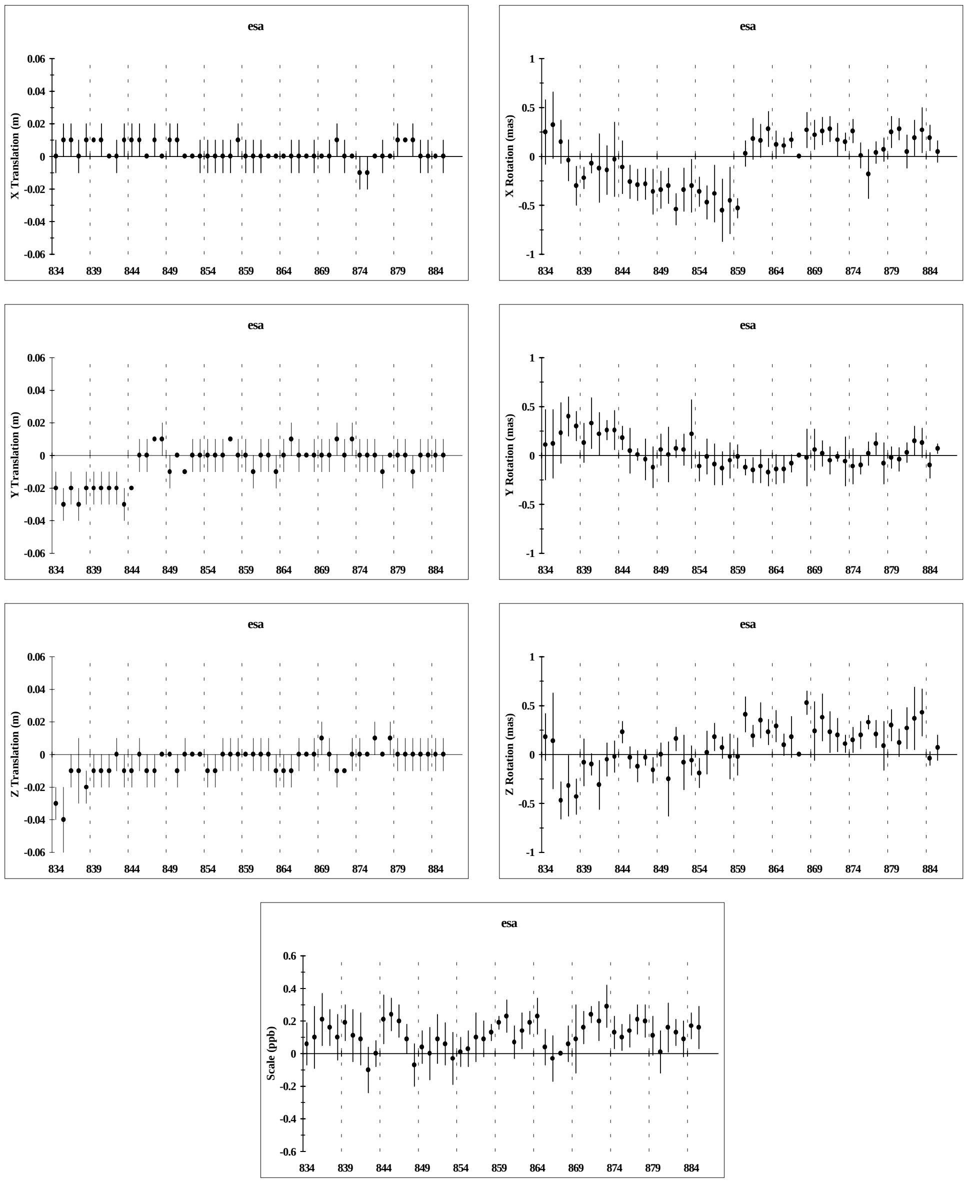


Figure A-4: ESA 1996: Final weekly mean seven-parameter Helmert transformations

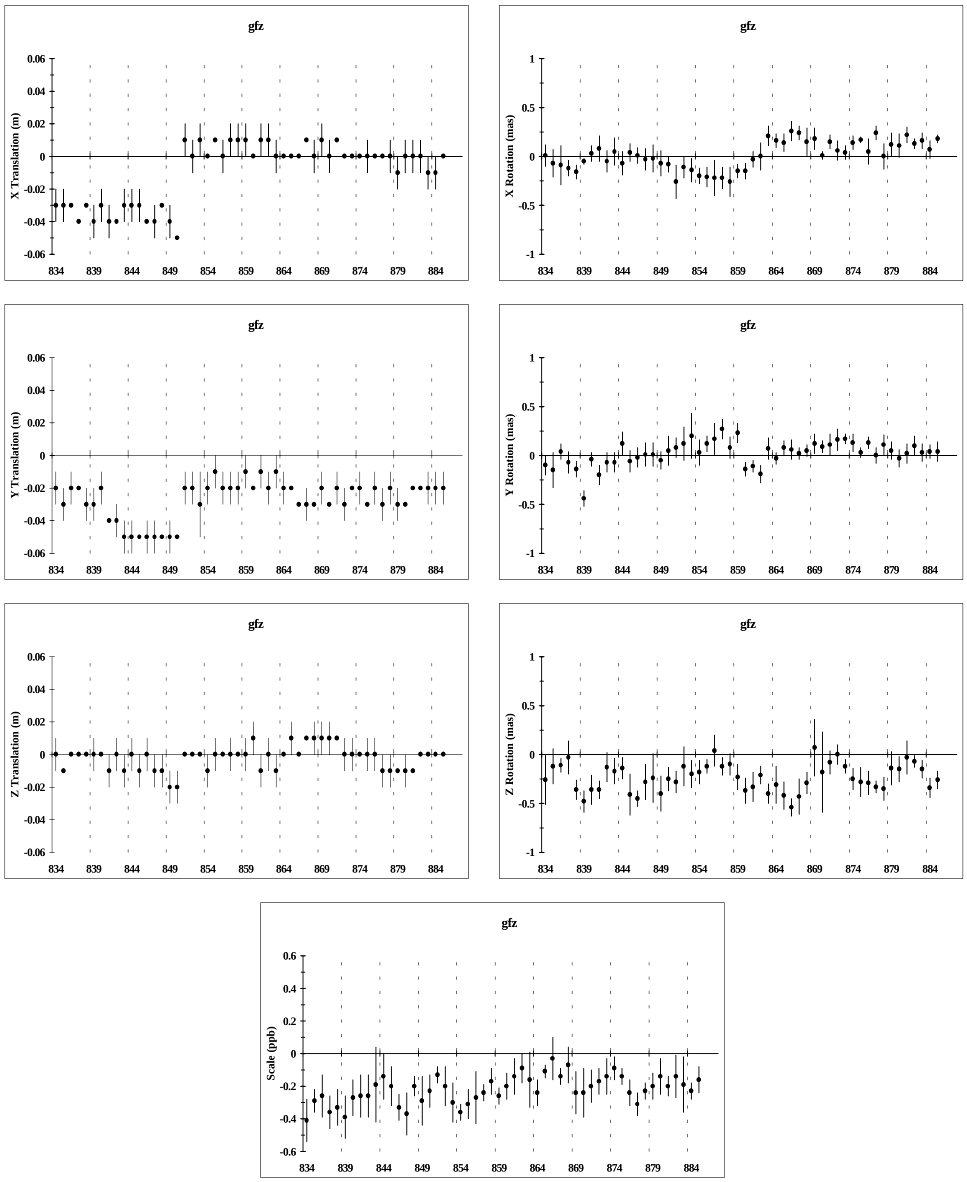


Figure A-5: GFZ 1996: Final weekly mean seven-parameter Helmert transformations

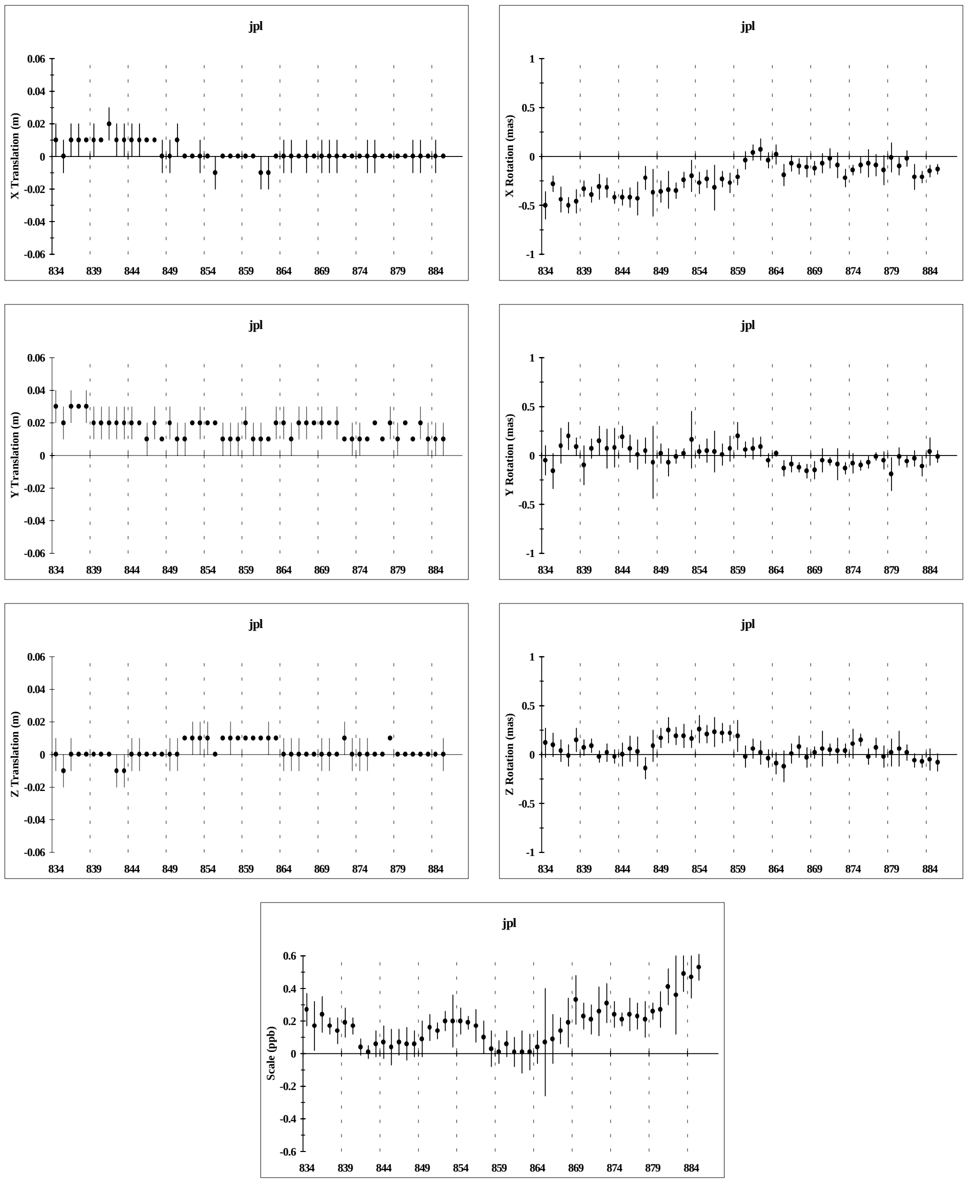


Figure A-6: JPL 1996: Final weekly mean seven-parameter Helmert transformations

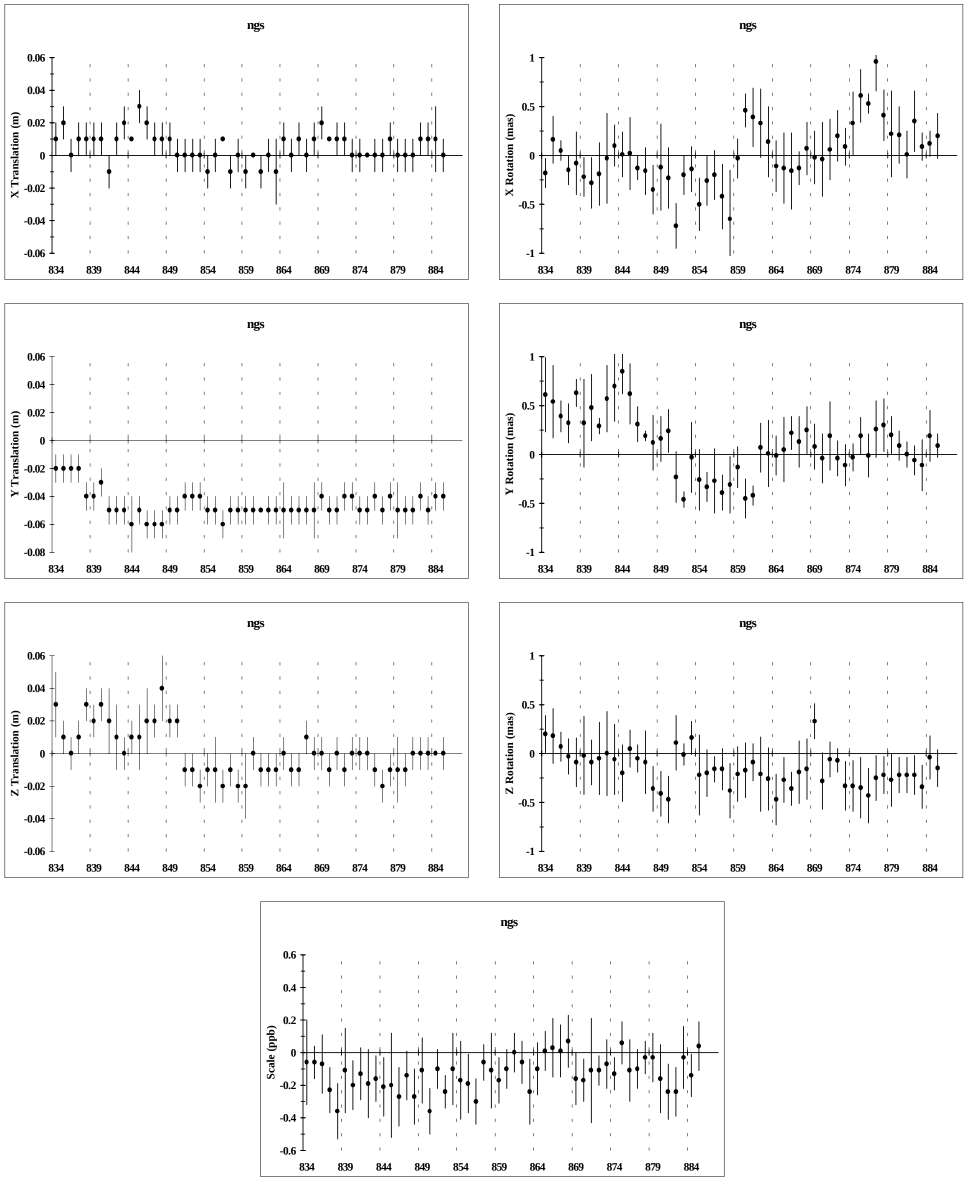


Figure A-7: NGS 1996: Final weekly mean seven-parameter Helmert transformations

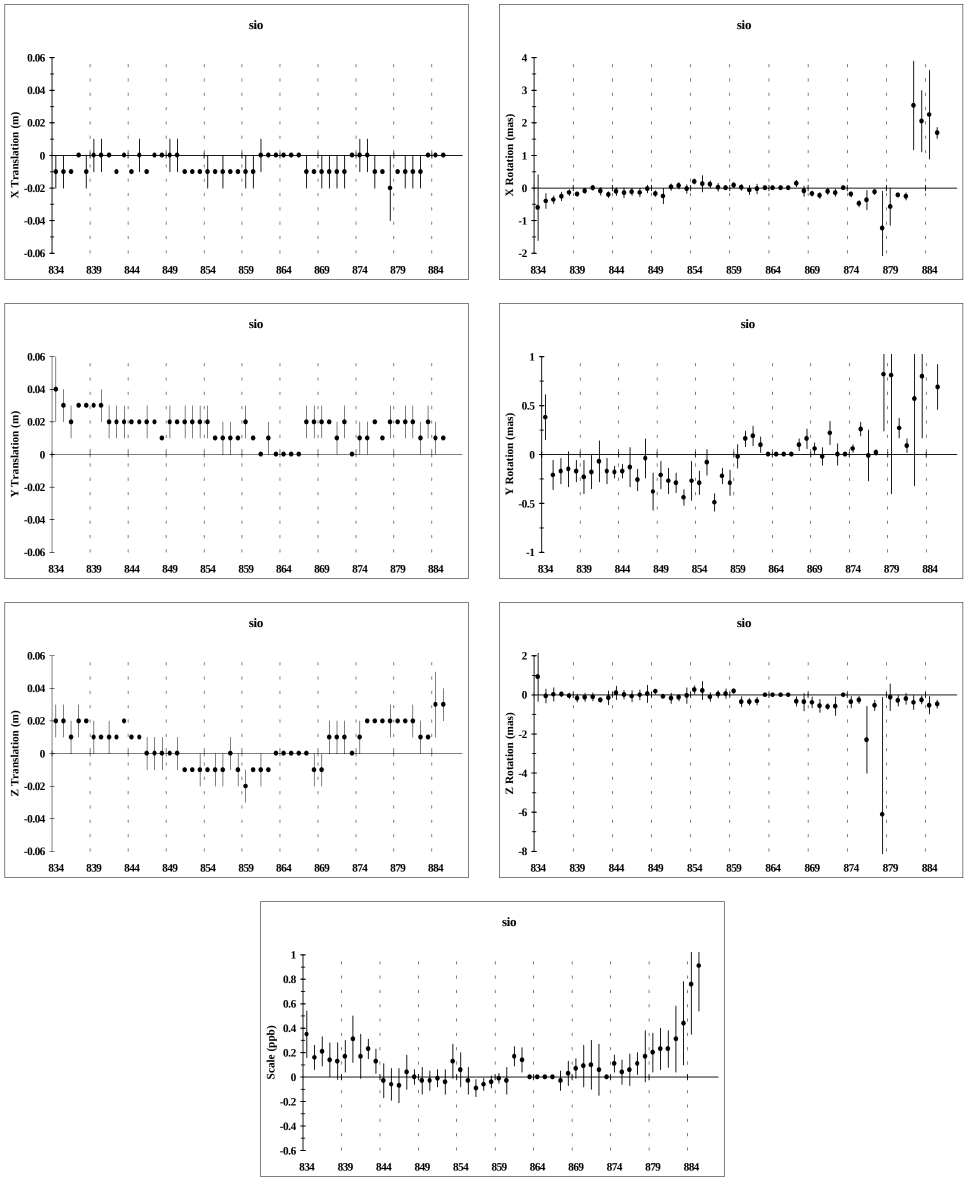


Figure A-8: SIO 1996: Final weekly mean seven-parameter Helmert transformations

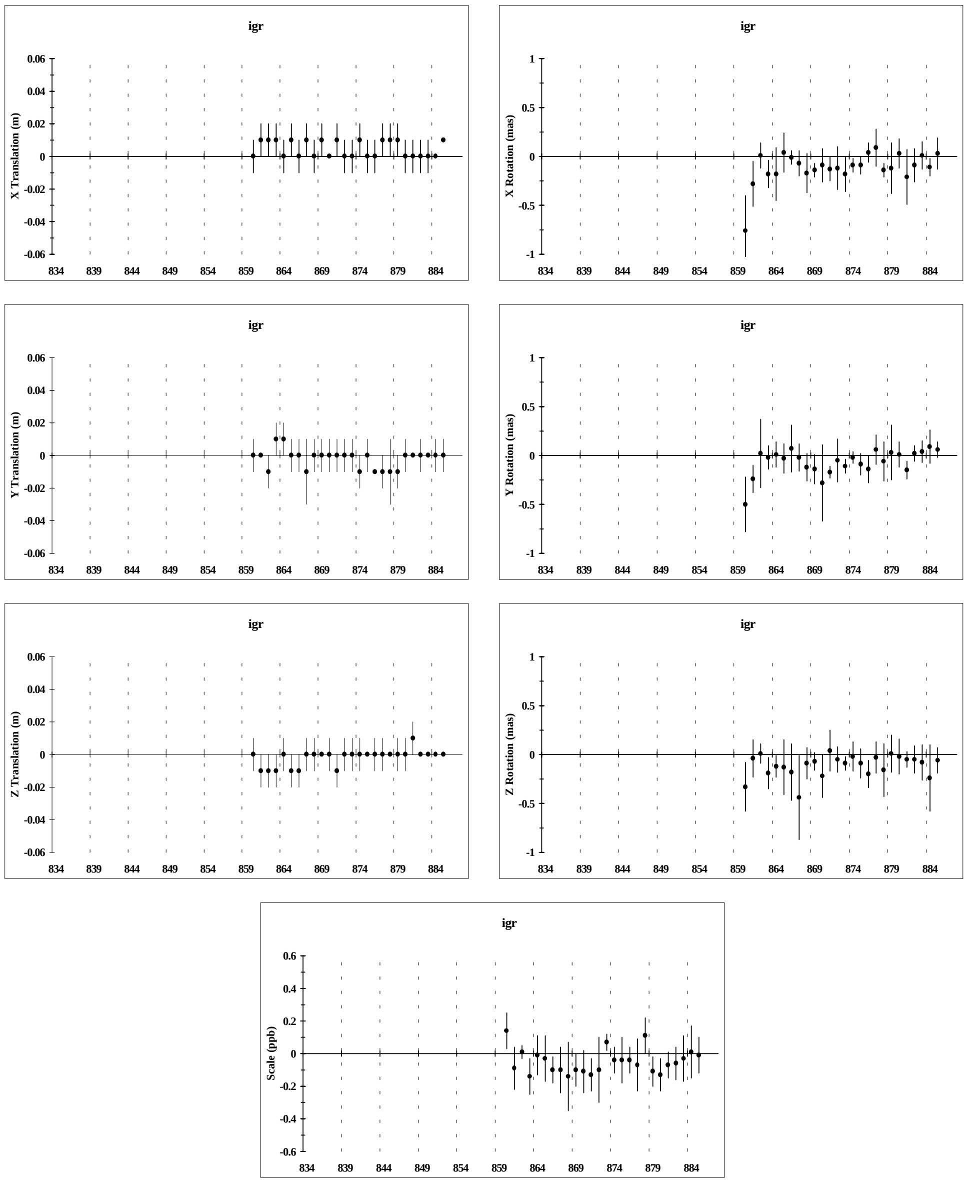


Figure A-9: IGR 1996: Final weekly mean seven-parameter Helmert transformations

Figure A-10 shows orbit coordinate rms of all ACs with respect to the IGS Final orbit combinations. Three types of rms are included in this figure: the weighted combination rms (WRMS), the combination rms, and the long-arc evaluation rms. Figure A-11 summarizes the Final clock combination rms. ACs used in the Final clock combination are COD, EMR, ESA, GFZ, and JPL. NGS and SIO are excluded because they provide either broadcast clock corrections

(NGS) or no clock corrections at all (SIO). ACs used in the Rapid clock combination are EMR, ESA, GFZ, and JPL. NGS and SIO are excluded for the same reasons as mentioned above while COD, as NGS, is excluded since it provides broadcast clock corrections in its Rapid submissions. For completeness, the clock information not used in the combination is compared to the combined solution (either IGS or IGR; e.g., NGS).

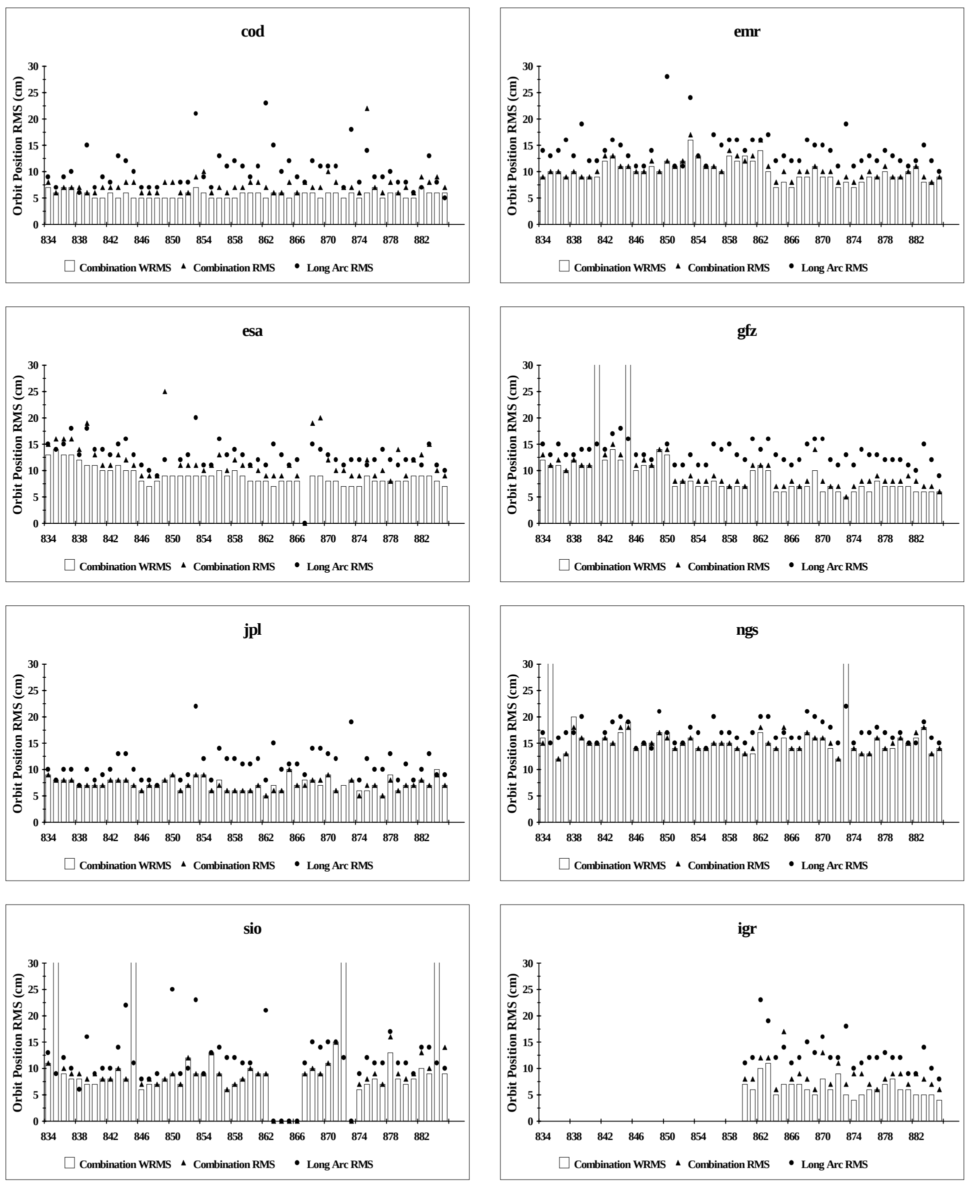


Figure A-10: 1996 Final weekly mean orbit position rms

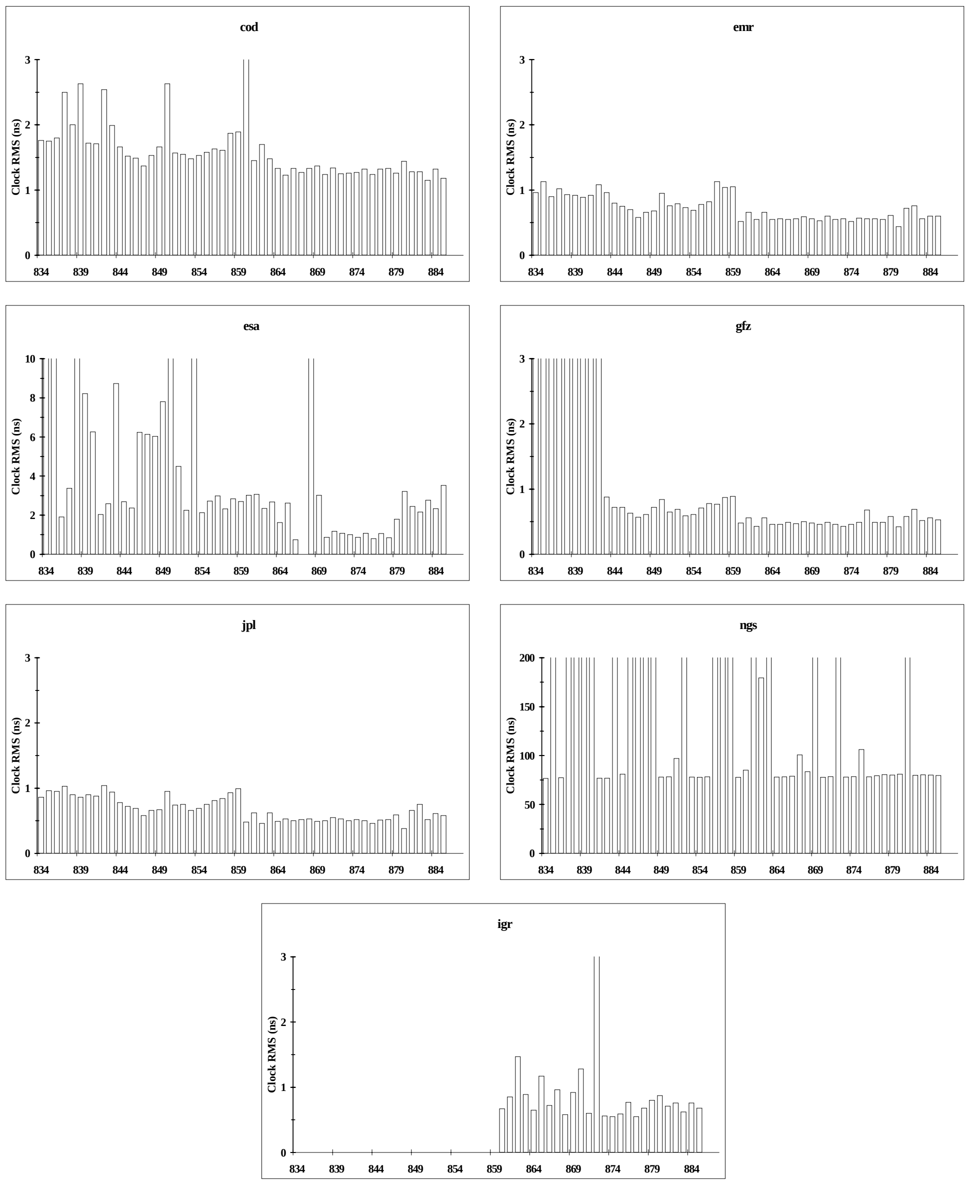


Figure A-11: 1996 Final weekly mean clock rms (all ACs except SIO)

Bad satellite orbit and/or clock solutions are excluded from the combination if they bias the IGS combined solution but are included in the rms computations. All exclusions are reported in the IGS weekly/daily summary reports. High clock rms for broadcast clocks are generally due to broadcast clock resets for one or more satellites, which are removed by ACs estimating clocks.

Examination of these figures shows that in 1996 a considerable effort was again made by all ACs to improve the quality of orbit and clock solutions. For the IGS Final combination, the best clock rms has now reached the 0.5-ns level for more than one AC, and the best orbit position rms has been consistently approaching the 5-cm level. For the Rapid combination (IGR), the best clock rms are very close to the 0.5-ns level, whereas the best orbit position rms varies between 5 and 10 cm and all these results have been obtained with less than 1-day delay !

A.6 IGS Orbit Prediction Combination

The AC and IGS orbit prediction generation and testing started as early as April 1996 by COD (COP—GPS Wk 850). It was followed by JPL (JPP—GPS Wk 856) and GFZ (GFP—GPS Wk 866). The purpose of this pilot project was to generate a 2-day orbit prediction (24 to 48 h) from previous IGR or AC Rapid orbits.

Extensive testing and comparisons were performed during Fall 1996 using the three AC predictions. Combination of all AC orbit predictions could produce more reliable, complete, and in most cases more precise results than the best contributing AC. Tests were extended up to March 1997 with SIO (SIP—GPS Wk 883) and EMR (EMP—GPS Wk 887) providing their predictions in late 1996 and early 1997, respectively. A similar conclusion to use a combination approach can also be drawn from results of the 15-week period (GPS Wks 880–894) summarized in Figure A-12. This figure shows the median of satellite rms (rms after a seven-parameter Helmert transformation with respect to IGR) for individual satellites. The median was chosen because it is insensitive to occasional outliers that could bias the AC global orbit rms statistics. Nevertheless, PRNs 14, 16, and 23 and to a certain extend 18, were somewhat difficult to model during this period.

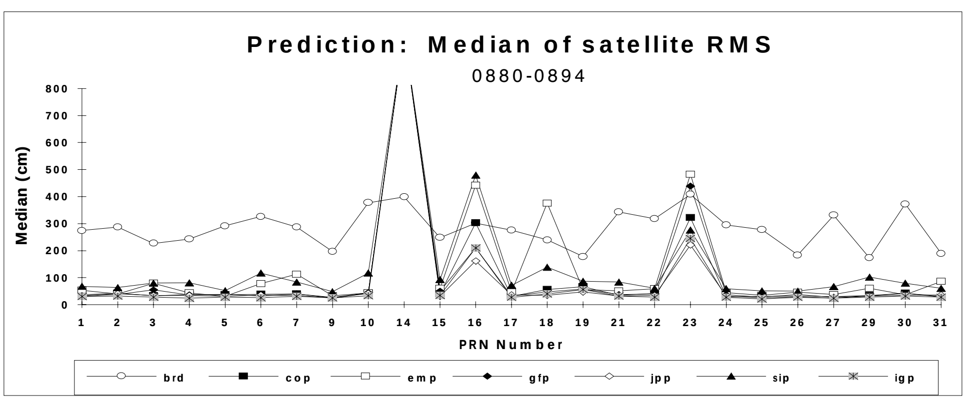
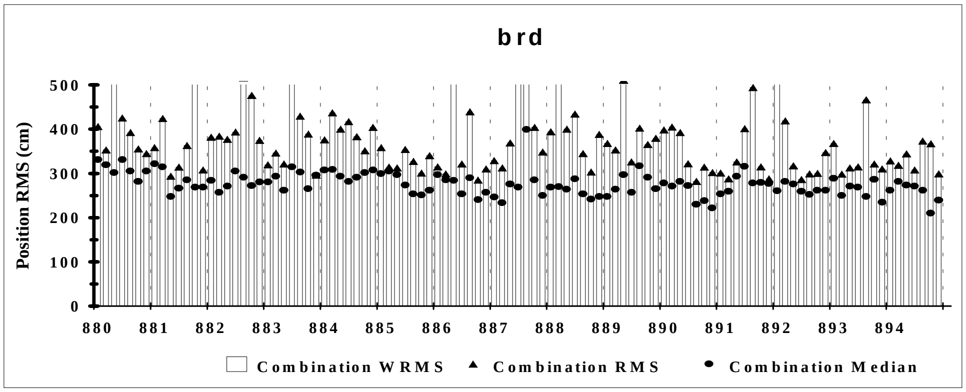


Figure A-12: Median of orbit prediction position rms (GPS Wks 880–894)

On the average, the median of satellite position rms for the broadcast orbits (BRD) were at the 250- to 300-cm level, while all AC 2-day predictions were at 50 to 100 cm. The combined IGS prediction (IGP) results were consistently at the

50-cm level except for some problem satellites mentioned above. Figure A-13 shows for the same period the daily orbit position wrms, rms, and median of rms (with respect to IGR after a seven-parameter Helmert transformation) for both the broadcast (BRD) and the prediction combination (IGP). With the exception of an occasional high rms, one can see that the IGP precision is much better than the broadcast (~50-cm median for IGP compared to 250 to 300 cm for BRD).



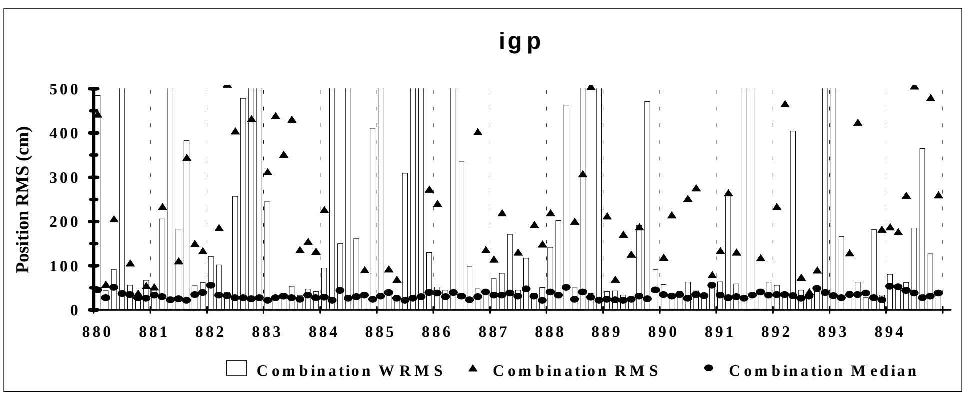


Figure A-13: Daily mean orbit prediction position rms (GPS Wks 880–894)

The IGS prediction combination started officially on GPS Wk 895 (March 2, 1997). ESA started submitting predictions (ESP) on GPS Wk 899. The prediction combination is performed around 23:00 UT on a daily basis and is made available shortly after or at the latest before 23:30 UT, i.e. about 30 minutes prior to the start of the second prediction day. Table A-5 gives a very brief overview of the IGP performance between GPS Wk 895 (official start) and GPS Wk 902. Both BRD and IGP are included in this table, which gives the means and standard deviation of the daily Helmert transformation parameters with respect to IGR along with the median of orbit rms. In general, the overall IGP combination precision is much better than the broadcast orbits.

Table A-5: IGS prediction combination (IGP)—GPS Wks 895–902 (performed directly in the ITRF94 reference frame); means (μ) and standard deviations (σ) of the daily Helmert Transformation Parameters

Center		DX	DY (meters)	DZ	RX	RY (mas)	RZ	SCL (ppb)	Median rms (m)	Days
BRD	μ	0.01	0.01	0.11	–1.01	1.35	1.17	–3.4	2.05	56
	σ	0.12	0.14	0.11	2.56	3.13	7.69	2.6		
IGP	μ	–0.01	0.02	0.00	–0.16	–0.41	–0.95	–0.2	0.34	56
	σ	0.01	0.02	0.03	0.98	1.11	2.60	0.4		

Status of the IGS Pilot Project to Densify ITRF

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1 Introduction

From the beginning, the IGS has been concerned with the support and integration of regional and special application surveys. Since 1993, several IGS workshops dealt with the topic and, by 1995, the groundwork was completed for an efficient, multilevel approach that could accommodate a large number of regional analyses [1,2]. The approach is based on a combination of global and regional unconstrained station solutions that are equivalent to the addition of reduced normal equations and performed by Global and Regional Network Associated Analysis Centers (GNAACs and RNAACs).

First, a suitable exchange format for station solutions had to be developed and tested. In March 1996, the first version of the Software INdependent EXchange (SINEX) format was proposed by the SINEX working group led by G. Blewitt. Since June 30, 1996, the SINEX (version 1.00) has been adopted by IGS for all station solution analysis, submissions, and exchanges (the latest version of the SINEX format is described in `http://igscb.jpl.nasa.gov/igscb/data/format/sinex.txt`). In the fall of 1996, the responsibility for SINEX development and maintenance was transferred to the International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG) [3], the Project on Coordination and Combination of Space Geodetic Analysis (chaired by T. Herring).

Initially, the IGS combination approach was tested at the global level. Since September 1995, three GNAACs (JPL, MIT, and NCL) have been combining and submitting to IGS global (G-SINEX) solutions for more than 50 stations [4,5,6]. All seven IGS Analysis Centers (ACs) were producing SINEX solutions by early 1996 [7,8]. In July 1996, the regional level of the pilot project was initiated, and since then a second solution, the IGS polyhedron (P-SINEX) combination solution, has been produced weekly by two GNAACs for more than 120 stations from all the RNAAC and AC SINEX solutions submitted to IGS [9].

In this report, the current status of the project as well as some potential improvements for both the global and regional levels are discussed. For more details on individual approaches adopted by ACs, GNAACs, and RNAACs, consult the appropriate reports in this volume.

2 Global Station (G-SINEX) Combinations

The main purpose of the global-level station/EOP solution (G-SINEX) combination is to improve solution accuracy and reliability, and to provide timely feedback to contributing Analysis Centers (ACs). Such combinations could also provide input and support for global geophysical and atmospheric studies as well as for other applications. Furthermore, global combination solutions could facilitate unprecedented precision and consistency of ITRF realization for IGS as well as contribute significantly to the ITRF maintenance and timely delivery. The current IGS orbit/EOP/clock combination is a good example of combination solution benefits. Continuous improvements of solution quality and reliability have been sustained since 1994 through timely feedback and AC cooperation [10]. The G-SINEX station combinations are also likely to contribute to geocenter variation studies [11] and to ITRF/EOP combination and consistency studies providing that, as originally planned, the EOP solutions are retained in AC and GNAAC SINEX solutions. Combination approaches analogous to the IGS GNAAC analyses were strongly endorsed by a recent review organized by the International Earth Rotation service (IERS) [12].

After more than one year of GNAAC combinations, expected benefits and their corresponding impact are yet to be fully realized. The situation is complicated, as the GNAAC station combinations are more sensitive to station hardware/offset information than the orbit/EOP/clock combination solutions. Present inconsistencies in antenna offsets and site information have hindered GNAAC combination precision, its usefulness, and timely feedback. This problem has already been pointed out during 1995 [8] and again at the 1997 AC workshop, held in March 1997 at JPL. Nevertheless, the weekly GNAAC solution series are now long enough for a number of useful studies (e.g., [13]; see also GNAAC reports by JPL, MIT, and NCL in this volume).

During 1996, three GNAACs (JPL, MIT, and NCL) continued combination of weekly AC station solutions. Currently, since the project is still in a pilot phase, there is no firm plan to produce a single official GNAAC solution. To provide quality check and feedback to GNAACs and to potential IGS users, a regular weekly comparison report has been produced since March 1997 comparing the three GNAAC station combination (G-SINEX) solutions and evaluating the precision and consistency of station solutions as well as the implied geocenter and scale information. For completeness, the comparisons were made back to GPS Week (Wk) 0878. A sample of the weekly G-SINEX comparison (GCOMP) report is included in the Appendix. The GCOMP results are summarized in Table 1 and Figures 1 through 3.

Figure 1 shows the rms of position residuals (after seven-parameter transformations) for unconstrained G-SINEX pair comparisons (MIT–JPL, MIT–NCL and JPL–NCL) and, for the 13 fiducial stations, the rms with respect to the ITRF94 positions currently used for the IGS ITRF realization. The adopted

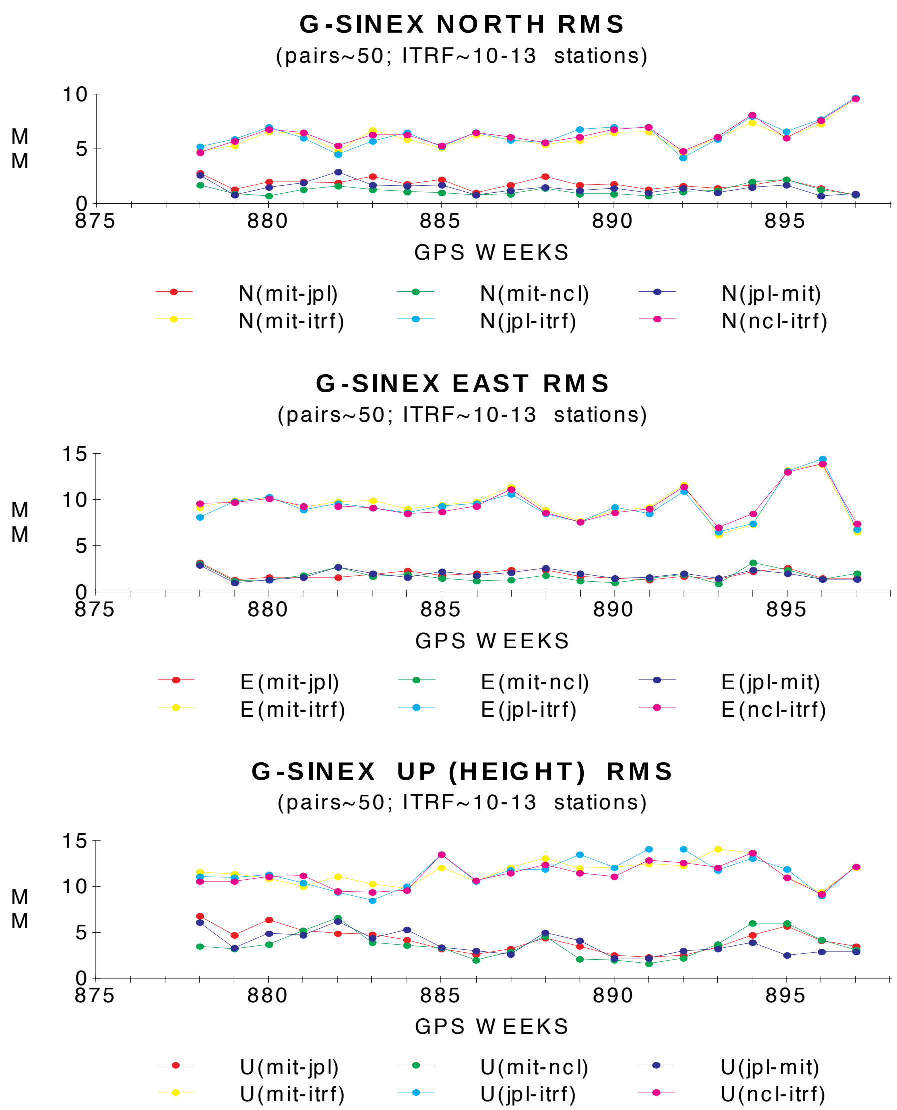

Figure 1: Position rms (North/East/Up) for pair comparisons of JPL, MIT, and NCL GNAAC weekly (G-SINEX) combination solutions (all stations), and position rms with respect to the 13 ITRF94 station positions

ITRF94 positions and velocities of the 13 stations can be found in [10]. The rms from comparisons are much smaller than the corresponding rms with respect to ITRF94; this is to be expected since a pair rms is not sensitive to the GPS biases and/or even the gross errors common to all three G-SINEX combinations. The pair rms agreement is approximately 2 mm in the north and east components and about 4 mm in the up (height) direction. This is an indication of the high quality of combination approaches used. Note that all three combinations should be similar since the input information is the same. However, differences in combination models, estimation approaches, relative weighting, and editing produce the results that are not the same. All three G-SINEX solutions are quite consistent and none seems to stand out as the best. The position rms with respect to ITRF94 are significantly larger, as they also reflect possible GPS and ITRF94 biases and errors. Again, the ITRF rms are very similar for all three GNAACs and, for most part, they are at or below the 10-mm level in each coordinate. The significantly increased variation of ITRF rms for the last few weeks was caused by serious data problems at one of the 13 ITRF stations. The station MADR experienced position biases as large as 50 mm for some weeks. No such deterioration could be seen in the pair comparisons as the three GNAAC solutions are affected the same way. The average rms corresponding to Figure 1 are listed in Table 1.

Table 1: Average position rms (North/East/Up) for the differences between JPL, MIT, and NCL GNAAC weekly (G-SINEX) combination solutions (all stations), and position rms with respect to the ITRF94 positions for the 13 IGS fiducial stations during GPS weeks 0878-897

Position	Component	MIT–JPL (mm)	MIT-NCL (mm)	JPL-NCL (mm)	MIT-ITRF (mm)	JPL-ITRF (mm)	NCL-ITRF (mm)
North	latitude	1.8	1.1	1.5	6.2	6.3	6.4
East	longitude	1.9	1.8	1.9	9.6	9.3	9.5
Up	height	4.1	3.7	3.8	11.6	11.6	11.3

The position repeatabilities are not tested here, but they are expected to be larger than the variations between GNAAC pairs and smaller than the ITRF rms. Repeatability is insensitive to long-period GPS biases and constant station offset errors. Station position biases may be real (local site effects) or may be caused by GPS biases. Such biases determined from G-SINEX repeatability and/or comparisons with ITRF and other independent positioning techniques could provide valuable feedback for ACs and facilitate interpretations.

The geocenter offsets implied in the unconstrained G-SINEX combinations and determined with respect to the ITRF94 fiducial station positions (up to 13) are shown in Figure 2. The time interval covered by the G-COMP reports (Wk 0878-0897) has been amended using results from previous G-SINEX comparisons, starting with Wk 0825, to cover the whole period of the G-SINEX

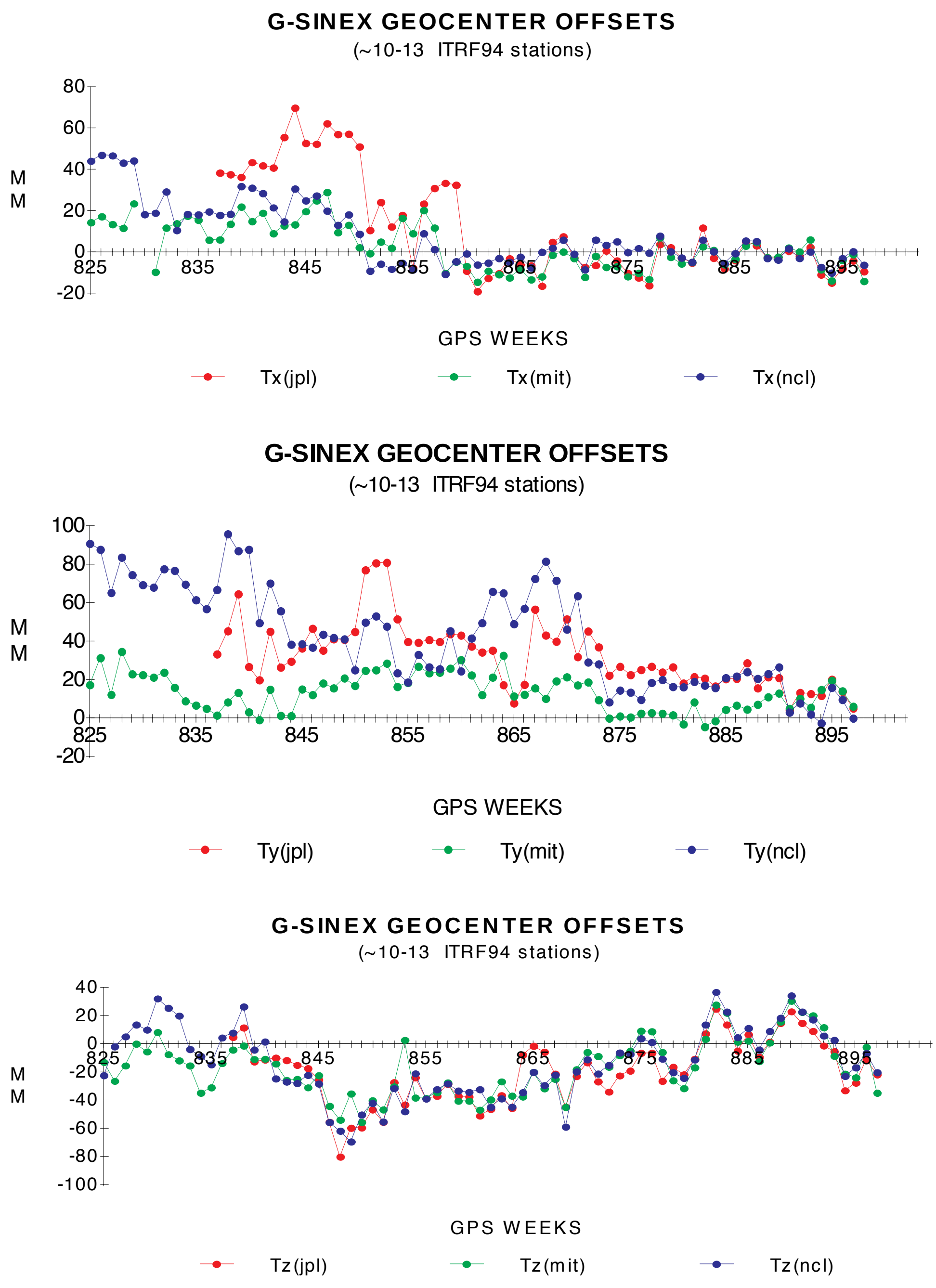

Figure 2: Implied geocenter offsets of unconstrained JPL, MIT, and NCL GNAAC weekly (G-SINEX) combination solutions with respect to the 13 ITRF94 station positions

combinations. JPL GNAAC started to produce their G-SINEX solutions about 3 months after MIT and NCL. An improvement trend can be observed for all three combined solutions, in particular after Wk 0860 (June 30, 1996) when a number of model and estimation improvements were implemented by all ACs [10]. Note that the change to ITRF94 (from ITRF93), also adopted on June 30, 1996 by all ACs and IGS, should not have any effect here as we are dealing with unconstrained solutions. Gradual improvements (decreased magnitude and variations) are also likely due to continuous improvements made by ACs and all three GNAACs. All three GNAAC solutions show similar behavior—in particular for the x and z geocenter offsets. This is likely due to common (GPS) biases related to missing data from the same ITRF stations, rather than real geocenter variations. The large differences and variation of the y-shift are caused by large (~100-mm) y-shift geocenter biases implied in some AC solutions. These problems were already noticed and addressed at the 1996 AC workshop [14]. MIT solutions have much smaller y-shifts than the other two GNAACs. This is due to the fact that MIT does not use seven-parameter transformations for the weight determination of individual AC SINEX solutions with respect to ITRF. Thus, the MIT relative AC weight scale (variance) factors also reflect possible geocenter offsets, i.e. the AC solutions with large geocenter offsets automatically receive small weights and the resulting G-SINEX combination is then better aligned to ITRF. In any case, the variations in the x- and z-geocenter shifts warrant further investigation.

Figure 3 shows scale offsets for the same time period with respect to the ITRF94 station positions. Similar to the geocenter shifts, the scale offset variation and consistency have been improving gradually, so that after about Wk 0880, all GNAAC scales are practically the same. The mean negative offset of about –2 ppb has been observed for all unconstrained AC global solutions. The decreasing trend for scale values at the end of the period may be caused by missing data from some ITRF stations. The mean scale bias in Figure 3 is

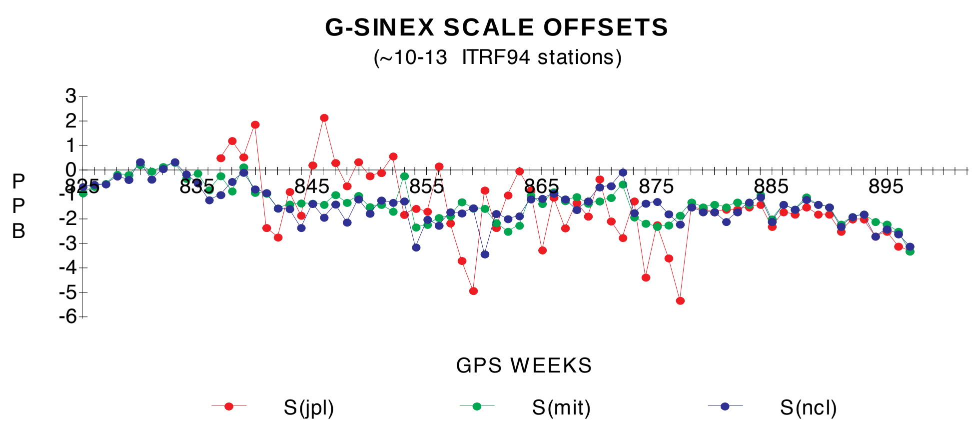

Figure 3: Implied scale offsets of unconstrained JPL, MIT, and NCL GNAAC weekly (G-SINEX) combination solutions with respect to the 13 ITRF94 fiducial station positions

–1.4 ppb. Applying the TDT-TCG relativistic correction of –0.7 ppb, while neglecting elevation and antenna phase center variation, implies that the adopted IGS L3 phase centers for the Dorne-Margolin antennas are correct to within 13 mm. Note that the IGS antenna calibration table is relative to Dorne Margolin antennas. Therefore, the global orbit modeling, the L3 phase center, the IERS conventions, and the ITRF94 TCG scale are quite consistent.

3 Regional Station Polyhedron (P-SINEX) Combinations

The main purpose of the regional level of the pilot project is to provide regional ITRF infrastructure to support regional, national, and special applications. An active participation in IGS is an efficient way to realize and maintain a national and/or continental geodetic reference frame (datum). The approach adopted here is similar to that adopted by the global level; i.e., it is equivalent to the addition of reduced normal equations for obtaining regional solutions by a number of Regional Network Associated Analysis Centers (RNAACs). The same benefits as those for the global combinations include increased reliability, precision, and better feedback by users of RNAAC solutions.

The position paper [2] outlined analysis requirements, including a timetable for both regional and global combinations. In summary, all RNAAC analyses require the IGS Final orbits and EOP products to be held fixed with a minimum of three global stations to be included in a weekly combination of seven unconstrained daily solutions in SINEX format. In addition, since June 30, 1996, the use of the IGS elevation-dependent antenna calibration table has become mandatory (for the adopted antenna calibration table see `http://igscb.jpl.nasa.gov/igscb/station/general/igs_01.pcv`). The RNAAC weekly solutions (R-SINEX), submitted within two weeks after the IGS Final orbits/EOP become available, are combined with the global (G-SINEX) combinations to form the IGS Polyhedron (P-SINEX) solutions. The IGS station polyhedron consists of about 200 well-distributed stations which is sufficient to support precise positioning applications [15,16].

Originally seven RNAACs responded to the IGS CFP issued at the beginning of 1996. The regional level of the pilot project officially commenced on June 30, 1996, but it took several more months before the first P-SINEX station solutions could be produced by GNAACs. Since April 1997, 16 RNAACs are contributing their regional (R-SINEX) solutions including some 50 additional regional stations (see Tables 2a,b). The European RNAACs (Table 2b) are part of the EUREF project of IAG demonstrating the capability and flexibility of this approach. Such combinations at a continental scale are clearly preferred to further enhance the scope and significance of the project. Continental-level combinations had not been considered in the original, well-conceived planning studies [2].

Two P-SINEX combinations are currently produced by IGS, as shown in Table 3. For completeness, all the GNAAC combination products are listed here as well as the total number of stations included. There is a considerable variation

Table 2a: IGS Regional Network Associate Analysis Centers—RNAACs (April 1997 and the total number of processed stations (regional + global)

RNAAC	No. of Stations	Region	Agency
AUS	14	Australia, Antarctica	Australian Surveying and Land Information Group
EUR	52	Europe	EUREF IAG Subcommission with 10 contributors
GIA	20	Arctic regions	Geophysical Institute of Alaska
GSI	18	Japan, SE. Asia	Geophysical Survey Institute of Japan
PGC	9	Western Canada	Pacific Geoscience Centre, NRCan
SIR	16	South America	DGFI/I on behalf of SIRGAS

Table 2b: IGS Regional Network Associate Analysis Centers—RNAACs, contributing to EUREF continental solutions (April 1997) and the total number of processed stations (regional + global)

RNAAC	No. of Stations	Agency
ASI	6	Nuova Telespazio S.p.A., Space Geodesy, Italy
BEK	13	Inter. Comm. for Global Geodesy of the Bavarian Academy of Sciences (BEK)
COE	33	European Solution of Center for Orbit Determination in Europe)
GOP	11	Geodetic Observatory Pecny, Czech Republic
IFG	14	Institute for Applied Geodesy in Germany (IfAG)
LPT	6	Bundesamt für Landestopographie (L+T), Switzerland
NKG	25	Nordic Geodetic Commission (NKG)
OLG	17	Observatory Lustbühel Graz (OLG), Austria
ROB	11	Royal Observatory of Belgium (ROB), Belgium
WUT	15	Warsaw University of Technology (WUT), Poland

in the number of stations used due to different criteria for global stations by GNAAC. While NCL strictly enforces the rule of 3+2 for their G-SINEX solutions (three ACs from two continents must process a station to attain an IGS Global station status [2]), JPL and MIT include all stations as submitted by ACs in their global solutions, even if they are of regional type. Typically, the seven AC solutions combined include about 100 stations as seen from the first two G-SINEX solutions in Table 3, although little more than 60 could be considered "global" according to the above rule. So, the global (GCOMP) comparisons (see the Appendix) are based on about 60 "global" stations since the stations must be included in all three G-SINEX combinations.

Table 3: IGS Global Network Associated Analysis Centers—GNAAC Global (G-SINEX) and Polyhedron (P-SINEX) combination products (April 1997)

GNAAC	No. of Stations	Product Files	Type	Agency
JPL	100	JPL*WWWW*G.SNX JPL*WWWW*G.SUM	global (G-SINEX)	Jet Propulsion Laboratory
MIT	98	MIT*WWWW*G.SNX MIT*WWWW*G.SUM	global (G-SINEX)	Massachusetts Institute of Technology
	147	MIT*WWWW*P.SNX MIT*WWWW*P.SUM	polyhedron (P-SINEX)	
NCL	63	NCL*WWWW*G.SNX NCL*WWWW*G.SUM	global (G-SINEX)	University of Newcastle
	125	NCL*WWWW*P.SNX NCL*WWWW*P.SUM	polyhedron (P-SINEX)	

There are also differences in the number of stations used by the MIT and NCL P-SINEX combinations due to different approaches adopted by the two GNAACs. While MIT simply includes all the RNAAC solutions in their G-SINEX, after proper weight scaling and allowing small adjustment corrections for the MIT G-SINEX stations, NCL does not allow any change to the NCL G-SINEX solutions. The NCL P-SINEX solution is then composed from the original G-SINEX augmented by the new regional stations (see [17]; MIT and NCL RNAAC reports, this volume). The NCL approach tends to be more restrictive as some RNAACs cannot be used, e.g., because they do not include the minimum of three "global" stations in the NCL G-SINEX combinations. There are arguments for and against both approaches; more solutions and longer series of P-SINEX combinations are required for proper evaluation.

4 Recommendations for Future Improvements and Developments

The term "ITRF densification" may be misleading. It is sometimes interpreted as meaning precise positioning with respect to ITRF. However, the intended meaning in this context relates to improved coverage, quality, and maintenance of the ITRF network, providing global and regional (continental/national) ITRF realizations. For the precise positioning densifications within ITRF, a new positioning approach described in [18] is very well suited. However, because it produces only a partial variance/covariance matrix with no (i.e., zero) covariances between stations, the approach may be less suitable for ITRF infrastructure densification and maintenance at the continental or even national scales. To achieve the objective of the pilot project (i.e., redundancy, consistency, and improved relative precision), a more complete variance/covariance matrix may be required. However, the necessary links and support for AC reference frame realizations have not yet taken advantage of the G-SINEX combinations. This would enhance precise positioning and provide more precise G-SINEX-based ITRF to a large number of users in an efficient way. Furthermore, a number of RNAACs have requirements to refer their local stations not included in P-SINEX to a consistent ITRF realization. These requirements can be met by integrating G-SINEX and P-SINEX weekly combined solutions with other regional solutions on an annual basis to produce a consistent set of station positions and velocities. There are already plans by the ITRF Section of IERS [19] to produce such combined solutions and to use them in AC and possible RNAAC analyses. Such yearly combinations would approximate a complete cumulative analysis of all IGS stations for a given period. Before such long-period combinations can be attempted, the current G-SINEX solutions need to be analyzed and, if possible, corrected for periodic signals due to neglected atmospheric and ocean loading effects and apparent geocenter variations [11].

With the increased G-SINEX precision and the need for proper consistency monitoring of EOP and the ITRF realization by the SINEX station solutions, EOP must be included in all AC SINEX solutions submitted to GNAACs. This is necessary to facilitate a proper station/orbit/EOP and ITRF consistency evaluation by IGS. The ITRF realized by IGS orbits and the corresponding IGS EOP are already continuously monitored for ITRF/EOP consistency [10]. Despite recommendations in [2] and more recent requests by the 1996 IGS AC Workshop [20], only three ACs and no GNAACs include the complete set of EOP in their weekly SINEX solutions.

The requirement for fixing rather than constraining the IGS orbits in RNAAC analyses may not be appropriate, in particular when RNAAC analyses are spanning up to half of the globe; the implied scale and geocenter shift may be too constrained even when the remaining parameters (i.e., mainly station coordinates) are very loose. For example, while an RNAAC solution extending over about 500 km implies a scale and geocenter constrained at about 1-meter level, a RNAAC covering half of the hemisphere implies a scale and geocenter at about the 10-mm level. The 10-mm scale and geocenter precision implied for some RNAAC solutions are at the same level as those for the AC and GNAAC global solutions. This is not desirable, in particular since RNAAC geocenter/scale may be more biased than the corresponding global AC/GNAAC solutions. Therefore, it is preferable to weight rather than fix the IGS orbits, although a 10-cm sigma for uncorrelated 25 IGS daily orbits over 7 days would correspond to only about an 8-mm sigma increase. A better approach to P-SINEX combinations would acknowledge that systematic shift and scale biases may exist in the R-SINEX solutions (e.g., due to coverage and/or analysis deficiencies) and would allow for position and scale transformation or corresponding modification of the R-SINEX matrices before performing P-SINEX combinations, which is equivalent to a priori weighting based on the same transformation.

5 Contact Information

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6 Acknowledgments

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Additional Reading

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"Densification of ITRF Through Regional GPS Networks" (1995), *IGS Workshop Proceedings*, edited by J. F. Zumberge and R. Liu, Pasadena, Cal., November 30–December 2, 1994.

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APPENDIX

GLOBAL SINEX (G-SINEX) COMPARISON (GCOMP) IGS REPORT FOR WK 0899

```
******************************************************************************
IGS Electronic Report    Mon Apr 28 12:33:32 PDT 1997     Message Number 3679
******************************************************************************

Author: AC Coordinator / NRCan GSDivision
Subject: WK 0899 G-SINEX Comparisons

Comparison of GNAAC Combined SINEX Solutions - Week 0899
(MAR 30, 1997 - APR 5, 1997)

Contacts: J. Kouba (kouba@geod.emr.ca)
          D. Hutchison(hutch@geod.emr.ca)

COMPARISON ALGORITHM:

   1. MIT and NCL GNAAC  combined  SINEX  solutions  for the week in question
      were deconstrained. The JPL SINEX file is already unconstrained.

   2. Any stations  not  present  in  all GNAAC combined SINEX files were de-
      leted  from the three combined solutions.  Every solution was then sub-
      jected to a 7-parameter transformation into a common reference frame
      defined by the 13 ITRF94 fiducial station positions.

   3. Outliers are determined at the 99.0% confidence level for each coordin-
      ate.  If a station  has  an outlier in either latitude,  longitude,  or
      height, it is ignored in all subsequent computations.


FILES COMPARED:
   mit0899g.snx at cddis.gsfc.nasa.gov
   jpl0899g.snx at cddis.gsfc.nasa.gov
   ncl0899g.snx at cddis.gsfc.nasa.gov

GNAACs: MIT JPL NCL

STATIONS WITH INCONSISTENT ANTENNA ECCENTRICITY INFORMATION:
(FILE: / STATION / L1 (UNE) / L2 (UNE) / ECCENTRICITY (UNE))
(UNE = Up North East (metres))

jpl0899g.snx: ANKR  .110  .000  .000   .128  .000  .000   .000  .000  .000
mit0899g.snx: ANKR  .110  .000  .000   .128  .000  .000   .060  .000  .000
ncl0899g.snx: ANKR  .110  .000  .000   .128  .000  .000   .060  .000  .000
                                     .
                                     .
jpl0899g.snx: ZIMM  .070  .000  .000   .068  .000  .000   .000  .000  .000
mit0899g.snx: ZIMM  .069  .000 -.003   .068 -.003 -.001   .000  .000  .000
```

```
ANTENNA PHASE CENTRE CONFLICTS IN FILE mit0899g.snx
   MDVO Multiple Sites

SITES AFFECTED BY ABOVE CONFLICTS, NON-FIDUCIAL SITES SUBSEQUENTLY EXCLUDED:
   Stations: MDVO

ANTENNA PHASE CENTRE CONFLICTS IN FILE ncl0899g.snx
   ASC1 Missing Antenna information
   AUCK Missing Antenna information
   CHAT Missing Antenna information
   DGAR Missing Antenna information
   KWJ1 Missing Antenna information
   MKEA Missing Antenna information
SITES AFFECTED BY ABOVE CONFLICTS, NON-FIDUCIAL SITES SUBSEQUENTLY EXCLUDED:
   Stations: ASC1 AUCK CHAT DGAR KWJ1 MKEA YAR1

CONFIDENCE  LEVEL  FOR OUTLIER DETECTION: 99%
OUTLIERS REJECTED (COORD/STATION/GNAACs):
   Lat MCM4 JPL-NCL   Lat BRAZ JPL-NCL   Lat SANT JPL-NCL
   Lon COCO JPL-NCL   Lon PAMA JPL-NCL   Lon PAMA MIT-JPL
   Lon COCO MIT-JPL   Hgt IRKT JPL-NCL   Hgt CRO1 JPL-NCL
   Hgt IRKT MIT-JPL   Hgt WUHN MIT-NCL

40 GLOBAL STATIONS:
   ALBH ALGO BOR1 BRMU CAS1 DAV1 FAIR FORT GOLD GUAM
   HART HOB2 KELY KERG KIT3 KOKB KOSG KOUR LHAS MAC1
   MALI MDO1 METS NLIB NYAL ONSA PERT POTS RCM6 REYK
   SHAO STJO TAIW TIDB TSKB WES2 WTZR YAR1 YELL ZWEN

10 FIDUCIAL STATIONS:
   ALGO FAIR GOLD HART KOKB KOSG TIDB WTZR YAR1 YELL

AVERAGE COORDINATE RMS:

             40    GLOBAL  STATIONS         10    FIDUCIAL   STATIONS
        MIT-JPL   MIT-NCL   JPL-NCL MIT-ITRF94 JPL-ITRF94 NCL-ITRF94
           (mm)      (mm)      (mm)       (mm)       (mm)       (mm)
        -------   -------   ------- ---------- ---------- ----------
Lat         1.9       1.4       3.0        5.7        6.1        5.5
Lon         1.9       1.4       2.4        8.2        8.1        7.6
Hgt         3.6       2.4       4.9        8.7        8.5       10.0
3D          4.5       3.1       6.2       13.2       13.2       13.8

VARIANCE FACTORS (CHI-SQUARE / (DEGREES OF FREEDOM)):

        40    GLOBAL  STATIONS         10    FIDUCIAL   STATIONS
   JPL-NCL   MIT-JPL   MIT-NCL MIT-ITRF94 JPL-ITRF94 NCL-ITRF94
   -------   -------   ------- ---------- ---------- ----------
     0.587     0.708     0.242      0.548      0.404      0.531
```

OFFSETS AND SCALE FACTOR WRT ITRF94 (FIDUCIAL STATIONS):

	Tx (mm)	STD(mm)	Ty (mm)	STD(mm)	Tz (mm)	STD(mm)	Scale (ppb)	STD(ppb)
JPL	2.8	5.2	13.9	5.4	-50.0	7.1	-2.7	0.6
MIT	0.6	4.3	13.2	4.4	-44.2	5.1	-2.4	0.6
NCL	2.5	5.0	23.8	5.2	-26.9	6.5	-2.1	0.6

REMARKS:
THE FOLLOWING FIDUCIAL STATIONS ARE MISSING FROM mit0899g.snx :
   Stations: TROM
THE FOLLOWING FIDUCIAL STATIONS ARE MISSING FROM ncl0899g.snx :
   Stations: TROM

MADR WAS NOT USED IN GLOBAL COMPARISON DUE TO LARGE COORDINATE DIFFERENCES WITH ITRF94, DESCRIBED BELOW:

LONGITUDE RMS AT 11 FIDUCIAL STATIONS HIGHER THAN USUAL. FOLLOWING STATIONS HAVE LONGITUDE DIFFERENCES WITH ITRF94 IN EXCESS OF 4 CM.:
   Stations: MADR
STATION / GNAAC / LONGITUDE DIFFERENCE (mm.):

MADR	JPL	56.5
	MIT	56.8
	NCL	49.0

Status and Activities of the Central Bureau

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1 The Role of the IGS Central Bureau

According to the IGS Terms of Reference, the "Central Bureau of the International GPS Service is responsible for the overall coordination and management of the Service." To fulfill this role, the Central Bureau (CB) must be active and engaged in the many activities of the IGS. Given the current scope of IGS activities and the directions of GPS applications, the personnel of the CB must have a number of different talents to collectively perform tasks to coordinate with various components of the service. One of the most noticeable changes in the last 3 years is the effort required to provide information and outreach to users of the service. In the first 2 years of IGS operations, the contributing agencies worked to achieve their objectives in the spirit of the IGS mission statement. During that period, it took time to develop and solidify the working relationships internal to the IGS, and so the focus was the cooperating agencies. Due to the success of the IGS and the awareness of our activities, more and more users are from outside the participating agencies. Based on the role that the CB plays, we are increasingly aware that additional effort is warranted in two areas: sustaining the fundamental infrastructure of the IGS and providing a closer and richer interface to users, both internal and external.

2 Activities and Services in 1996

Because 1996 is the third year of operations of the IGS, one would think that the level of effort is becoming very regular. Not so! The Central Bureau as well as all aspects of the service are continuously evolving. The Central Bureau was engaged in a number of activities during 1996, some of which are highlighted below.

- Participation in the National Research Council Workshop on GPS for the Geosciences, February, Boulder, USA.

- Coordination of the Silver Spring, March '96 Analysis Center Workshop; edited and published proceedings.
- Presentations at Asian Pacific Space Geodynamics (APSG) Project Meeting, May, Shanghai, China, where IGS was requested to act as the lead for GPS activities in the Pacific region.
- Presentations at the Western Pacific Geophysical Union Meeting, Brisbane, Australia, including a special open session describing the IGS, and how to access and use IGS products.
- Organization of the 6th IGS Governing Board Meeting, October, Paris, France.
- Business Meeting of the Governing Board, March and December.
- The CB has begun to manage IGS exhibits at conferences in order to promote information on the IGS. These exhibits include a computer with a slide show, a backdrop of information, publications for pickup or order, and attendants at the booth to answer questions. Exhibits were conducted at
  - American Congress on Surveying and Mapping, April, Baltimore, USA.
  - Spring Meeting of the American Geophysical Union, May, Baltimore, USA.
  - Western Pacific Geophysical Union Meeting, July, Brisbane, Australia.
  - Institute of Navigation GPS Annual Technical Meeting, September, Kansas City, USA.
  - American Geophysical Meeting, December, San Francisco, USA.
- Initial upgrade of the Central Bureau Information System (CBIS), an ongoing effort.
- 20,000 to 25,000 file transfers per month on the CBIS, which is an increase of nearly fivefold over early 1995. We think that this is due to the increased outreach of a number of people presenting talks on the IGS, the exhibits sponsored by the CB, and distribution of the IGS brochure.
- IGS Publications:
  - March '96 Workshop Proceedings
  - IGS Annual Report
  - IGS Directory 1997
  - IGS Brochure
  - IGS Resource Packets, updated quarterly

One of the key services provided by the Central Bureau is the CBIS. This is a flat-file database system accessible via the Internet on either the World Wide Web or Anonymous File Transfer Protocol:

World Wide Web: http://igscb.jpl.nasa.gov/
Anonymous FTP: igscb.jpl.nasa.gov (or 128.149.70.171)

The Web site is also mirrored in Europe at the Global Data Center managed by the Institut Géographique National, France:

Anonymous FTP: igs.ensg.ign.fr (195.220.92.14) (previously known as schubert.ign.fr)

Figure 1 shows the history of file retrievals on the CBIS at JPL during 1996. For those users who are not connected to the Internet, the Central Bureau sends information by mail and FAX.

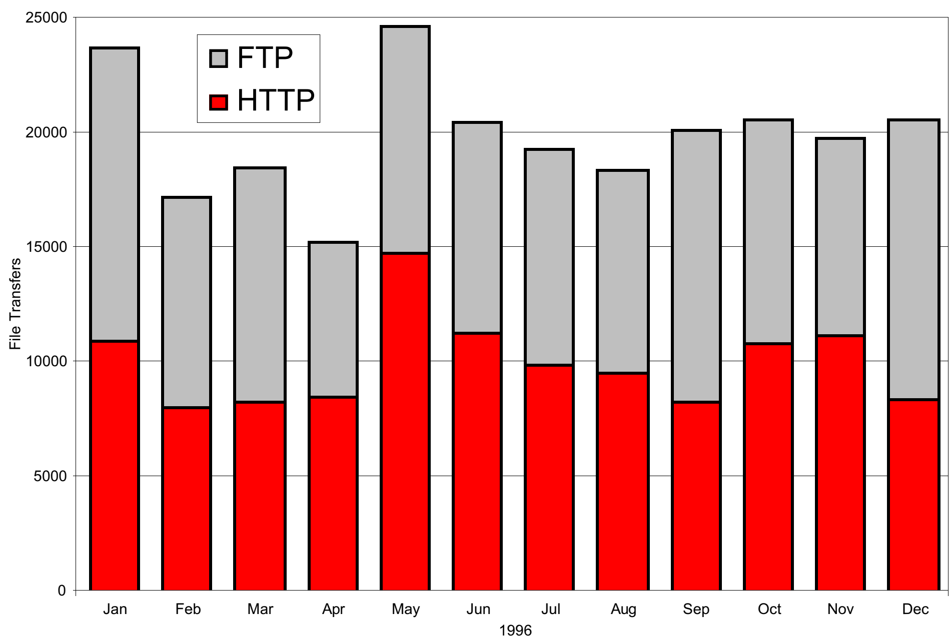

Figure 1: Total number of file accesses each month from the CBIS during 1996

The CB is interested in improving the monitoring and support of the IGS network. In September of 1996, discussions were initiated for the purpose of involving the University NAVSTAR Consortium (UNAVCO) into the Central Bureau in the capacity of "Network Engineering." UNAVCO, with direction from the Central Bureau, would monitor the entire IGS network, improve the completeness and accuracy of the station logs and other files on the CBIS, provide notice to network users of data flow problems, and provide general support to the Central Bureau. The start date of this proposal is 1997.

3 Recognition as a FAGS Service

During 1995, the CB prepared an application for IGS membership in the Federation of Astronomical and Geophysical Data Analysis Services (FAGS), which is part of the International Council of Scientific Unions (ICSU). The FAGS

Council Meeting was held in April 1996, and the IGS was approved as a FAGS service.

4 Acknowledgment

The Central Bureau is sponsored by the US National Aeronautics and Space Administration. The CB offices are located at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology, Pasadena, California. Members of the Central Bureau through 1996 include James Zumberge, JPL, Analysis Liaison; Robert Liu, JPL, technical support; Priscilla Van Scoy, JPL, Administrator; Werner Gurtner, the University of Berne, Switzerland, "Data Chief," and Steve Fisher, UNAVCO/JPL, engineering support.

5 IGS Publications Available at the Central Bureau

1995 Annual Report International GPS Service for Geodynamics, August 1995, edited by J. Zumberge, M. Urban, R. Liu and R. Neilan. IGS Central Bureau, JPL Publication 96-18, Jet Propulsion Laboratory, Pasadena, California.

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Densification of the ITRF through Regional GPS Networks, Workshop Proceedings, November 30–December 2, 1994, edited by J. Zumberge and R. Liu, IGS Central Bureau, JPL Publication 95-11, Jet Propulsion Laboratory, Pasadena, California.

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

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

IGS - Monitoring Global Change by Satellite Tracking, brochure describing the IGS, August 1997, IGS Central Bureau, JPL Publication 400-552, Jet Propulsion Laboratory, Pasadena, California.

IGS Directory: addresses, and contact information for approximately 1000 persons worldwide participating or interested in the IGS. Updated annually, distributed in January of each year.

IGS Resource Information: network information, station location, specific contact information, and synopsis of IGS. Updated every four to six months.

IGSnet and IGS Station Statistics

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1 Summary

A system developed at the Central Bureau in early 1996 has been used since then as a tool for monitoring the performance of the IGS network. Weekly reports contain scores on quantity, quality, and latency as a function of station. These reports are distributed by e-mail to station operators. The system also contains time series of these scores, as well as a global map with color-coded indicators of recent status. The system has been in continuous and automatic operation since May 1996 and can be viewed at

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

2 IGSnet

One of the tasks of the Central Bureau (CB) is to "monitor network operations" (see IGS Terms of Reference). To aid in this task, the Satellite Geodesy and Geodynamics Systems Group (SGGS) at the Jet Propulsion Laboratory (JPL) developed an automated tool that regularly collects information on IGS stations and displays the results in both text and graphics at

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

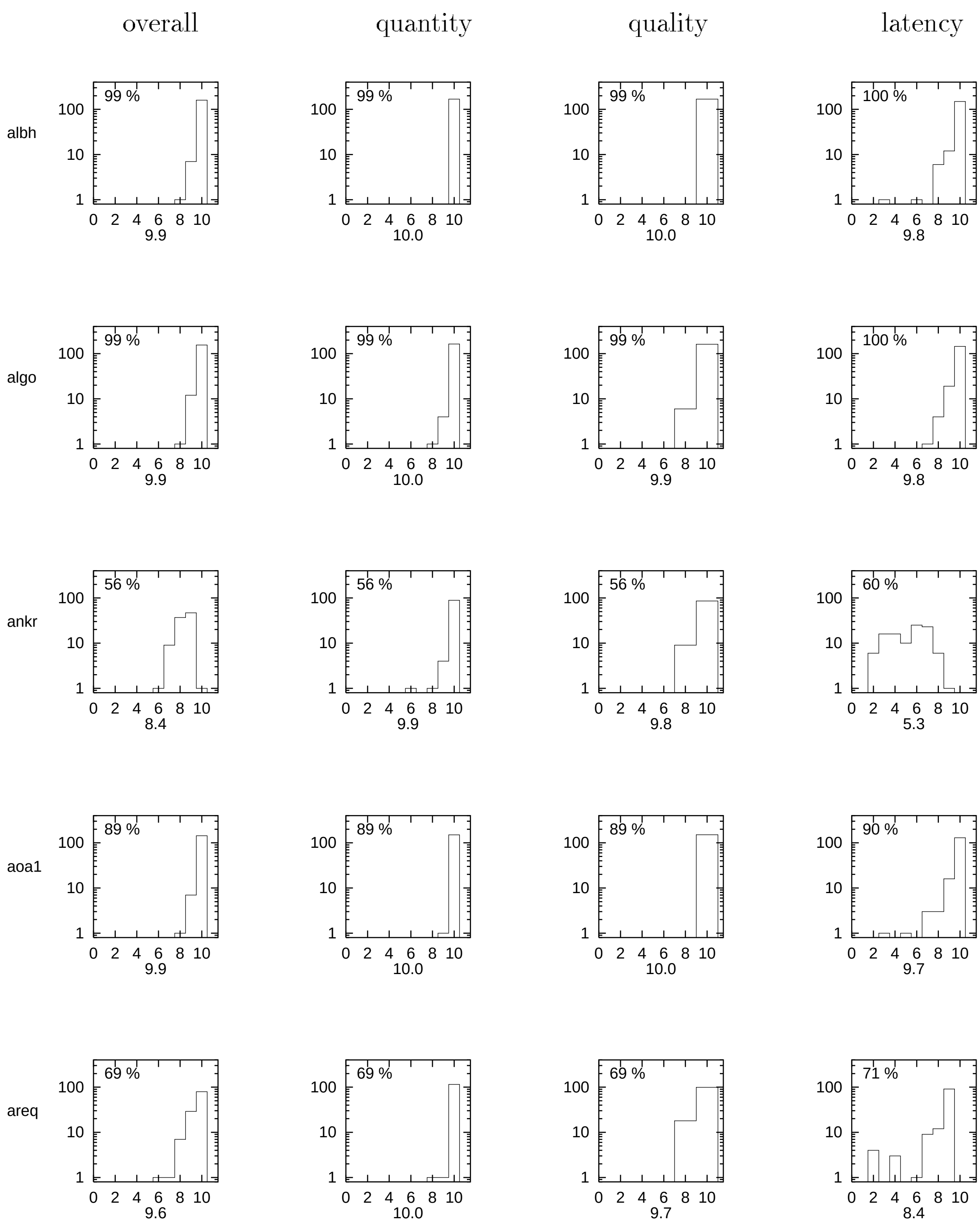
Technical documentation is available at

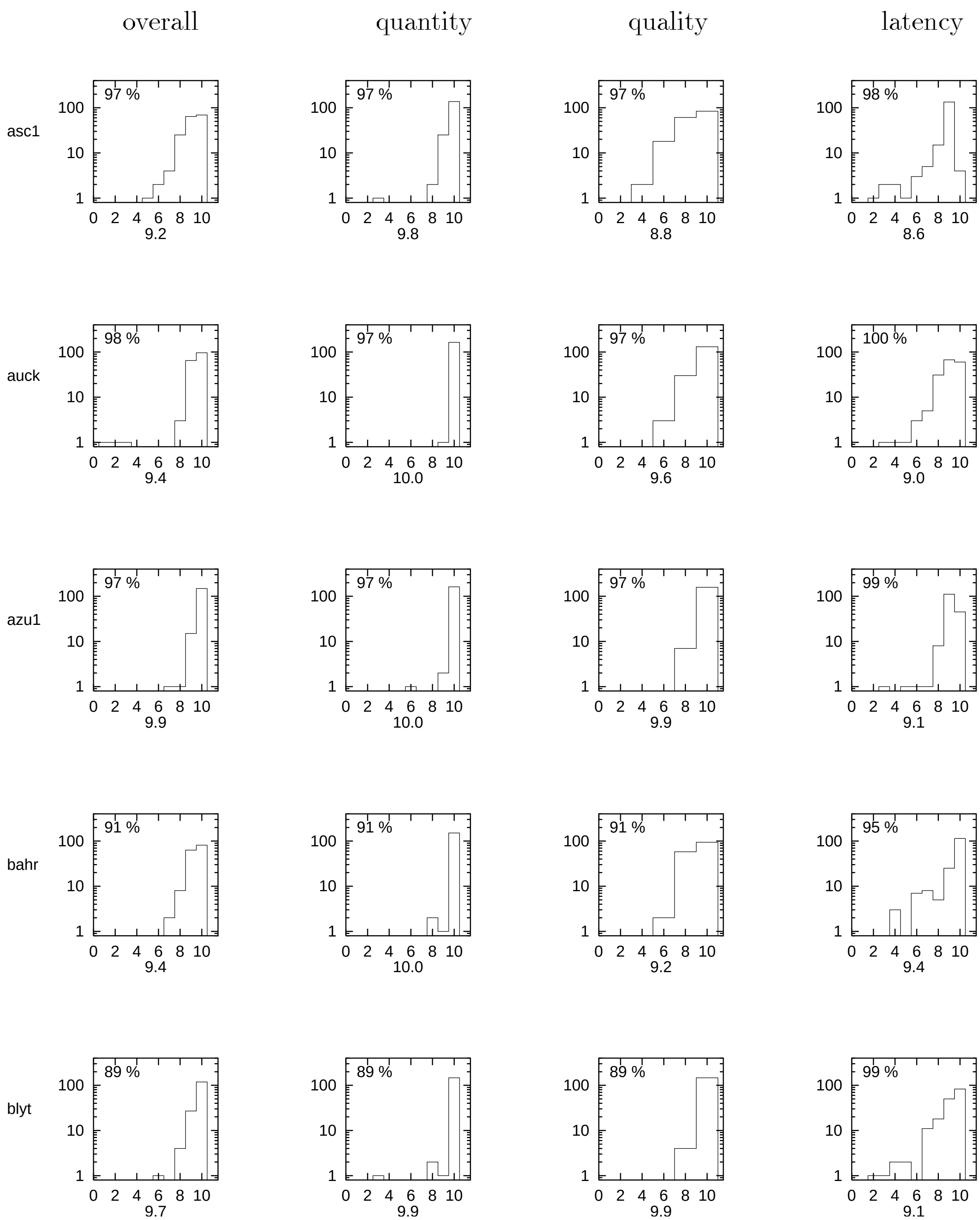
`ftp://igscb.jpl.nasa.gov/igscb/data/network/igsnet.doc.`

This file is included as the Appendix.

3 Station Statistics

Based on 169 daily IGSnet reports spanning the period October 12, 1996, through April 11, 1997, we show in the following pages four histograms for each station that indicate the distribution of scores in the overall, quantity, quality, and latency categories. The number below the x axis indicates the mean value of nontrivial scores. Zero or "•" are considered trivial and not included. The number in the upper-left-hand corner indicates the number of times the report had an entry; this is expressed as a percentage of the total.


overall
quantity
quality
latency
albh
99 %
99 %
99 %
100 %
9.9
10.0
10.0
9.8
algo
99 %
99 %
99 %
100 %
9.9
10.0
9.9
9.8
ankr
56 %
56 %
56 %
60 %
8.4
9.9
9.8
5.3
aoa1
89 %
89 %
89 %
90 %
9.9
10.0
10.0
9.7
areq
69 %
69 %
69 %
71 %
9.6
10.0
9.7
8.4
1
10
100
0 2 4 6 8 10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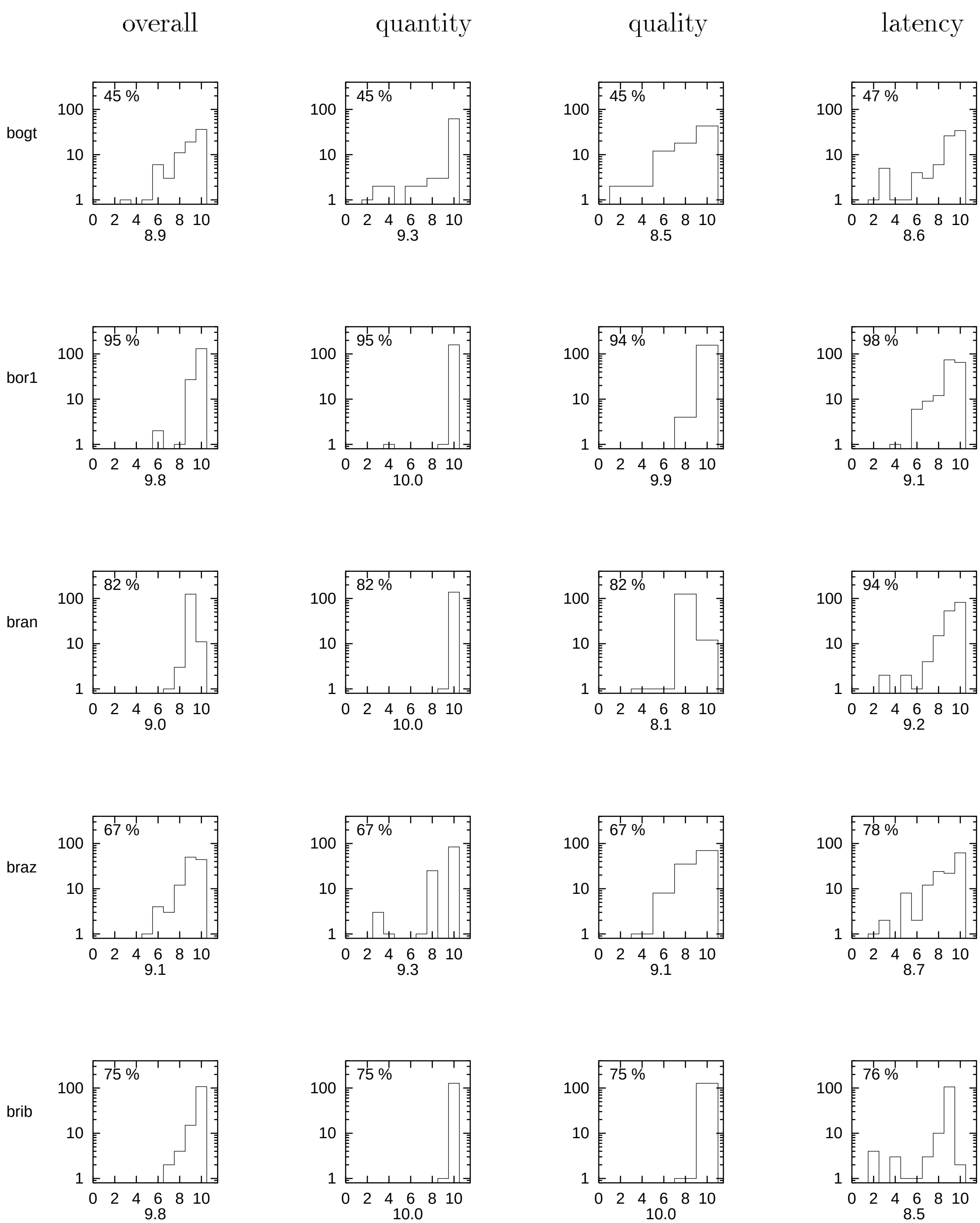
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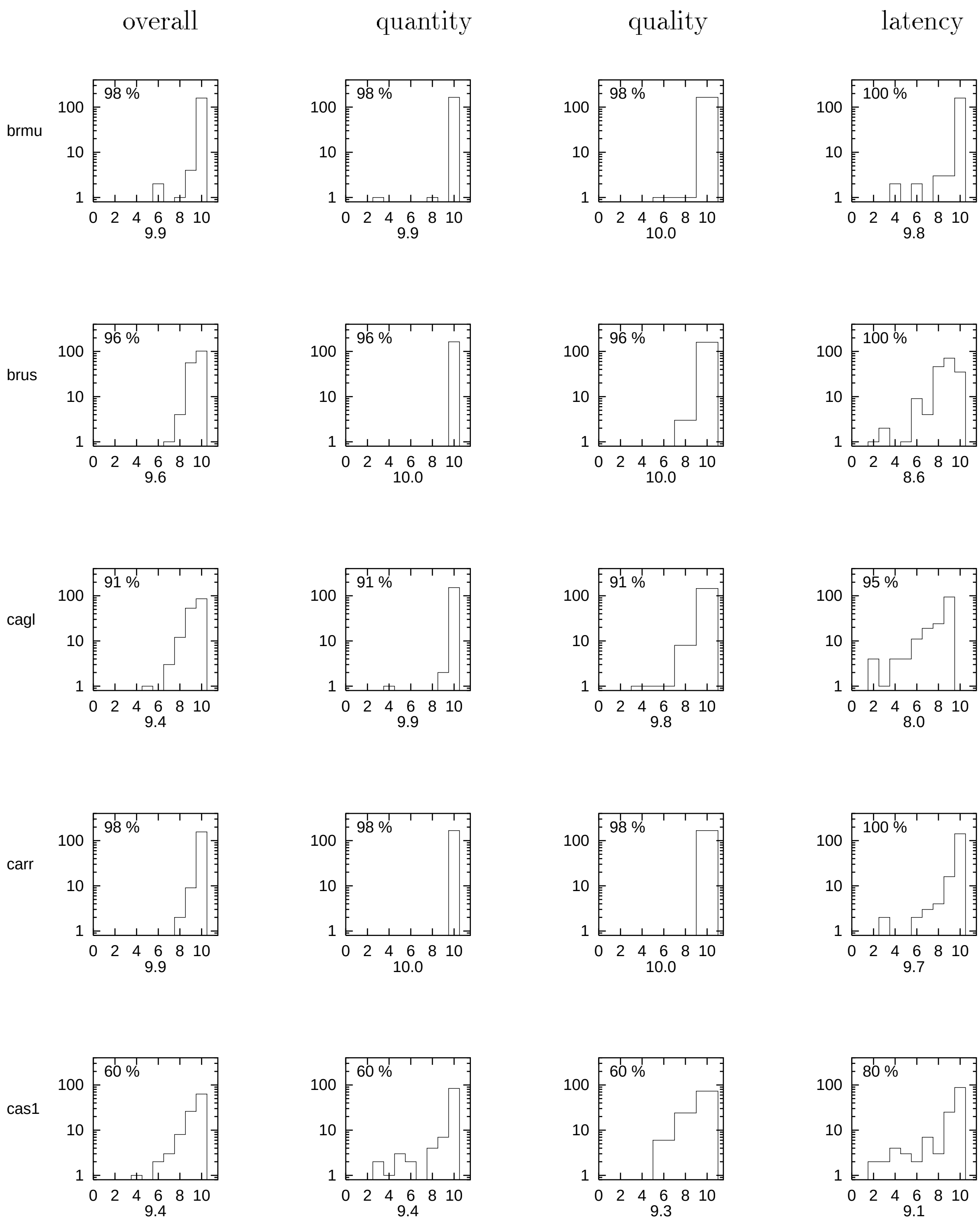

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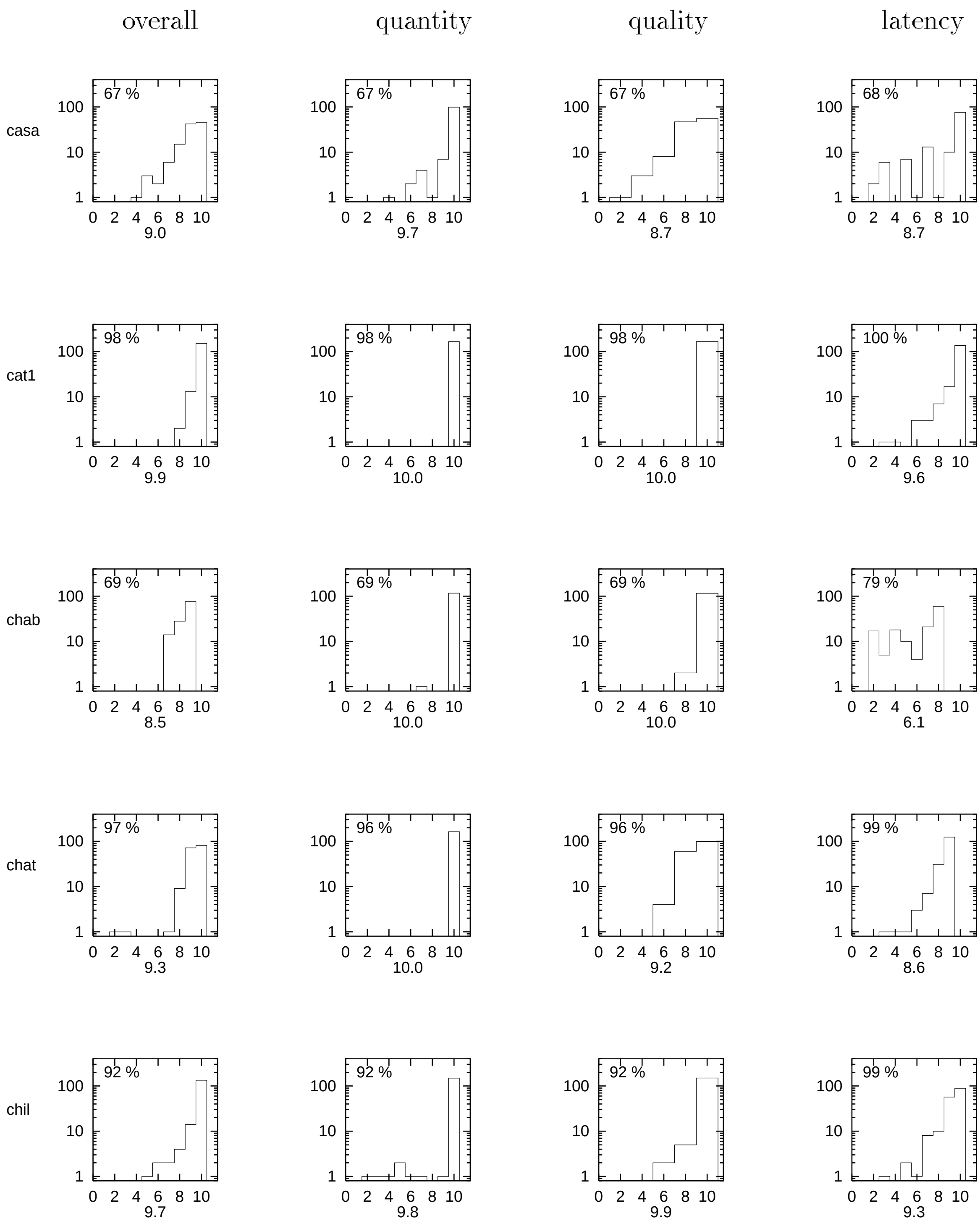
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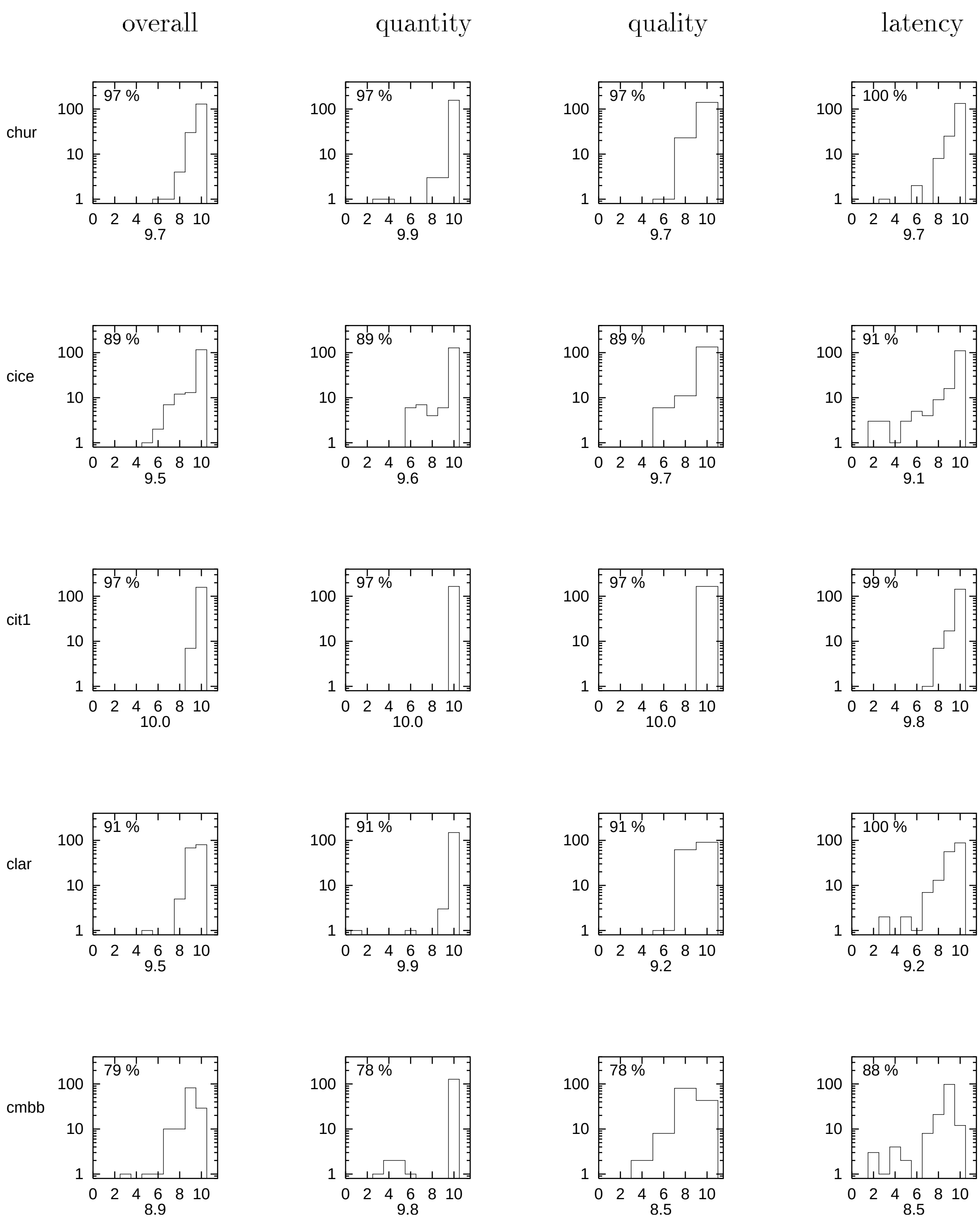
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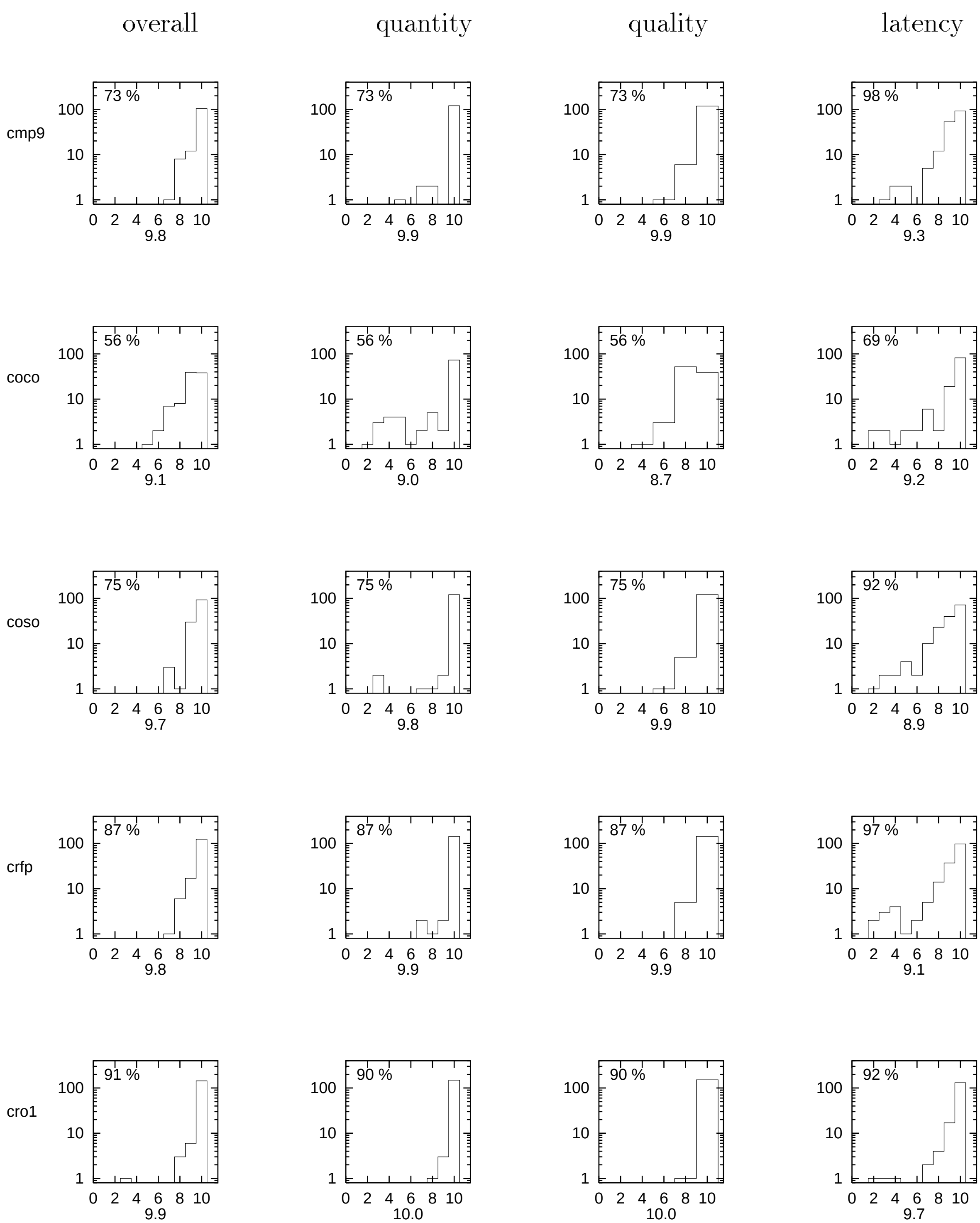
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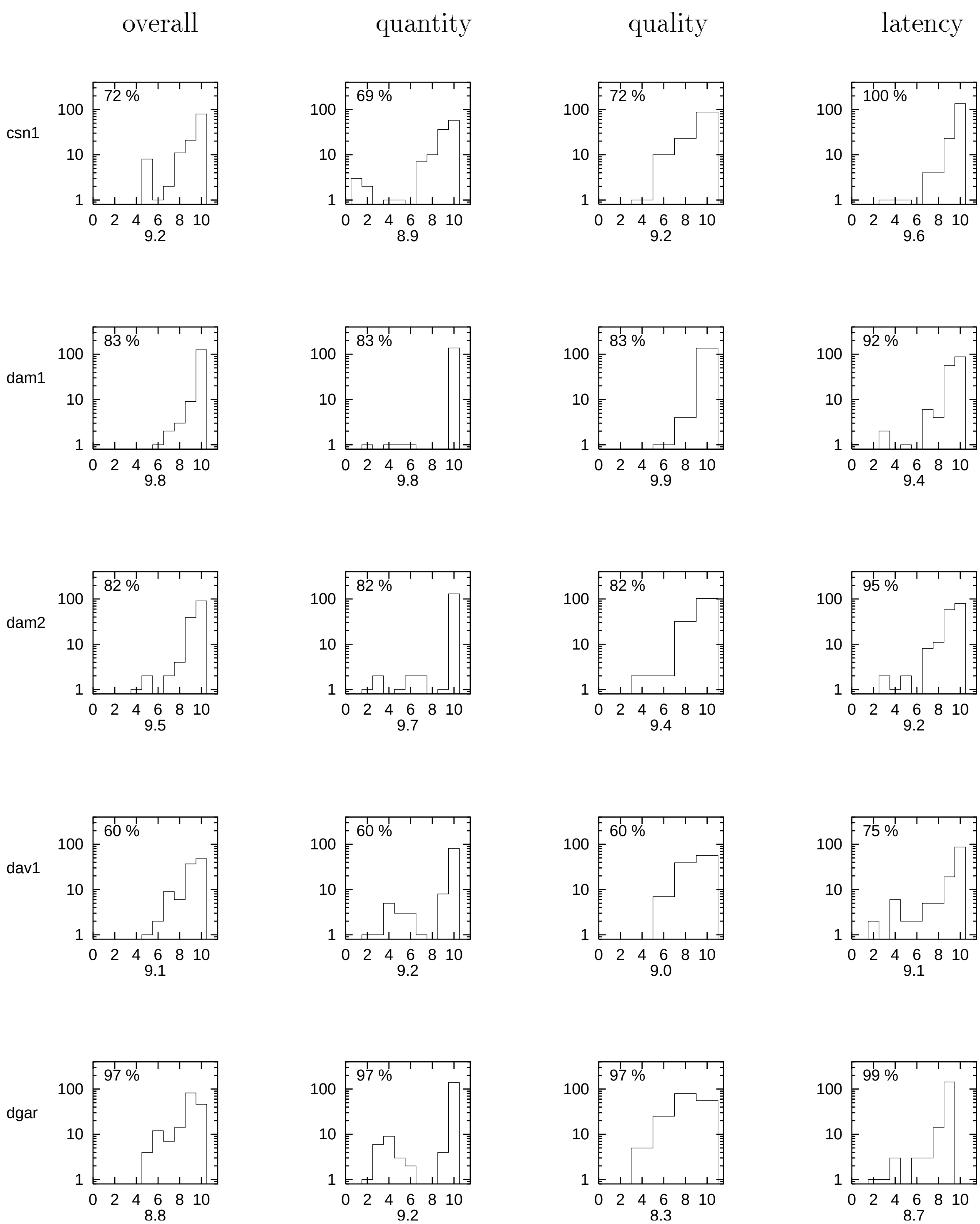
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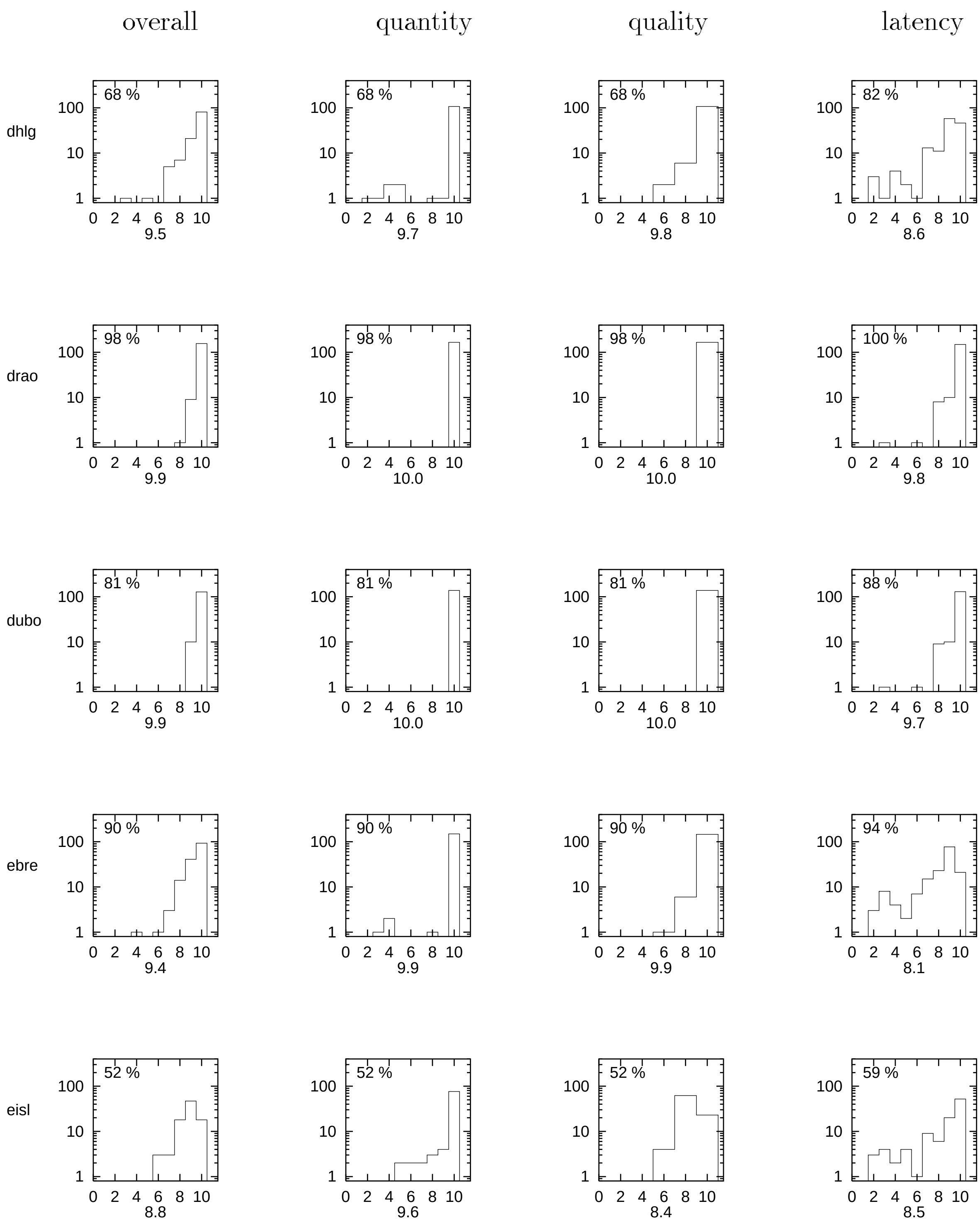
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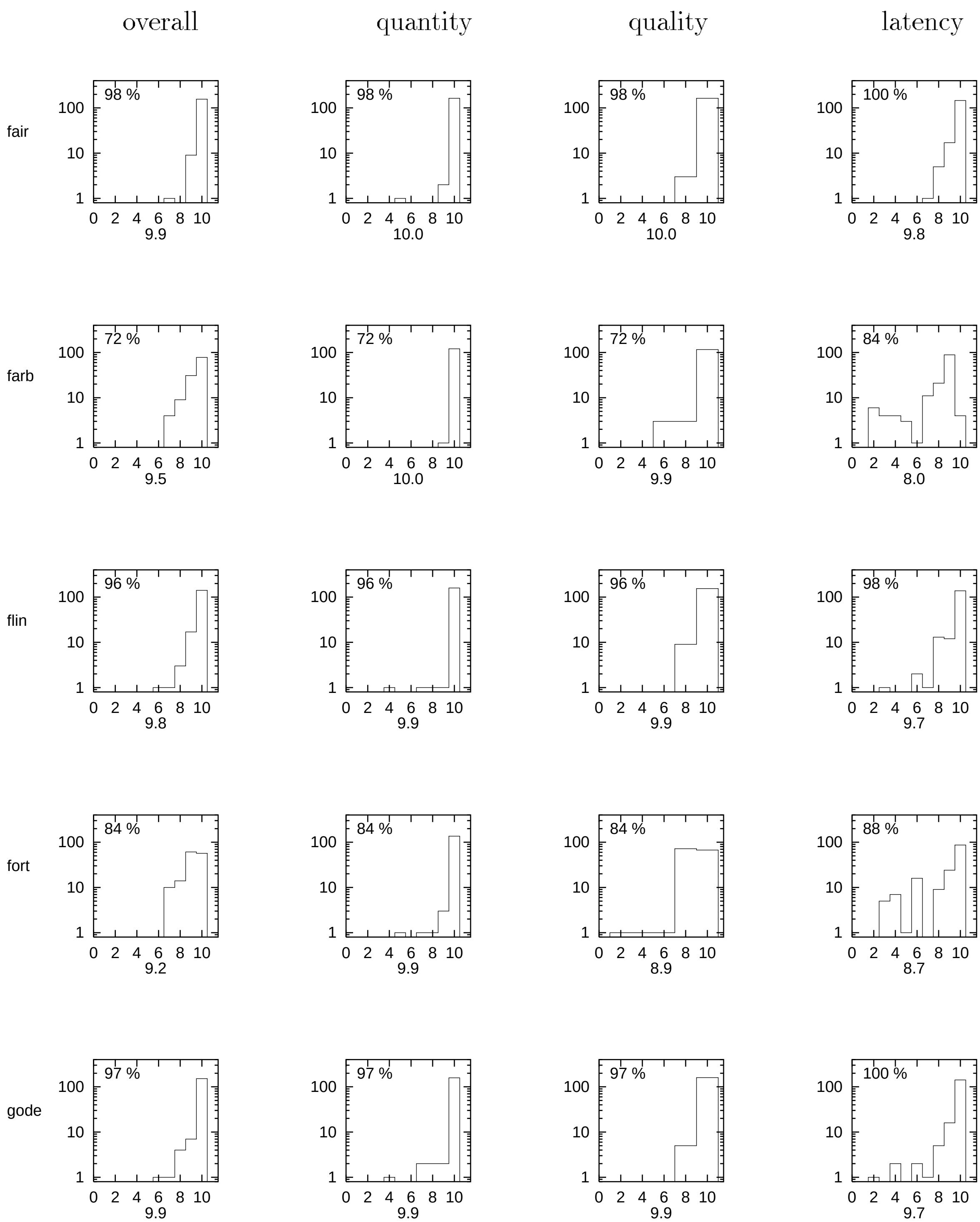

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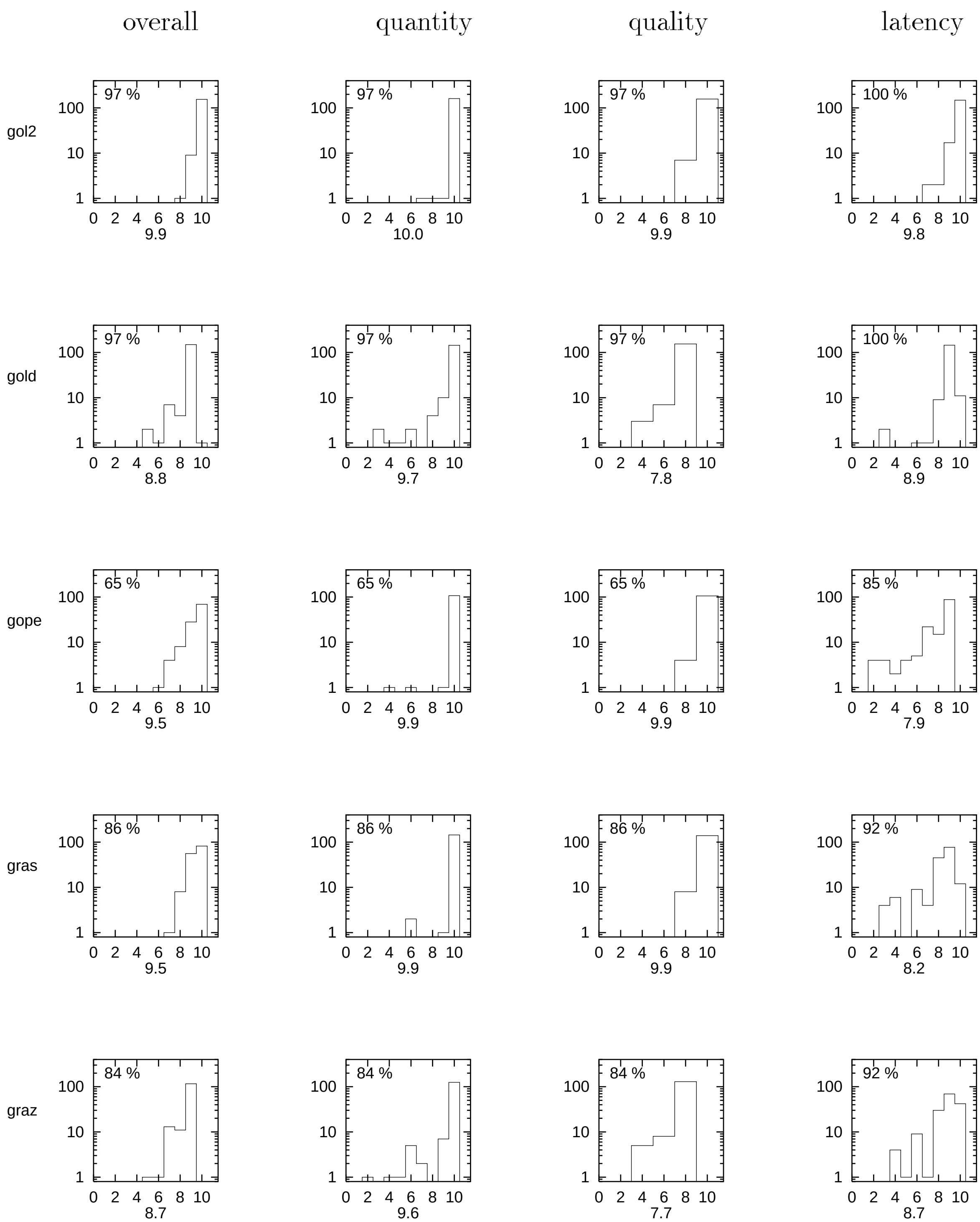
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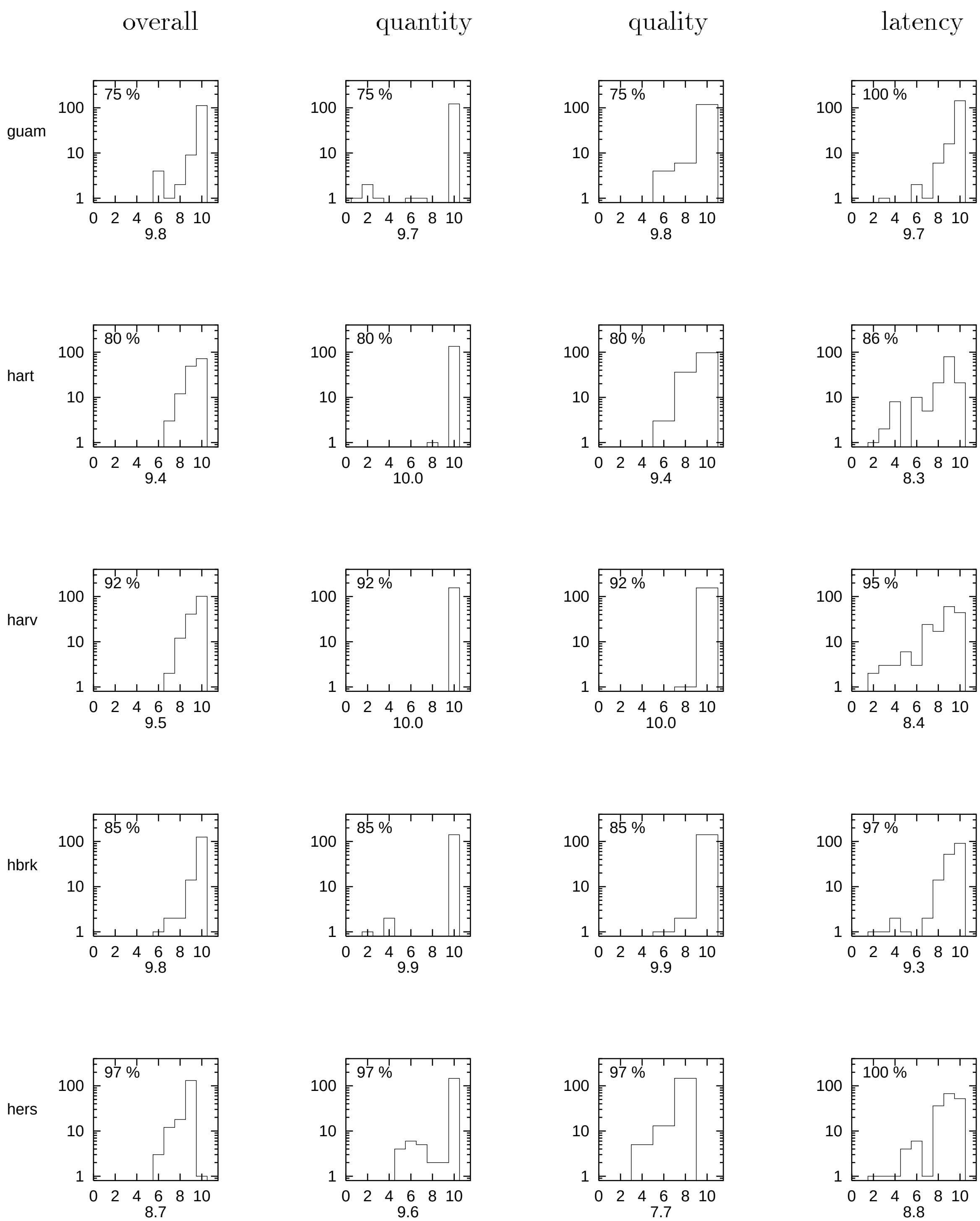
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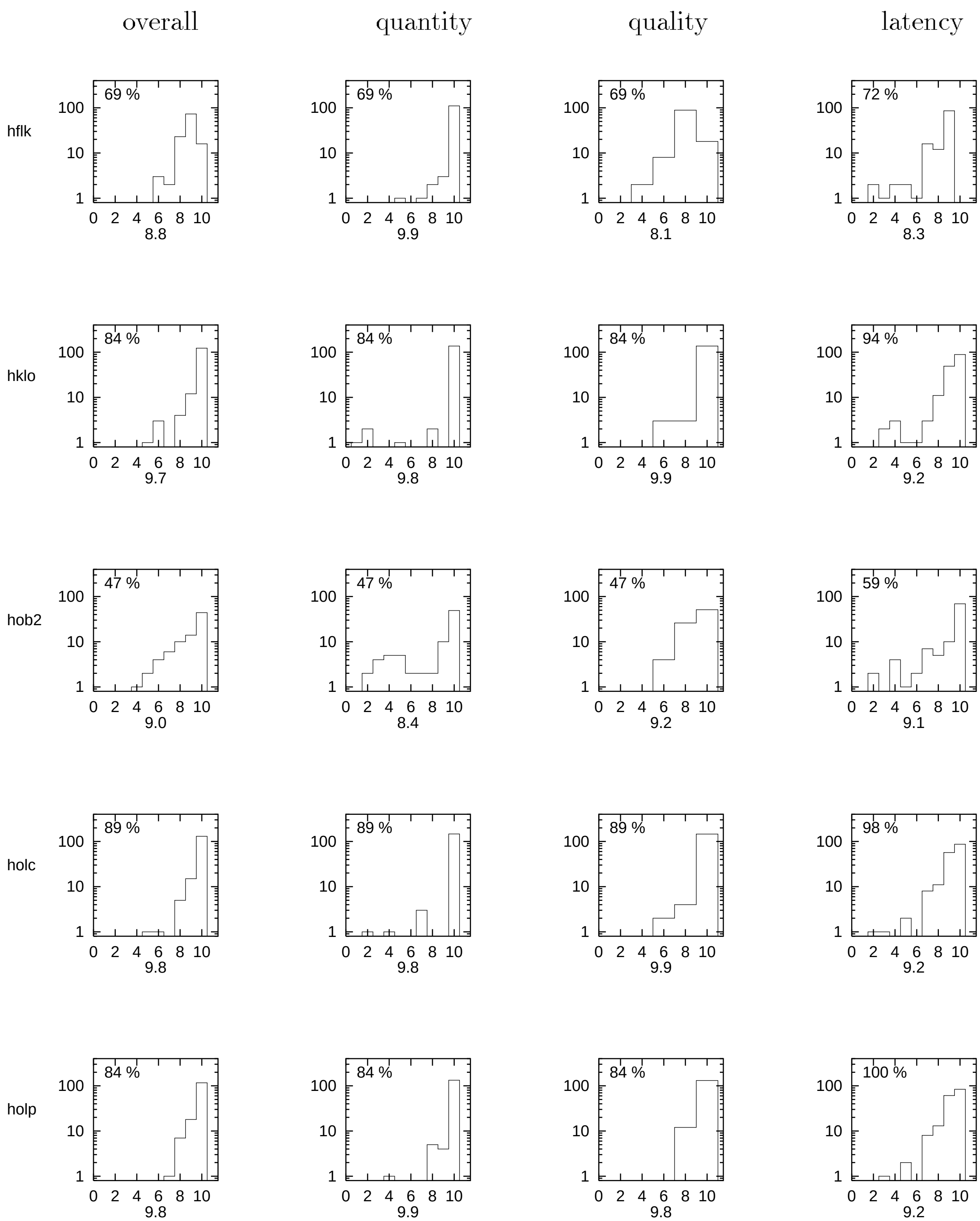
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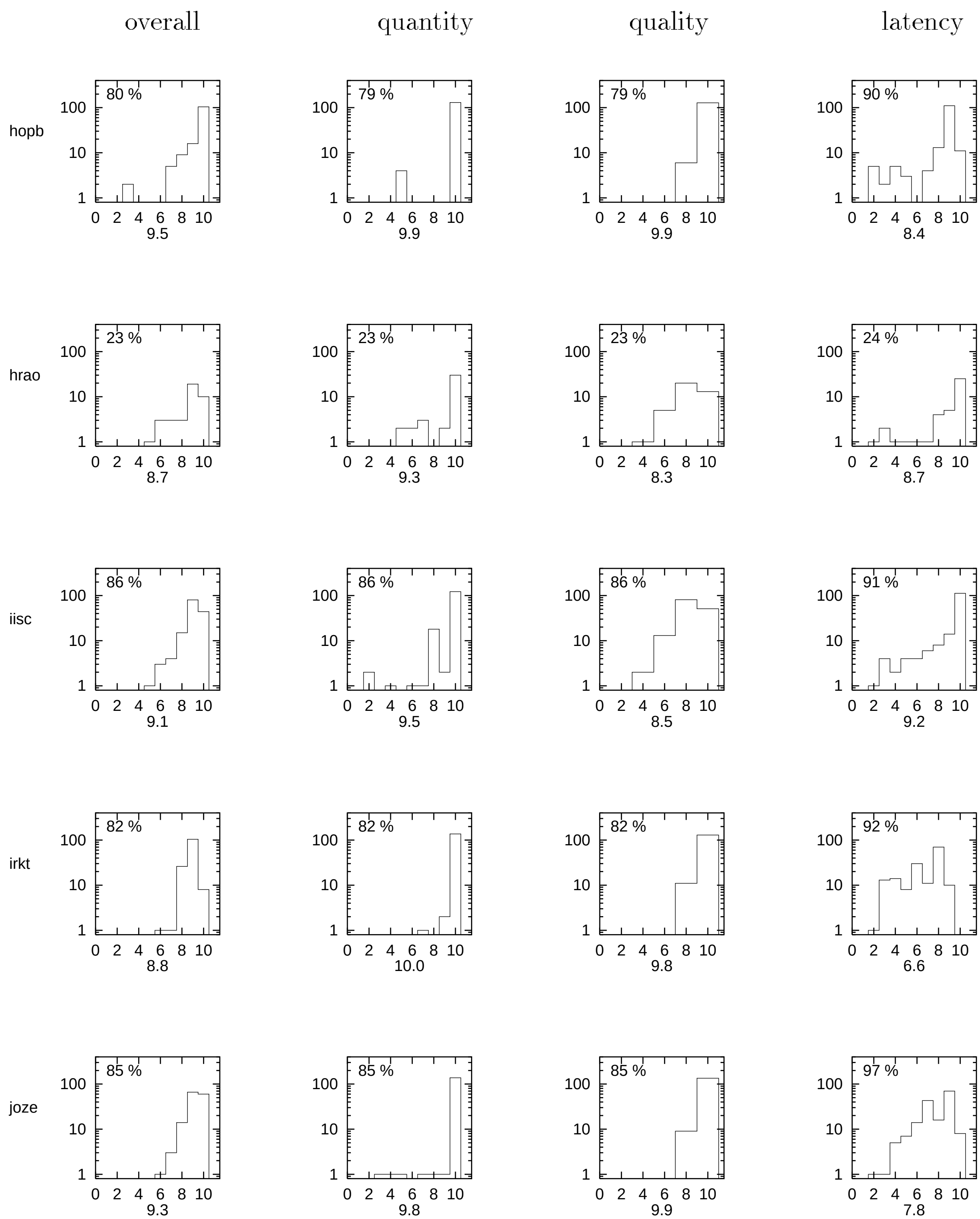
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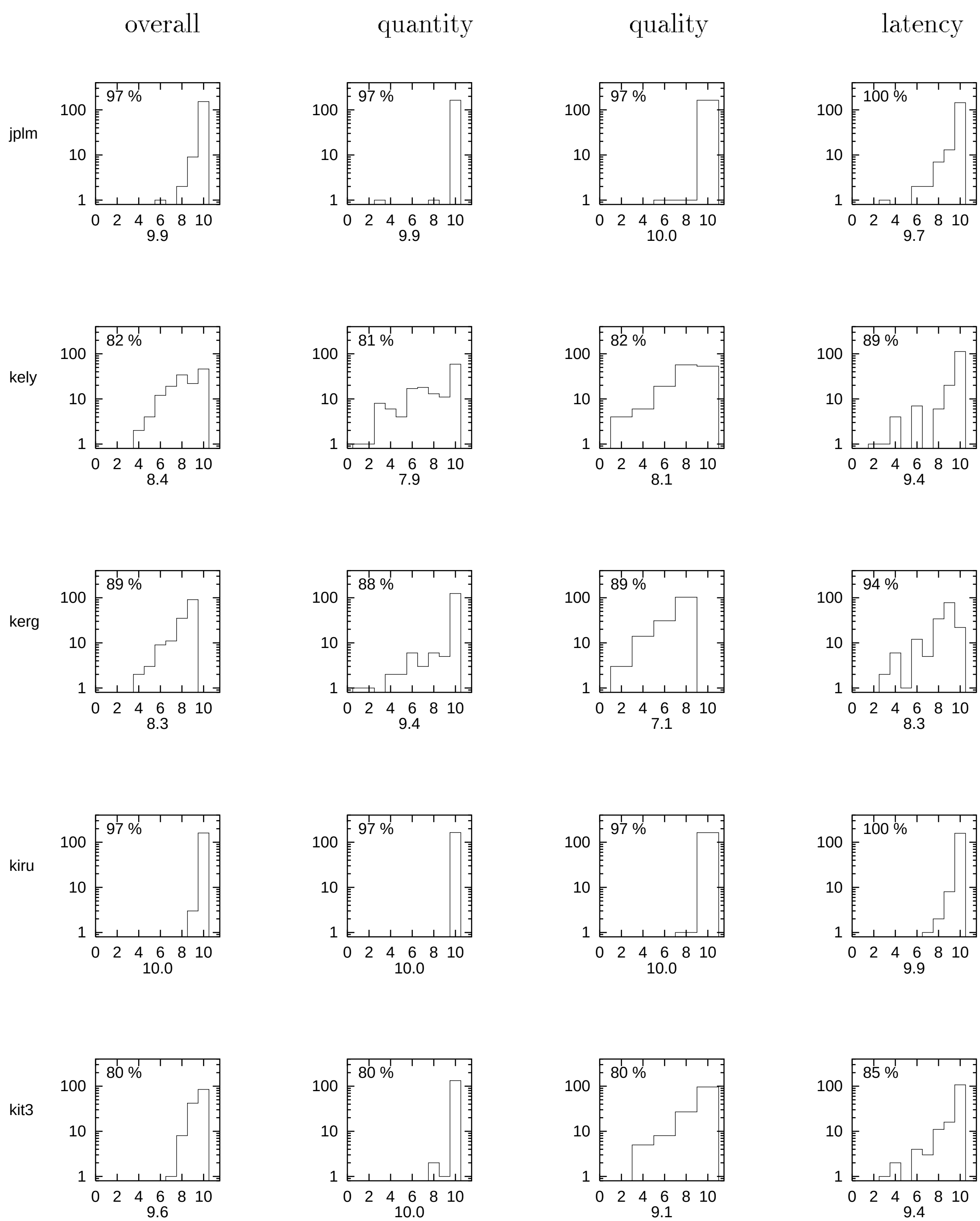
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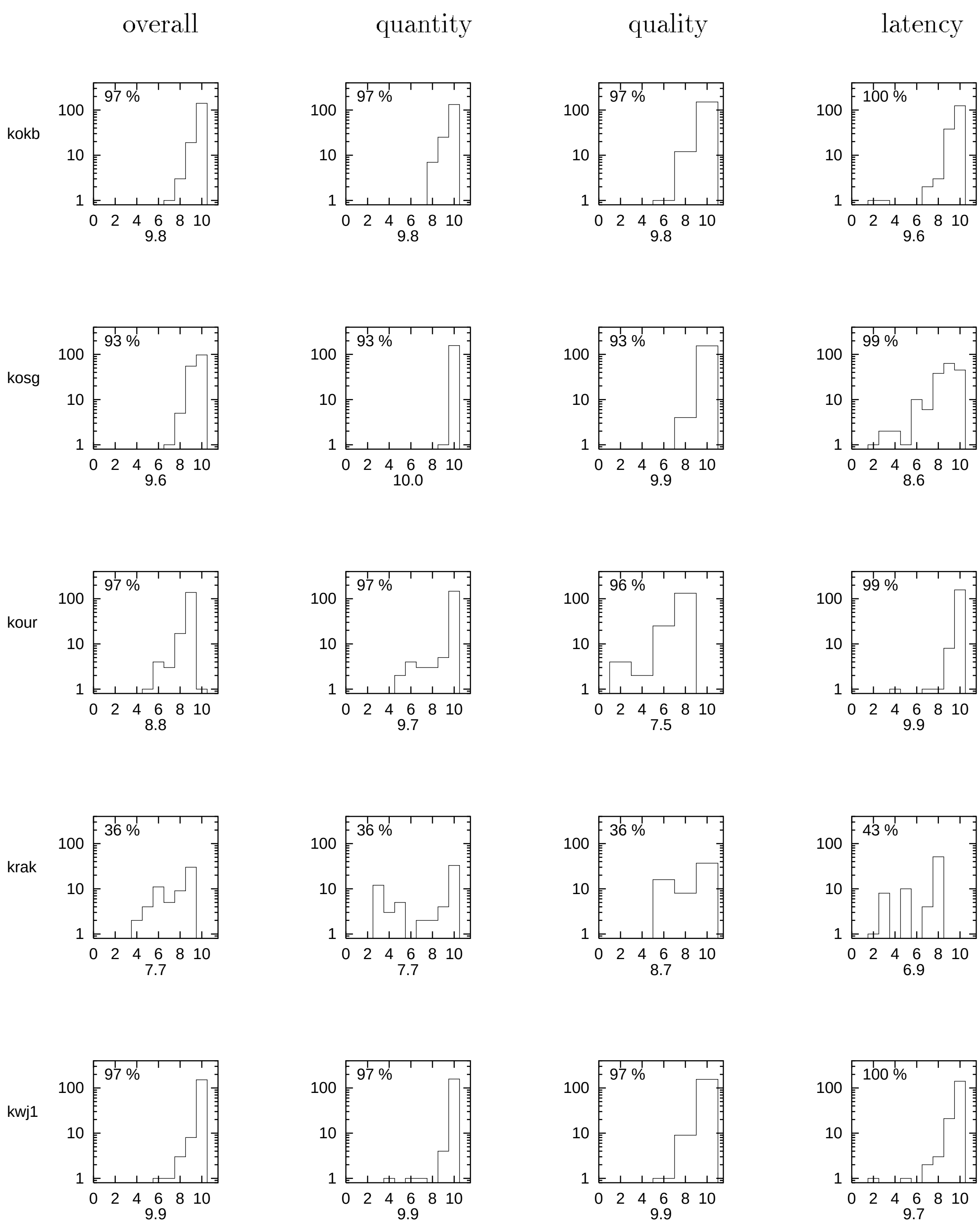
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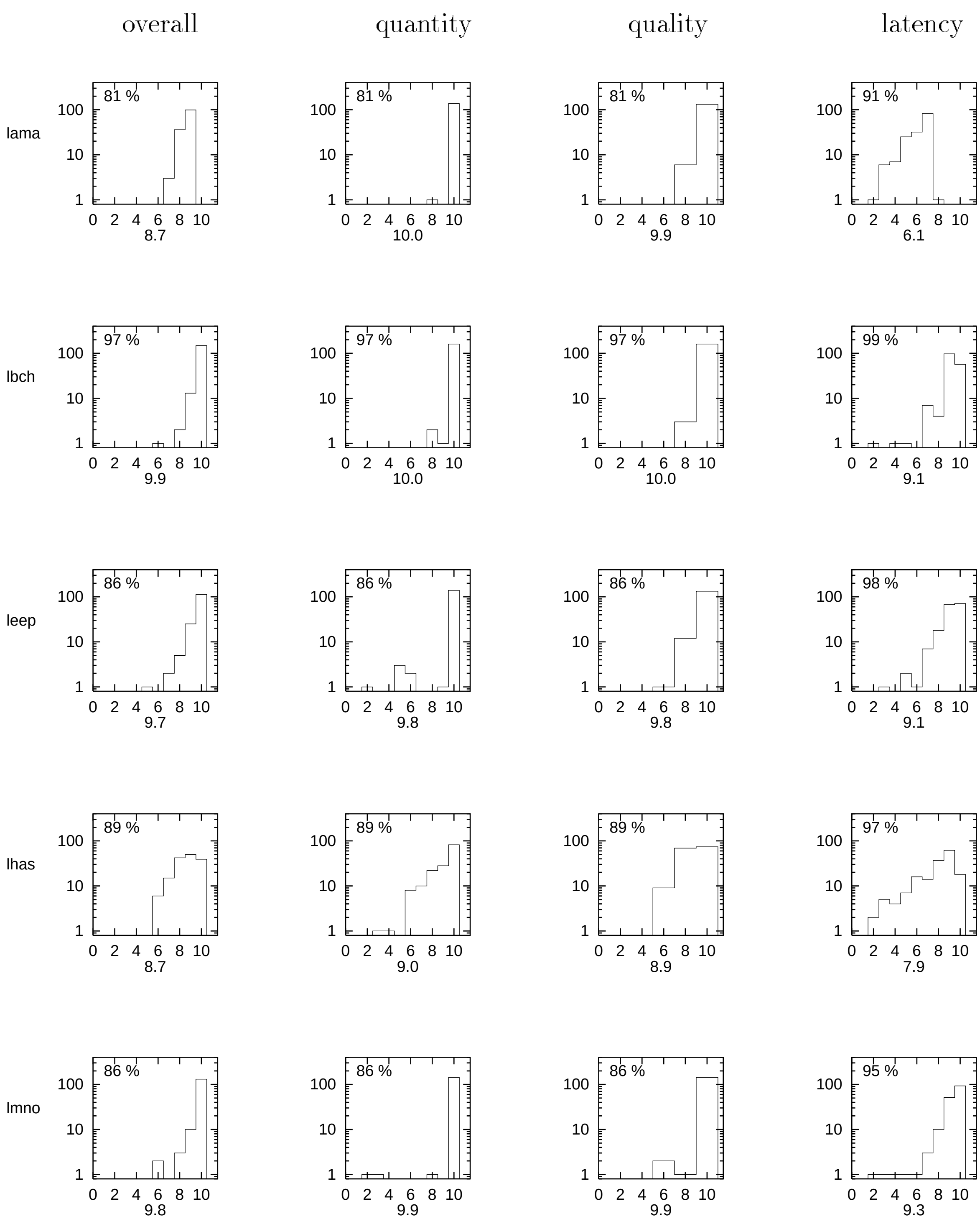
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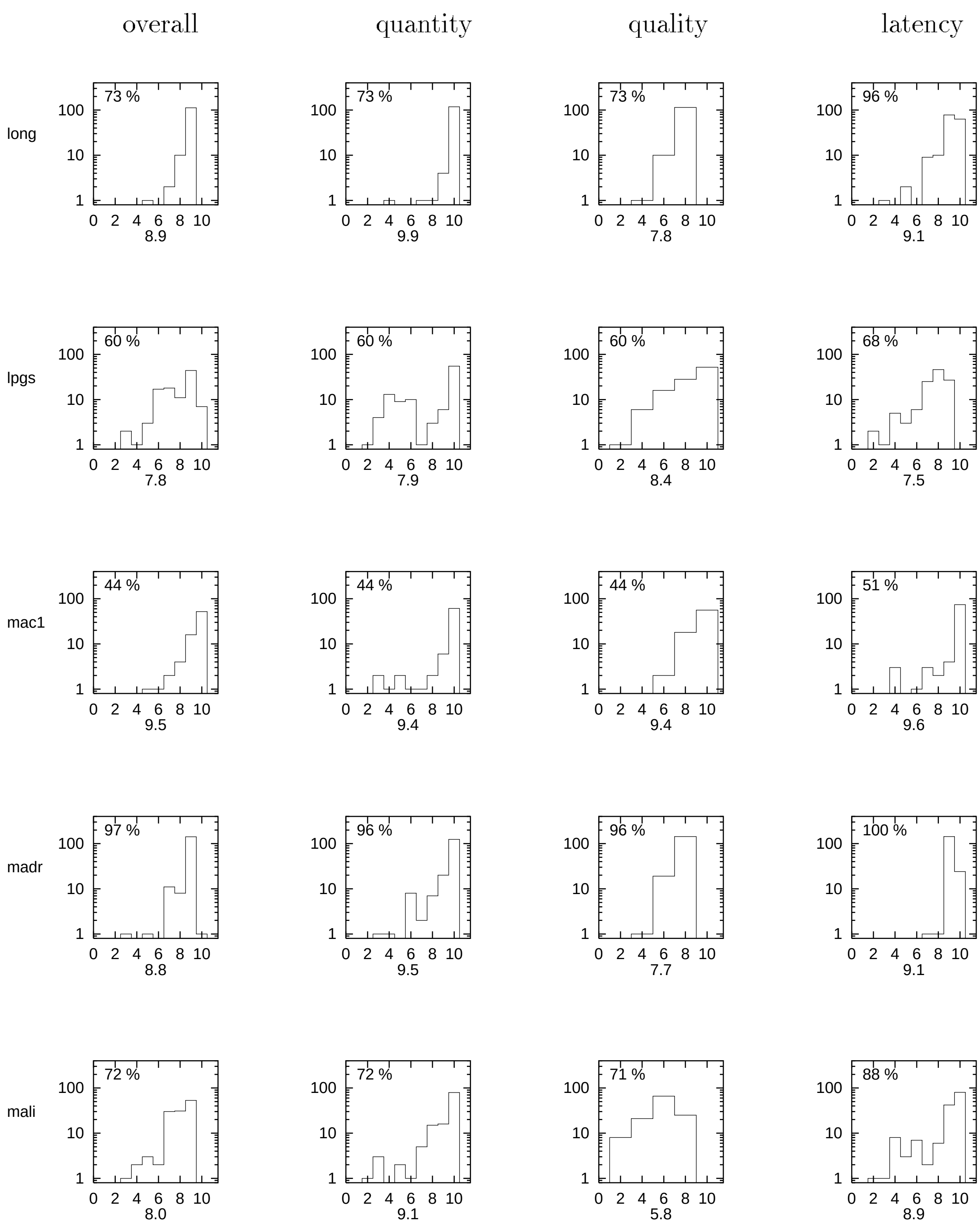
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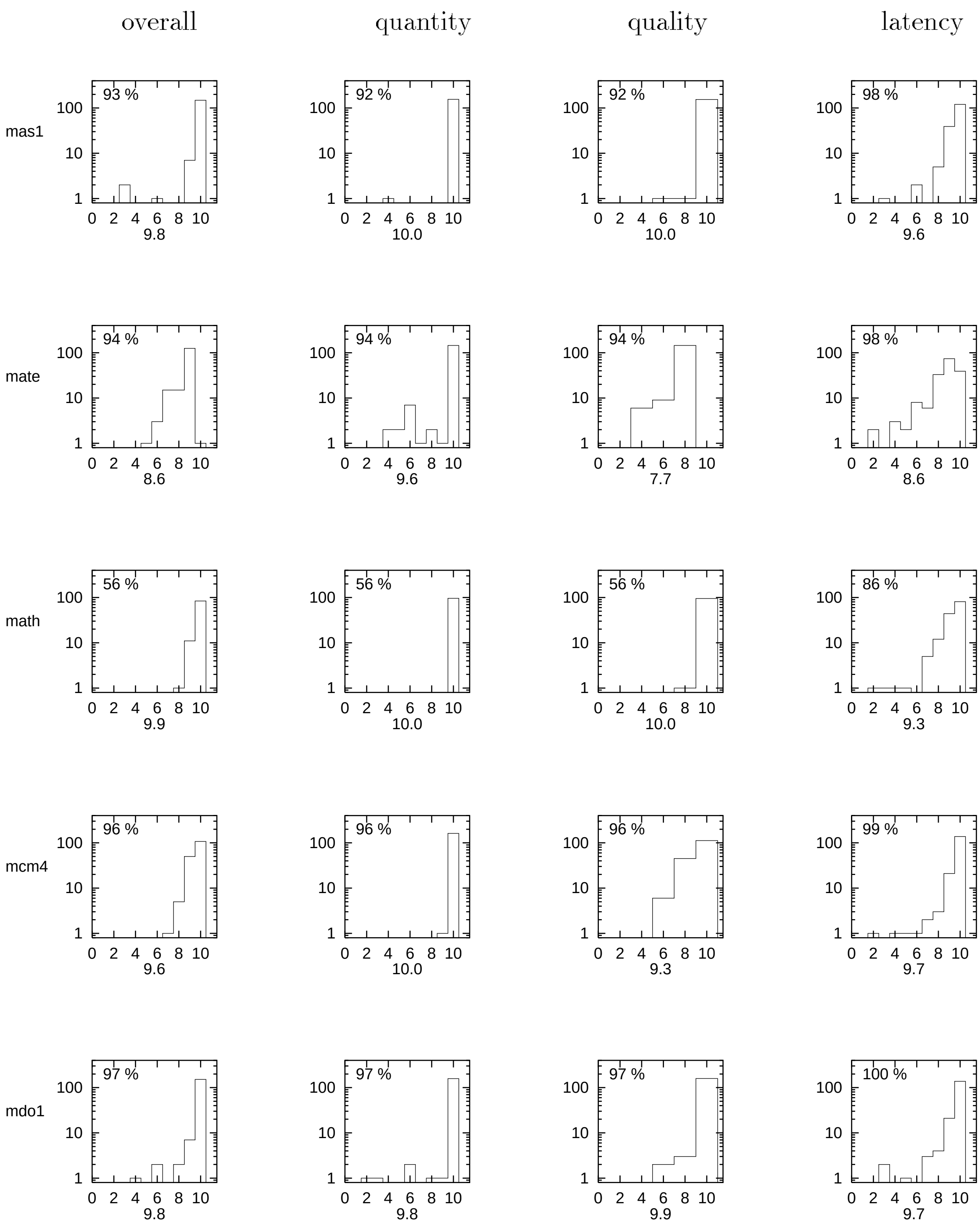
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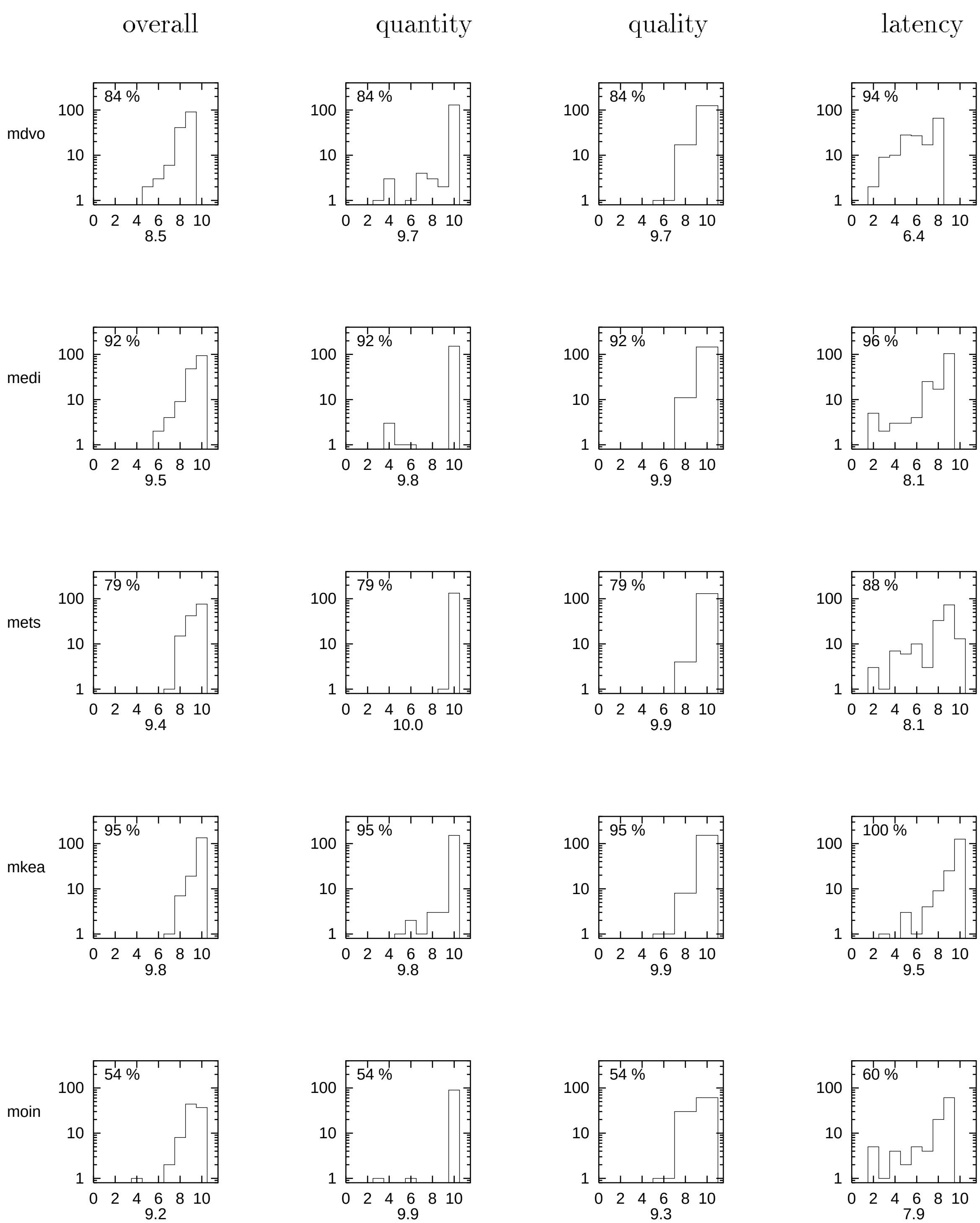
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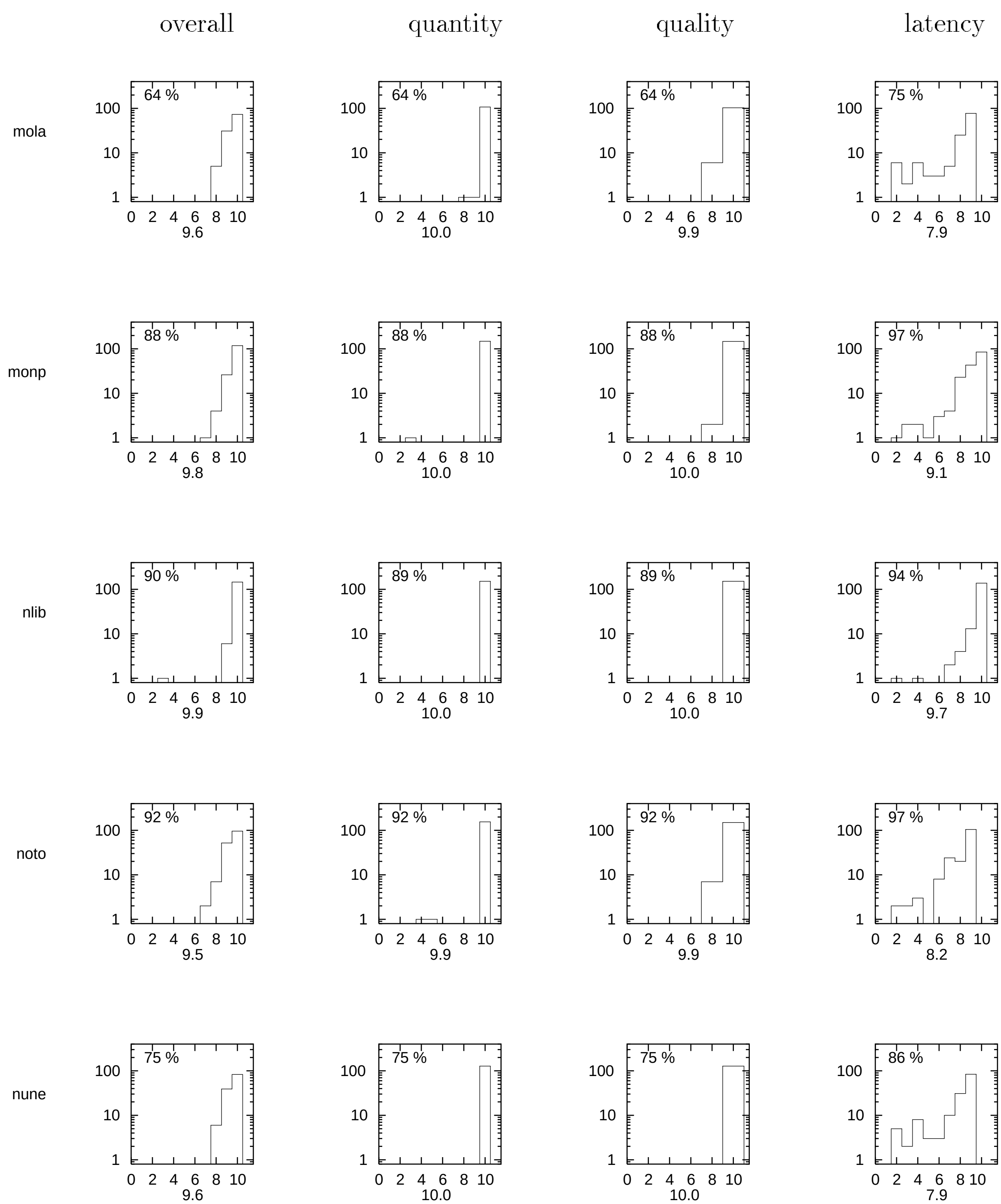
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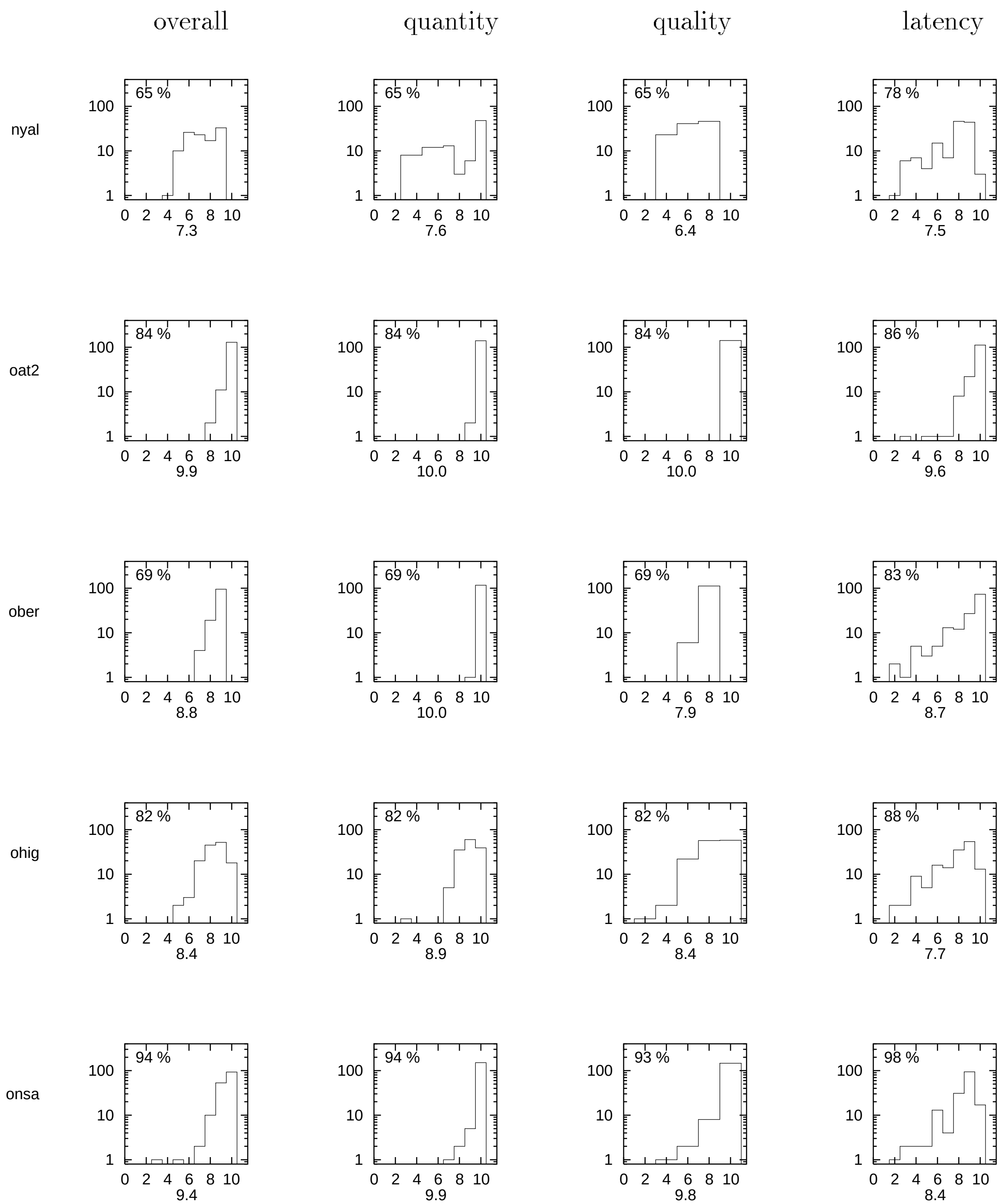
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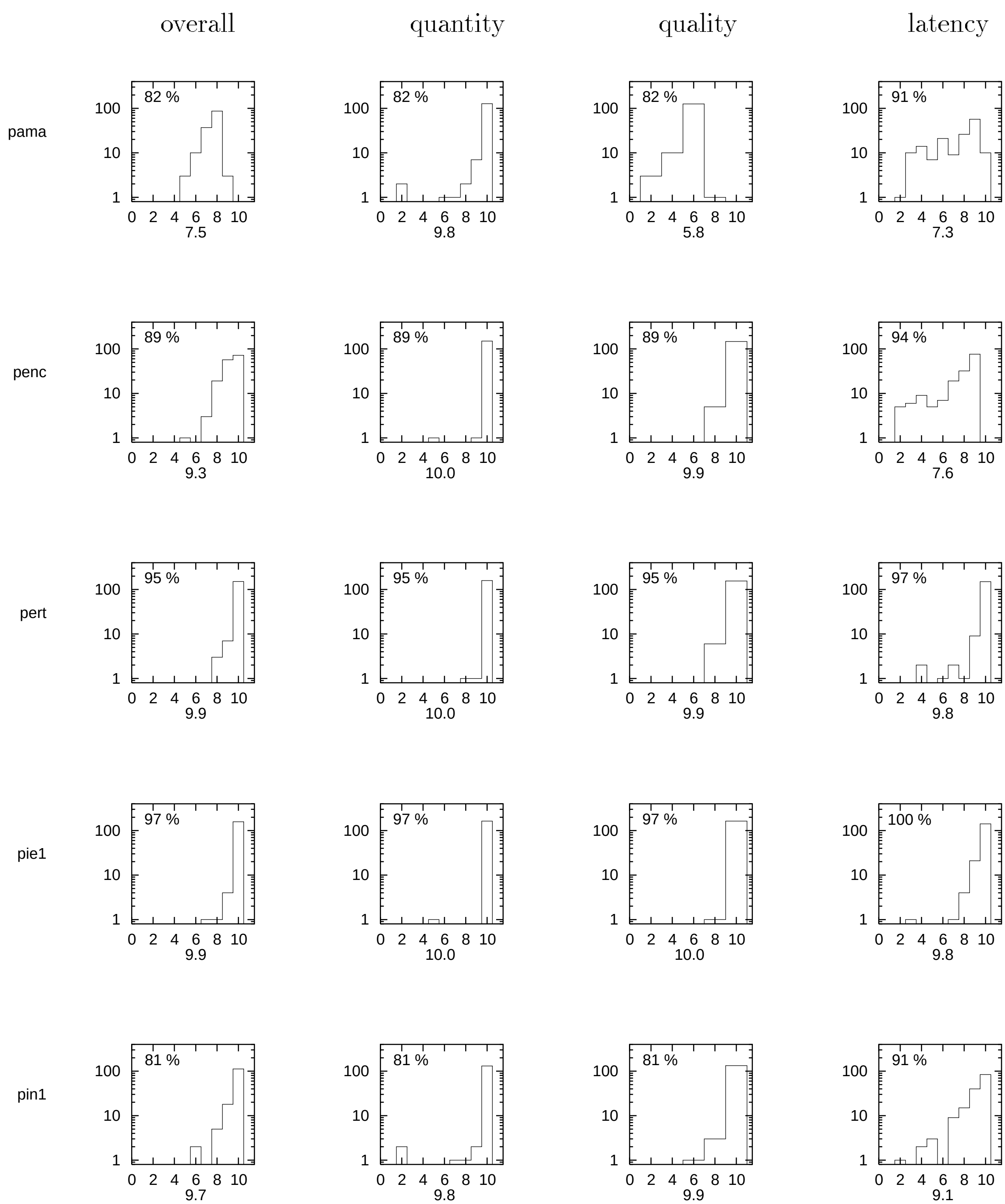
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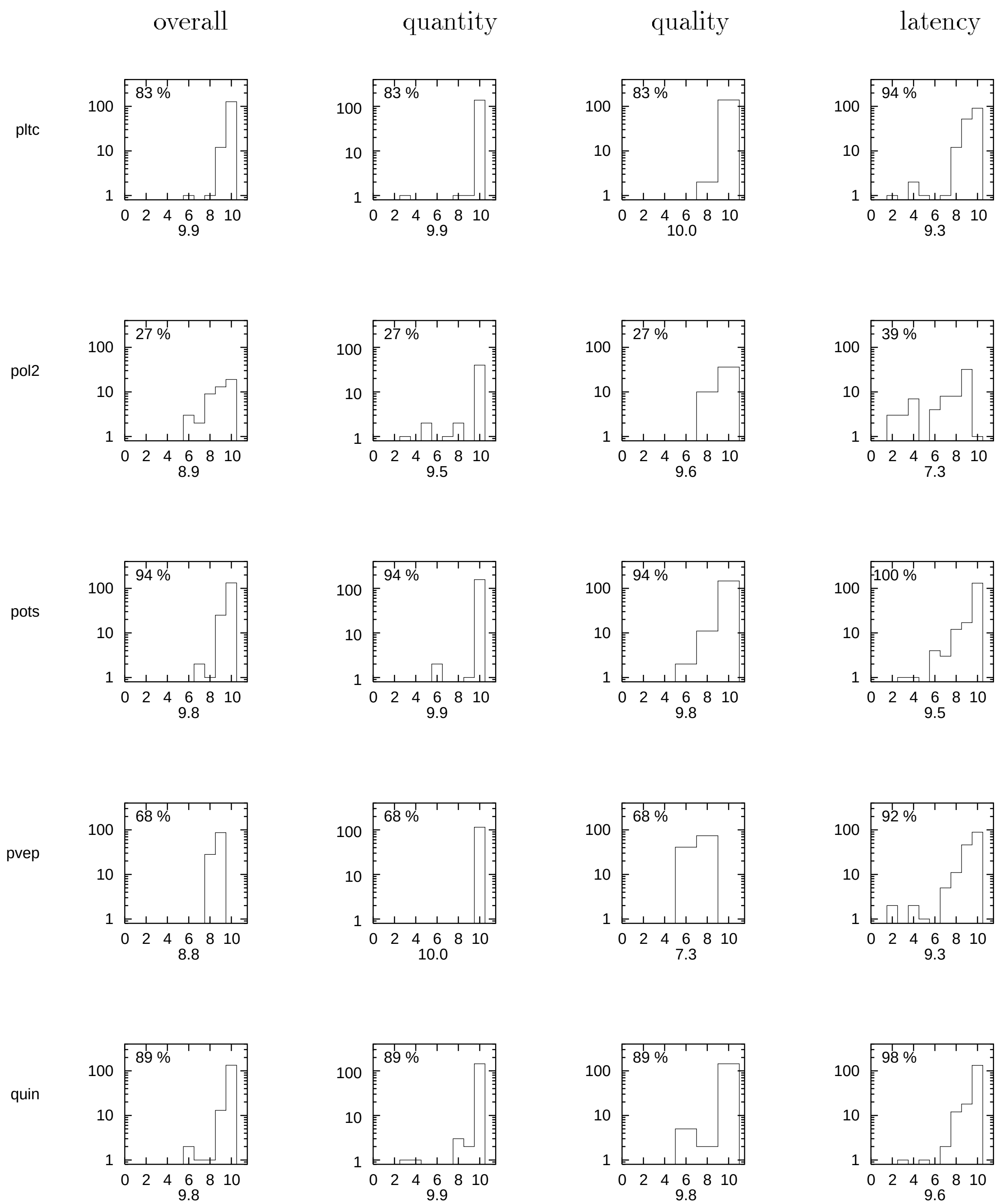
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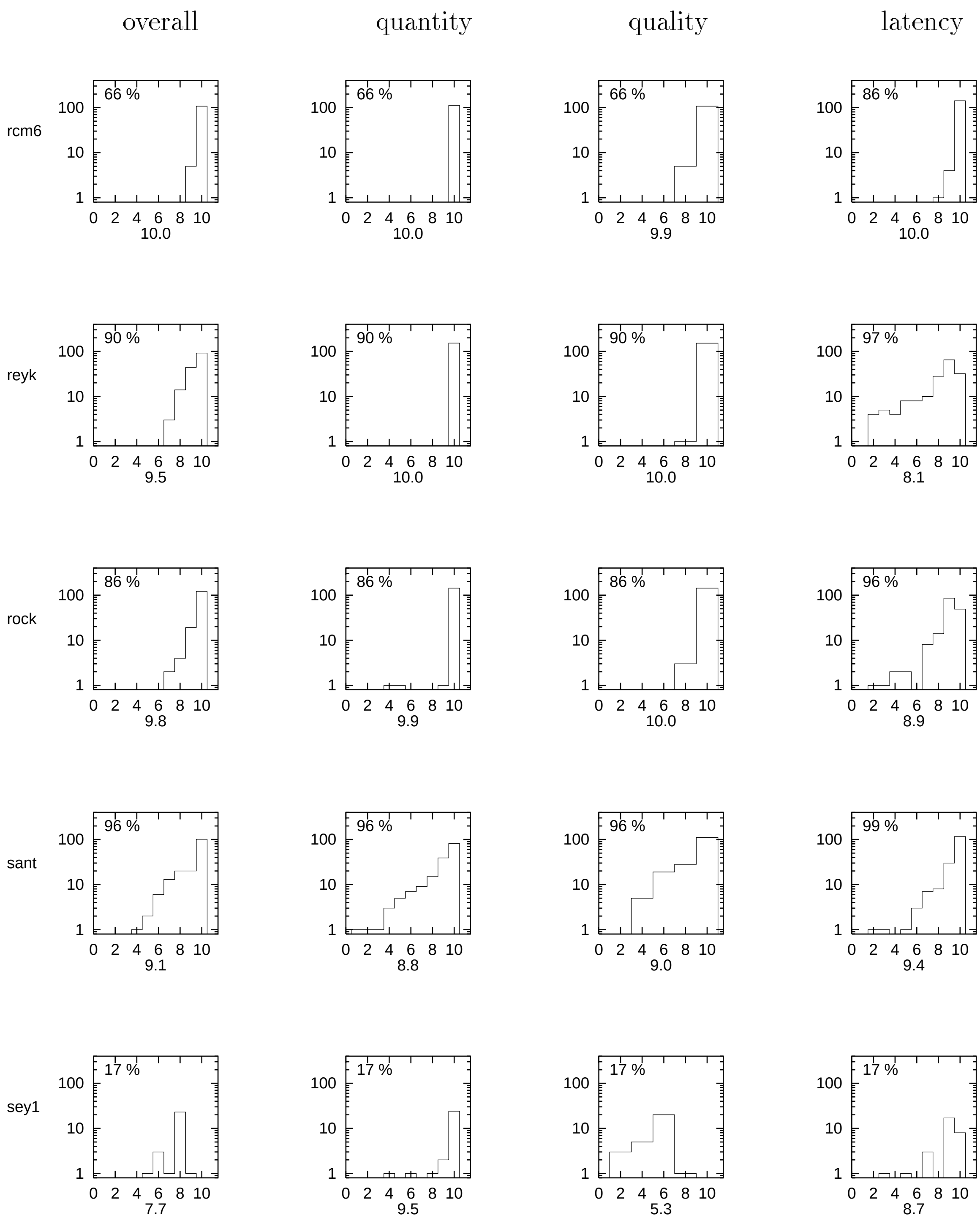
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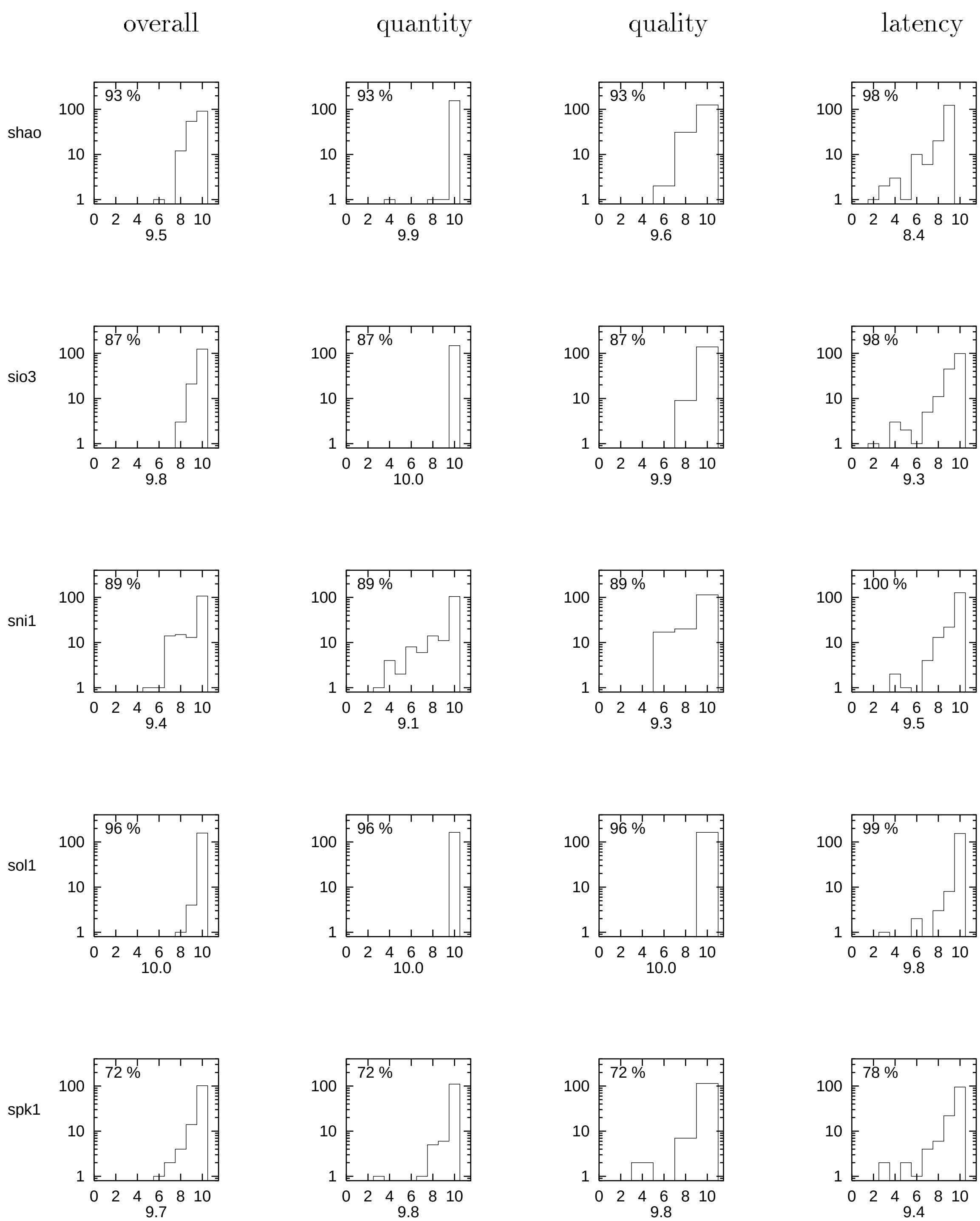
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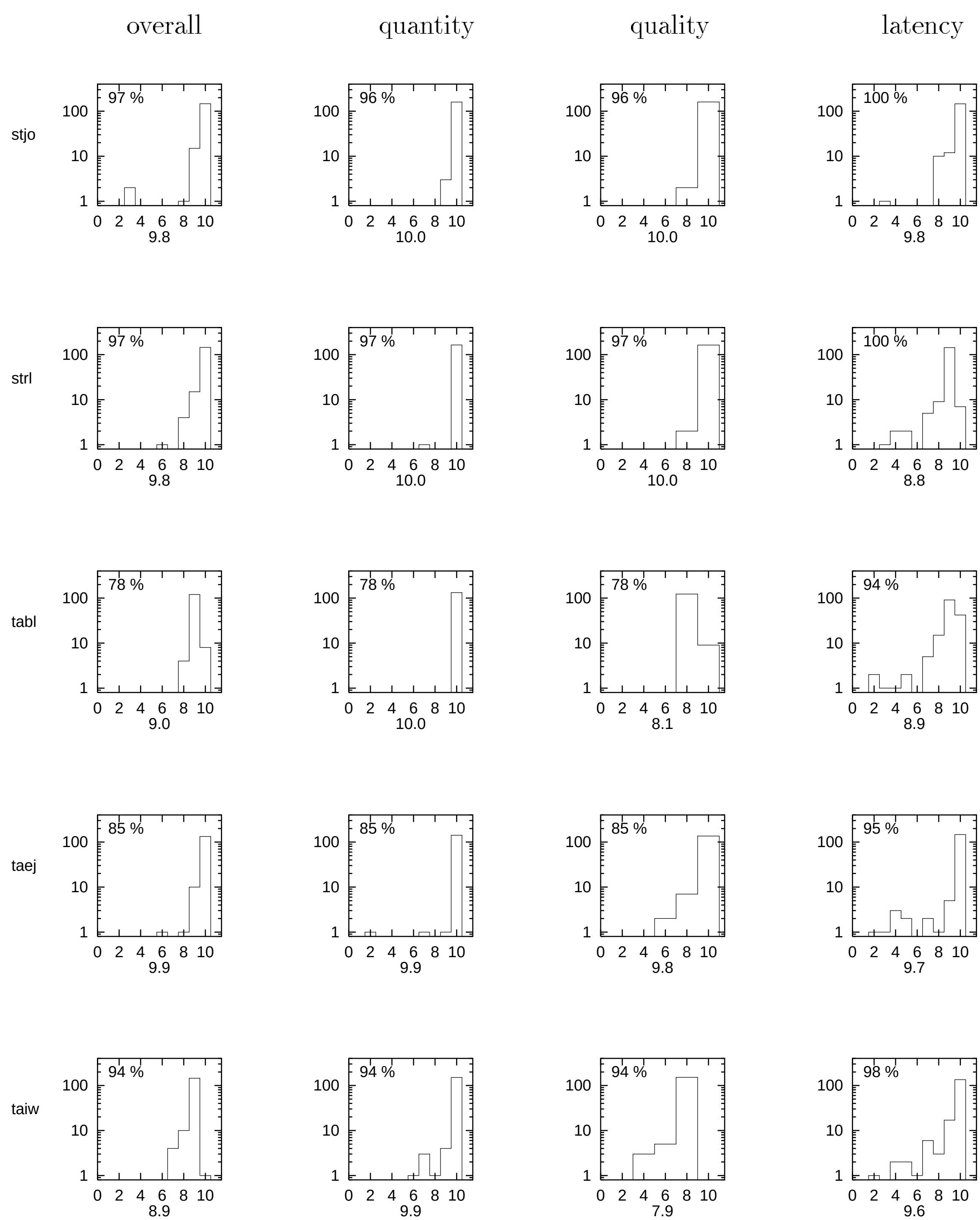
overall
quantity
quality
latency
stjo
97 %
9.8
96 %
10.0
96 %
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strl
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tabl
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taej
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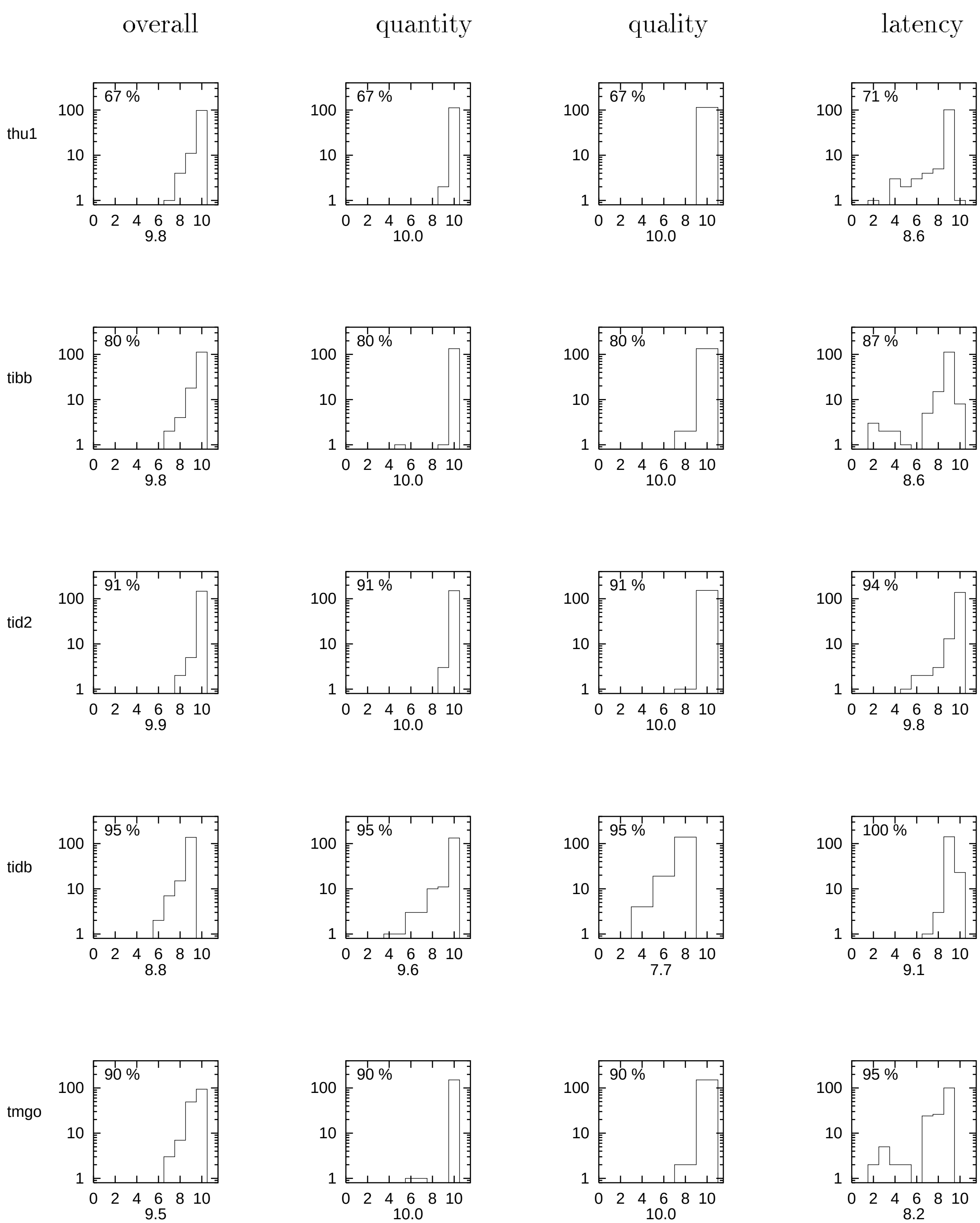
overall
quantity
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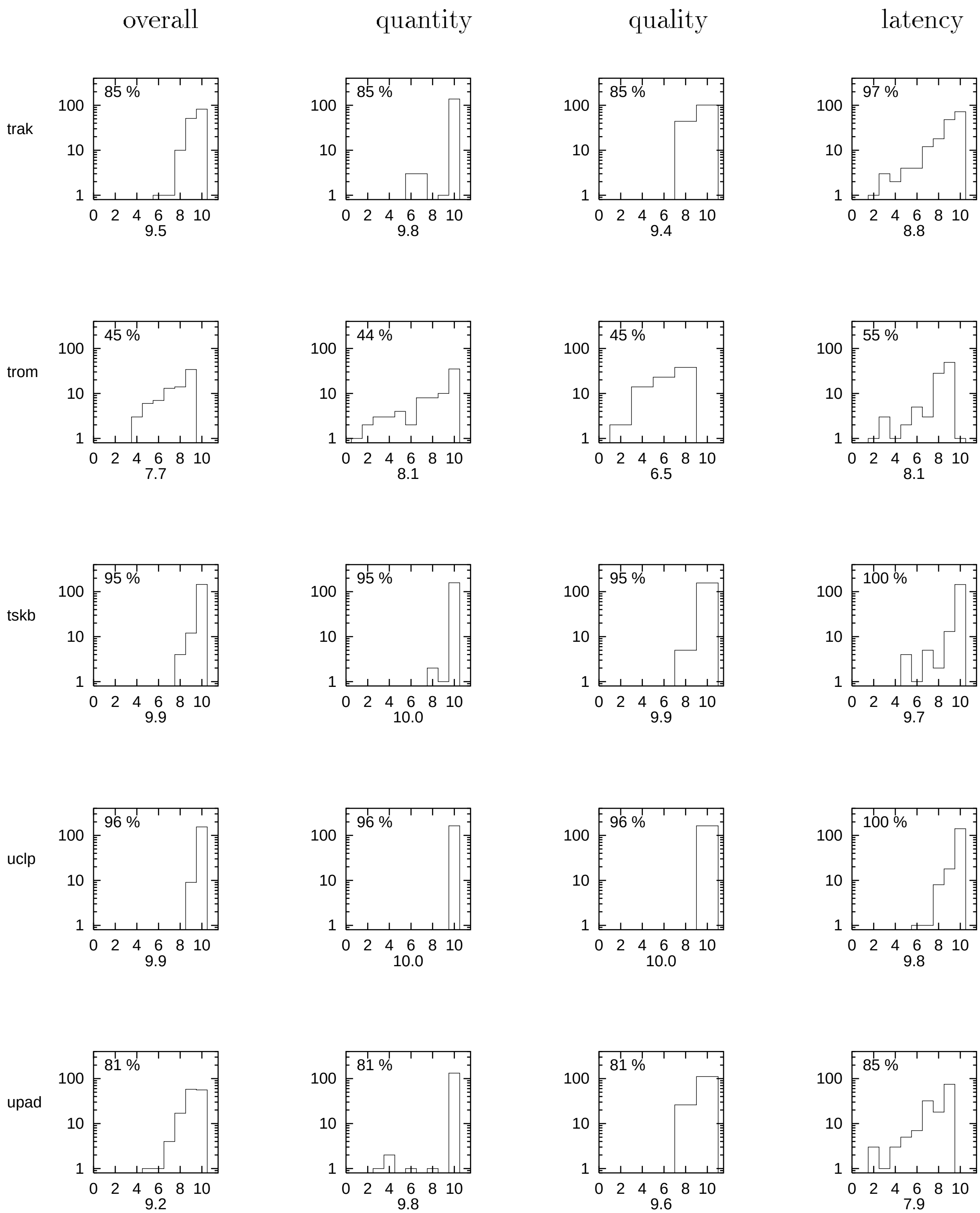
thu1
67 %
67 %
67 %
71 %
9.8
10.0
10.0
8.6
tibb
80 %
80 %
80 %
87 %
9.8
10.0
10.0
8.6
tid2
91 %
91 %
91 %
94 %
9.9
10.0
10.0
9.8
tidb
95 %
95 %
95 %
100 %
8.8
9.6
7.7
9.1
tmgo
90 %
90 %
90 %
95 %
9.5
10.0
10.0
8.2
1
10
100
0 2 4 6 8 10


overall
quantity
quality
latency
trak
85 %
9.5
85 %
9.8
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9.4
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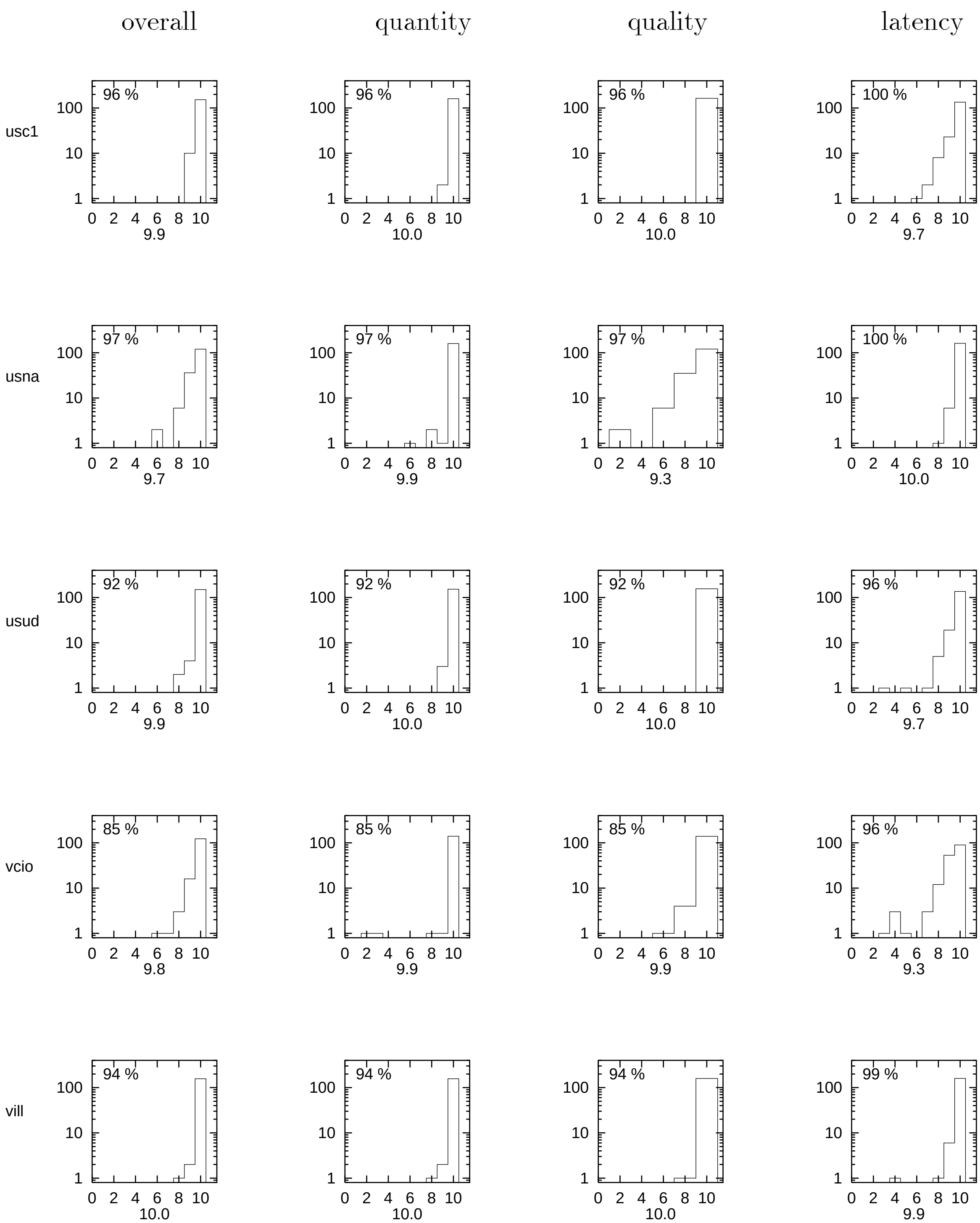
trom
45 %
7.7
44 %
8.1
45 %
6.5
55 %
8.1
tskb
95 %
9.9
95 %
10.0
95 %
9.9
100 %
9.7
uclp
96 %
9.9
96 %
10.0
96 %
10.0
100 %
9.8
upad
81 %
9.2
81 %
9.8
81 %
9.6
85 %
7.9


overall
quantity
quality
latency
usc1
96 %
9.9
96 %
10.0
96 %
10.0
100 %
9.7
usna
97 %
9.7
97 %
9.9
97 %
9.3
100 %
10.0
usud
92 %
9.9
92 %
10.0
92 %
10.0
96 %
9.7
vcio
85 %
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85 %
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85 %
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96 %
9.3
vill
94 %
10.0
94 %
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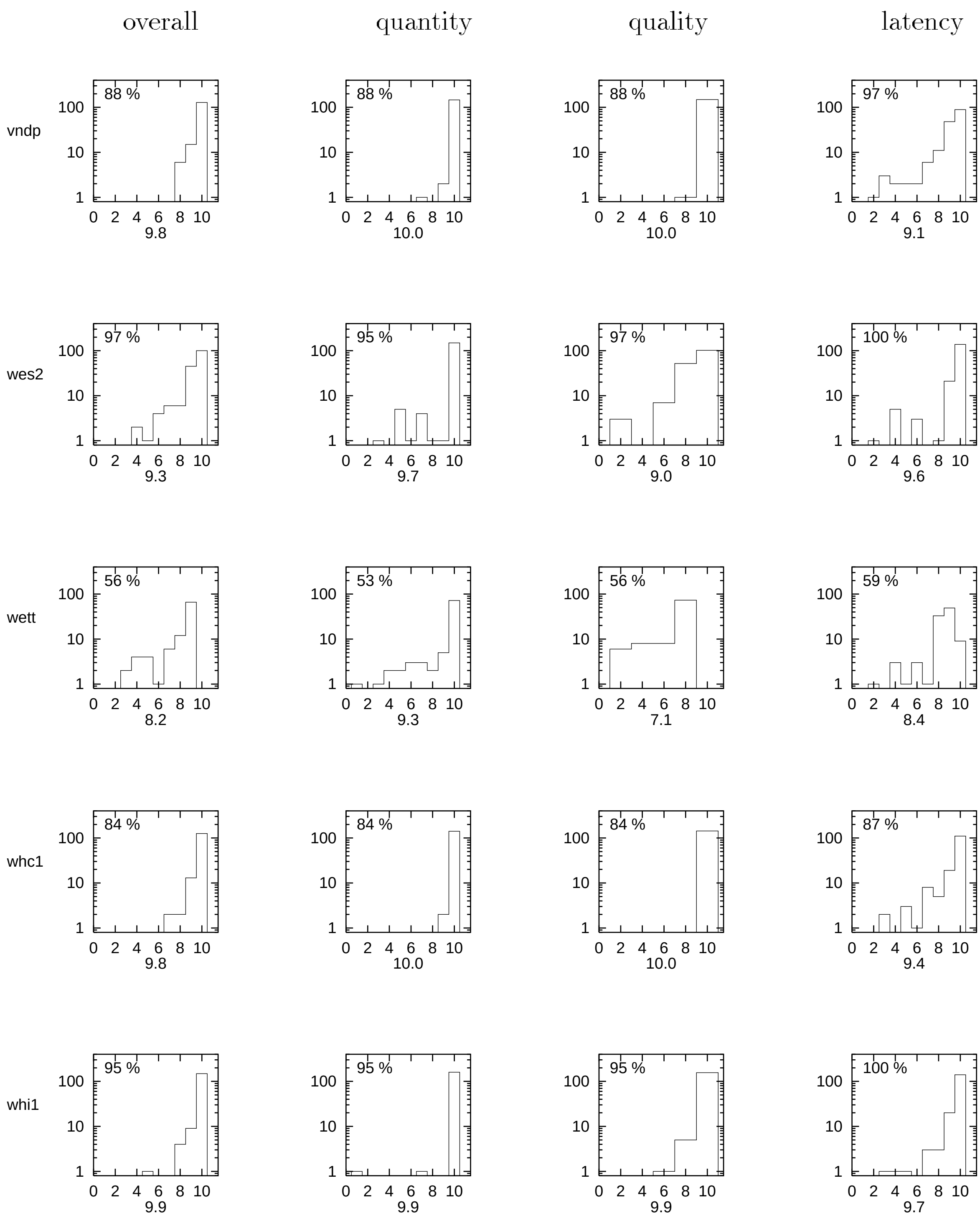
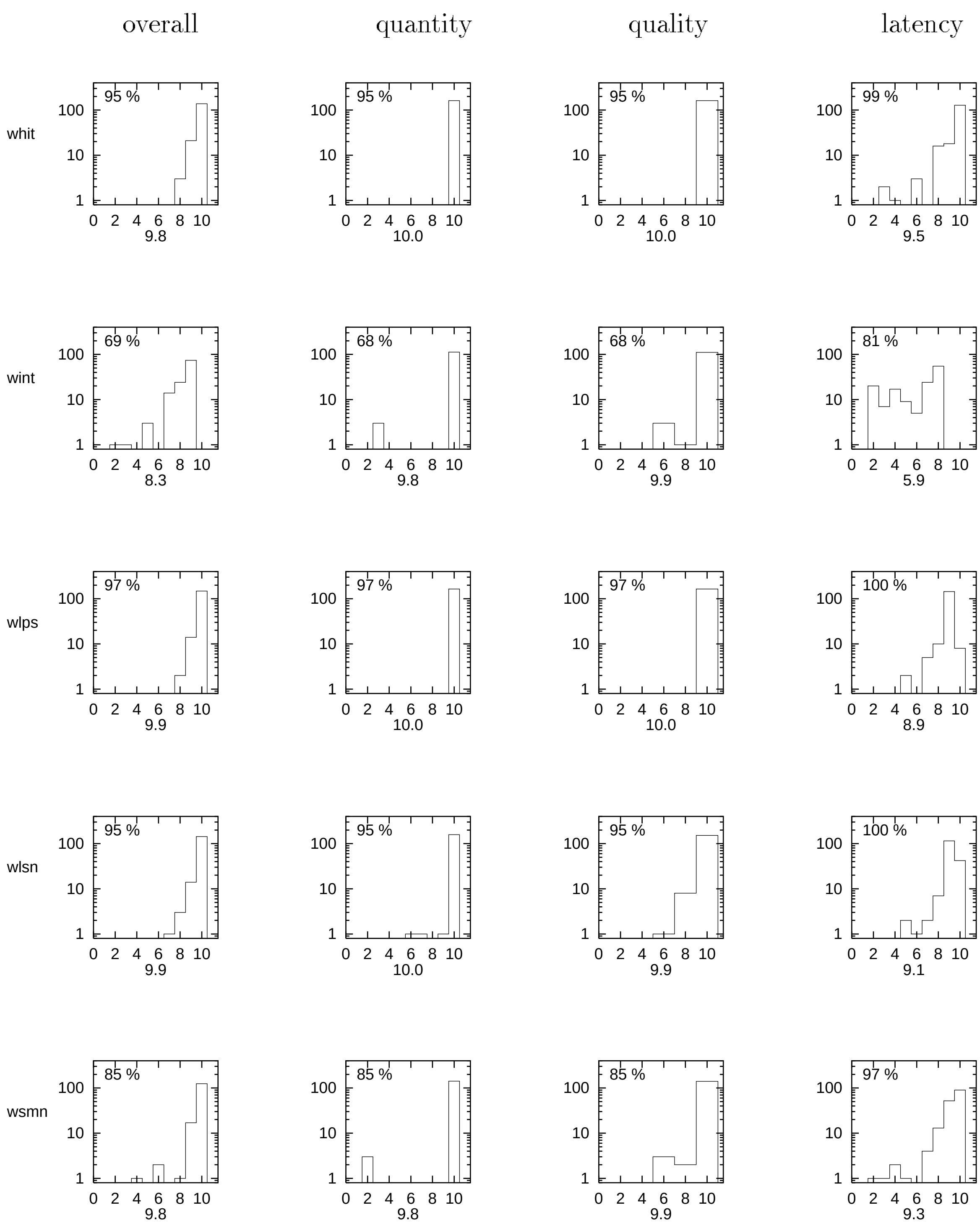
94 %
10.0
99 %
9.9
100
10
1
0 2 4 6 8 10


overall
quantity
quality
latency
vndp
88 %
9.8
88 %
10.0
88 %
10.0
97 %
9.1
wes2
97 %
9.3
95 %
9.7
97 %
9.0
100 %
9.6
wett
56 %
8.2
53 %
9.3
56 %
7.1
59 %
8.4
whc1
84 %
9.8
84 %
10.0
84 %
10.0
87 %
9.4
whi1
95 %
9.9
95 %
9.9
95 %
9.9
100 %
9.7
100
10
1
0 2 4 6 8 10


overall
quantity
quality
latency
whit
95 %
95 %
95 %
99 %
9.8
10.0
10.0
9.5
wint
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68 %
68 %
81 %
8.3
9.8
9.9
5.9
wlps
97 %
97 %
97 %
100 %
9.9
10.0
10.0
8.9
wlsn
95 %
95 %
95 %
100 %
9.9
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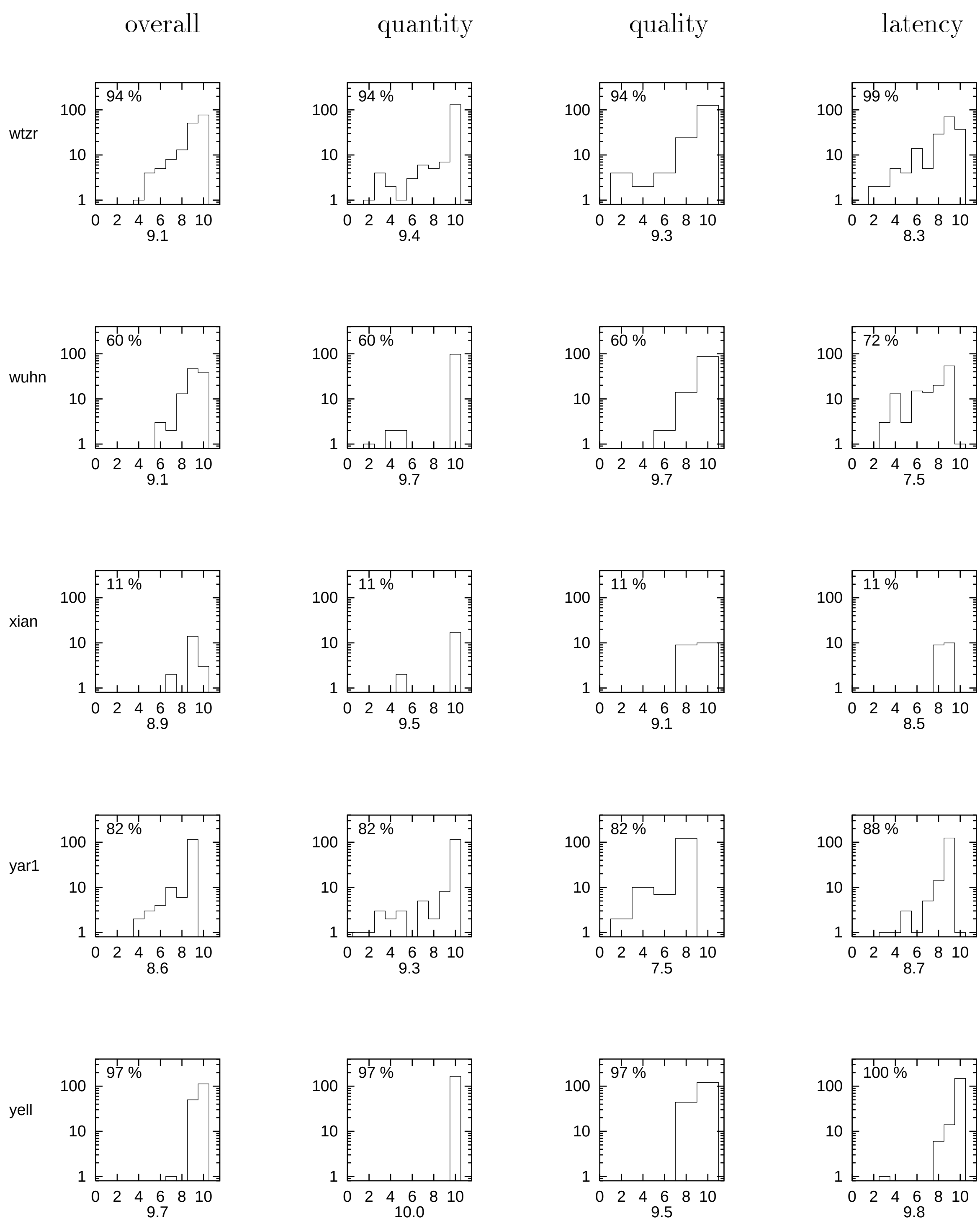
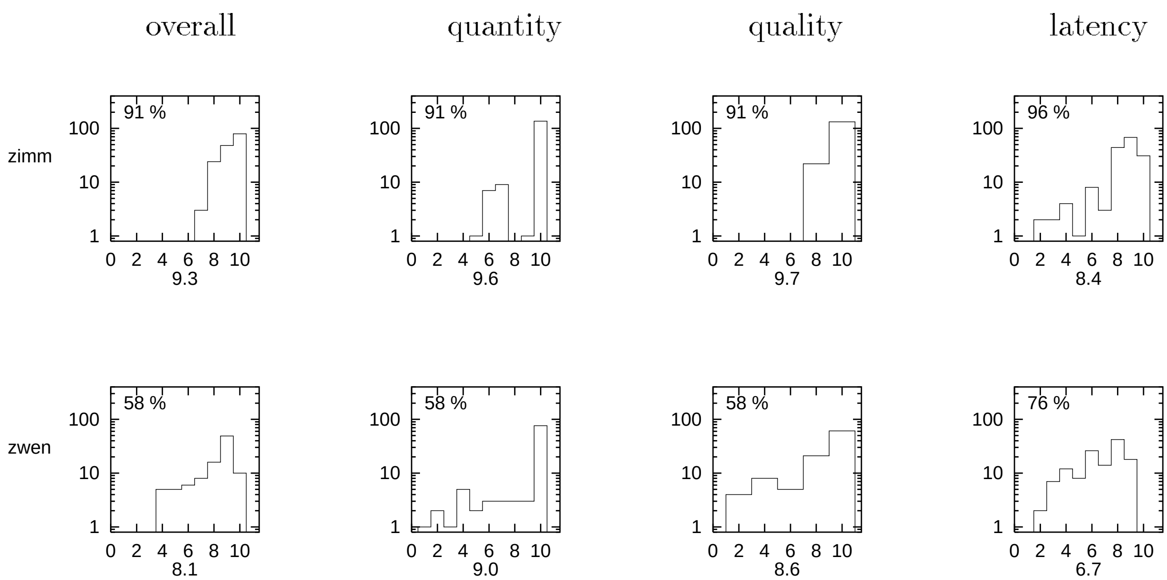
9.9
9.1
wsmn
85 %
85 %
85 %
97 %
9.8
9.8
9.9
9.3


overall
quantity
quality
latency
wtzr
94 %
9.1
94 %
9.4
94 %
9.3
99 %
8.3
wuhn
60 %
9.1
60 %
9.7
60 %
9.7
72 %
7.5
xian
11 %
8.9
11 %
9.5
11 %
9.1
11 %
8.5
yar1
82 %
8.6
82 %
9.3
82 %
7.5
88 %
8.7
yell
97 %
9.7
97 %
10.0
97 %
9.5
100 %
9.8


overall
quantity
quality
latency
zimm
91 %
91 %
91 %
96 %
9.3
9.6
9.7
8.4
zwen
58 %
58 %
58 %
76 %
8.1
9.0
8.6
6.7
1
10
100
0 2 4 6 8 10

Appendix

96/06/07
J F Zumberge jfz@cobra.jpl.nasa.gov

This document describes the Station Report that is generated periodically for the IGS Central Bureau by JPL's Satellite Geodesy and Geodynamics System (SGGS) Group, based on Rinex data provided by the GPS Networks and Operations (GNO) Group. An example is given in Table 1.

There are four numeric fields: "overall", "quantity", "quality", and "latency". Each is a floating point number, although the results are rounded to the nearest integer. The overall field is the average of the other three fields. The highest and best value for each field is 10.

Before describing how these numbers are computed, we first refer to the procedure announced in IGS mail 1187, (Jan 16, 1996):

> Rapid precise GPS orbit and clock solutions are now available from JPL in sp3 format (see below for access details) within about 20 hours of the close of the UTC day. These rapid orbits typically agree with the final JPL IGS orbit to about 20 cm rms. Earth orientation is adjusted in these solutions and reported to the IGS, IERS, and USNO.
>
> These solutions are used to compute rapid solutions from over 100 sites daily, including all SCIGN sites in southern California. These rapid positions typically agree with our final positions at the sub-cm level. Publicly available Rinex data from new sites will be processed as the sites become operational. Results are available upon request for sites of interest.
>
> A 3-day predicted orbit is also available in the sp3 format. Because of the rapid turn-around, this means that a real-time orbit, based on extrapolations of between 20 and 44 hours, is available, with an accuracy significantly better than the broadcast orbits. We find that 24 hour predicted orbits are typically 50-80 cm, and 48 hour predictions generally 1-2 meters.
>
> The final JPL IGS orbit and Earth orientation are now computed with a 4 day lag (access details below). All sites are also processed using this final orbit, with ambiguities resolved for regional networks.

One of the results of the "rapid solutions" mentioned in this excerpt is shown in Table 2. (Several of the fields in the full database from which Table 2 was extracted can be viewed graphically at http://milhouse/eng/eng.html.) There is one rapid solution for each site on each day (assuming that the Rinex file has been made available to the SGGS Group by the GNO Group). The phase and pseudorange data are used to estimate the usual receiver-specific parameters: Cartesian coordinates, receiver clock, and zenith troposphere delay. Transmitter parameters -- satellite positions and clock corrections -- are fixed at their values determined in the rapid global solution.

In Table 2, the "number of time tags for which clock solution is valid" field, call it N, reflects data availability. The normal data rate analyzed is 5 minutes; there are thus 288 times in a 24-hr period for which data exists. The value of the "quantity" field is therefore

$$\text{quantity} = \langle N \rangle / 28.8,$$

where <N> is the average value of N over the period of interest, usually 1 week. This number can be less than 10 if there are missing data or if some of the data have been rejected as outliers.

The quality field is also the average over one or more days of a daily quality figure. The daily quality figure is based on several categories. One quality point is awarded on each day for each of the following conditions:

- there are at least 250 valid clock solutions

- there are fewer than 100 phase bias resets (the last field in Table 2)

- the 3d formal error of the solution for station location is less than 1 cm (this field is not in Table 2, but is in a related database)

- the pseudorange rms residuals (field 8 in Table 2) are less than 86 cm (this is true 95% of the time), and the number of pseudorange measurements is at least 90% of the number of phase measurements

- the phase rms residuals (field 10 in Table 2) are less than 13 mm (also true 95% of the time)

Thus a site can be awarded up to 5 quality points every day. The quality field is

$$\text{quality} = \langle P \rangle / 0.5,$$

where <P> is the average number of points awarded over the period (again, typically a week) reported.

The latency field measures the delay between the beginning of data in the file and the availability of the file, minus 1 day to account for the span of the data. A latency database is maintained for each of the three IGS Global Data Centers. The latency for a given site and day is the minimum value from the three centers. (If no centers have the data, then the latency is based on the GNO value.) Very late or missing files are assumed to have a latency of 100 hr. The latency is calculated as

$$\text{latency} = 10 - \langle H \rangle/10,$$

where <H> is the average latency, in hours, over the period.

[A subset of engineering data -- like shown in Table 2 -- can be made available on request. Questions/comments should be directed to me at the e-mail address listed above.]

Table 1 Example of Station Report

Station Report for 7 days beginning 1996-05-26
(generated 1996-06-07 11:48)

NOTICE: The information listed below results from JPL IGS Analysis Center procedures based on Rinex data available from JPL's GPS Networks and Operations Group, and does not necessarily reflect the operational quality of any site.

For all numeric fields, a 10 is the highest (and best), a 0 is the lowest. The "overall" field is the average of the quantity, quality, and latency fields. The "quantity" field indicates how much usable data from the site was available. The "quality" field accounts for amount of data, number of phase breaks, formal errors of (precise) point-positioned coordinates, and pseudorange and phase residuals. (A dot means that no data from the site were processed at JPL for the days covered.) The "latency" field will be 10 for a site whose data are available, on average, within 5 hours of the end of the GPS day. It will be reduced by 1 point for each additional 10 hours of delay. (More detailed information can be found in ftp://igscb.jpl.nasa.gov/igscb/data/network/igsnet.doc. Also, raw engineering data are displayed graphically in http://milhouse/eng/eng.html)

IGS Fiducial Sites

site	overall	quantity	quality	latency	agency	location
algo	10	10	10	10	NRCan-GSD	Canada
fair	10	10	10	9	JPL	USA
gold	9	10	8	9	JPL	USA
hart	9	10	10	8	CNES	South Africa
kokb	9	10	9	9	JPL	USA
kosg	9	10	10	8	DUT	The Netherlands
madr	9	10	8	9	JPL	Spain

sant	.	.	.	0	JPL	Chile
tidb	9	9	8	9	JPL	Australia
trom	9	10	8	9	NMA	Norway
wett	9	10	8	8	IfAG	Germany
yar1	8	8	7	9	JPL	Australia
yell	10	10	10	10	NRCan-GSD	Canada

Other IGS Global Sites

site	overall	quantity	quality	latency	agency	location
albh	10	10	10	10	NRCan-GSC	Canada
ankr	4	5	7	1	IfAG	Turkey
areq	9	10	9	8	JPL	Peru
bor1	9	10	10	7	SRC-PAS	Poland
brmu	10	10	10	10	NOAA	USA
brus	9	10	10	8	ROB	Belgium
cas1	10	10	10	9	AUSLIG	Antarctica
chat	9	10	9	8	JPL	New Zealand
fort	9	10	9	10	NOAA	Brazil
guam	7	10	7	6	JPL	Guam
hob2	7	10	10	0	AUSLIG	Australia
iisc	8	10	6	9	JPL	India
irkt	9	10	10	6	DUT	Russia
kely	8	9	7	8	NOAA	Greenland
kerg	6	10	8	0	CNES	Kerguelen Islands
kiru	9	10	9	9	ESA	Sweden
kit3	9	10	10	8	GFZ	Uzbekistan
kour	8	9	5	8	ESA	French Guiana
lpgs	8	10	9	5	GFZ	Argentina
mac1	10	10	10	9	AUSLIG	Australia
mali	7	9	5	7	ESA	Kenya
mas1	9	9	9	9	ESA	Spain
mate	8	10	8	7	ASI	Italy
mcm4	10	10	10	9	JPL	Antarctica
mdo1	10	10	10	9	JPL	USA
mdvo	8	10	10	5	DUT	Russia
mets	9	10	9	9	FGI	Finland
nlib	10	10	10	9	JPL	USA
ohig	7	10	8	5	IfAG	Antarctica
onsa	9	10	10	8	OSO	Sweden
pama	7	10	6	7	CNES	Tahiti
pert	10	10	10	9	ESA	Australia
pie1	10	10	10	9	JPL	USA
pots	7	6	6	9	GFZ	Germany
rcm5	8	9	7	9	NOAA	USA
sey1	.	.	.	0	JPL	Seychelles
shao	9	9	9	8	JPL	China
stjo	10	10	10	10	NRCan-GSD	Canada
taiw	9	9	8	9	IES-AS	Taiwan
thu1	9	10	10	8	JPL	Greenland
tskb	10	10	10	10	GSI	Japan

usud	10	10	10	9	JPL	Japan
vill	9	10	9	9	ESA	Spain
zwen	9	10	10	7	GFZ	Russia

Other IGS Sites (retrieved by JPL)

site	overall	quantity	quality	latency	agency	location
aoa1	10	10	10	9	JPL	USA
asc1	8	8	8	8	JPL	Ascension Island
auck	9	10	9	8	JPL	New Zealand
blyt	10	10	10	9	SIO	USA
bogt	5	9	6	0	JPL	Columbia
bran	8	10	8	7	USGS-SIO	USA
braz	.	.	.	0	IBGE-JPL	Brazil
cagl	8	9	9	7	ASI	Italy
carr	10	10	10	9	JPL	USA
casa	10	10	10	9	JPL	USA
cat1	10	10	10	9	JPL	USA
chil	9	10	10	8	USGS-SIO	USA
cit1	10	10	10	9	JPL	USA
coso	9	10	10	8	SIO	USA
crfp	10	10	10	9	SIO	USA
cro1	10	10	10	9	NRAO-JPL	US Virgin Islands
dav1	10	10	10	9	AUSLIG	Antarctica
drao	10	10	10	10	NRCan-GSC	Canada
ebre	.	.	.	0	ICC	Spain
eisl	8	10	8	7	JPL	Chile
gode	8	9	9	6	NASA-GSFC	USA
gope	9	10	10	7	RIG	Czech Republic
gras	.	.	.	0	CNES	France
graz	9	9	8	9	ISR	Austria
harv	9	10	10	8	JPL	USA
hers	9	10	8	9	RGO	United Kingdom
hflk	9	10	8	9	ISR	Austria
holc	9	10	10	8	USGS-SIO	USA
joze	9	10	10	6	IGGA-WUT	Poland
jplm	10	10	10	9	JPL	USA
kwj1	7	10	9	3	JPL	Kwajalein Atoll
lama	8	8	9	7	OUAT	Poland
lbch	10	10	10	9	JPL	USA
lhas	.	.	.	0	IfAG	China
long	9	10	8	8	USGS-SIO	USA
math	7	10	10	1	SIO	USA
medi	8	10	10	4	ASI	Italy
monp	7	10	10	2	SIO	USA
noto	9	10	10	7	ASI	Italy
nyal	7	7	6	7	NMA	Norway
oat2	10	10	10	9	JPL	USA
pin1	10	10	10	9	SIO	USA
pol2	9	10	10	7	UNAVCO	Kyrgyzstan
pvep	9	10	7	9	SIO	USA

quin	9	9	9	9	JPL	USA
reyk	7	10	10	0	IfAG	Iceland
sfer	.	.	.	8	ROA	Spain
sio3	10	10	10	9	SIO	USA
sni1	.	.	.	0	JPL	USA
spk1	10	10	10	9	JPL	USA
taej	9	9	9	9	KAO	Korea
trak	9	10	9	9	SIO	USA
uclp	10	10	10	9	JPL	USA
upad	9	10	10	6	UP	Italy
usc1	10	10	10	9	JPL	USA
vndp	10	10	10	9	SIO-JPL	USA
wes2	10	10	10	10	NOAA	USA
whc1	10	10	10	9	JPL	USA
whi1	10	10	10	9	JPL	USA
wlsn	10	10	10	9	JPL	USA
wtzr	9	10	10	8	IfAG	Germany
zimm	9	10	10	8	FOT	Switzerland

Other IGS Sites (not retrieved by JPL)

site					agency	location
roch	.	.	.	0	SIO	USA

Other Sites (no log file at IGS CB)

site	overall	quantity	quality	latency	agency	location
brib.	9	10	10	9	UC-Berkeley	USA
chab.	8	10	10	6	USGS	USA
cice.	10	10	10	9	JPL	Mexico
clar.	9	10	9	8	USGS	USA
cmbb.	7	7	7	8	UC-Berkeley	USA
cmp9.	9	10	10	8	USGS	USA
csn1.	9	10	10	7	JPL	USA
dam1.	9	10	10	8	USGS	USA
dam2.	9	10	10	8	USGS	USA
denc.	.	.	.	0	CORS	USA
dgar.	5	3	6	6	JPL	Diego Garcia
farb.	8	10	10	5	UC-Berkeley	USA
gala.	7	10	10	0	JPL	Galapagos Islands
gol2.	10	10	10	9	JPL	USA
hbrk.	9	10	9	9	CORS	USA
hklo.	9	10	9	9	CORS	USA
holp.	9	10	10	8	USGS	USA
hopb.	10	10	10	9	UC-Berkeley	USA
krak.	9	10	10	7	JPL	USA
leep.	9	10	10	8	USGS	USA
lmno.	9	10	8	9	CORS	USA
moin.	.	.	.	0	JPL	Costa Rica
mola.	8	10	10	4	USGS	USA
nune.	8	10	10	4	USGS	USA

pltc.	10	10	10	9	CORS	USA
rock.	9	10	10	8	USGS	USA
sol1.	9	10	10	8	NOAA/NASA	USA
strl.	9	10	9	9	CORS	USA
tabl.	7	9	5	8	USGS	USA
tibb.	7	6	8	6	UC-Berkeley	USA
tid2.	10	10	10	9	JPL	Australia
tmgo.	9	10	10	8	CORS	USA
usna.	9	10	10	8	NOAA/NASA	USA
vcio.	10	10	10	9	CORS	USA
wint.	8	10	10	6	USGS	USA
wlps.	10	10	10	9	CORS	USA
wsmn.	10	10	10	9	CORS	USA
wuhn.	9	10	10	6	NOAA-JPL	China

Table 2 Engineering data for precise-point-positioned sites

```
 date
 |          site
 |          |     number of time tags for which clock solution is valid
 |          |     |   rms deviation from straight line of clock solution (ns)
 |          |     |   |         drift of clock solution (parts per trillion)
 |          |     |   |         |         clock solution (usec) at start of day
 |          |     |   |         |         |         # of pseudorange meas.
 |          |     |   |         |         |         |     rms (cm)
 |          |     |   |         |         |         |     |   # of phase meas.
 |          |     |   |         |         |         |     |   |     rms (mm)
 |          |     |   |         |         |         |     |   |     |   orig
 |          |     |   |         |         |         |     |   |     |   |    tot
 |          |     |   |         |         |         |     |   |     | <-breaks->
 |________  |___  |_  |_______  |_______  |_______  |___  |_  |___  |_  |_   |_
```

...

1996-02-25	IISC	288	69.9	0.247	-0.00443	1677	70	1675	13	69	69
1996-02-25	IRKT	287	147	9.47	-0.214	1650	46	1650	8	51	51
1996-02-25	JOZE	286	36.2	-94.8	181	1653	50	1653	7	39	39
1996-02-25	JPLM	288	41.7	114	1.4e+03	1667	26	1667	6	44	47
1996-02-25	KERG	288	70.9	7.06	-660	0	.	1552	5	53	53
1996-02-25	KIRU	288	3.08	-0.00867	11.7	1427	50	1427	10	67	80
1996-02-25	KIT3	288	126	0.0974	-0.0181	1642	66	1642	11	47	47
1996-02-25	KOKB	288	0.131	0.366	0.00596	1661	55	1661	6	45	50
1996-02-25	KOSG	288	1.02	-3.94	20.5	1324	38	1324	5	44	44

...

IGS

ANALYSIS CENTER REPORTS

GFZ Analysis Center of IGS—Annual Report 1996

Gerd Gendt, Galina Dick, and Wolfgang Söhne

GeoForschungsZentrum Potsdam
Potsdam, Germany

1 Introduction

In the past year, GFZ has continued its IGS related activities. During this period of time a number of changes and improvements took place. Great efforts were made to further improve the automation for all the different products. Some interesting new sites came on line; these sites improved the overall station distribution on the southern hemisphere. The number of sites actually included into the daily analysis is about 50. Their distribution is given in Figure 1.

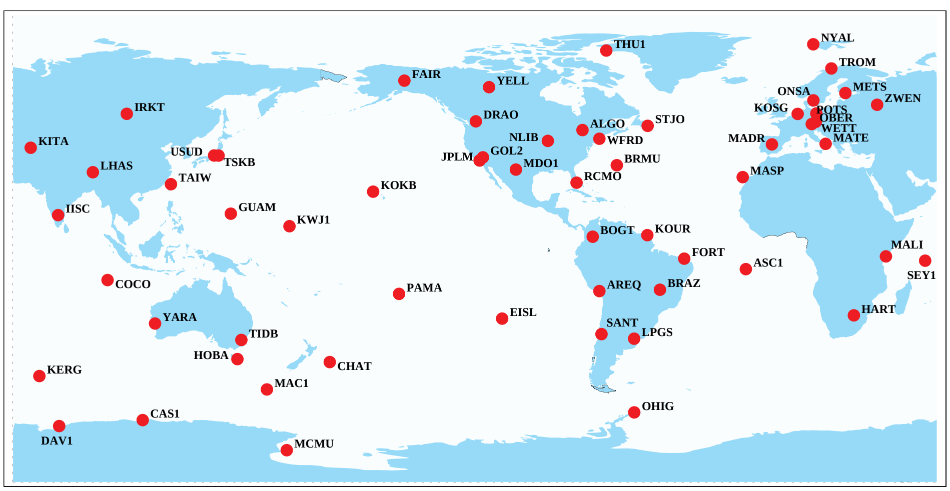


Figure 1: Global distribution of stations used in the IGS analysis of GFZ

2 Routine IGS Processing—Overview

From the beginning of 1996 up to March 1997, not only new or modified products were generated, but also changes in the software and technology took place through which various improvements in the products could be achieved. An overview of the changes is presented in Table 1.

Table 1: Modification in software and technology

Week	Date	Description
843	Mar. 3, 1996	Improvement of clock determination
851	Apr. 28, 1996	Estimation of stochastic impulse, all satellites, 12:00 UT
		Use of 24-h data intervals instead of 32-h intervals
860	June 30, 1996	New terrestrial reference frame (ITRF94)
		Use of subdaily polar motion model (Ray)
		Use of elevation-dependent antenna phase model IGS–01
		Switch from 36-h to 23-h delay for rapid orbits
864	July 28, 1996	Estimation of daily polar motion trend
866	Aug. 11, 1996	Start of computation of predicted orbits
892	Feb. 9, 1997	Use of 3-day arcs for final orbits
890	Jan. 26, 1997	Estimation of ZPD with 1-h sampling rate

There were three major changes that significantly improved our products:

- Estimates of stochastic impulses.
- Use of subdaily polar motion model and elevation-dependent antenna phase center variations.
- Use of 3-day arcs for the final orbits.

In connection with the introduction of stochastic impulses and in preparation for the combination of three 1-day arcs into one 3-day arc, we switched from 32-h overlapping to 24-h nonoverlapping arcs.

In the summer of 1996, the delay for the rapid products was reduced from 36 h to 23 h with the consequence that the deadline is now near local midnight. Therefore, manual interactions during all the steps of the analysis were not possible any longer. This was a challenge to improve and automate the whole process of analysis and quality check.

An overview of both GFZ products and all daily as well as weekly activities is given in Table 2.

Table 2: Overview of IGS routine analysis and generated products (D denotes actual day)

Data transfer (all new sites for D-1 to D-10)	
1-day orbits	
Rapid analysis for D-1 (12:00, 19:00 UT)	
DD-Cleaning	gfz*wwwwd*.sp3
Analysis and postfit-cleaning (iteratively)	gfz*wwwwd*.erp
Updating ERP initial values for final analysis	*including sat-clocks (14 +21 UT)*
Predictions	gfp*wwwwd*.sp3
IGR-products for D-4 to D-2 and	
GFZ-rapid products for D-1 used	
Final analysis (D-4)	
DD-Cleaning	
Analysis and postfit-cleaning (iteratively)	
Final Solutions, end of GPS-week	
3-day orbits by combining the NEQ of 1-day orbits	gfz*wwwwd*.sp3
7-day combinations (NEQ from 1-day orbits)	
(a) with "fixed" core stations to compute ERP including daily rate	gfz*wwww*7.erp
(b) loosely constrained SINEX solution containing station coordinates and ERP	gfz*wwww*7.snx
Daily reanalysis for tropospheric parameters	gfz*wwwwd*.tro
Output of NEQ with trop sampling rate of 1 h	
Use of NEQ to compute variants of trop estimates	

2.1 Data Transfer

Most of the data transfer, especially for past days (D-2 and older), is now carried out at night. However, to meet the 23:00 UT deadline for the rapid products and in order not to lose a large number of important data coming into the global data centers after 6:00 UT, it was necessary to get data from those sites also during the European working hours (this had been a file transfer problem for a long time, but has improved in 1997). Now 2-h checks for data in all global data centers are carried out during daytime.

2.2 Daily Analysis

All analyses are based on 1-day orbits covering exactly the 24-h interval of the day. Using the GPS data directly, these jobs are rather time consuming. Each day the analysis starts with the rapid products (see Section 3 for some details).

If this rapid product is ready, it serves for the prediction of day D+1. For the computation of the predicted orbits, an interval of 4 days (D–4 to D–1) is used, where for the days D–4 to D–2 the available official IGR orbits are taken.

Additionally, every day the final analysis for day D–4 is performed, having now available the data of the complete set of global sites (there are only a few exceptions where this day is analyzed a third time if some interesting late sites were coming in before the weekly deadline).

2.3 Weekly Analysis

For the generation of the weekly final products, the archived unconstrained normal equations (NEQs) are used. All computations with these NEQs are very fast. The final orbit products are taken from the middle day of overlapping 3-day arcs. Much better results can be achieved here by constraining the middle-day orbits at the day boundaries by the adjacent days (see Section 3). The Earth rotation parameters (ERP) and station coordinate solution products (SINEX; SNX) are formed combining 9 respective 7 days.

Since 1997, a new product, the gfz*wwwwd*.tro file, containing the tropospheric estimates of all global sites, is routinely produced in our analysis. Currently, a reanalysis of the original days is performed using a higher sampling rate (1 h) than in the routine analysis (4 h). This procedure is somewhat time consuming and therefore software implementations are under way that will allow us to use given sp3-orbits, clocks, and ambiguities to make an effective run with new parameters, possibly also with changed elevation cutoff angles.

3 Orbit Products

The changes belonging to the orbit products include rapid, final, and predicted orbits.

3.1 Pseudostochastic Impulses

Starting with GPS week 851, the estimation of pseudostochastic impulses was implemented in the software. It is performed for the rapid orbits as well as the final 1-day arcs. The estimation of the pseudostochastic impulses is carried out for all satellites and for each day, so it is not restricted to problem cases, e.g., eclipsing satellites. The estimation epoch is fixed to 12:00 UT. For each satellite, three impulses are solved (in radial, along-track, and out-of-plane direction). To fit the orbits, it was necessary to rather tightly constrain the impulses for the 1-day arcs.

In Figure 2, the improvement of introducing pseudostochastic impulses on the final orbits can clearly be seen. Prior to week 851, the rms is about 12 cm, whereas after week 851, it is about 8 cm.

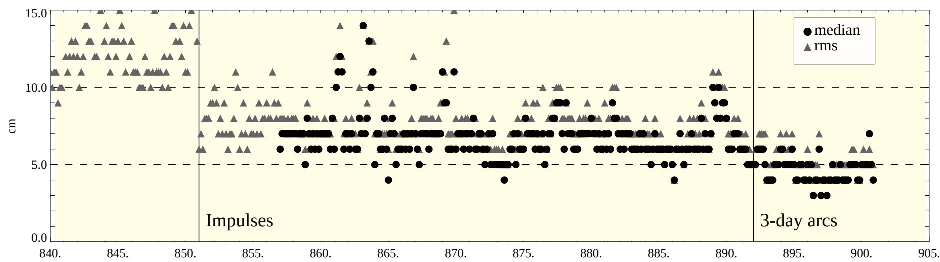


Figure 2: Daily rms and median of GFZ final orbits compared to official IGS Products. The introductions of stochastic orbit impulses and 3-day arcs are indicated

3.2 Rapid Orbits

Since the IGS rapid orbit (IGR) deadline is at 23:00 UT, the complete orbit processing scheme had to be fully automated. Besides data acquisition and preprocessing, this automation includes the decision about exclusion of satellites (e.g., maneuvers) and bad station data, as well as quality tests at the end (e.g., checking the minimum number of stations) and sending the products to the combination center. To form the rapid products, two jobs are running every day with the data from the day before (D–1). The first job should give only a general overview of the quality of the data of the day (especially the inspection of all satellites and the identification of maneuvers) and runs before noon, even if there is a very poor station distribution. The proper "rapid job" waits for more sites but no later than 19:00 UT to meet the 23:00 UT deadline. The results for the rapid orbits are presented in Figure 3. The median varies between 5 and 15 cm. The dependency of quality on the number of stations is clearly visible; if the number of stations drops below 30, median and rms values increase.

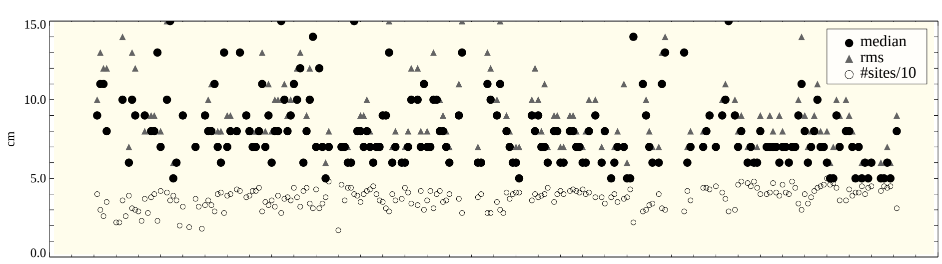


Figure 3: Daily rms and median of GFZ rapid orbits compared to official IGS Products. Number of used sites are given at the bottom of the figure (divided by 10)

Starting with GPS week 902, the deadline changed to 21:00 UT. To meet the earlier deadline for the rapid products and to start the computation as late as possible, the number of stations used for the rapid analysis was reduced and combined with an effective search of the best configuration of available stations.

3.3 Orbit Prediction

The computation of predicted orbits started with GPS week 866. For its determination, a 15-parameter model is used including the 9-parameter model for radiation pressure according to Beutler [1]. The predictions are based on sp3-products for the days D–4 to D–1. The best fitting orbits for these days are extrapolated up to 48 hours to give the necessary predictions for D+1. For feasibility tests during the first months, all ACs used IGS Rapid Products as the basis for their predictions. But when starting to produce real-time predictions, the only product each AC can rely on for the day D–1 is its own product. Therefore, we use a mixture of IGR and GFZ sp3-products together with the Earth rotation parameters taken as initials during our IGS final analysis.

Figure 4 shows the results of orbit prediction compared to the IGS final orbits. The quality of the predictions is mainly about 30 to 40 cm. But there are also some poorer predictions, especially for eclipsing satellites.

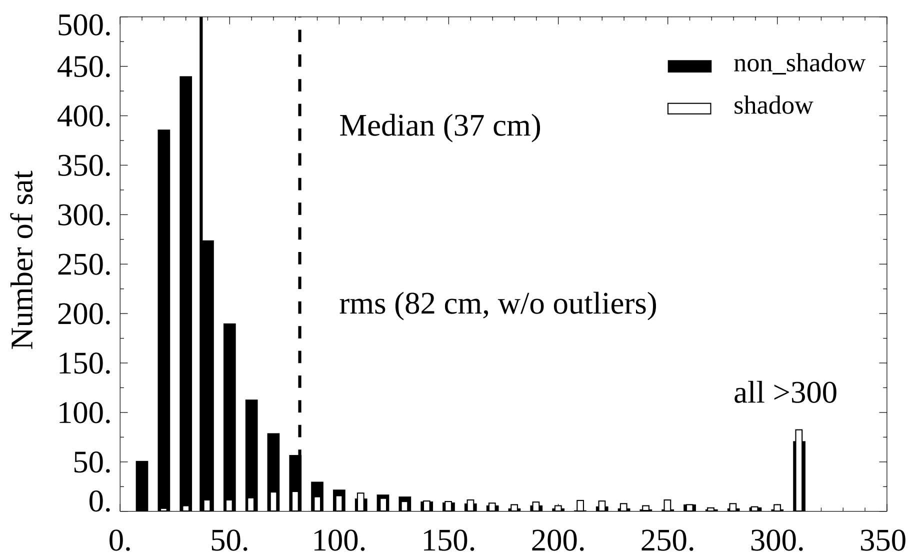


Figure 4: Histogram for GFZ predictions separated for shadow and nonshadow satellites

Starting with GPS week 902, it will be possible to perform the prediction completely with IGR—since the IGR deadline is now at 21:00 UT—provided that the latest IGR orbits will be available via data transfer. Otherwise the product type produced now will be sent as the actual prediction.

3.4 Final Orbits

Starting at 00:00 UT, usually 24 h of observations are used to estimate the parameter set, including the orbit parameters (orbital state vector, reflectance coefficient, Y-bias, and pseudostochastic impulses). These independent 1-day solutions normally show jumps in position and velocity at the day boundaries, typically 0.5 to 1.0 m in position and 0.5 to 1.0 m/s in velocity. Since physically there may not exist any jumps in the satellite orbits, the orbits of successive days are connected to ensure a smooth behavior of positions (and velocities) at the day boundaries. Practically 3 consecutive days are combined, so each day of observations is included in three single adjustments. From every calculation, the middle day is used for further processing, i.e., product generation. Altogether, the data of 9 days is necessary for processing 1 week (including the last day of the week before and the first day of the following week). Compared to the 1-day solutions, the additional computation of the 3-day arcs is not very time consuming. In general, the implemented procedure is not restricted to 3 days.

The orbit combination is carried out in the software component SUMP on the basis of the normal equation system. Strictly, the observation equation system is extended by the condition equations; establishing the normal equations leads to a summation within the normal equation system. Only the two neighboring days are considered. The applied condition demands that the estimates of position and velocity of the two days "i" and "i+1" should be identical at the day boundary "i+1":

$$\vec{x}_i\left(t_{i+1}\right) = \vec{x}_{i+1}\left(t_{i+1}\right)$$

For the linearization of the condition equation,

$$\left(\vec{x}_i\left(t_{i+1}\right)\right)_0 + \sum_{k=1}^{n}\left(\frac{d\vec{x}_i\left(t_{i+1}\right)}{dx_{ik}}\right)_0 * \Delta x_{ik} = \left(\vec{x}_{i+1}\left(t_{i+1}\right)\right)_0 + \sum_{k=1}^{n}\left(\frac{d\vec{x}_{i+1}\left(t_{i+1}\right)}{dx_{i+1,k}}\right)_0 * \Delta x_{i+1,k}$$

the partial derivatives of all unknowns—initial position, initial velocity, and the additional parameters—have to be known. They are derived in the software component ORBIT by either analytical or numerical methods. The new extended normal equation system processed by SUMP consists of the accumulated parts of those unknowns that are identical for successive days (e.g., station coordinates) and, one behind the other, of the parts for those unknowns that are not identical for these days: Earth orientation and orbit parameters.

For those satellites for which the condition equations can be established—the satellites that are included in the adjustment of both days—the matrices with the partial derivatives and with the initial values are set up and connected with the corresponding elements of the normal equation system. Within this approach there is no distinction between the various types of orbital parameters. Using a weighting matrix, it is possible to influence the extent of connection individually for each satellite. The first step, running with loose constraints, is a control, whether any satellites should be excluded from the orbit connection (but not from the computation in general) at specific day boundaries due to big jumps at this boundary. In the last step, the calculation is carried out with the final weighting matrices.

Without linking the velocities at the day boundary, a behavior comparable to the implementation of pseudostochastic impulses at the day boundary can be achieved. With a rigid condition for velocity combination, the results show a deterioration for the long orbits. At this point, a loosening of the a priori constraints of the daily 12-h-pseudostochastic impulses leads to noticeably better results.

Because the final orbit solutions come from different adjustments, small residuals remain at the day boundaries.

The improvement of the orbit combination can be seen from Figure 2. After week 892, the rms has been reduced to 6 cm and better.

4 Earth Rotation Parameters

In mid-1996, the estimation of polar motion rates was added to the IGS products. But it is not possible to get highly accurate rate solutions using only the data of one day. However, with a combination of consecutive days, stable rate solutions can be achieved while constraining the polar motion to no jumps at the day boundaries. This way, the weekly ERP solution is formed using NEQs of 9 days.

In the following, some effects of introducing the subdaily polar motion model of Jim Ray should be discussed. Comparisons of LOD solutions with VLBI [2] show significant yearly and fortnightly periods, if this model is not applied in our GPS analysis (see Figures 5 and 6 for details). For the time span July 1994 to July 1996 (Week 859), the mean and standard deviation of the difference compared to VLBI are –0.027 ms and 0.061 ms, respectively. Even for the 24-h intervals, the subdaily periods do not cancel out for the trend (only for UT itself). If this effect is corrected, the differences reduce to –0.019 ms and 0.046 ms. Since week 860, this model is used as a standard within the IGS.

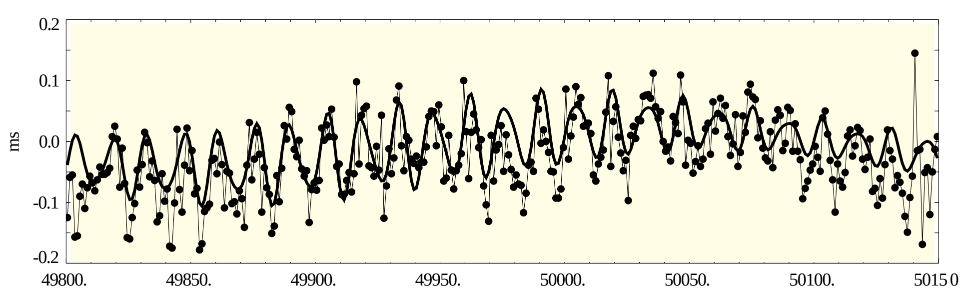


Figure 5: LOD differences between VLBI and GFZ. The values from the subdaily model are given as a solid line

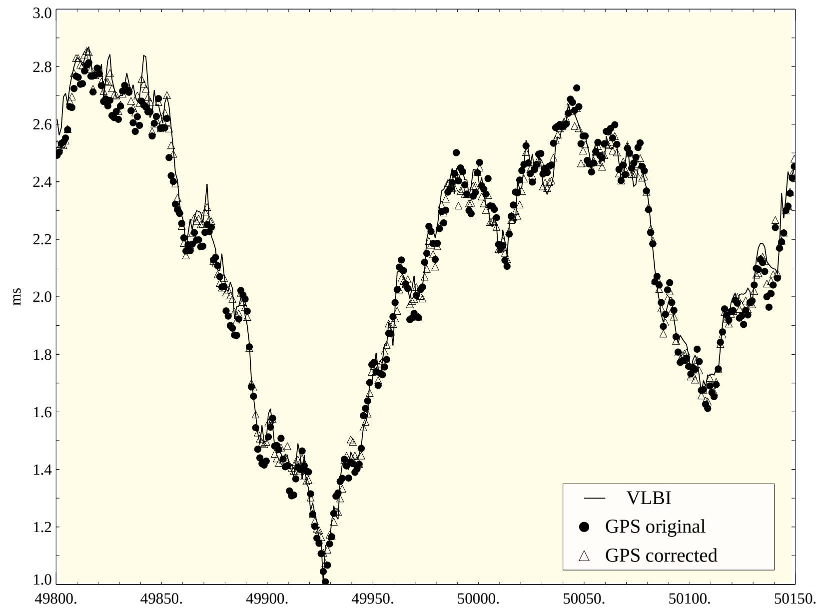


Figure 6: Comparison of LOD from VLBI, GFZ GPS, and corrected GFZ GPS (corrected for subdaily Earth rotation model)

Figure 7 shows details for the difference of GFZ polar motion including rates to the IGS Final ERP results. For the interval 860 to 897 (July 1996 to March 1997) we got

x-pole and rate: ±0.12 mas and ±0.29 mas/d

y-pole and rate: ±0.14 mas and ±0.28 mas/d

In this figure the subdaily polar motion effects for the rates are also given. It can obviously be seen that their amount is rather high, so it is important for the recent IGS accuracy level to have the subdaily effects modelled.

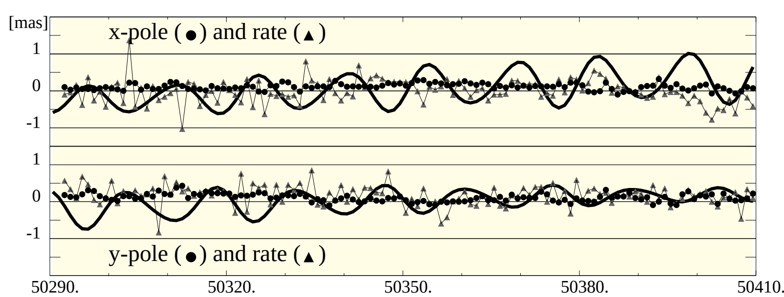


Figure 7: Differences of GFZ polar motion and polar motion rate to the IGS final results. The polar motion rate from the subdaily Earth rotation model is shown (solid line)

5 Determination of the Global Reference Frame and Plate Kinematics

For the determination of station coordinates and velocities, the daily fiducial-free and unconstrained normal equations, which are stored in the routine GFZ IGS analysis and contain station coordinates and ERP, were combined into weekly normal equations [3,4]. The parameters of no interest (e.g., ERP) have been eliminated during the combination. The combined normal equations can be extended by parameters for site velocities. Station position time series have been computed from weekly station coordinate solutions. These time series as well as weekly repeatabilities give insight into the stability and accuracy of the solution and help to check the data quality. Some problems with stations MADR, WETT, and MATE were detected which can be seen from their weekly repeatabilities (Figure 8). The bad data intervals were therefore rejected from weekly normal equations. For WETT a drift of 2 cm/yr in the north component can be derived starting from week 810. All these data were also rejected from the global solution. After that, the weekly normal equations were combined into a 4-year system to derive a global station position solution for 68 sites. To define the orientation, 3 horizontal site parameters were held fixed. The site velocities were fixed to the ITRF94 values, except for POTS, for which the GFZ adjusted velocity was used.

A second solution for the reference frame was determined where the site positions and velocities were adjusted simultaneously. Velocities for sites with less than 6 months of data were fixed.

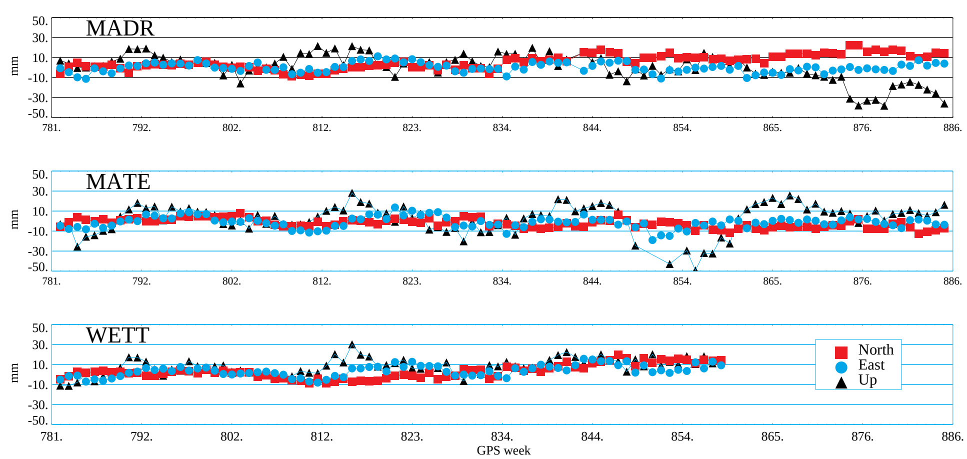


Figure 8: Weekly repeatabilities of station coordinates in longitude, latitude, and height for selected sites with data problems

The stability and accuracy of the determined reference frame can be demonstrated from the results of 7-parameter similarity (HELMERT) transformations. Transformations between 4 adjacent annual solutions and between GFZ global solution and ITRF94 have been performed (Table 3). The 4 annual solutions of 1993 to 1996 coincide within 3 to 4 mm in horizontal components and 4 to 6 mm in the height. If we fix the GFZ adjusted velocities to determine again global annual solutions, then we get better results than with ITRF94 velocities.

Table 3: Helmert transformations of global coordinate solutions (unit: mm)

Solutions compared	Number of sites	ITRF94 velocities			GFZ velocities		
		N	E	H	N	E	H
GFZ93–GFZ94	21	3.6	3.8	3.9	2.8	3.0	3.8
do, only Europe	7	0.9	1.1	1.9	0.8	0.6	1.5
GFZ94–GFZ95	31	2.9	2.8	5.6	2.7	2.8	5.4
do, only Europe	9	1.0	1.9	3.6	0.5	0.7	3.6
GFZ95– GFZ96	38	3.9	3.9	6.3	2.1	2.8	5.0
do, only Eur. and No. Am.	17	1.9	3.2	4.4	1.6	2.2	3.1
do, only Europe	9	1.0	2.7	3.6	0.9	1.5	3.5
GFZ93–96—ITRF94	28	4.8	5.5	6.7	4.0	5.1	6.2

A comparison of the 4-year global solution with ITRF94 yields an accuracy of 5 mm in the horizontal components and 6 mm in the height. However, some problems have to be mentioned, e.g., POTS, which shows discrepancies of 40 mm in the height compared to ITRF94 (due to wrong height velocity in ITRF94).

Figure 9 demonstrates the station velocities determined from a global simultaneous adjustment over 4 years. Due to densification of the IGS network in the last year, a large number of new sites of special interest for global applications became available. The agreement with NUVEL-1 and ITRF94 velocities, given for comparison, is obvious for a large number of stations, also for new sites such as CAS1, BISH, KIT3, and IISC. Some differences for other new stations (e.g., ASC1, LHAS, and MALI) can be explained with the short time span of observations or a bad data quality. However, the comparison also indicates remaining large discrepancies to ITRF for a number of “old” sites with a nearly complete observation span of 4 years (e.g., AREQ, TAIW, and USUD) as well as for “relatively new” sites with about 2 years of data (e.g., EISL, GUAM, and KERG). This holds especially true for sites located near the plate boundaries (e.g., GUAM, TSKB, and USUD). These large discrepancies, arising partly due to problems with receiver, marker, or data quality, have to be investigated more carefully.

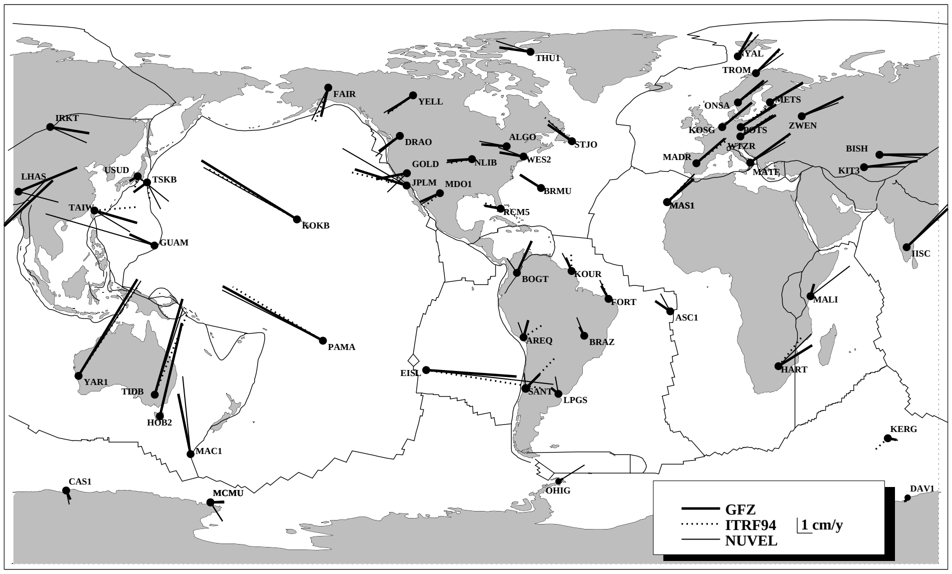


Figure 9: Site velocities from 4 years of IGS data (NUVEL-1 and ITRF94 values are given for comparison)

6 Contact Information

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Jet Propulsion Laboratory
IGS Analysis Center Report, 1996

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1 Summary

Jet Propulsion Laboratory (JPL) activities as an IGS Analysis Center continued throughout 1996; regular deliveries of rapid (1-day) and precise GPS orbits and clocks, Earth orientation parameters, and free-network ground station coordinates (now in SINEX 1.0) were maintained. Several new products were made available in 1996 and the beginning of 1997, namely high-rate (30-s) orbits and clocks, troposphere estimates, and 24-h predicted satellite orbits. The incorporation of global carrier phase ambiguity resolution has greatly improved the accuracy of our solutions. Enhancements have been made to our site selection and automation processes.

2 Evolution in 1996

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

Table 1 indicates the evolution of our activities during 1996. A major event was the implementation of global carrier phase ambiguity resolution (see Section 6).

Table 1: Analysis evolution in 1996

Action	Date
Preselect set of sites with highly stable clocks to aid in high-rate clock determination via postprocessing	Jan 1
Use rapid-service point-positioning statistics to validate reference clock	Jan 30
Use TurboRogue GOL2 in place of Rogue GOLD as fiducial station	Mar 11
Use TurboRogues TID2, WTZR in place of Rogues TIDB, WETB as fiducial stations	Mar 31
Exclude pseudorange from sites having a rms pseudorange postfit residual (from rapid-service solutions) greater than 1 m	Apr 14
Submit predicted orbits for the IGP orbit/clock combination	May 30
Use ITRF94 nominal station coordinates	Jun 30
Resolve global network phase ambiguities	Apr 21
Produce high-rate clocks and orbits in sp3 format	Aug 11
Model relativity effects in nominal orbit calculation	Aug 16
Lower nominal orbit fit convergence threshold to 25 m	Aug 23
Evaluate global distribution of available sites every 4 h to determine if daily analysis should begin	Sep 2
Reinstate deweighting of any specified satellites at a scale factor of 10^9	Sep 22
Reduce scale factor for deweighting satellites to 10^2	Oct 2
Produce troposphere files in IGS Exchange format	Jan 26 ('97)
Produce station coordinate files in with SINEX 1.0 format	Jan 26

3 Product Summary

Tables 2 and 3 summarize the regular products that result from JPL IGS AC activities. New products are high-rate precise orbits and clocks and JPL's contributions to the IGS preliminary (IGP) orbit/clock combination. These are respectively described in Sections 7 and 8. Also, beginning in 1997, we deliver files containing site-specific troposphere estimates, described in Section 9. Table 4 indicates addresses of World Wide Web pages with related information.

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

Example File	Contents
0885/jpl0885.sum.Z	Narrative summary for GPS week 0885
0885/jpl0885[0-6].sp3.Z	Precise orbits for days 0 to 6 (Sun through Sat) of GPS week 885
0885/jpl0885[0-6].yaw.Z	Yaw-rate information for eclipsing satellites, days 0 to 6, GPS week 885
0885/jpl08857.erp.Z	Fixed-network Earth orientation parameters for GPS week 885
0885/jpl08857.snx.Z	Free-network station coordinates for GPS week 885
0890/jpl0890[0-6].tro.Z	Fixed-network troposphere solutions for GPS week 890 (start in 1997)
hirate/JPL0885[0-6].sp3.Z	High-rate (30-s) precise orbits and clocks for days 0 to 6, GPS week 885
1996.eng.Z	Engineering data for 1996, sites in global solution
1996_p.eng.Z	Engineering data for 1996, point-positioned sites
ytd.eng	Year-to-date engineering data, sites in global solution
ytd_p.eng	Year-to-date engineering data, point-positioned sites

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

Example File	Contents
RapidService/orbits/jpl0885[0-6].sp3.Z	Quick-look precise orbits for days 0 to 6 (Sun through Sat) of GPS week 885
RapidService/orbits/jpl0885[0-6]_pred.sp3.Z	Quick-look 3-day predicted orbit for days 0 to 6, GPS week 885
RapidService/orbits/1996-11-17.*	Daily quick-look and predicted files for use in GIPSY
1996/clocks/1996-11-17.*	1996 daily free- and fixed-network clocks and yaw-rates for use in GIPSY
1996/orbits/1996-11-17.*	1996 daily free- and fixed-network precise orbits, polar motion, shadow-events data for use in GIPSY
hrclocks/1996-11-17.*	High-rate clocks (in TDP format) for use in GIPSY
IERSB/*	IERS Bulletin-B information

Table 4: Addresses of relevant web pages (all have prefix `http://`)

Address	Contents
`sideshow.jpl.nasa.gov/mbh/series.html`	Graphical time-series of site coordinates
`milhouse.jpl.nasa.gov/eng/jpl_hp2.html`	Summaries and plots of station and satellite performance

4 Site Selection

Due to the continual 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 Nth site is chosen so as to maximize its distance from the nearest of the N-1 already chosen sites. The rms isolation ζ (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 ALGO).
- Use 24-hour rapid-service processing results to make a separate list of stations with highly stable clocks. These are any stations (although they are usually those with H-masers) for which there are at least 250 5-min clock solutions (out of a maximum of 288) that are within 40 mm (0.13 ns) of the mean of their nearest neighbors.
- Based on isolation, choose the next eight most isolated sites from the list of stable clock sites. These will aid in postprocessed high-rate clock production (see Section 7).
- Add any sites not yet selected that are fiducial sites and use pseudorange observations (i.e., TurboRogue 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.

5 Automation

Toward the end of 1996, the automation of JPL's daily GPS orbit determination was enhanced. Previously, the automatic UNIX "cron" process controlling the daily analyses used a hard-coded minimum lag of N+4 days (which could be changed manually if necessary) to begin processing of day N. Now that quick-look (rapid-service) solutions are available, "processing readiness" is primarily based on the global distribution (ζ function) of available stations. This evaluation is performed six times each day, once every 4 h. If ζ is less than 2000 km for a total of 37 selected sites, the global network is deemed suitable to produce highly accurate (< 20 cm) orbits.

There are also some secondary criteria used in determining when the daily analyses begin:

- At least one of the three CPUs routinely used for processing must not have an analysis already in progress.
- At least 20 of the 37 chosen sites must have quick-look solutions for day N+1 (because a 30-h data arc centered on noon of day N is used).

Finally, to avoid delays in product delivery, if N+4 days have elapsed since an analysis for day N was first attempted, the processing for that day will begin automatically. This default condition occurs occasionally, and is usually caused by the absence of highly isolated stations that do not allow ζ to be sufficiently low. Since these modifications have been made, the lag in the start of the analyses has averaged 3.6 days.

6 Global Phase Ambiguity Resolution

The two signals used in GPS satellite orbit determination are dual-frequency pseudorange (P1,P2) and carrier phase (L1,L2). The latter inherently contains a bias; that is, an integer number of cycles that must be added to the phase to correctly represent the satellite-to-receiver range measurement. This quantity is unknown, and a real-value estimate is made for each satellite/station pair along with the other satellite and receiver parameters each day. It has been shown that greater accuracy in satellite and ground station positions can be achieved if the exact integer values of the phase biases are realized (resolved). Note that only double-differenced biases are conventionally resolved due to small transmitter and receiver biases in the undifferenced carrier measurements.

In our processing, separate solutions for L1 and L2 phase ambiguities are obtained by double differencing over baseline pairs, and combining the widelane ambiguities (determined from pseudorange averaging for sites from which pseudorange is used, predominantly TurboRogue stations under AS) with the estimated, real-value narrowlane (ionosphere-free L1-L2 combination, or LC) ambiguities. More background information and details on the method can be found in [4].

Note that because of our site selection process, the smallest baselines used are about 2000 km. Sufficiently precise pseudorange (even under AS) and highly accurate atmospheric and dynamic models allow phase biases to be "fixed" on baselines of this length and those ranging up to 9000 km, resulting in "global" ambiguity resolution. On average, for a network of 37 ground stations and 25 satellites, we resolve approximately 400 double-differenced biases per day. The effect of this strategy enhancement has been a significant improvement in satellite, station, and particularly geocenter repeatabilities, the details of which can be found in [4].

7 High-Rate Clock Products

IGS mail message 1538 (Feb 12, 1997) announced new 30-s precise GPS clock solutions. The estimation strategy begins with a site selection procedure. The station used as the reference clock in the regular FLINN solution for the day is selected first. Next, clock solutions of other sites used in the FLINN solution are examined for temporal smoothness, as measured by consistency between each clock solution and an estimate of it based on the four nearest (in time) neighbors. Sites with sufficiently smooth clock solutions are considered as candidates for inclusion. (The FLINN site selection procedure, described earlier, is intended to ensure several candidates.)

Seven of the candidates, together with the reference clock site, are chosen to give good global distribution. Data from the eight sites at the full rate of 30 s are then used to estimate GPS clocks every 30 s. All other parameters are fixed to their values as estimated in the FLINN free-network solution (station clocks and troposphere estimates are interpolated from their 5-minute values to every 30 s), and only GPS clock solutions are estimated. This strategy is computationally efficient, in that it allows a partition of the data by satellite.

The 30-s clock solutions thus determined are consistent with the FLINN free-network orbit. A high-rate clock solution consistent with the FLINN fiducial orbit is determined by time interpolation of the slowly varying difference between FLINN fiducial and free-network clock solutions. This difference is then added to the just-determined high-rate free-network clock solution. The results are available as listed in Tables 2 and 3.

8 Predicted Orbit Products

The IGS has been producing "preliminary," or projected GPS orbits, clocks, and Earth orientation parameters since January 1996 (see IGS mail message 1202). In May 1996, JPL began to contribute solutions to this effort. The purpose of these products is to provide the best possible orbits for real-time and near-real-time applications.

The JPL predicted orbits are extrapolated from a fit to the four most recent days of IGR (IGS Rapid) solutions. After the fit, the orbit is propagated 48 h forward, the last 24 h of which are submitted to the IGS. If the IGR solution for the fourth day of the fit is not available on time, we use the JPL Rapid Service [5] orbit in its place. The transformation between the Earth-fixed IGR solutions and an inertial frame suitable for orbit integration is done using the JPL Rapid Service

Earth orientation parameters. The JPL solutions for any particular day are delivered well before 00:00 UTC of that day, so that the IGP combination orbit may be computed and available within 38 h. The IGP solutions may be obtained in a similar manner as the IGR and IGS combined orbits, from:

```
ftp://igscb.jpl.nasa.gov/igscb/product/igp<wwww><d>.sp3.Z
```

where <wwww> indicates the 4-digit GPS week and <d> indicates the day of week (0 for Sun, ···, 6 for Sat).

9 New in 1997

Beginning with GPS week 890 (January 26, 1997), JPL submits 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. In our analyses, troposphere parameters are estimated using the Lanyi troposphere mapping function, a satellite elevation cutoff of 15 degrees, and a random walk model with 1.7 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.

Simultaneously, JPL station coordinate solutions conform to the SINEX 1.0 format. We express sincere appreciation to Remi Ferland of NRCan for providing the SINEX conversion utilities and assisting in their implementation at JPL.

10 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 and the use of global phase bias fixing.

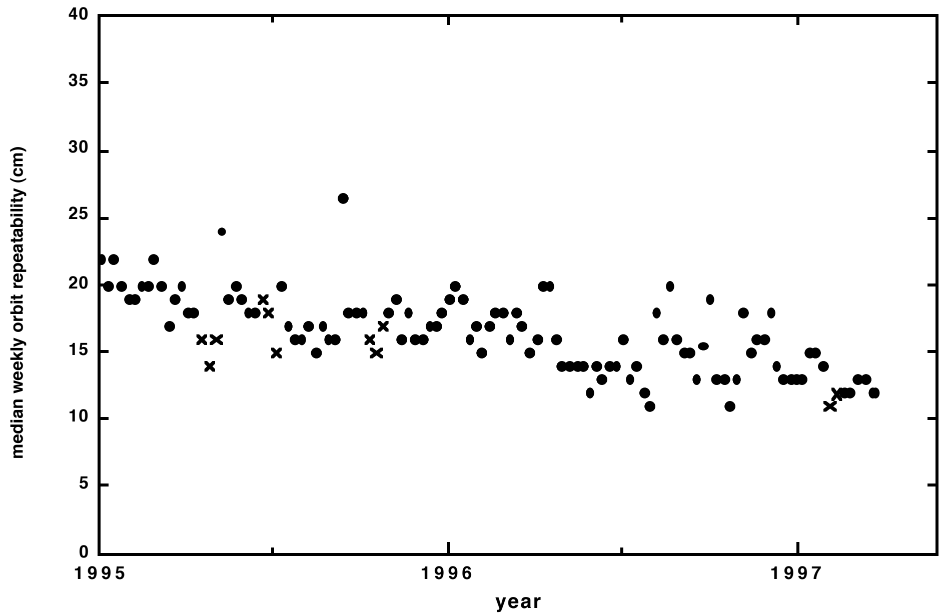

Figure 1: JPL orbit repeatability (3 drms) since 1995. Each data point indicates the median over all satellites and days for a particular GPS week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Weeks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

Shown in Table 5 are the means and standard deviations of the difference between the FLINN Earth orientation parameters (based on the fiducial solution) and the IERSB Final values. Shifts in the means on Jun 30 are due to our change from ITRF93 to ITRF94 used in coordinates of the IGS fiducial stations. For completeness we also show the early 1997 results, which reflect another shift in the mean due to the new IERS convention (IERS Gazette No. 08, Oct 29, 1996, `http://hpiers.obspm.fr/iers/info/gazette.8`).

Table 5: Differences between Flinn fiducial EOP and IERSB Final

	X Pole (mas)		Y Pole (mas)		LODR (mas)	
Period	mean	sd	mean	sd	mean	sd
Jan 1–Jun 29	-0.32	0.43	-0.20	0.44	-13	53
Jun 30–Dec 31	0.53	0.34	1.33	0.38	22	72
Jan 1–Feb 24 ('97)	0.12	0.38	0.02	0.29	-56	47

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[1] J. F. Zumberge, M. B. Heflin, D. C. Jefferson, M. M. Watkins, and F. H. Webb, "Jet Propulsion Laboratory IGS Analysis Center 1994 Annual Report," in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

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The ESA/ESOC IGS Analysis Centre

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1 Introduction

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

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

We have been participating as an IGS Analysis Centre from the beginning of the IGS. Our first solutions for orbital and polar motion parameters were transmitted to the CDDIS on July 24, 1992, about one month after the start of the

Epoch 92 campaign. By early August, the delay with respect to real time was reduced to about 10 days. Along with several other centers, ESOC continued to process IGS data after the decision of the IGS Campaign Committee in October 1992 to continue the IGS activity in the form of an "IGS Pilot Service" and then in January 1994 as the IGS Operational Service. These series have guaranteed continuity of the IGS activities after the success of the first campaign.

2 ESOC IGS Analysis

ESOC is using the observations from most of the Rogue and TurboRogue receivers in the IGS network. Those that are always used are from the 13 fixed stations and our own stations. Additional receivers up to a total of about 40 are added to improve the global distribution of observations. We use phase double differences as our basic observable, because they are especially well-suited for batch estimation. With double differences, the satellite and clock biases for every epoch do not need to be estimated with the same accuracy as that of the measurement, so the total number of parameters to be estimated is greatly reduced. Precise clock biases are produced in postprocessing, after the orbits have been determined.

3 Preprocessing

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

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

GPSOBS also estimates the station clock biases to correct the time tags of the measurements. Double-difference phase measurements are output every 6 minutes. Observations of eclipsing satellites are excluded during eclipse and 30 minutes after it. We are not modeling the biased-satellite yaw model, because it does not fully predict the attitude of the satellite.

4 Orbit and Geodetic Parameter Estimation

Orbit and geodetic parameter estimation is performed using the program BAHN. BAHN is a batch least-squares estimator for dynamic orbit determination. We use a 48-hour arc in order to obtain the precise orbit and Earth rotation parameters (erps) for each day, with 12 hours before and after the central day. Starting in February 1996, we are taking into account the correlations of the double-difference observables in our estimation process.

5 Measurement Models

Velocity of light:	299 792.458 km/s.
Troposphere:	Saastamoinen model.
Ionosphere:	First-order term removed by using the so-called ionospheric-free combination.
Plate motions:	ITRF values used when available; if not, Nuvel-NNR.
Tidal displacements:	Wahr model used for solid earth tidal displacement. Pole tide and ocean and atmospheric loading are not modeled.

Only Rogue and TurboRogue receivers with Dorne-Margolin choke-ring antennas used.

6 Dynamic Models

Geopotential:	GEM-T3 up to degree and order 8 with the GM (398 600.4415 km^3/s^2), C21 and S21 from the IERS standards.
Third-body forces:	Sun, Moon and four planets regarded as point masses. Ephemeris form JPL DE200, GM of Sun 132 712 440 000.0 km^3/s^2, GM of Moon 4902.7991 km^3/s^2.
Solar radiation pressure:	ROCK4 and ROCK42 approximations denoted as T10 and T20 used for Block I and Block II satellites. One scale factor and one Y-bias estimated per arc.
Tidal forces:	Wahr model for solid-earth tides, Schwiderski for ocean tides.

7 Reference Frames

Inertial:	Geocentric, mean equator and equinox of 2000 January 1 at 12:00 (J2000.0).
Terrestrial:	ITRF reference frame realized through a set of 13 station coordinates and site velocities.
Interconnection:	Precession, IAU 1976 Precession Theory; nutation, IAU 1980 Nutation Theory; celestial pole offsets from IERS Bulletin B; relation between UT1 and GMST, Aoki 1982; pole and LODR estimated as constants for 24-hour intervals; tidal variations in UT1, Yoder model.

8 Numerical Integration

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

9 Estimated Parameters

Station coordinates:	13 stations fixed to the agreed ITRF positions. Remaining station positions estimated.
Orbital parameters:	Initial position and velocity, solar radiation pressure scale factor, and y-bias estimated as constant through the 48-hour orbital arc.

Double-difference phase ambiguities estimated as real values.

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

Receiver clock biases and drifts estimated as constant parameters between clock resets. Maneuvers estimated as instantaneous velocity changes. Tropospheric zenith delay and shape parameter estimated linear in 6-hour intervals. Velocity discontinuities for eclipsing satellites at the times of the eclipse exits. Newly implemented in February 1996. Allow for small velocity discontinuities for noneclipsing satellites every 12 hours. Newly implemented in February 1996. Replaced in March 1997 for the estimation of sine and cosine one-cycle-per-revolution empirical accelerations in the orbital plane.

10 Precise Clock Bias Estimation

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

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

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

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

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

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

11 Postprocessing and Quality Control

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

Quality control is performed by checking the following:

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

12 BATUSI

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

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

Every week a SINEX [1] file is generated using the normal equations from each of the 7 days.

13 "Rapid" Orbits

At the beginning of 1996, we started to produce orbits that are available with a maximum delay of 21 hours since the last observations were collected.

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

14 "Predicted" Orbits

The daily submission of ESA predicted orbits started in April 1997.

Observables are used for the positions contained in the last available IGS rapid orbits and in the ESA rapid orbits for the case where the corresponding IGS products are not available or cannot be retrieved. An arc of four rapid orbit days is the basis for the propagation.

Earth rotation parameters are taken from the IGS rapid solutions for the fitted arc and from the NEOS Bulletin A for the propagated arc. The offset between both intervals is applied to the predicted erps.

15 Products

Our routine products are the following:

- Final orbits esawwwwd.eph, being wwww the gps week and d the day of the week (0-6), distributed via CDDIS; 11 days delay.
- Rapid orbits esawwwwd.eph, being wwww the gps week and d the day of the week (0-6), distributed via EMR. 21 hours delay since April 1997
- Predicted orbits espwwwwd.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

We are also producing and archiving satellite clock bias files at 30-second intervals. For these we are using our own internal format. They are available on request.

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

- EOP (ESOC) 94 P 01: an eop solution, including the integration of the LODR values to obtain a continuous UT1 series.
- SSC (ESOC) 95 P 01: a free network station coordinate and velocity solution based on 274 days of observations in 1994. It is referred to the IERS terrestrial reference frame by fixing the EOP at their Bulletin B values and by loose constraints on the positions and velocities to the ITRF92 values.

Reference

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Annual Report 1996 of the CODE Analysis Center of the IGS

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1 Introduction

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

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

Although CODE is primarily a global IGS Analysis Center (producing all global IGS products), it lays special emphasis—according to its name and the participating institutions—on Europe. This is reflected mainly in three activities at CODE:

- About one-third of the sites included in the global CODE solutions are European sites. This should guarantee that the CODE orbits are of the best possible quality over Europe.
- A network of about 35 European sites is processed on a daily basis since day 204 (July 23), 1995, using different processing options.
- The CODE Analysis Center has also been appointed to combine the weekly solutions (in SINEX format) of presently 10 regional processing centers in Europe into one official weekly European Reference Frame (EUREF) solution.
- More details concerning the latter two activities may be found in [1].
- CODE is located at the AIUB. All solutions and results were produced with the latest version of the Bernese GPS Software [2].

This report covers the time period from May 1996 to April 1997. It focuses on

- Major changes in the routine processing (Section 2.2).
- Reprocessing of the 1995 and 1996 data (Section 3).
- Product quality and results (Section 4).

The developments until April 1996 are described in previous Annual Reports of the CODE Analysis Center [3,4].

The work load at CODE further increased during 1996. Figure 1 shows the number of global IGS stations processed from January 1996 to May 1997. Although the number of global stations available constantly increased during all the year 1996, there is a clear *decline* in spring 1997. This and the fact that during holidays (and even weekends) the number of available stations may suddenly drop by 25 percent give rise to serious concerns about the reliability of the global IGS network.

The number of parameters (including site coordinates, tropospheric zenith delays, orbit parameters, ambiguities, and center-of-mass coordinates) estimated in the global 1-day solutions in the ambiguity-free and ambiguity-fixed case is given in the same figure. Almost no increase is seen in the number of parameters of the ambiguity-fixed solutions (a denser network leads to shorter baselines and a higher percentage of resolved ambiguities).

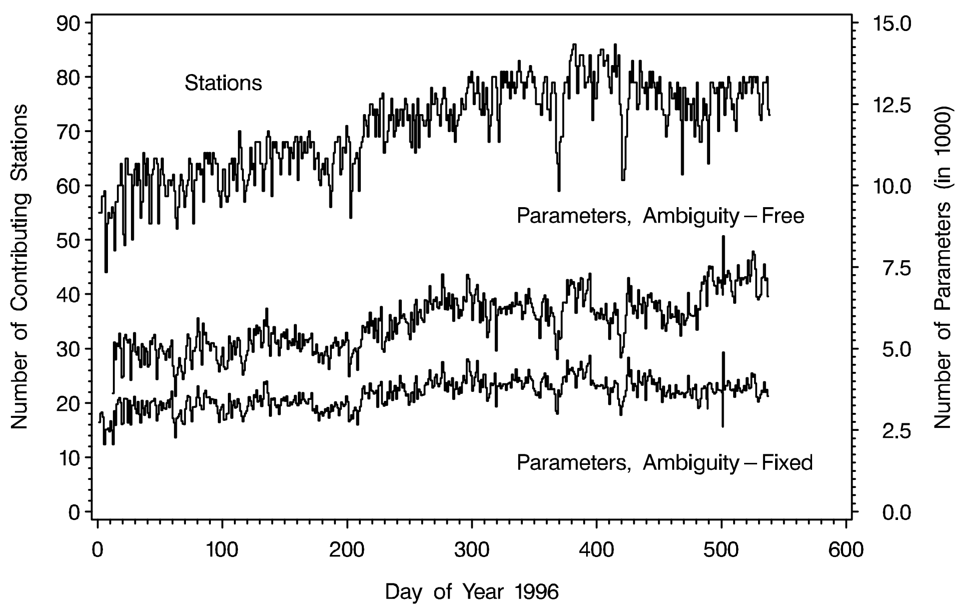

Figure 1: Statistics of global 1-day solutions computed at CODE

2 Changes in the Routine Processing and Present Status at CODE

2.1 Overview of Changes

The major changes implemented in the routine CODE analysis since April 1996 are listed in Table 1. Previous modifications have already been reported in last year's annual report [4].

Table 1: Modification of processing scheme at the CODE Analysis Center from April 1996 to April 1997

Date 1996	Day/Year	Description of Change at CODE	Section
Apr. 2	093/96	Start of a new European solution using a 15-degree cutoff angle.	—
Apr. 7	098/96	Improved a priori pole file generated by integrating the GPS-derived UT1–UTC drifts starting with a VLBI value (Bulletin A) about 15 days in the past.	—
Apr. 23	114/96	48-hour predicted orbits deduced from IGS rapid orbits and submitted to the AC coordinator.	—

Table 1: (continued)

Date 1996	Day/Year	Description of Change at CODE	Section
May 13	134/96	Rapid orbit solution switched to the extended solar radiation pressure model (parameters: direct and Y bias and the periodic terms in these directions, but no X terms). Pseudostochastic pulses now set up for all satellites.	4.2
May 21	142/96	Predicted orbits generated based on our own x- and y-pole predictions (better than Bulletin A).	—
June 8	160/96	3-day arcs used for rapid orbit estimation (previously 5-day arcs).	—
June 30	182/96	Change of the reference frame to ITRF94. Phase center corrections with model IGS 01.PCV . Model by R. D. Ray [5] for subdaily variations in the Earth rotation introduced as a priori model.	—
June 30	182/96	Orbit force model changed: JGM3 (previously GEMT3); General Relativity term implemented; Love number changed from 0.285 to 0.300 (IERS Standards [5]).	4.2
July 1	183/96	Rapid Global Ionosphere Models (GIMs) produced and used for ambiguity resolution in rapid orbit computation.	4.5
July 15	197/96	Predicted orbits now based on UT1-UTC values predicted from our UT1-UTC estimates (not Bulletin A values).	—
Aug. 7	220/96	Change in the set of parameters of the extended radiation pressure model that are estimated in the rapid orbit solution: constant terms in all three directions and periodic X terms are set up.	4.2
Sept. 29	273/96	CODE final orbits are now based on a solution using the extended radiation pressure model (the same parameters as in the rapid orbit computation, see previous entry). In addition, several minor improvements of the force field were implemented.	4.2
Nov. 7	312/96	15-degree cutoff angle for rapid orbit solution.	—
Dec. 29	364/96	Degree and order of spherical harmonics expansion for European ionosphere models increased from 5 to 8.	—

Table 1: (continued)

Date 1997	Day/Year	Description of Change at CODE	Section
Jan. 19	019/97	Satellite clocks estimated using phase-smoothed code observations.	4.3
Apr. 4	094/97	New daily European test solutions activated with following features: Niell mapping function, 5-degree cutoff angle, elevation-dependent weighting of the observations, estimation of troposphere gradients.	—
Apr. 5	095/97	CODE contribution to EUREF combination based on 15-degree solution from now on.	—
Apr. 27	117/97	Troposphere SINEX file generated once per day for all site.	4.5
Apr. 30	120/97	First experiments with a 5-degree cutoff angle in the global solution.	—

2.2 Daily and Weekly "Routine" Activities

The general scheme of the daily routine processing (going from 1-day to 3-day solutions) is still the same and may be found in [4], page 155. Four additional solutions related to troposphere modeling were implemented in the processing of the European network: the Niell mapping function [6], elevation-dependent weighting of the observations, processing of data down to 5 degrees elevation, and estimation of troposphere gradients. Test series are described and discussed in [7]. Depending on the success of these strategies, they will be tested for our global solutions, too, and might eventually be implemented into the global routine processing.

Two new weekly activities that are now part of the CODE procedures should be mentioned:

- A few weeks ago, the weekly submission of daily troposphere SINEX files (together with the final CODE results) started.
- The SINEX files from about 10 regional analysis centers in Europe are combined into an official EUREF solution. This EUREF SINEX file is sent to the global data centers as well.

We found that the biggest improvement of the satellite orbit quality resulted from introducing the extended orbit model. By smoothing the code observations with the phase observations, satellite clock estimates are obtained with a quality comparable to the quality of the best ACs.

2.3 Products

CODE makes available several of its (IGS) products on the anonymous ftp account, which may be accessed at

```
ftp ubeclu.unibe.ch  (130.92.6.18)
userid:  anonymous
passwd:  "your e-mail address"
cd aiub$ftp
```

Our anonymous ftp area is divided into three product directories: the directory `CODE`, containing our official IGS products; the Bernese Software User directory `BSWUSER`, with Bernese-specific information like daily coordinates and troposphere estimates; and a new directory `EUREF`, which contains the official EUREF SINEX files. More details may be found in [4].

Table 2 contains a list of the new products, their location, and the naming conventions associated with the data files.

Table 2: New CODE products available through anonymous ftp

File Name	Directory	Description
CODwwwwd.TRO	CODE	CODE 2-hour tropospheric delays (SINEX)
COEwwww7.SNX	EUREF	CODE weekly European solution (SINEX)
EURwwww7.SNX	EUREF	Official EUREF weekly combined solution (SINEX)
EURwwwwd.ION	BSWUSER/ATM	CODE daily European ionosphere models

3 Reprocessing of GPS Data

In order to improve CODE solutions and products, a continued development of software and strategies is necessary. With such changes, we try to maintain the highest possible level of quality for our routine products. The time series of solutions, however, become very inhomogeneous and difficult to interpret due to such modifications (see Table 1). Occasional reprocessing of older GPS data is therefore a necessity to generate consistent time series over long time intervals using the best currently known strategies and models. The reprocessing took place in two phases and covered the data span from January 1, 1995 (day 001), to March 23, 1996 (day 083, where our routine series with the new orbit model started):

- Phase 1: Reprocessing of the data span from March 1995 (day 127) to March 1996 (day 083) by Ronald Stolk from the Delft University of Technology in spring 1996.
- Phase 2: Reprocessing of the data span from January 1995 (day 001) to March 1995 (day 083) by Serge Botton from the Institut Géographique National, Paris, in November 1996.

The result of these reprocessing steps was not only an improved, continuous series of daily site coordinates, troposphere estimates, Earth rotation parameters (ERPs), and new orbit files, but also a complete series of subdaily ERP estimates, i.e., a series of more than 860 days (about 2.5 years). An example for the importance of such a series may be found in Section 4.4.

It is already clear that reprocessing—going back to earlier data—has to be completed soon. Data covering the time interval 1995–1997 are now available in such a form that a reprocessing effort will be much smaller than it was the first time. It is our goal as a Global IGS Analysis Center that in the future we will be able to reprocess data from the start of the official IGS service about once every 2 years.

4 Product Quality and Results

4.1 Coordinates and Velocities

For the official IERS submission of 1996, CODE computed a new global solution for site coordinates, velocities, and ERPs. This solution is based on results from a time interval of about 4 years. For the first time, not only horizontal but also vertical velocities were estimated and submitted by CODE. Vertical velocity components were set up only for sites with an observation history of more than 1.5 years. This accounts for the fact that the station height estimates are, in general, worse by about a factor of 2 to 3 compared to the horizontal components, and that heights suffer from problems like antenna changes and multipath. The temporal development of the reference frame was established by fixing the velocity vector of the site Wettzell to the ITRF94 value.

Figures 2 and 3 show the horizontal and vertical velocity estimates, respectively. Thanks to the time span of 4 years, the vertical velocities are, in general, reasonably well determined and are of the order of a few millimeters per year for most sites. Considerable vertical movements—that might be real—are observed in Tsukuba (TSKB, –23 mm/y), Easter Island (EISL, +37 mm/y), Santiago (SANT, +19 mm/y), and a few other sites. Much care and a longer history are needed to successfully distinguish between antenna problems, tropospheric long-term effects, and real geophysical movement.

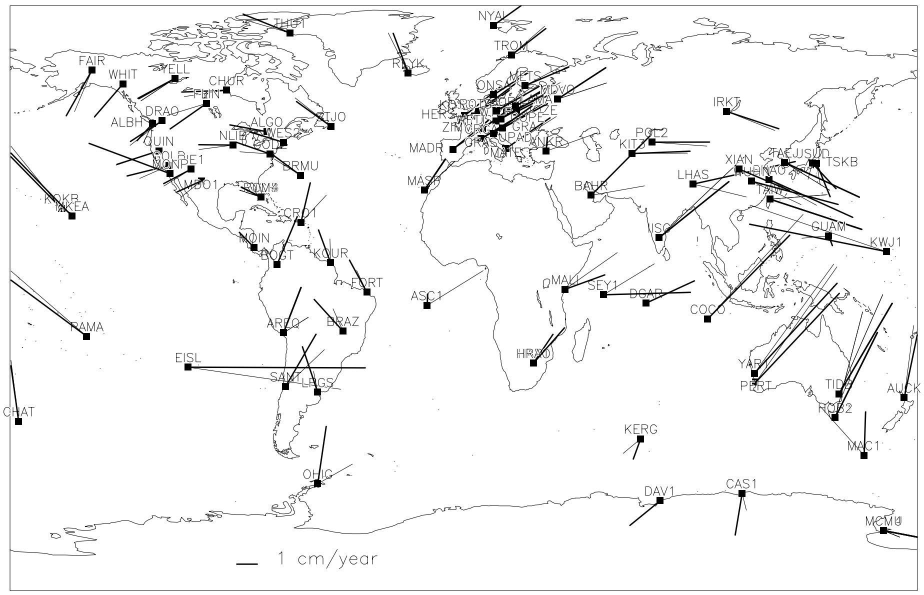

Figure 2: Horizontal site velocities estimated from 4 years of GPS data. CODE velocities are indicated by thick lines and ITRF94 values (for comparison) by thin lines

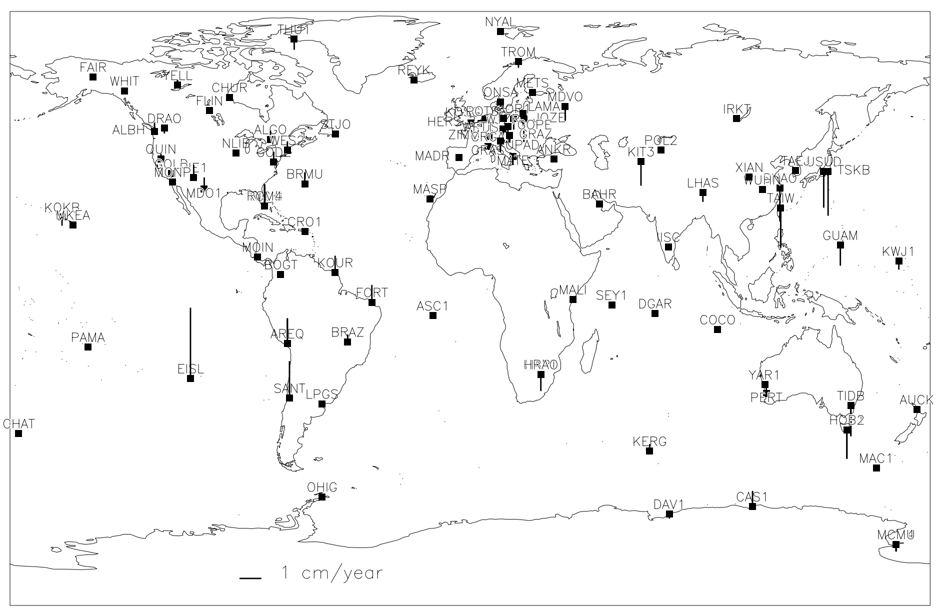

Figure 3: Vertical site velocities estimated from 4 years of GPS data (only for sites with more than 1.5 years of data)

4.2 Orbit Modeling

The most significant change in the quality of the CODE precise orbits could be achieved by implementing the so-called extended solar radiation pressure model [8]. This model is defined by

$$\vec{a}_{rpr} = \vec{a}_{ROCK} + D(u)\cdot \vec{e}_D + Y(u)\cdot \vec{e}_Y + X(u)\cdot \vec{e}_X$$

where

$$\begin{aligned} D(u) &= a_{D0} + a_{DC}\cdot cos(u) + a_{DS}\cdot sin(u) \\ Y(u) &= a_{Y0} + a_{YC}\cdot cos(u) + a_{YS}\cdot sin(u) \\ X(u) &= a_{X0} + a_{XC}\cdot cos(u) + a_{XS}\cdot sin(u) \end{aligned}$$

and

$\vec{a}_{rpr}$ = total acceleration due to solar radiation pressure

$\vec{a}_{ROCK}$ = acceleration according to the ROCK4/42 models

$\vec{e}_D$ = unit vector in the direction of the Sun – satellite

$\vec{e}_Y$ = unit vector in the direction of the solar panel axis

$\vec{e}_X$ = unit vector forming a right - hand system with $\vec{e}_D$ and $\vec{e}_Y$

u = argument of latitude of the satellite

$a_{D0},\ a_{Y0},\ a_{X0},\ a_{DC},\ \cdots,\ a_{XS}$ are the nine parameters of this extended model. a_{D0} and a_{Y0} are the two parameters of the “classical” model: the direct radiation pressure coefficient and the Y-bias.

Because of the high correlations of some of these radiation pressure parameters (especially with the UT1–UTC and nutation rates and the geocenter coordinates), it is not appropriate to estimate all nine parameters. After extensive tests with different sets of these nine parameters, we decided to adopt a model for the generation of the official CODE orbits where we determine five out of the nine parameters, namely the three constant terms $(a_{D0},\ a_{Y0},\ \text{and}\ a_{X0})$ and the periodic terms in the X direction $(a_{XC}\ \text{and}\ a_{XS})$. All other parameters, although set up and available in the normal equation system, are constrained to zero in our official 3-day solutions. The selection was mainly based on an optimization of orbit quality and quality of the UT1–UTC rate estimates. There is a small scale factor of about 0.3 ppb between the results of the extended model and our previous “classical” model.

That the use of this extended radiation pressure model with five parameters indeed gives a much better orbit representation may be concluded from the results obtained:

- When comparing the 3-day orbits from CODE using the extended model with, e.g., the orbits of JPL, a much higher agreement is found for the first and last day of the 3-day arcs than in the case of the classical model. (A comparison with the final IGS orbits is not too instructive because the CODE solutions using the classical model contributed to the final IGS orbit combination with a considerable weight).
- The orbit overlap study performed for a time interval of 126 days (beginning in 1995) during the second reprocessing phase (see Section 3) compares the satellite positions of one 3-day solution at the end of the middle day (24h UT) with the positions of the consecutive (overlapping) 3-day solution at the beginning of the middle day (0h UT). The satellites were divided into eclipsing and noneclipsing satellites, and a mean position difference was computed for each group of satellites and for each day. Figure 4 reveals quite a dramatic improvement in the overlap quality (about a factor of three) for the extended model compared to the classical model in the case of the noneclipsing satellites. The differences between the two models are even more pronounced for the eclipsing satellites.

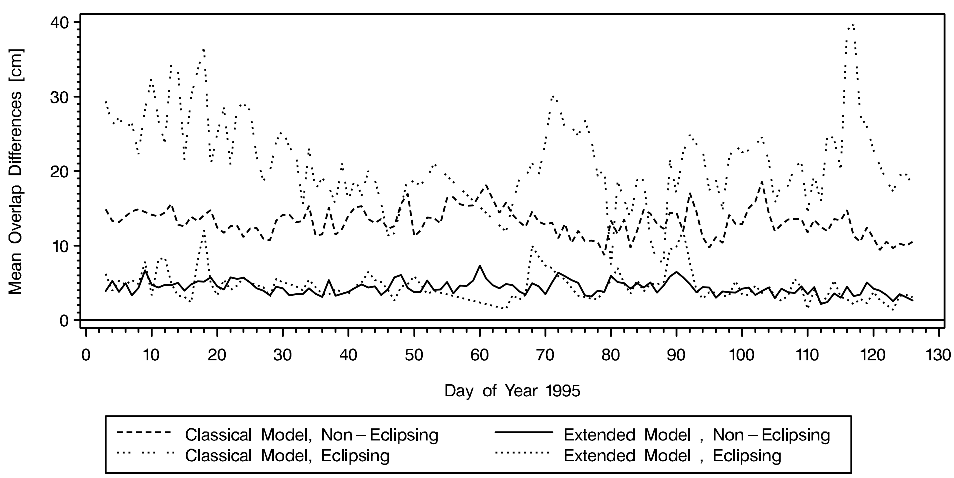

Figure 4: Orbit overlap results for the extended five-parameter and the classical two-parameter solar radiation pressure model. Mean overlap differences in position for the eclipsing and noneclipsing satellites

- The subdaily ERP values of the first and third day of a 3-day solution are much more consistent if the extended radiation pressure model is used (see Figures 9 and 10 in Section 4.4).
- The global site coordinates show a slight improvement when using the extended model.
- The pseudostochastic pulses in radial and along-track direction that are estimated every 12 hours (in addition to the five parameters of the

extended model and the initial conditions) are considerably smaller in absolute value with the new model. In Figure 5, the radial pulses are shown for all satellites for a time span that includes the change from the classical to the extended model (day 273, 1996; GPS week 873).

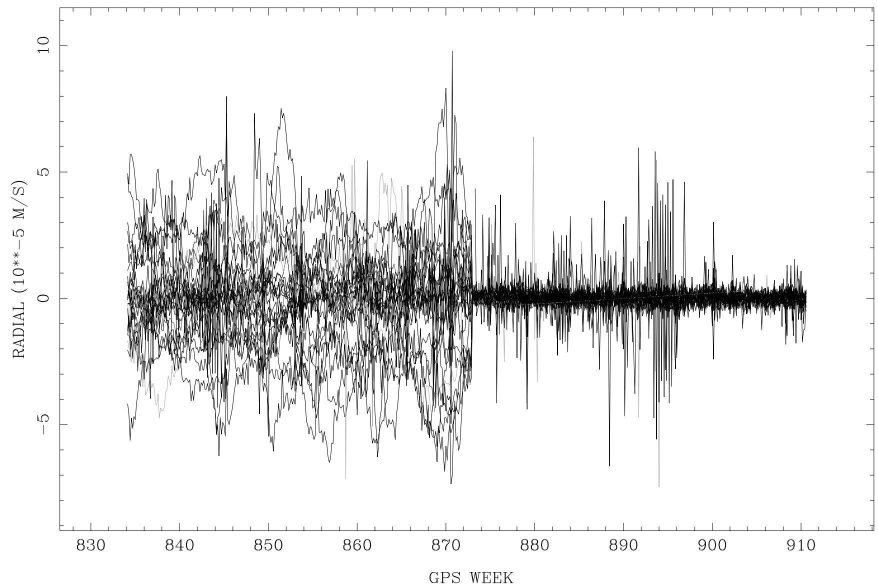

Figure 5: Radial component of the pseudostochastic orbit pulses estimated once per revolution for all satellites using the classical (until GPS Week 873) and the extended radiation pressure model (afterwards)

In view of these obvious improvements, the final orbit procedure was changed to contain the extended model starting with day 273, 1996 (GPS week 873). Before that, the extended model (day 220, 1996) was used for the rapid CODE orbits.

Various refinements were implemented into the force field of the satellites in two steps:

- GPS week 860 (day 182, 1996):
  - — Use of JGM3 gravity potential (GEMT3 was used before).
  - — General relativity term of the force field added [5].
  - — Improved Earth tidal model.
  - — Love number k_2 changed from 0.285 to the standard value of 0.30.
- GPS week 873 (day 273, 1996):
  - — Use of JPL Planetary Ephemeris DE200 for the Sun and Moon, including some planets.
  - — IERS 1996 Conventions for the elastic Earth [5]: step 1 and 2 corrections, pole tides, as well as ocean tides.

The rapid CODE orbits are presently based on 3-day arcs, as are the final solutions. The rapid orbits together with 24-hour and 48-hour predictions (which may be used for real-time applications) are made available—with few exceptions—before 12 UTC of the day following the observation day (12 hours after the last observation was taken).

4.3 Satellite Clock Estimation

Since September 10, 1995 (GPS week 818), precise satellite clocks have been routinely determined at CODE and reported to the IGS Global Data Centers in the precise orbit format (SP3 format). Starting with GPS week 889 (January 19, 1997), the quality of our clock estimates was improved significantly thanks to the implementation of a code smoothing. The procedure to estimate the satellite and station clocks is the last step of our IGS routine processing. The clock estimation currently consists of five major steps.

The first step is the code smoothing step. Here the RINEX data are screened, station by station, checked for outliers in both the code and phase observations, and for cycle slips in the phase observations. This code and phase cleaning is done in three steps. First, the so-called Melbourne–Wuebbena linear combination of code and phase data is formed. The wavelength of about 86 cm of this combination makes it relatively easy to detect cycle slips and outliers, provided the code observations are of good quality (about 50 cm rms). In the second step, the so-called geometry-free linear combination is analyzed. As the name implies, all position, clock, orbit, and troposphere information is eliminated in this combination. Only ionospheric refraction effects and data noise remain. The size the cycle slips previously detected in the Melbourne–Wuebbena linear combination can be determined in this step. As third step, the difference between the ionosphere-free linear combinations of code and phase is formed. This difference should contain only noise; therefore, it allows a meaningful check of the cycle slip and outlier detection performed previously. After correcting all code and phase data problems, the phase data are used to smooth the code observation. The smoothing interval equals the length of a continuous piece of phase observations. When a new cycle slip that cannot be repaired is detected, , a new smoothing interval is started.

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

In the third step—the actual clock estimation, all (smoothed) code observations are processed simultaneously to estimate all satellite and station clocks except the clock of the selected reference station. We use data only of receivers that do not have (e.g., AS related) biases in the observations. No Rogue receivers, but most of the TurboRogue receivers and all Trimble receivers, are included. For the clock estimation, we make use of our final orbit, ERP, coordinate, and tropospheric delay estimates to guarantee that the clocks are consistent with all other final CODE products. The estimated satellite clocks are then used in a code single-point positioning for all stations. This step is performed to allow removal of some outliers from the data. After this step, the actual clock estimation is repeated.

In the fourth step, a single-point positioning for all stations—estimating only offset and drift for each receiver clock instead of epochwise clock offsets—allows us to check whether the reference clock had a jump during the 1-day session and shows us which stations have good external oscillators connected to the GPS receivers.

In the fifth and last step, we again perform a code single-point positioning but now use only the data from stations flagged as "bad." This allows us to verify whether the data of such a station could be used for the clock estimation or whether the station has to be excluded on subsequent days.

Figure 6 shows the evolution of the quality of the CODE satellite clock estimates. The weekly rms differences of the clock estimates of the individual centers with respect to the combined IGS satellite clock values, as computed by the IGS Analysis Center Coordinator each week, are shown. The figure starts with GPS week 818, which corresponds to the time when satellite clock estimation started at CODE. Initial problems were encountered in the first few weeks due to software-related problems. After this initial phase, the satellite clocks (based solely on code measurements) reached an accuracy of ±1.3 ns. Starting with GPS week 889, a clear jump from the 1.3-ns level to the 0.5-ns level can be recognized. This corresponds to the time when the code smoothing was implemented at CODE. Figure 6 also shows that with code smoothing, the satellite clock estimates are now of a quality comparable to the (phase) satellite clock estimates from other IGS Analysis Centers.

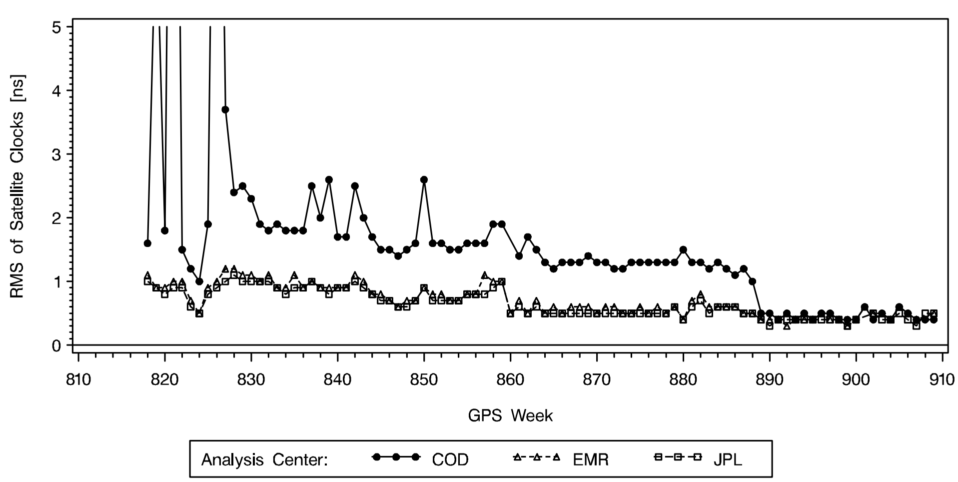

Figure 6: Evolution of the quality of the CODE satellite clock estimates. For comparison, the results from EMR and JPL are plotted as well

4.4 Earth Rotation Parameters and Nutation

At CODE, two activities in the field of Earth rotation deserve special attention: the series of subdaily ERP estimates (x and y components of the pole and UT1–UTC) and the series of nutation drifts in obliquity and longitude. These ERP series are, as GPS-derived series, unique in their length.

Due to the reprocessing steps mentioned in Section 3, a series of subdaily ERP estimates is available at CODE covering a time span of almost 2.5 years (about 860 days: January 1995 to the present). A small section of 10 days in this series (the x- and y-pole components) is shown in Figures 7 and 8 to illustrate that the subdaily variations very neatly follow the Ray model (IERS Standards, see [5]) derived from ocean tide models. A similar consistency—although not shown here—can be seen in the subdaily UT1–UTC values. Using these ERP series, amplitudes for the major ocean tide terms were computed; these terms are of a quality similar to those derived from many years of VLBI data. Our GPS-derived series are much denser in space and time, however.

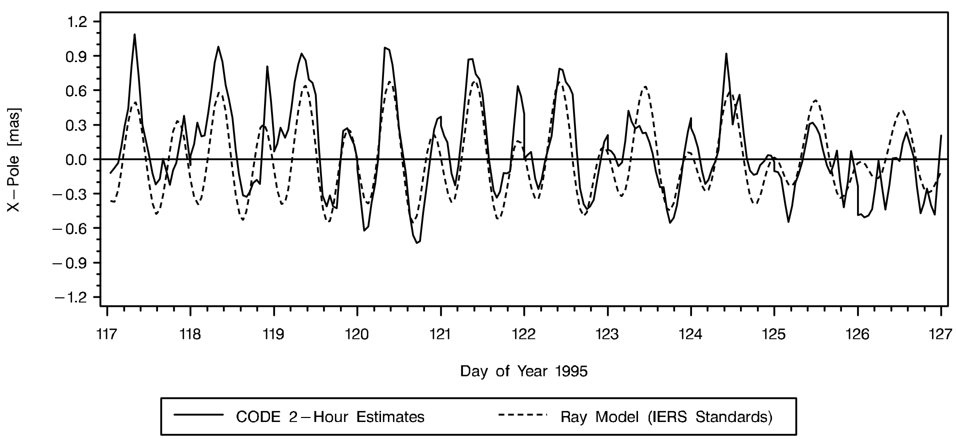

Figure 7: Zoom on 10 days of subdaily x-pole estimates compared to the model by R. D. Ray (IERS Standards)

It should be mentioned that a considerable improvement in the quality of the subdaily ERP estimates could be obtained by switching from the "classical" two-parameter radiation pressure model to the extended model described in Section 4.2 for the satellite orbit parametrization. This can be seen in Figures 9 and 10, where the differences in the x-pole values between the GPS estimates and the Ray model are shown for the classical and extended radiation pressure model, respectively. The three GPS series stem from extracting the values of the first, then of the middle, and finally of the last day, respectively, from the overlapping 3-day solutions. The degraded quality of the series stemming from the first and last days of the 3-day solutions is evident in the case of the classical orbit model. Such a behavior may be expected if the orbit parametrization is insufficient. With the extended radiation pressure model, all three days of the 3-day solutions are in much better agreement and the differences from the Ray model are smaller.

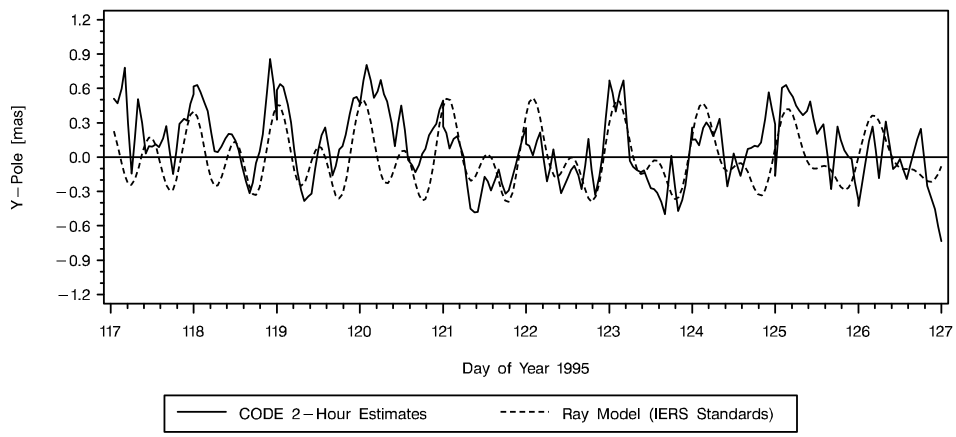

Figure 8: Zoom on 10 days of subdaily y-pole estimates compared to the model by R. D. Ray (IERS Standards)

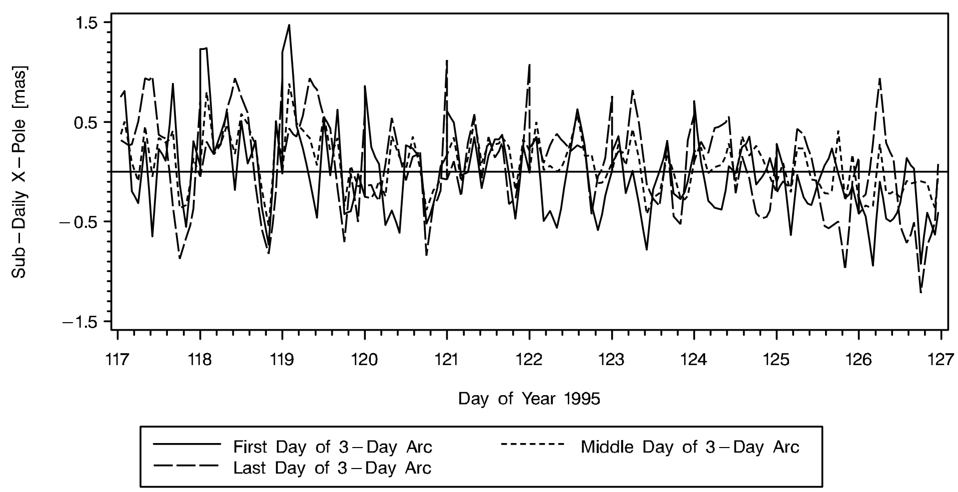

Figure 9: Comparison of subdaily x-pole estimates from the first, middle, and last day of the overlapping 3-day solutions using the classical radiation pressure parametrization (two parameters)

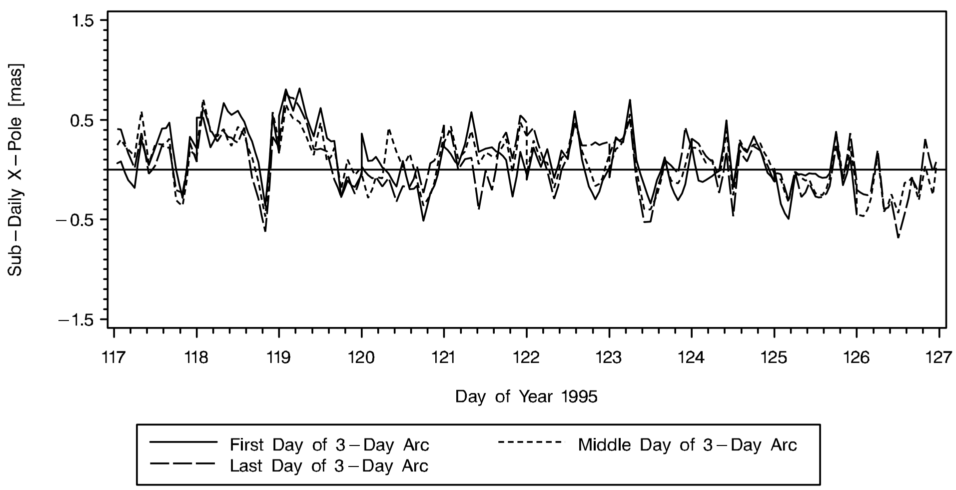

Figure 10: Comparison of subdaily x-pole estimates from the first, middle, and last day of the overlapping 3-day solutions using the extended radiation pressure parametrization (five parameters)

The series of nutation drift estimates from GPS now covers a time interval of 3 years (April 1994 to the present). Although the estimates are quite noisy, it is possible to gain valuable information about the nutation model, information independent of VLBI results. Detailed analyses indicate that, in particular, the nutation terms dominated by the Moon are accessible to GPS (e.g., the 13.6-day term), whereas the "solar" terms are affected by the estimation of solar radiation pressure parameters of the satellite force field.

4.5 Atmospheric Modeling

In spring 1997, the first tests with the new SINEX troposphere files were performed. By now, the generation of SINEX files containing tropospheric delay estimates is already part of the routine processing at CODE, and SINEX troposphere files are available for all days since January 1, 1997 (see Section 2.3).

At CODE, estimated troposphere delays were saved since January 1994, a long time before the availability of the troposphere SINEX format. Two typical examples of troposphere delay series—as they are available for all global sites processed by CODE—are given in Figures 11 and 12. The behavior of the total tropospheric zenith delays are quite different for the two sites. At Tsukuba (TSKB, Japan), very pronounced seasonal variations of the order of about 30 cm (peak to peak) are visible. These are mainly due to the hot and extremely humid summer seasons. At McMurdo (MCM4, Antarctica), the climate is more "moderate" (in a certain sense!) and there is almost no humidity in winter. A small annual period (with a phase shift of half a year compared to Tsukuba) can also be detected for this site as well as the jump in the delay values around the beginning of 1995, when the McMurdo antenna was displaced by a few hundred meters.

If meteorological measurements (in particular pressure and temperature) are available for these sites, the total zenith delay values can be converted into integrated precipitable water (IPW), a quantity of great interest to climatologists and meteorologists.

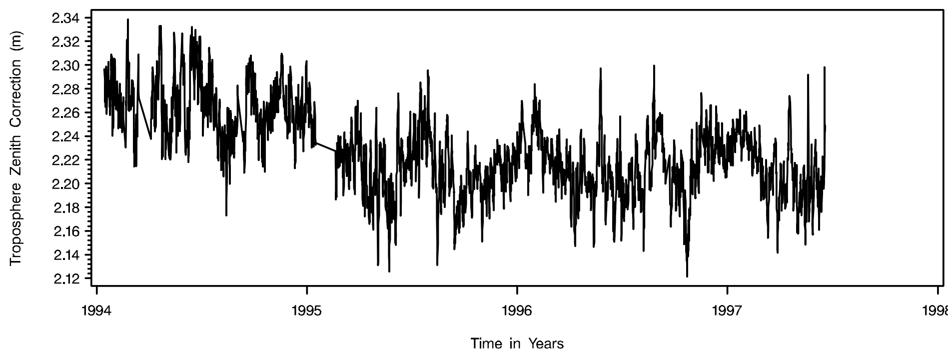

Figure 11: Total troposphere zenith delays for McMurdo (Antarctica) estimated at CODE using global 3-day solutions

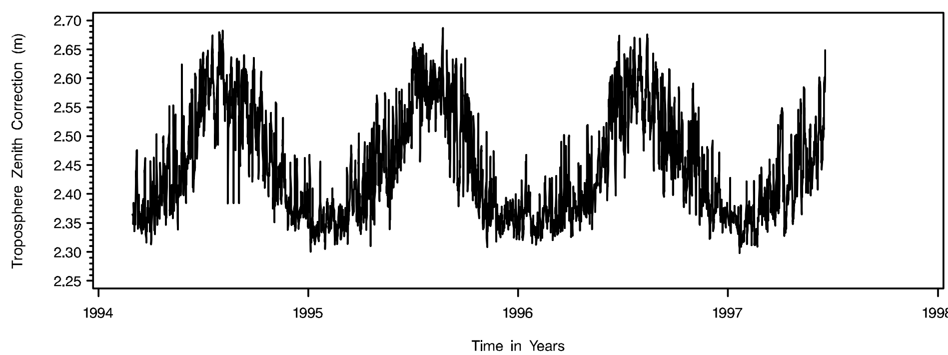

Figure 12: Total troposphere zenith delays for Tsukuba (Japan) estimated at CODE using global 3-day solutions

The estimation of global and European ionosphere models started in January 1995. Figure 13 summarizes the mean electron density values determined on a global scale and indicates that the minimum of the 11-year cycle of solar activity was reached around July 1996. According to predictions, quite a high ionospheric maximum has to be expected around the year 2000. Detailed knowledge about the ionosphere will become more and more important as we are approaching the next maximum.

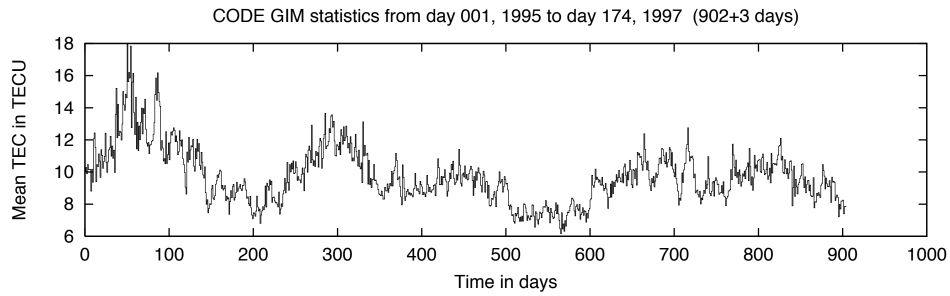

Figure 13: Global ionosphere models from CODE. The TEC values for the last 3 days stem from rapid GIM solutions (available about 12 hours after data collection); all other values are from final solutions

5 Outlook

Although almost 5 years have past since the beginning of the IGS Test Campaign in June 1992, this report shows that there are still major improvements possible in many different domains of global GPS data analysis. And although most of the global products were improved by at least one order of magnitude in the 5 years, there is no end of developments in view yet, and the friendly competition between the global IGS Analysis Centers stimulates further progress. We hope to contribute to the quality of the IGS products in the next year, too. Important aspects we have to address in the very near future are the inclusion of low-elevation data, modifications necessary to process GLONASS data, the modeling of the troposphere and the satellite attitude, and subdaily site coordinate displacements.

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NRCan Analysis Centre Annual Report for 1996

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1 Summary

A major focus of the NRCan Analysis Centre activities in 1996 was the production of rapid satellite orbits, clocks, and EOPs. The availability of the IGS rapid combined products also impacted NRCan orbit computations by offering a better means of data and orbit validation.

2 Processing Strategy in 1996

Several changes, listed in Table 1, were made in 1996 and early 1997 to the NRCan processing strategy. The basic NRCan approach [1,2] of using previous-day solutions as a priori estimates with properly updated variance–covariance matrices has not been modified, and the NRCan orbit processing is still carried out using the JPL GIPSY–OASIS II software. In 1996, NRCan used the IGS rapid orbits to improve the quality control of its precise orbits and to simplify the data validation.

In order to eliminate a small geocentre misalignment of the NRCan products with respect to the ITRF, a stochastic reset of the solar pressure GX and GZ components was implemented on February 18, 1996. The reset is performed once per day at 12 noon GPS time. This, however, succeeded in removing only some of the y translation seen in NRCan products. Table 2 lists translations and scale of the seven-parameter transformation between the NRCan unconstrained SINEX solutions and the ITRF reference frame, before and after the implementation of the stochastic reset, as computed from the MIT IGS Associated Analysis Centre weekly reports [3].

Table 1: Modifications to NRCan orbit processing strategy

GPS week	Date (m/d/y)	Modification
836	01/14/96	Stopped using pseudo-range observations from non-TurboRogue receivers.
840	02/11/96	Replaced WETT by WTZR as a fiducial station.
841	02/18/96	Once-per-day stochastic reset of the solar pressure parameters GX and GZ. Introduced consistent orientation of the daily NRCan sp3 orbit files with the weekly NRCan station and EOP (SINEX) combined solutions.
846	03/24/96	Introduced SINEX Version 1.0.
847	03/31/96	Replaced GOLD by GOL2 as a fiducial station.
860	06/30/96	ITRF94 station coordinates have superseded ITRF93. Implemented modelling of diurnal and sub-diurnal EOP components and introduced estimation of polar motion rates.
879	11/10/96	Replaced TIDB by TID2 as a fiducial station.
894	02/23/97	Corrected and implemented consistent ocean-loading parameters for all stations used in the NRCan orbit analysis.

Table 2: Alignment of the NRCan station coordinate solution to ITRF (from the MIT T2 Analysis Reports)

GPS weeks	X-tran/sig (cm)	Y-tran/sig (cm)	Z-tran/sig (cm)	Scale/sig (ppb)
823–840	–1.1/2.0	15.2/1.5	5.0/4.70	0.475/0.798
841–885	–0.5/1.9	11.7/2.8	–9.7/5.7	–1.223/0.664

Because NRCan orbit computation uses 24-hour data sets without data overlap, its daily solutions are subject to small reference frame inconsistencies due to variations in the daily data quality and availability. One way to reduce this effect is by combining daily station positions and EOPs into weekly solutions and then reorienting the daily orbital solutions to account for the improvement of the EOP estimates. Since GPS Week 841, all the final NRCan weekly products, i.e., orbits, EOPs, and SINEX station coordinate solutions, are consistent.

On June 30, 1996 (GPS Wk 860), the Silver Spring IGS Analysis Workshop recommendations were implemented in NRCan processing strategy. In addition, NRCan also began estimating and reporting polar motion rates. Table 3 lists the discontinuities in NRCan products resulting from the changes made on June 30. The discontinuities were estimated by reprocessing GPS Week 859, once using the new strategy including all updates and once using the old strategy. Also, since the GPS Week 860, the NRCan weekly SINEX combinations have been done using ITRF94 constraints, which are more realistic with respect to the NRCan orbits, EOP's, and station position sigmas.

Table 3: June 30, 1996, discontinuities in NRCan products (ITRF94 to ITRF93)

Solution	T1(cm)	T2(cm)	T3(cm)	D(ppb)	R1(mas) (Ypol)	R2(mas) (Xpol)	R3(mas) (–UT1)[a]
Stations	–1.8	0.1	–0.1	.2	–1.23	–.85	–.67
sigmas	.1	.1	.1	.1	.05	.05	.03
Orbits	–1.2	0.5	–0.1	.0	–1.13	–.89	–.87
sigmas	.04	.04	.04	.03	.06	.08	.10
EOP					–1.18	–.95	–.72
sigmas					.05	.07	.18

[a]Signs reflect the IERS transformation convention.

3 Improvement in Processing Automation

NRCan orbit computations are automatically initiated and performed daily with a 3-day lag for the final and a 1-day lag for the rapid solutions. In order to meet the deadline for submission of rapid products to IGS as well as to benefit from the availability of the IGS rapid products, the NRCan automation procedures have been improved in 1996. An automatic selection of the reference clock station was implemented. Four stations with H-maser clocks—ALGO, NRC1, FAIR, and YELL—have been identified as potential reference clock stations. RINEX data files of these stations are processed in sequence by the GIPSY data input module until a station with no tracking gap is detected.

An automatic station selection scheme was implemented in order to ensure a strong network geometry for the rapid orbit computation. A maximum of 26 stations are used from the 49 selected. The stations are grouped based on their spatial proximity in subsets of a maximum of three and are organized in order of preference. For example, an IGS fiducial station, if available, would always be selected. A data retrieval script is run as the first module of the automated orbit processing in order to ensure that a required number of stations is available.

This station selection scheme was introduced in late November 1996 and is currently used for the NRCan rapid orbits. Figures 1 and 2 show that since December 1996, NRCan has improved the regularity with which it meets the IGS rapid orbit submission deadline and increased the number of IGS fiducial stations used in NRCan solutions, although the submission deadline was reduced from 36 to 23 hours on June 30, 1996.

The availability of IGS rapid products has made it possible to increase the automation of NRCan orbit validation. Identification of weak orbital solutions is performed by comparison of the NRCan orbits with the IGR combined rapid orbits. This makes it possible to automatically modify the next day processing and to unconstrain a satellite poorly determined or to reinitialize from broadcast orbits the estimation for a satellite exhibiting severe modelling problems.

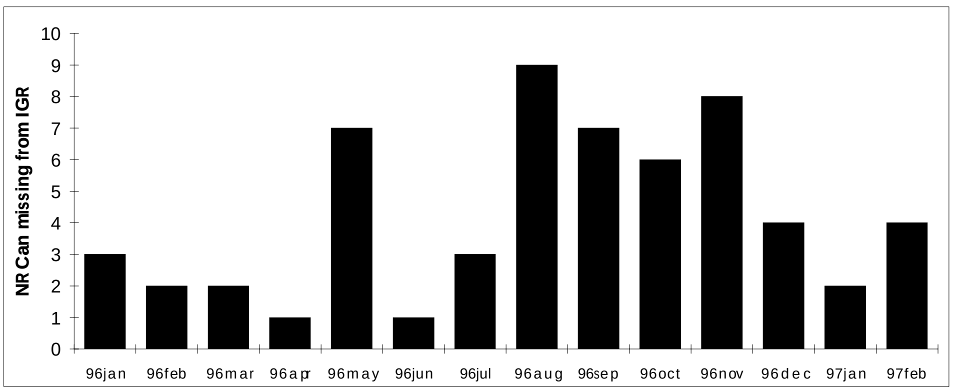


Figure 1: Number of times NRCan was missing from the IGR orbit combination

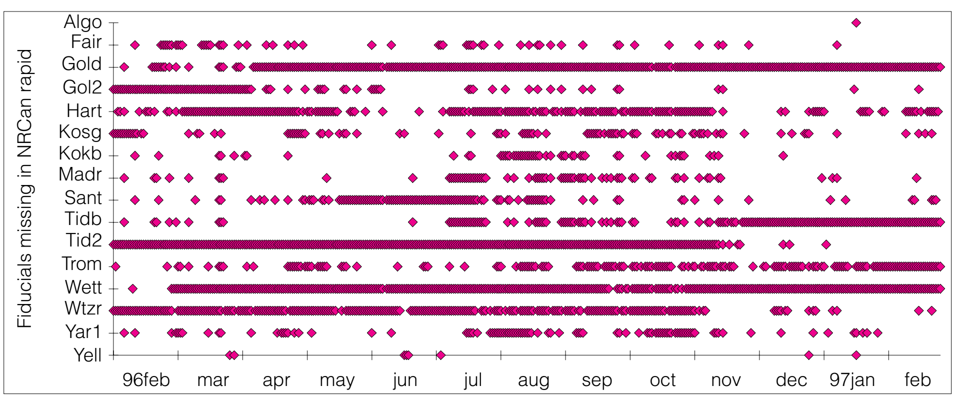


Figure 2: Missing fiducial stations in daily NRCan rapid orbit solutions

4 Results and Discussions

In early 1997, a strong signal with a 13.7-day period was detected in the 2.5-year NRCan station position residual series. This was due to incorrect ocean loading coefficients used in NRCan orbit processing.

As shown in Figure 3, which is typical of most stations, the 24-hour average ocean loading has a signal with a 13.7-day period and semiannual and annual periods for station KOKB. The same periods, but with much larger magnitudes, are also present for ocean-loading-induced station velocity over 24 hours. Table 4 lists most significant periods, at the 99% confidence level, in the 2.5-year series of KOKB position residuals. These periods are typical of most NRCan station horizontal position residual series showing variations mainly in amplitude.

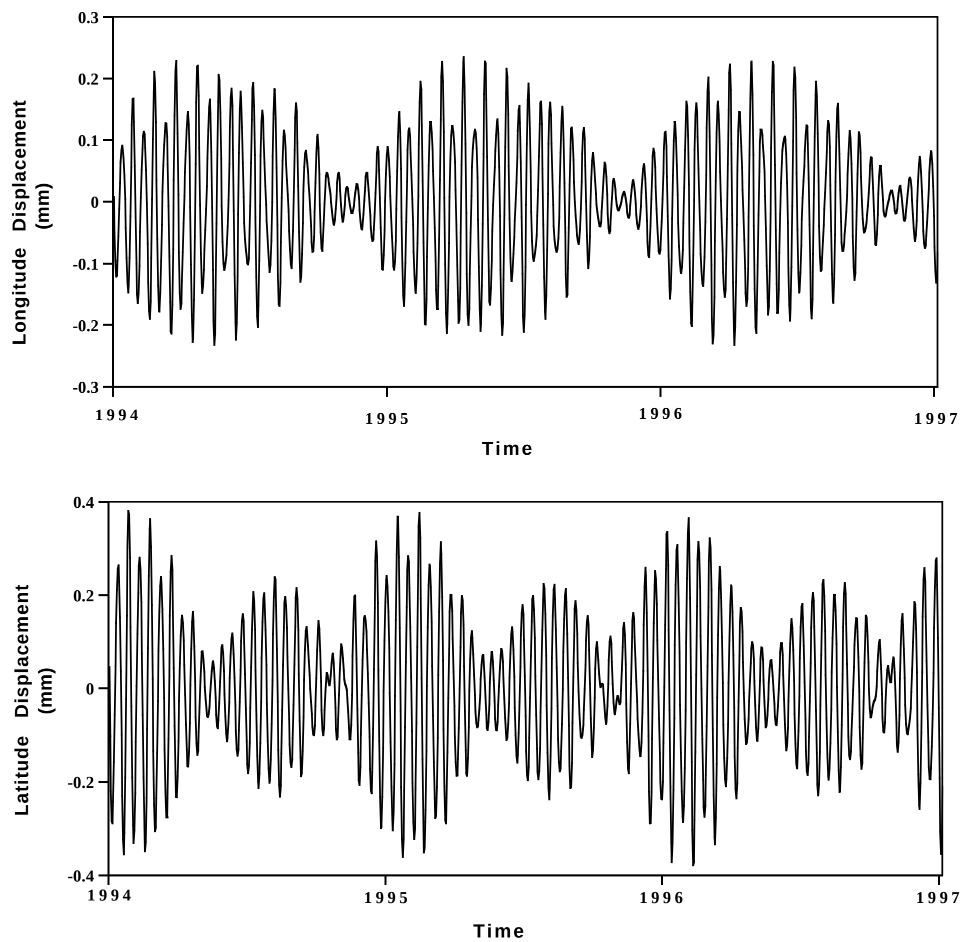


Figure 3: Ocean-loading displacement for KOKB: (a) longitude displacement; (b) latitude displacement

Table 4: Significant periods (99% confidence level) in the 2.5 year (1994.0 to 1996.5) NRCan residual series for KOKB position

Latitude		Longitude	
Period (days)	Amplitude (mm)	Period (days)	Amplitude (mm)
191.8	1.7	378.5	2.8
142.8	1.1	193.7	1.4
13.6	1.4	105.5	1.6
		69.2	1.7
		26.2	1.1
		13.7	1.3

Ocean loading displacement in height is not shown since the proper ocean loading coefficients were used for that component. As of February 23, 1997, corrected ocean loading parameters [4] have been implemented for all stations included in NRCan orbit processing.

The consistency of NRCan products for 1996 and early 1997 was estimated by comparing the NRCan station coordinate solutions with the ITRF coordinates and the NRCan orbits and EOP solutions to the IGS orbits and EOPs. Comparisons were performed for the following GPS Weeks: 834 to 896, 834 to 859, and 860 to 896. On GPS Week 860, IGS switched from the ITRF93 to the ITRF94 reference frame. Table 5 lists the means and sigmas of those weekly differences. UT1–UTC was not included due to its long-term drift, which prevailed in the weekly averaged means and sigmas. The short-term stability of the NRCan UT1–UTC estimates is, however, quite good [2]. Figure 4 shows the weekly averaged differences between NRCan and IGS daily EOP series.

A consistent set of station coordinates, station velocities, and daily EOPs constrained to ITRF94 epoch 1996.0 were obtained by combining the NRCan 1995 and 1996 daily SINEX files. To produce the 2-year final solution, all the archived 1995 and 1996 daily solutions were retrieved. Station coordinates and EOP parameters were extracted and subjected to statistical testing and editing with emphasis on improving daily station solutions. The a priori (ITRF93/ITRF94) coordinate and sigma constraints at the 13 stations were removed. These unconstrained variance–covariance matrices (scaled by a variance factor of 25) as well as the solutions for station coordinates and EOP were then combined into a single 2-year solution containing station coordinates, velocities and daily EOP, hereafter called final EOPs. Velocities were estimated for stations that had more than 6 months of daily solutions. The final solution is thus equivalent to the rigorous addition of reduced normal equations. The same strategy was used, using 1 year of daily solutions, to produce two annual solutions for station coordinates, velocities, and daily EOPs.

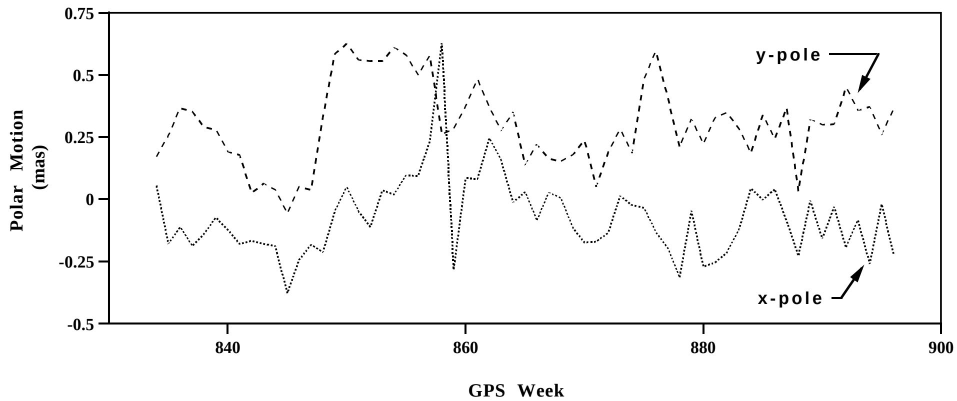
Table 5: Weekly averaged differences between the NRCan and ITRF/IGS Products

Solution	T1(cm)	T2(cm)	T3(cm)	D(ppb)	R1(mas) (Ypol)	R2(mas) (Xpol)	R3(mas)
GPS Weeks 834-896							
Stations[a]	0.1	–0.8	–0.2	0.49	0.178	0.029	–0.007
sigmas	1.4	0.5	1.3	0.35	0.123	0.029	0.023
Orbits[b]	–0.1	–0.7	–0.6	–0.10	0.347	–0.039	0.338
sigmas	0.7	1.3	0.6	0.12	0.184	0.151	0.165
EOP[c]					0.301	–0.075	
sigmas					0.166	0.158	
GPS Weeks 834–859 (ITRF93)							
Stations[a]	0.1	–1.3	–0.2	0.32	0.307	0.024	–0.002
sigmas	0.2	0.5	0.1	0.38	0.120	0.035	0.033
Orbits[b]	0.3	–1.4	–0.7	–0.08	0.418	–0.063	0.404
sigmas	0.7	1.4	0.6	0.14	0.175	0.173	0.125
EOP[c]					0.317	–0.071	
sigmas					0.218	0.197	
GPS Weeks 860–896 (ITRF94)							
Stations[a]	0.1	–0.5	–0.2	0.59	0.119	0.031	–0.009
sigmas	0.1	0.1	0.1	0.30	0.032	0.025	0.014
Orbits[b]	–0.5	–0.1	–0.4	–0.10	0.293	–0.021	0.287
sigmas	0.7	0.7	0.6	0.10	0.175	0.133	0.175
EOP[c]					0.289	–0.078	
sigmas					0.118	0.127	

[a] Combined NRCan weekly SINEX coordinate solutions vs ITRF coordinates for the 13 IGS fiducial stations.

[b] Weekly averaged transformation between NRCan and IGS daily orbits.

[c] Weekly averaged differences between NRCan and IGS daily polar motion.



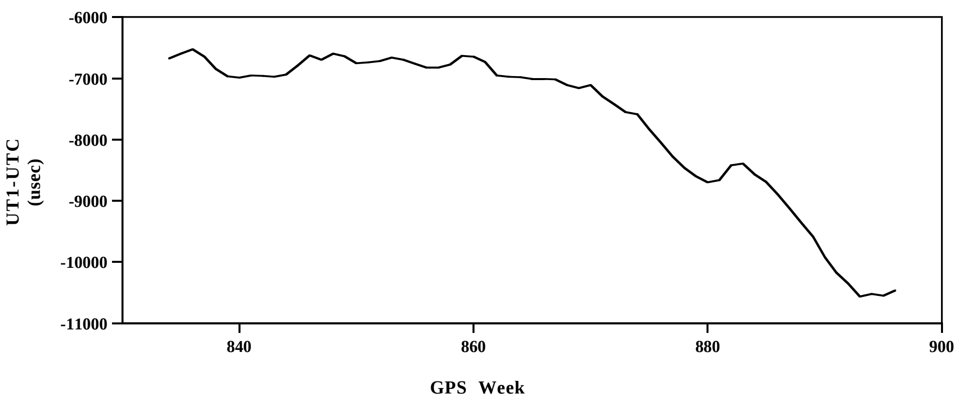


Figure 4: Weekly averaged differences between NRCan and IGS daily EOP series: (a) Polar Motion (X and Y); (b) UT1–UTC

The daily 1995 and 1996 solutions were also combined to produce weekly solutions without station velocities. One set of station coordinates and seven daily EOPs, hereafter called weekly EOPs, were produced for each week. Table 6 lists the average differences between the weekly and final NRCan and the daily IGS polar motion solutions. Table 7 lists the differences between the NRCan combined station coordinates and the ITRF94 station coordinates at epoch 1996.0. A complete description of the NRCan final combined station coordinate and EOP solutions (EMR97P01) can be found in the 1996 IERS annual report [5].

NRCan 1996 and early 1997 rapid orbits were compared to the IGS final orbits and the results summarized in Table 8. The marked improvement after GPS Week 880 is a result of the improved station selection and retrieval algorithm implemented at the start of that GPS Week. A more detailed assessment of NRCan rapid and final orbits and EOP's can be found in this volume [6].

Table 6: Differences between the NRCan 1996 weekly and final polar motion solutions and the IGS polar motion solution

Solutions	GPS weeks	PM-X/sig (mas)	PM-Y/sig (mas)
Weekly	834–859	–0.069/.232	0.317/.260
Weekly	860–886	–0.065/.171	0.282/.172
Final	834–859	–0.133/.199	–0.033/.180
Final	860–886	–0.154/.132	0.015/.154

5 Future Plans

In 1997, NRCan analysis centre activities will focus on improvements of its rapid and final products. NRCan Analysis Centre will continue to contribute to IGS satellite orbits and clocks, station coordinates and EOPs as well as support the introduction of new products such as tropospheric path delays.

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[1] P. Tétreault, J. Kouba, R. Ferland, and J. Popelar, "NRCan (EMR) Analysis Report," in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

[2] P. Tétreault, R. Ferland, J. Kouba, and J. Popelar, "NRCan (EMR) Analysis Centre 1995 Annual Report to the IGS," in *International GPS Service for Geodynamics, 1995 Annual Report*, edited by J. F. Zumberge, M. P. Urban, R. Liu, and R. E. Neilan, JPL Publication 96-18, Jet Propulsion Laboratory, Pasadena, California, 1996.

[3] T. Herring, "Series of MIT T2 Analysis Reports to IGS," IGS Central Bureau, Jet Propulsion Laboratory, Pasadena, California, 1995, 1996.

[4] S. Pagiatakis, Personal Communication, NRCan, Geomatics Canada, Natural Resources Canada, 1997.

[5] IERS, *Annual Report for 1996*, Central Bureau of IERS, Observatoire de Paris, Paris, 1997.

[6] J. Kouba and Y. Mireault, "Analysis Coordinator Report," in *International GPS Service for Geodynamics, 1996 Annual Report*, Jet Propulsion Laboratory, Pasadena, California (this volume).

Table 7: Differences between NRCan 1996 combined constrained solution and ITRF94 at epoch 1996.0 for the 13 IGS fiducials

	Latitude (mm)		Longitude (mm)		Height (mm)	
	diff	sig	diff	sig	diff	sig
Position						
ALGO	5.40	8.22	5.25	8.94	–4.80	7.91
FAIR	5.55	8.13	–2.71	8.84	–10.51	7.36
GOLD	6.29	13.28	–6.23	13.62	–9.74	13.30
HART	–2.03	12.83	9.33	14.79	–21.93	14.11
KOKB	–2.38	9.48	3.76	9.54	–14.58	8.34
KOSG	–2.81	7.00	–6.42	9.30	5.61	6.79
MADR	3.12	7.67	–6.70	9.19	–3.43	7.29
SANT	–1.52	12.07	10.28	13.09	20.80	11.53
TIDB	–1.45	10.52	1.74	10.42	14.60	10.15
TROM	–4.23	8.43	–11.47	9.54	–4.00	8.31
WETT	.59	7.42	–4.57	8.05	–2.60	7.48
WTZR	.88	8.42	–5.27	8.44	1.37	8.47
YAR1	–10.73	9.53	7.47	9.25	–6.82	8.34
YELL	6.18	8.69	–3.22	8.38	9.24	7.51
	Latitude (mm/yr)		Longitude (mm/yr)		Height (mm/yr)	
	diff	sig	diff	sig	diff	sig
Velocity						
ALGO	1.26	1.77	3.02	1.89	–.55	1.90
FAIR	1.20	1.76	1.27	1.88	–2.66	1.86
GOLD	4.48	3.77	–2.18	3.96	–2.49	4.09
HART	–2.87	3.34	2.65	3.83	–3.58	3.86
KOKB	1.67	2.15	–4.06	2.19	–3.12	2.02
KOSG	1.17	1.53	–2.24	2.03	.24	1.65
MADR	2.23	1.65	–1.21	2.00	–1.33	1.78
SANT	–4.98	3.21	.88	3.66	5.89	3.30
TIDB	.41	2.58	2.83	2.69	.80	2.78
TROM	.39	1.94	–3.31	2.27	.32	2.11
WETT	1.71	1.64	.02	1.87	.44	1.85
WTZR	.57	1.82	–.81	2.07	.49	1.97
YAR1	–3.23	2.10	.80	2.08	–.79	2.01
YELL	2.25	1.85	1.83	1.89	–1.02	1.89

Table 8: Precision of NRCan rapid orbits

GPS weeks	Orbit rms (cm)	Median value (cm)
834-898	20	15
834-859	23	16
860-879	20	18
880-898	14	13

Appendix

Stations Used in NRCan Daily Orbit Processing

Rapid GPS Orbit

Selection				Selection		
First	Second	Third		First	Second	Third
ALGO[a]	nrc1			madr	mas1	vill
dav1	kerg	cas1		mcm4		
FAIR	albh	drao		nyal		
fort	asc1	kour		pama		
GOL2				rcm6		
guam	kwj1			SANT	areq	bogt
HART	hrao	mali		stjo	sche	
iisc	dgar			TID2		
irkt				TROM		
kely	reyk			tskb	taiw	usud
kit3	lhas			WTZR	wett	
KOKB				YAR1	pert	
KOSG	ONSA			YELL		
			Totals:	26	16	7

Precise GPS Orbit

ALGO	areq	chur*
dav1	drao	dubo*
FAIR	flin*[b]	fort
GOL2	guam	HART
iisc	irkt	kerg
KOKB	KOSG	lhas
MADR	mali	mcm4
nrc1	pama	rcm6
SANT	sche*	stjo
taiw	TID2	TROM
tskb	whit	will
WTZR	YAR1	YELL
albh		
Total:		37 stations

[a] Stations in capital are fiducials.

[b] Asterisks denote the group of stations from which a single station is selected for inclusion in NRCan orbit processing on any given GPS Week. A different station is selected each week.

IGS

ASSOCIATE ANALYSIS CENTER REPORTS

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GLOBAL NETWORK ASSOCIATE ANALYSIS CENTER REPORTS

Newcastle-Upon-Tyne Global Network Associate Analysis Centre Annual Report 1996

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1996 was the first full year of participation in the IGS for the Newcastle-upon-Tyne Global Network Associate Analysis Centre (GNAAC). Our Annual Report gives some figures on the continuing growth of the Polyhedron and details our method of producing a consistent weekly estimate of all IGS stations from Analysis Centers (ACs) and Regional Network Associate Analysis Centre (RNAAC) SINEX network components (see Beutler and Neilan, this volume). Time-series results are also presented. The Newcastle GNAAC combined solution has median station rms repeatability of 7 mm vertically and 2 to 3 mm horizontally with respect to estimated linear motion. Both the median case and worst case station repeatabilities are better than any AC network. Compared to the AC global networks, week-to-week discontinuities are reduced, and network scale is more stable over time. Geocentre estimate repeatability is as good as the best AC network.

1 Introduction

A Global Network Associate Analysis Centre (GNAAC) of the IGS was established by the Department of Geomatics at the University of Newcastle (NCL) as part of the Pilot Project for International Terrestrial Reference Frame (ITRF) Densification in August 1995. During 1996, the GNAAC underwent continuous development and improvement. This report is an overview of our analysis procedures and products as of early 1997 and a presentation of time-series quality results based on the first eighteen months of IGS SINEX submissions.

For the details of the Pilot Project and the GNAAC role, see various contributions to the volumes edited by Zumberge and Liu [1], Gendt and Dick [2], Neilan et al [3] and Zumberge et al [4]. The GNAAC products are two weekly SINEX-format station coordinate solutions with summary files, as follow (N.B. The network solutions contained in A-SINEX, R-SINEX, G-SINEX and P-SINEX[1] files are here called A-networks, R-networks, G-networks, and P-networks, respectively):

(a) The weekly G-SINEX gives coordinates of the IGS Global station subset. This is obtained from the set of weekly A-SINEXes, one of which is produced by each IGS Analysis Centre (AC) from their global GPS analysis. We define a Global station as one that appears in at least three A-SINEXes in the week concerned (we ignore the IGS stipulation that the three ACs must be on more than one continent). The NCL G summary file gives comparison statistics between the input A-networks and the G-network, and information on station information discrepancies between the A-SINEXes. The G-SINEX and summary file are available from IGS Data Centres two weeks after the end of each GPS week.

(b) The weekly P-SINEX gives coordinates for the complete IGS Polyhedron (i.e., for all stations in the IGS network that are available for processing). This is created from the A-SINEX set and the set of weekly R-SINEXes, one of which is produced by each IGS Regional Network Associate Analysis Centre (RNAAC) from their regional GPS analysis using the IGS combined orbit. Each Regional network includes at least three Global stations. The P summary file gives comparison statistics between the input R-networks and the P-network. The P-SINEX and summary file are available five weeks after the end of each GPS week.

The NCL weekly G-network and P-network both have a nominal epoch at the mid-point of the GPS week, include a full covariance matrix, and are both constrained to the same IGS 13-station Core subset in ITRF94, with these constraints given in the file. Removal of constraints yields free G- and P-networks with loose global orientation constraints. The proposals in [1] do not specify the details of the GNAAC analysis method, so each GNAAC has a unique approach. The method used to create the NCL products is set out in Sections 2 and 3 below. Sections 4 and 5 present station repeatability statistics of the NCL G-network and P-network.

The basis of the NCL Polyhedron solution is the G-network, which is regarded as a first-order Polyhedron component because the Global stations

[1] A-SINEX (Analysis Solution-Independent Exchange) files are from the IGS Analysis Centers for their daily analyses and orbit determination.
R-SINEX files are regional network solutions produced by Associate ACs.
G-SINEX are Global SINEX files generated by combining the ACs' A-SINEX files.
P-SINEX is the final combination of the Regional and Global Solution files for the "Polyhedron-SINEX" file.

have a high AC estimation redundancy which provides reliability in the GNAAC analysis. The number of AC estimates available for each IGS station is therefore crucial to the quality of the GNAAC Polyhedron. Figure 1 shows the number of stations in each category of AC redundancy, from one AC to six ACs (during 1996, only six IGS ACs were submitting weekly A-SINEXes), over the first 18 months of the Pilot Project. We have highlighted the plot of stations estimated by at least three ACs, this being the Global station criterion. The introduction of the SIO and ESA A-networks in GPS weeks 825 and 839, respectively, can be seen. The number of Global stations each week is now about 70. The addition of Regional stations has brought the complete Polyhedron (IGS network) to about 140 stations.

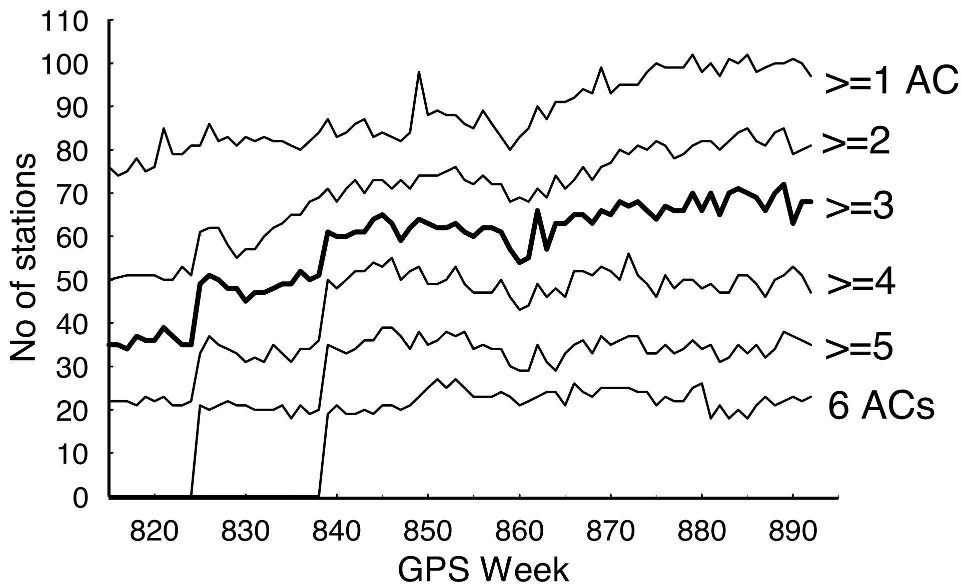


Figure 1: Numbers of IGS stations estimated by one to six ACs in the first 18 months of the Pilot Project. The bold line shows Global station criterion. Jumps in weeks 825 and 839 are the introductions of SIO and ESA

2 G-SINEX Analysis Method

2.1 SINEX Processing

Weekly A-SINEX files from ACs COD, EMR, ESA, GFZ, JPL, and SIO are obtained from CDDIS (N.B. Centre NGS (National Oceanic and Atmospheric Administration) began producing weekly A-SINEX in week 0898, and is now included in the NCL Polyhedron. No results for NGS are shown in this report). Usually these files are available 11 days after the end of the GPS week concerned.

Known format problems are automatically corrected before processing. Each A-SINEX is processed with respect to a SINEX-format station catalogue, which contains details of all IGS stations. This catalogue is manually updated when new stations appear or site equipment changes. Discrepancies between each A-SINEX and this catalogue are recorded and coded in Section 7 of the NCL G summary file. The estimate and a priori parameter vectors and covariance matrices are extracted from each A-SINEX using the catalogue for common parameter identification.

2.2 Changing Network Constraints

All A-SINEXes except JPL state applied station constraints, although those from ESA (European Space Agency) and SIO (Scripps Institution of Oceanography) are very loose. All stated constraints are removed by subtracting the (reordered) inverse a priori covariance matrix from the inverse estimate covariance matrix and hence computing the deconstrained solution. It is assumed that only minimal constraints are left in the deconstrained A-networks, i.e., they should be unbiased solutions except for reference system differences.

The three axial rotation constraints of each A-network are loosened, to effectively discard the artificial network orientation information that would otherwise bias the G solution in Section 2.3 below. This is equivalent to augmenting the deconstrained covariance matrix with loose constraints of three equations of X, Y, and Z rotation about the origin, though in this case the weight-space formulae are more efficient (see [5]). Note that the linear combinations of the translation and scale frame parameters are not augmented, since global network geocentre and scale are estimable. The deconstrained parameters are unaffected by this step, since we are changing minimal constraints.

A covariance matrix scaling factor (variance component) is applied to each A-network. These components change over time (see Section 2.5).

2.3 Estimating the G Solution

We model no correlation between the A-networks. A parameter list of Global stations is written, using the Global station criterion in Section 1. A normal equation block is formed from each deconstrained, rescaled A-network using the weight-space parameter deletion formula. The normal equations are in terms of coordinates only, no reference frame parameters being estimated. The normal equation blocks are summed and solved to give the G solution parameter vector and covariance matrix. The G solution origin and scale are therefore a least-squares combination of those of the A solutions. Its orientation is arbitrary.

2.4 Iterative Outlier Removal

We use three-dimensional datasnooping on the station estimates (coordinate triplets) of the deconstrained A-networks, using all observation correlation information. A single unmodelled error of unknown magnitude and direction is hypothesised in each A-network station coordinate triplet in turn. For each triplet, the 'T-statistic' described by Kosters and Kok [6] is computed and tested against a chi-square distribution with three degrees of freedom at the 99.9% confidence boundary. The furthest-outlying station triplet that fails the test is excluded, and Sections 2.3 and 2.4 are iterated until no station triplets fail the test. A station iteratively excluded from two A-networks is entirely excluded from that week's Polyhedron.

Figure 2 shows the number of AC station estimates excluded from each A-network each week and the total number of exclusions, in relation to the dotted line denoting 5% of the total number of station estimates. We aim to keep station exclusions below 5% of the total Global input data. The "ALL" category is the number of stations entirely excluded from the G-network after being iteratively excluded from two A-networks.

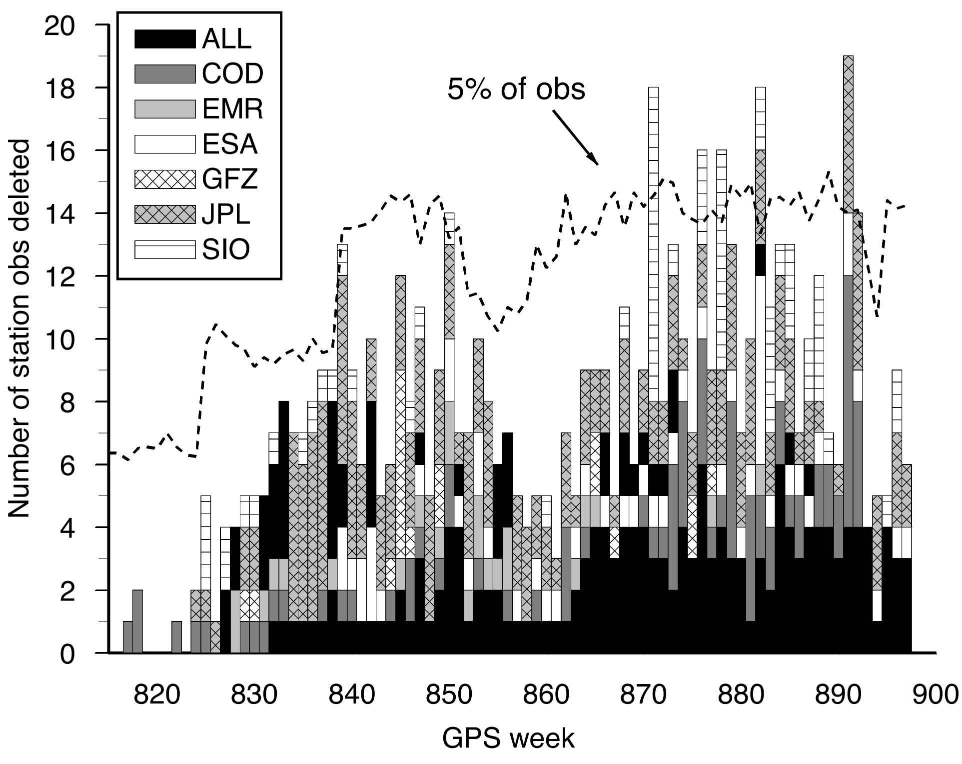


Figure 2: Numbers of AC station observations iteratively deleted as outliers from each AC in the G-network estimation over the first 18 months of the Pilot Project. The dotted line indicates 5% of the total AC "observations" of Global stations

2.5 Variance Component Estimation

An important aspect of the G-network procedure is the determination of A-network variance scaling factors, to balance the influence of Analysis Centres in the G-SINEX and to calibrate the outlier hypothesis test in Section 2.4. A single week's G-network estimation does not give enough redundancy to determine these factors from scratch, especially when large outliers are simultaneously hypothesised. On the other hand, if AC scaling factors are fixed from week to week, ad hoc decisions would have to be made to change them periodically, possibly disturbing the G-network time-series.

To avoid both problems, we allow variance components to change over time by estimating them each week after the iterative G solution outlier rejection, using an iterated MINQE method. An ad hoc "damping factor" is used so the variance components do not react to high-frequency variations caused by outliers in the A solutions. Thus the variance component used for a particular AC in week i+1 is influenced 80% (say) by the value carried over from week i, and 20% by the MINQE variance component estimated from the week i data after iterative outlier rejection. The time-series of changing variance components for each Analysis Centre are shown in Figure 3. Only the GFZ component varies greatly over time. Note that variations in these components may indicate changing A-network quality, or just changes in A-network covariance matrix scaling, or both.

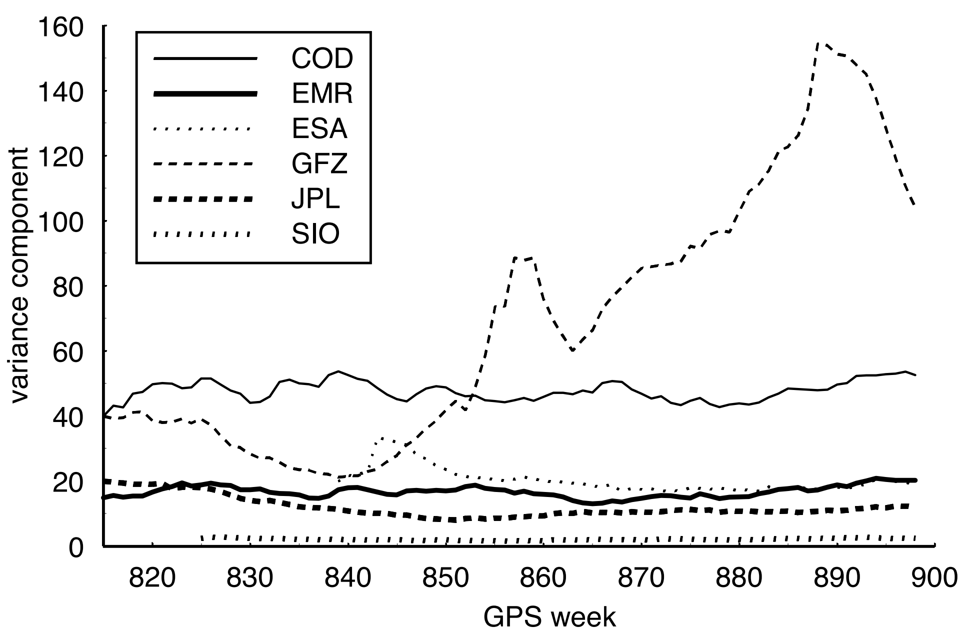


Figure 3: AC variance components changing over time by the "damped" iterated MINQE Variance Component Estimation approach, for the first 18 months of the Pilot Project

2.6 Product Generation

An additional normal equation block of a priori constraint is added to the normal equations sum in Section 2.3 to give the constrained G-network. This is obtained from the IGS 13-station Core subset of ITRF94 mapped to the solution epoch. The ITRF covariance matrix is used without rescaling. This constrained G solution is written in the G-SINEX file, including its a priori constraints so the free-network G solution can be regained by users. Station information is copied from the SINEX-format catalogue.

Seven-parameter Helmert transformations are estimated between each pair of deconstrained A solutions and between each deconstrained A-solution and the free-network G-solution. The parameters, residual rms, and residual Weighted rms of these transformations are included in the G-SINEX summary file. A table of A-SINEX station information discrepancies with the NCL catalogue is also included.

3 P-SINEX Analysis Method

3.1 SINEX Processing and Constraint Changes

Weekly R-SINEXes from RNAACs EUR, GSI, and SIR have been used since GPS week 860. Recently R-SINEXes from PGC and AUS have been included. SINEX editing and processing proceeds as for A-SINEXes, and a priori station constraints given in the SINEX file are removed to give the deconstrained R solutions. The covariance of each is augmented to give large SDs of all seven Helmert frame parameters (3D rotation, 3D translation, and scale) with respect to the origin, again using weight-space formulae for efficiency. This is the stochastic model equivalent of estimating a geocentric Helmert transformation when attaching each R-network to the Polyhedron; that is, the reference system definition of the R-network is discarded in favour of that provided by the Global Anchor stations. An ad hoc variance scaling factor is applied to each R-network. However, note that in the "attachment" method described in Section 3.2, R-network covariance matrix scaling does not affect any Polyhedron coordinates, only the (co)variances of Regional stations.

In order to include the non-Global A-network stations in the Polyhedron, an "extra" R-network is formed by a least-squares combination of A-networks including only the non-Global stations plus a core set of Globals as Anchor stations. Any stations that also appear in a "real" R-network are deleted from this block. This fake R-network is treated as the others Section 3.2.

3.2 Attaching R Networks to the G Network

We do not perform a least-squares combination of A- and R-networks. Instead, R-networks are adjusted to fit the G-network by backsubstitution of G-network coordinates and covariance for the R-network Anchor station parameters (again, weight-space formulae are used to reduce the number and size of matrix inversions required). The effect is that the deconstrained, loose-frame R-networks are 'stretched to fit' the Global Anchor coordinates in accordance with their full covariance matrices, without affecting the G-network parameters or covariance matrix. The R-network Anchor station estimates are then discarded.

The Polyhedron coordinates obtained in this method are the same as would be obtained by (1) a least-squares combination of A and R networks with very large R-network covariance matrix scaling, or (2) a Helmert-Wolf blocking solution (each A and R network being an 'observation block') in which the R-network contribution to the common parameter combination is omitted. The improvement in station repeatability of Global stations over non-Globals shown by Sections 4 and 5 below, which is due to the stochastic model adjustment and iterative outlier detection in the highly redundant G-network estimation, justifies this approach of treating the G-network as a primary frame that is not influenced by the integration of the nonredundant R networks.

The Polyhedron is therefore a concatenation of the G-network and the adjusted R-networks, for which the full covariance matrix is computed block by block. Because the R-network reference system information was discarded in Section 3.1, the formal errors of the Helmert frame parameters of the complete Polyhedron are identical to those of the G-network, with loosely constrained arbitrary orientation. At no point is the full P-network covariance matrix inverted, so many R-networks can be added to the Polyhedron without prohibitive increases in computation time.

3.3 Product Generation

The ITRF-constrained Polyhedron solution is obtained by backsubstituting the ITRF-constrained G-network (from Section 3.2) into the R-networks. The ITRF-constrained Polyhedron estimate and full matrix is written out in a P-SINEX file. This includes the same a priori constraints block as the G-SINEX. These constraints can be removed by users to give loosely constrained G- and P-networks that have the same datum definition. The P-SINEX includes all the stations in the input A and R SINEXes except the multiple outlier-test failures noted in Section 2.4. The stations also included in the G-SINEX are considered “first order” stations.

The P-SINEX summary file summarizes the input and output data of the analysis and Helmert transformations between each deconstrained R-network and the NCL G-network, and between each deconstrained R-network and the NCL P-network.

4 G-Network Station Repeatability

For a very simple comparison of week-to-week consistency of the AC A-networks and the NCL G-network, Figure 4 shows the Helmert (seven-

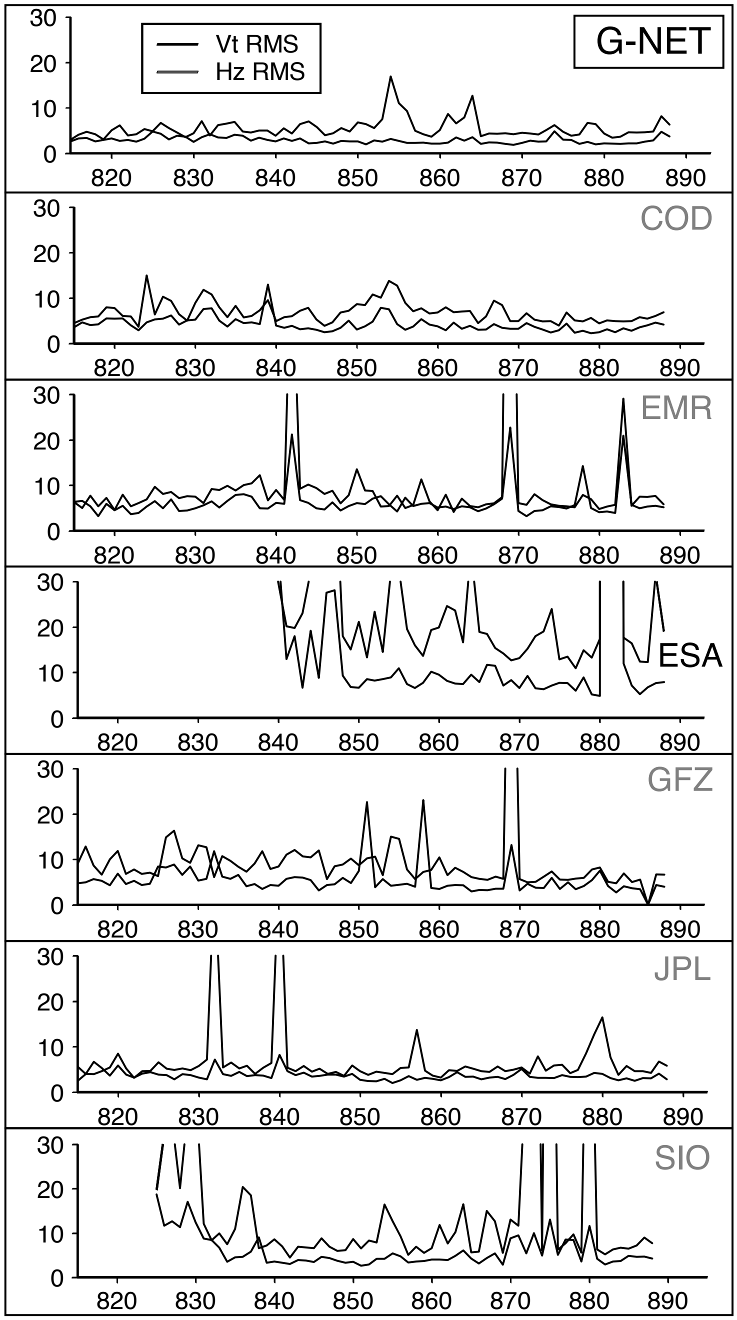


Figure 4: Time-series of vertical and horizontal residual rms (mm) of Helmert transformations between consecutive weekly networks in the NCL G-network and six A-network series

parameter) transformation vertical and horizontal residual rms series between pairs of consecutive weekly solutions for each of these networks. The spikes in these rms plots are caused by step functions in station position. It is clear that the G-network, estimated as described in Section 2, is far less prone to these discontinuities than a typical A-network. Analysis Centre COD (Centre for Orbit Determination) looks to be the most consistent AC on this plot for absence of week-to-week discontinuities.

For a comparison of station repeatability between G-network and A-networks, we first have to estimate a kinematic solution (i.e., reference epoch position and 3D velocity for each station) for each network series, and look at the kinematic residuals obtained by mapping the kinematic solution to the epoch of each weekly solution and estimating a Helmert (seven-parameter) transformation between kinematic and epoch solutions to give the weekly "kinematic residuals". Here we estimated a separate kinematic solution for each A-network and for the NCL G-network from the first 18 months of weekly SINEX data (up to week 0892), using free-network solutions with full covariance matrices. The A-SINEX files used were those archived at IGS Data Centres, but the G-network series was reprocessed using the current analysis method described in Section 2. Deliberately, no attempt was made to fix station step functions and other problems in any series—rather, we want to highlight these. Only stations present in at least 20 weekly epoch networks were included.

The kinematic solutions are mapped to each weekly epoch and a Helmert transformation estimated to obtain the kinematic residuals at each epoch. We have omitted plots of the Helmert parameters of these transformations here; to summarize their variability, Table 1 shows the rms of the time-series of translation and scale parameters of the transformations between epoch and mapped kinematic solutions, and the rms of the vertical and horizontal residual

Table 1: Rms value of the translation and scale parameters, vertical residual rms and horizontal residual rms of the Helmert transformations between weekly epoch solutions and mapped kinematic solutions for 18 months of weekly A- and G-networks

Network	X transl rms (mm)	Y transl rms (mm)	Z transl rms (mm)	3D transl rms (mm)	Scale rms (p.p.b.)	Vt resid rms (mm)	Hz resid rms (mm)
NCL	8.1	11.4	22.0	26.0	0.23	5.2	3.0
COD	7.4	9.6	23.0	26.0	0.40	7.0	4.1
EMR	19.2	18.9	75.3	80.0	0.74	10.5	6.6
ESA	16.5	26.4	59.3	61.8	1.55	18.2	9.8
GFZ	24.9	40.4	56.3	73.6	0.45	8.7	8.4
JPL	8.2	10.4	30.4	33.2	0.94	15.8	3.9
SIO	10.5	32.0	45.9	56.9	0.48	11.1	5.9

rms of these transformations. From column 5, we see the repeatability of the G-net geocentre estimate is the same as that of the most consistent A-network (COD). Column 6 shows that the G-network scale is more stable than that of any A-network. Columns 7 and 8 show that the time-series rms of weekly kinematic residual rms of the G-network in both vertical and horizontal components is smaller than that of any A-network.

We also assemble the kinematic residual time-series for each station and compute the horizontal and vertical kinematic residual rms for each station in each network. In Figure 5, the station kinematic vertical and horizontal residual rms values obtained for the NCL G-network and each A-network have been arranged in ascending order so their distributions can clearly be seen. Table 2 summarizes the minimum, median, and maximum station kinematic residual rms values in vertical, north, and east components. In each column of the table except the last, the G-network has the lowest station series rms.

5 P-Network Station Repeatability

An unusual aspect of the NCL P-network is that R-networks are attached without allowing the Global stations to move, as described in Section 3. We call this the R-network "attachment" method. Here we compare this with a Least Squares combination of G-network and R-networks (the "combination" method), to see if either method gives superior time-series station repeatability. In the combination method used for this test, we combined the weekly G-network with weekly R-networks from the EUR, GSI, and SIR RNAACs, leaving R-network covariance matrix scaling unchanged, and not excluding any R-network station estimates as outliers.

Separate kinematic solutions were estimated from the 18-month "attachment" and "combination" P-network series, again not attempting to fix any station series step-functions. In Figure 6 we show ascending-order plots of the station series vertical and horizontal kinematic residual rms for each of these Polyhedron series. The upper plot includes all Polyhedron stations. We see that the median station kinematic residual rms is about 7 mm in the vertical and 2 to 3 mm horizontally. The attachment method seems to give slightly better repeatability at the noisy end of the ordered plot, but this gap might be closed by an improved combination approach.

The lower plot in Figure 6 shows the same statistics again for a subset of Polyhedron stations, this time with separate ordered plots for the Anchor stations and Regional stations of the EUR and GSI R-networks (each of which have a time-series of 32 weeks in this data set). There is no great difference in station repeatability between the Global Anchor stations and the Regional stations in either R-network, and the "attachment" method appears to offer only marginal improvement in repeatability over "combination."

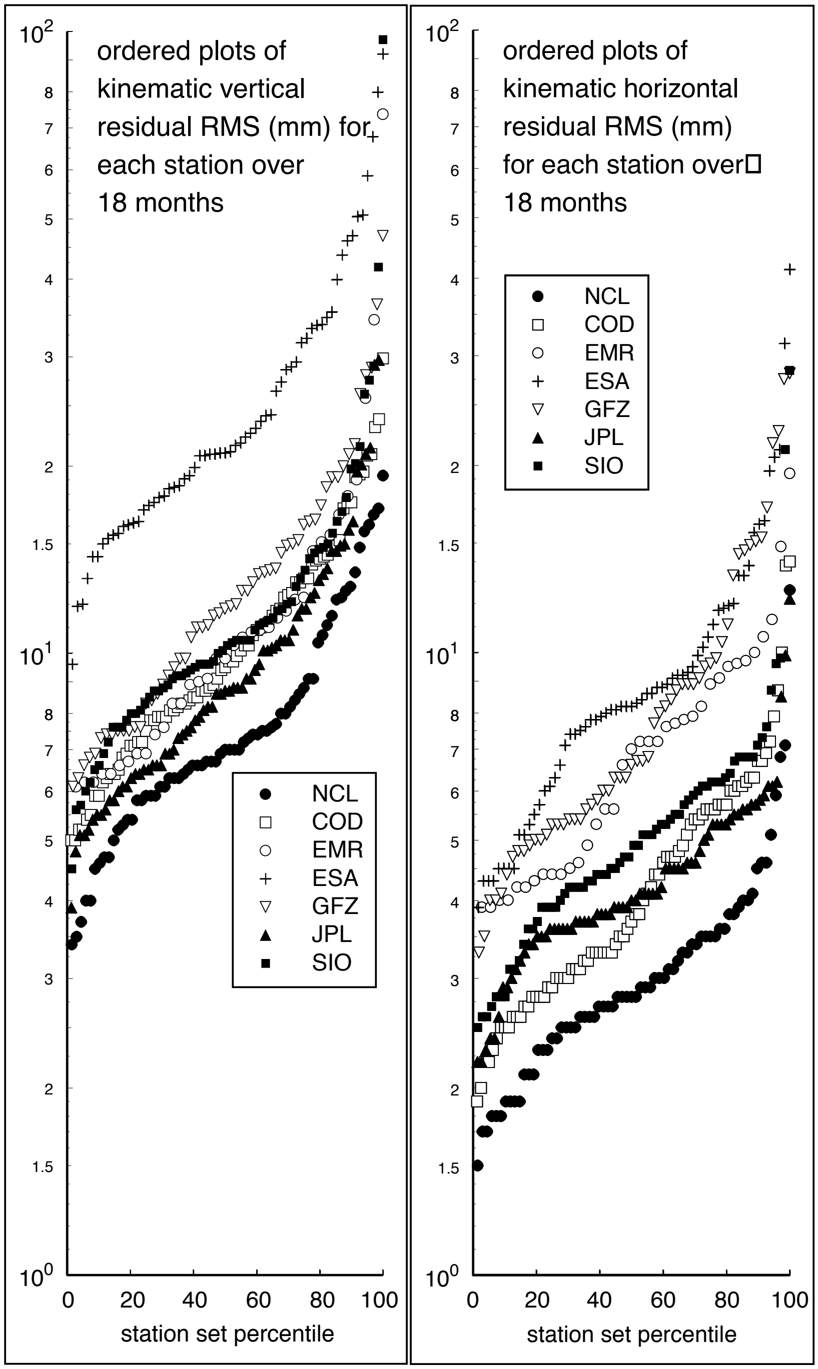


Figure 5: Ordered plots of station time-series horizontal and vertical kinematic residual rms over 18 months of weekly A-networks and the G-network (labeled NCL)

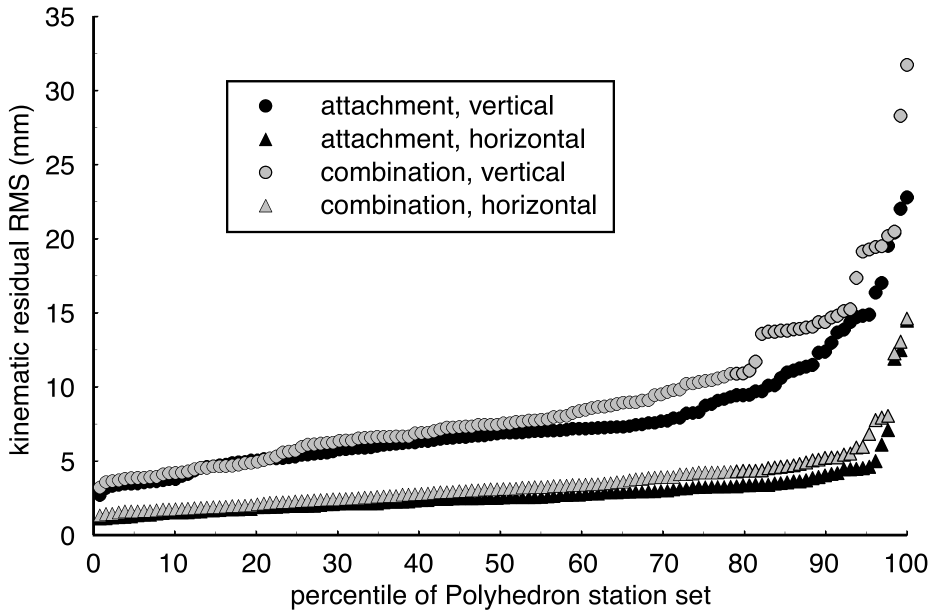
Table 2: Minimum, median, and maximum station kinematic residual rms for the NCL G-network and each A-network over 18 months

A/G	Vertical (mm)			North (mm)			East (mm)		
Net	min	med	max	min	med	max	min	med	max
NCL	3.4	7.0	19.3	1.3	2.6	11.7	1.7	3.0	13.5
COD	5.0	9.5	29.8	1.7	3.2	12.8	2.0	4.2	17.8
EMR	6.1	9.8	73.6	2.6	4.8	16.5	3.8	8.4	26.7
ESA	9.6	21.0	92.0	3.5	6.9	44.0	3.2	8.7	58.1
GFZ	6.1	11.8	46.9	2.4	5.6	20.5	3.3	7.0	39.2
JPL	3.9	8.7	165.4	1.9	3.5	12.6	1.9	4.4	12.8
SIO	4.5	10.3	97.0	2.4	4.1	12.5	2.4	5.2	39.4

6 Conclusions

The IGS network continues to grow, and the multi-agency Densification scheme involving ACs, RNAAC, and GNAAC components has now been operating successfully for 20 months with a station set of up to 140 stations including up to 70 with Global status. The results presented here (Figures 4 and 5, Tables 1 and 2) show that for the high-reliability Global station subset, the NCL G-network solution has significantly better time-series performance than any AC network. This is by no means an obvious result, since the weekly AC networks are based on the same GPS data sets and so are not really independent. We attribute the improvement to careful variance component estimation and iterative outlier removal in GNAAC analysis, which balances the relative quality of the A-networks and removes station-specific gross errors. This report shows that this week-by-week analysis leads to better repeatabilities in the genuinely independent time-series.

Further, the GNAAC process densifies the Polyhedron by building on this proven high-reliability G-network as a primary frame. By attaching RNAAC components and not allowing Global station estimates to change in this step, we avoid dependence on R-network variance scaling factors, and the absence of an R-network component in a particular week does not threaten the Polyhedron's week-to-week consistency.



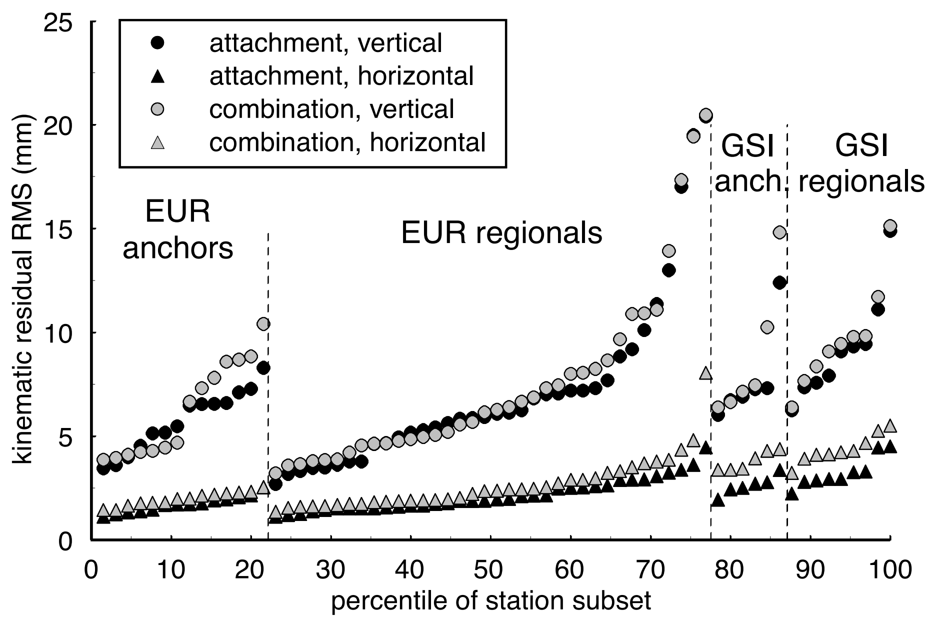


Figure 6: Ordered plots of station time-series horizontal and vertical kinematic residual rms from attachment and combination methods. Upper plot: all Polyhedron stations; lower plot: Anchor and Regional station subsets only for EUR and GSI R-networks

The NCL Polyhedron method is designed to be immediately extendible to many hundreds of stations by introduction of new Regional networks. This requires only that the SINEX format written by ACs and AACs is robust (i.e., manual file correction by the GNAAC is eliminated), and that station information is consistent between all groups. Although the SINEX written by ACs and AACs has improved during 1996, occasional unexpected format errors still occur, and this is an impediment to achieving full automation of the GNAAC step. IGS station names and antenna heights also still suffer from occasional inconsistencies between Analysis Groups - it is hoped that the new machine-readable station logs maintained by IGSCB will help to minimize this problem.

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Comparison of Coordinates, Geocenter, and Scale from All IGS Analysis Centers: GNAAC Activities at JPL for Weeks 813 to 897

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Global Network Associate Analysis Center (GNAAC) activities at JPL began 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 in week 890. To date, 85 comparison summaries have been mailed to the IGS. In addition, the weekly GPS combination and summary are submitted to the CDDIS.

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

A free-network combination of solutions from all centers is also computed. Each solution is scaled and edited according to the results of pairwise 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 seven-parameter Helmert transformation. The WRMS residuals are tabulated in the report.

Results for weeks 837 to 897 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 weekly comparisons. GPS weeks 837-897

Center	North, mm	East, mm	Vertical, mm
COD	3	3	11
EMR	4	8	11
ESA	4	8	38
GFZ	3	9	13
JPL	2	3	8
NGS	10	15	14
SIO	2	3	8

Table 2: Mean geocenter and scale offsets with respect to JPL. GPS weeks 837-897

Center	TX, cm	TY, cm	TZ, cm	Scale, ppb
COD	0.8	-0.5	0.0	0.2
EMR	1.0	-11.9	6.7	-0.4
ESA	0.5	3.8	-2.6	3.6
GFZ	-1.6	-10.3	2.2	0.3
NGS	0.5	-19.6	5.4	-3.1
SIO	0.0	-0.4	1.8	-0.5

The GNAAC comparisons reveal some differences in performance among the seven analysis centers. The mean WRMS coordinate residuals for all centers over all weeks is 4 mm North, 7 mm East, and 15 mm Vertical. Geocenter offsets range from the mm level to more than 10 cm. Scale differences are less than 1 part per billion for all but two centers. Overall, the agreement in horizontal coordinates is at the mm level, the agreement in vertical coordinates is at the cm level, the agreement in geocenter is at the 1- to 10-cm level, and the agreement in scale is at the level of a few parts per billion.

MIT T2 Associate Analysis Center Report

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1 Analysis Procedures

Two analyses are performed each week. One of these uses the IGS Analysis Center (AC) weekly A-SINEX[1] files to generate a 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. G-SINEX file generation started in GPS week 822 with approximately 85 stations in the combination. Between 98 and 107 stations are now included in the G-SINEX files. P-SINEX file generation started in week 860 with approximately 115 stations and now typically has 140 to 150 stations included. The two types of combinations are similar, but there are differences in the methods used to compute the variance re-scaling factors for each of the centers.

The G-SINEX-combination analysis is composed of several steps: (a) remove the AC constraints, (b) determine the appropriate variance scaling factor for each AC, (c) combine the loosely constrained AC analyses in both tightly and weakly constrained solutions, and (d) compare the coordinate estimates with the coordinates from the combined and individual AC SINEX files. Each week a summary file and the constrained combined SINEX file are submitted to the Crustal Dynamics Data Information System (CDDIS). An unconstrained solution can be generated from the submitted SINEX file by removing the constraints as discussed in Section 1.1. The starting dates of the SINEX files processed in the MIT analyses are listed in Table 1 (along with other statistics discussed in Section 1.2).

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[1] A-SINEX (Analysis Solution-Independent Exchange) files are from the IGS Analysis Centers for their daily analyses and orbit determination.
G-SINEX are Global SINEX files generated by combining the AC's A-SINEX files.
R-SINEX files are regional network solutions produced by Associate ACs.
P-SINEX is the final combination of the Regional and Global Solution files for the "Polyhedron-SINEX" file.

The R-SINEX combination is done in a similar fashion except that the computation of the variance scaling factors is performed differently. Each week the combined P-SINEX and summary files are submitted. The generation of these products lags 4 weeks behind the G-SINEX file generation.

1.1 Deconstraining AC SINEX Files

The procedure used to deconstrain the AC and AAC SINEX files is described in [1] and the same procedures are still used. We have noticed numerical stability problems with the COD and PGC SINEX files, and we have solved these by scaling the diagonal of the covariance matrix by a small amount (the addition of 1 part per million seems to stabilize these matrices). This scaling seems to be necessary only when multiple SINEX files are combined, and we suspect, in the case of COD, that it is due to the propagation of small errors in the near-unity negative correlations associated with a very precisely determined center of mass position. For the PGC files, we are not sure why the instabilities exist, but it could be due to these files being generated with one station fixed and then the addition of additional covariance information to allow the system to translate. In general, whenever tight constraints are applied and later loosened, there is some loss in the precision of the covariance matrix. The loss of precision can adversely effect the stability of long-time combinations of SINEX files.

1.2 AC Variance Rescaling

For all ACs, we first compute a variance scaling factor; the AC's covariance matrix is multiplied by this factor before it is combined with other AC analyses. We compute this factor from the χ^2 of the fit of the AC's loose analysis to the ITRF94 coordinates of the 13 core sites. In this analysis, we allow the coordinate system to rotate (parametrized as polar motion and UT1-UTC), but we do not allow explicit scaling or translation of the coordinate system. Those centers that yield coordinates aligned with the center of mass of the Earth (as realized through the ITRF94 coordinates) tend to have smaller rescaling values with this approach. The average value of scaling factors used between the start of SINEX file submission and Week 900 are given in Table 1 in the column labeled "Average Variance Scale." The scaling factors are computed independently each week.

Table 1: Summary of statistics of Centers. The column entries are: Start Week is the first week of SINEX file submission; Average variance scale is the average value of the multiplier used to scale the covariance matrix; $\langle \chi^2/f \rangle$ is the average χ^2/f of the combination of each center by itself over all of the SINEX files available to Week 900. If the average variance scaling were correct, this latter value should 1.0

Center	Start Week	Average variance scale	$\langle \chi^2/f \rangle$
COD	819	15.1	3.3
EMR	819	26.2	0.9
JPL	819	10.3	2.0
GFZ	819	90.3	1.3
SIO	822	1.4	4.5
NGS	822	474	1.1
ESA	840	9.9	2.2
AUS	884	35.6	3.3
EUR	860	16.6	11.1
GIA	860	22.2	2.1
GSI	860	5.9	2.5
PGC	860	2.2	2.8
SIR	860	26.7	6.7

For the AACs, computation of the variance scaling factors is more complicated because with these SINEX files we do not have a large set of core sites that can be constrained to generate a χ^2 increment. Instead, we combine the individual R-SINEX files with the G-SINEX file from the AC combination and compute the variance scaling from this increment in χ^2. The reliability of the estimate will depend on the number of overlapping sites. For some of the AACs, the overlap is only one or two stations, and in these cases the computation may not be reliable. Again, we allow the R-SINEX file to rotate but not to explicitly translate or scale.

With over a year of A-SINEX files and 9 months of R-SINEX files available, we can assess the variance scaling factors by computing the χ^2 per degree of freedom (χ^2/f) when all of the SINEX files from each center are combined. These values are shown in Table 1 for each center. Much of the difference between centers in the values of the average variance scaling factors can be explained by the different noise assumptions made and different sampling rates used by the centers. Specifically, different sampling rates between 30 seconds and 5 minutes, for example, seem to have little impact on the quality of geodetic position estimates, and yet when errors in the carrier phase measurements are assumed to be white noise, the variance of the estimates would differ by a factor of 10 at these two extremes of sampling rates. The improvement expected from using more data is not seen in practice, indicating the GPS carrier phase measurements have noise components with temporal correlation times of at least 5 minutes.

The temporal changes in the variance rescaling factors show interesting patterns for some centers. In Figure 1, we show the rescaling factors for the COD center. Superimposed on the variance rescaling values is a fit to an annual signal, which seems to well match the behavior of the factors, suggesting that seasonal effects on the quality of geodetic position estimates are present in the COD analysis. Such seasonal variations have been seen in VLBI analyses and are thought to arise from the seasonal variations in the variances of water vapor delays. The seasonal signal is not so evident in the χ^2/f increments as the SINEX files from this center alone are combined. The lack of the seasonal signal in this case is probably due to more balance between northern and southern hemisphere sites in the combination. (The variance rescaling is computed from only the 13 core sites, of which 9 are in the northern hemisphere). Similar variations are seen in the JPL analyses, but for the other centers any such patterns seem to be masked by the effects of processing strategy changes over the last year.

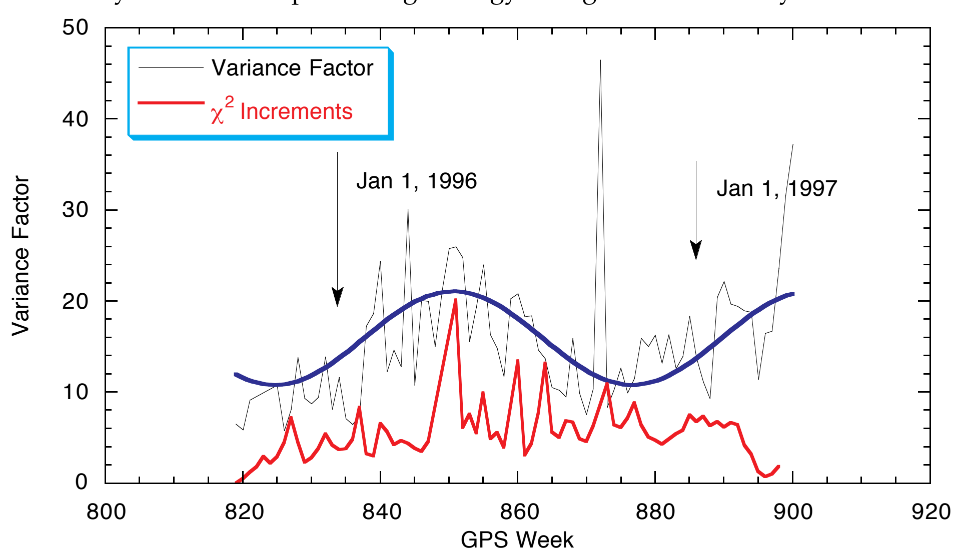


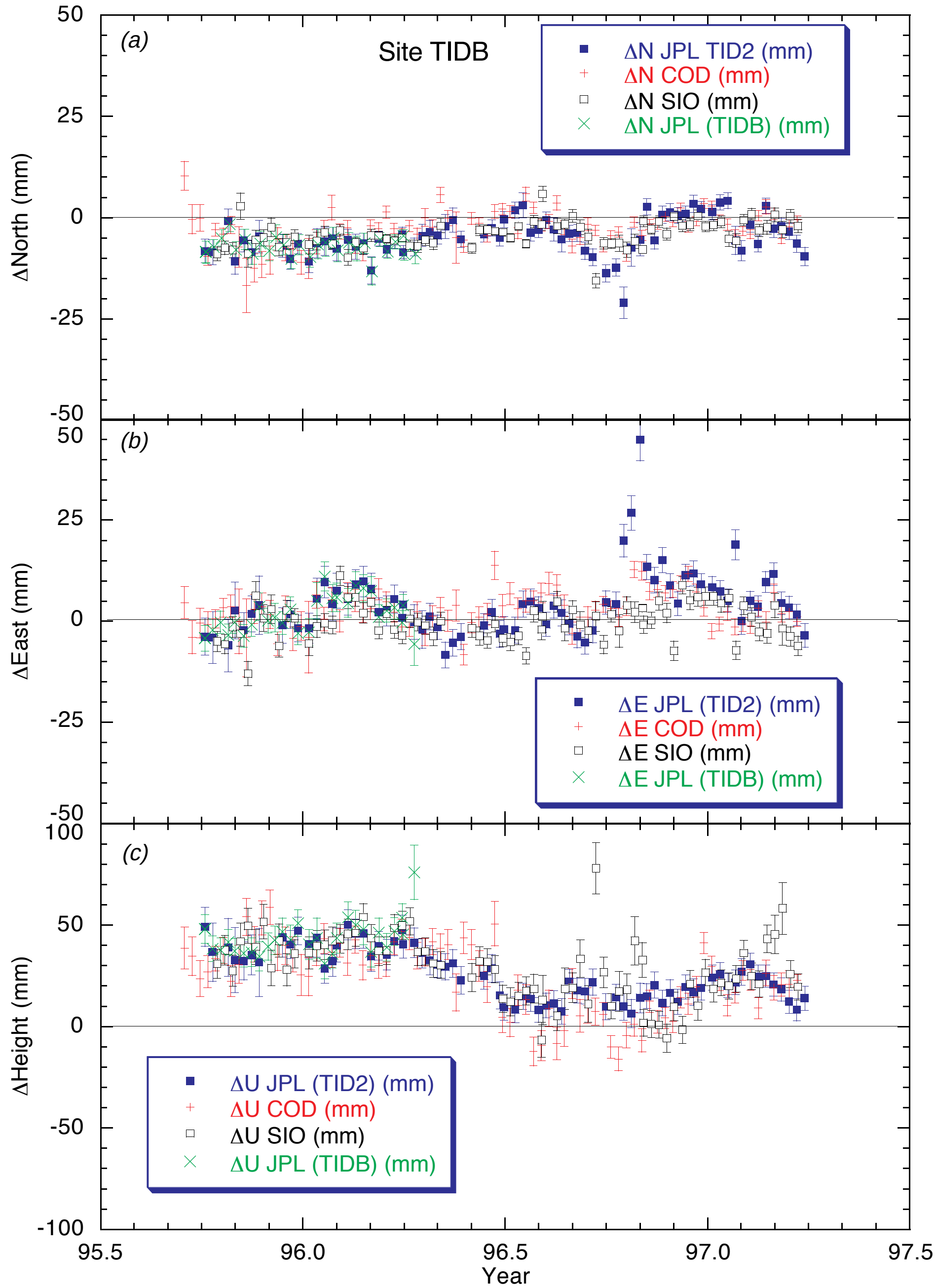
Figure 1: Variance rescaling factors for the COD analysis center as a function of GPS week number. The thin line is the weekly estimate of the variance factor reported in the MIT summary files; the rough thick solid line is the χ^2/f increments each week as the SINEX files are combined after applying an average variance rescaling factor of 15.1 (Table 1); the smooth thick line is a fit of the annual signal to the variance scaling factors. The parameters of the fit are 15.9 + 4.6 sin $(2\pi T)$ - 2.2 cos $(2\pi T)$ where T is time in years from January 1, 1996

The other aspect of note in Table 1 is that even after using an average variance scaling factor for each center, the combination of many months of data generates average χ^2/f increments in excess of unity. This behavior shows that there are noise components with correlation times in excess of 1 week. These types of correlations are discussed in [2] for regional GPS results but are also evident in global GPS results. An example is shown in Figure 2 for the site at Tidbinbilla in Australia. For clarity, we show position estimates from only three ACs (COD, JPL, and SIO). The systematic deviations from a linear fit to the components of the site position are evident and are correlated between the different analysis centers. These deviations and their temporal correlations contribute to the additional χ^2 increments when the SINEX files are combined. This case is also somewhat unique in that the JPL analysis uses the data from the TID2 receiver, whereas the SIO and COD analyses use the data from TIDB, which is a different receiver although it uses the same antenna as TID2.

Not all systematic deviations from linear trends are exactly common to all AC results. Examples are shown (again for COD, JPL, and SIO) in Figures 3 and 4. In Figure 3 (YELL), similar trends are seen, but there are time-dependent differences that develop. In Figure 4, we see a very clear case of systematic height differences between the analysis centers even after correcting the antenna height error in the JPL analysis for this site. This deviation at IRKT may be related to the different elevation angle cutoff used by COD compared with that used by JPL and SIO and is similar in magnitude to the systematic deviations with elevation cutoff angle reported in [3].

1.3 Combination Analysis

Two combined solutions are formed each week using all information from all the centers. In our combinations, we do not remove sites from any of the analyses. We do, however, change some of the estimated site coordinates if an incorrect antenna height is used in the analysis. Provided the change in position is small compared with the constraints on the a priori station coordinates, this procedure should yield the same results as those that would have been obtained had the correct station height been used. Errors in antenna heights have been a major problem in the combinations. As of Week 901, the centers with the largest number of incorrect heights are JPL with 17 sites and GIA with 13 sites, although in the case of GIA only one of the sites with errors is actually used in their analysis (i.e., their SITE/ECCENTRICITY block contains more sites than are used in the analysis). GIA also raises the problematic issue that the SITE/ECCENTRICITY block is just a generic block “pasted” into the SINEX file rather than directly generated from the actual information used during the analysis. SIO and ESA have two sites wrong, and EMR has 1 site wrong. While many centers correct antenna-height problems shortly after they are reported in the summary files, some centers seem to ignore these errors and simply continue processing with the incorrect heights.


Site TIDB
(a)
ΔN JPL TID2 (mm)
ΔN COD (mm)
ΔN SIO (mm)
ΔN JPL (TIDB) (mm)
ΔNorth (mm)
(b)
ΔE JPL (TID2) (mm)
ΔE COD (mm)
ΔE SIO (mm)
ΔE JPL (TIDB) (mm)
ΔEast (mm)
(c)
ΔU JPL (TID2) (mm)
ΔU COD (mm)
ΔU SIO (mm)
ΔU JPL (TIDB) (mm)
ΔHeight (mm)
Year
95.5
96.0
96.5
97.0
97.5

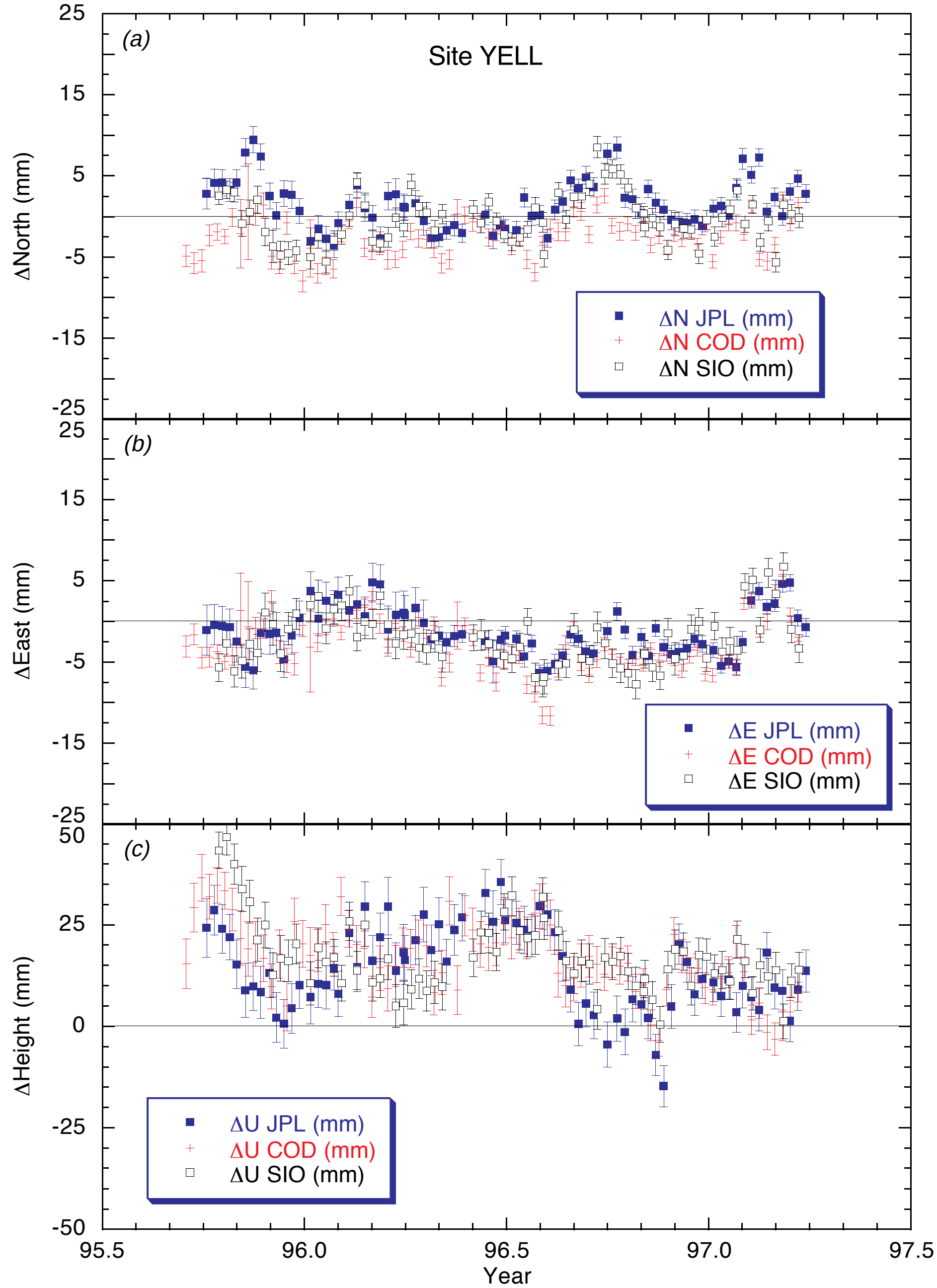
After correction for any station eccentricity errors, the corrected AC analyses are combined into a single analysis using the program GLOBK. The combination estimates all station positions and allows for rotations between the AC's SINEX files. No scale factors or explicit translations are estimated in this combination. In the "tight" combination submitted to the CDDIS, the 13 core-IGS sites are constrained to a few millimeters, as reported in the summary file also submitted to the CDDIS. Also each week (and lagging 4 weeks behind the AC analysis), we combine all the AAC R-SINEX files with the G-SINEX file generated from the AC SINEX files into to single P-SINEX files, which typically contains about 150 sites. The summary file for these combinations reports the rms difference of the horizontal site position estimates for the sites common to the G-SINEX and the P-SINEX files. These rms differences are usually between 1 and 2 mm, but in some cases can be larger if a site is present in only a few of the A-SINEX files.

1.4 Comparisons With ITRF94 and Combined Analysis

We carried out several types of analyses with the available SINEX files. In one class of analysis, we have combined each center separately (used to generate Table 1), and in another we have combined all of the centers into a single analysis.

The results from the single combined analysis of all the SINEX files are shown in Figure 5. Here we show the differences between the estimated coordinates and velocities for the 41 sites in the ITRF94 coordinate system that are used in these SINEX files. The overall rms differences in positions and velocities for all 41 sites are—for positions (referred to 1997.25)—North 11.9 mm, East 11.4 mm, Height 21.9 mm and—for velocities—North 4.5 mm/yr, East 4.0 mm/yr, and Height 10.8 mm/yr. The overall χ^2/f for the combination was 5.5 even after scaling each center so that its internal χ^2/f was unity. The reason for this increase in χ^2/f is evident in Figure 4, where clearly there are mean differences in the position estimates of some sites that we believe are related to the local geometry of the antenna setup. Other differences arise from the changing use of phase center models in the analyses.

Figure 2: Deviations of the TIDB and TID2 position estimates from the secular motion (position and velocity) determined from the combined analysis of all the AC and AAC SINEX files given in Table 1. Results from only three centers are shown; the JPL TIDB crosses show results for this center only until April 1996. Systematic deviations are common to all three centers and between the TIDB and TID2 receivers


(a)
Site YELL
ΔNorth (mm)
ΔN JPL (mm)
ΔN COD (mm)
ΔN SIO (mm)
(b)
ΔEast (mm)
ΔE JPL (mm)
ΔE COD (mm)
ΔE SIO (mm)
(c)
ΔHeight (mm)
ΔU JPL (mm)
ΔU COD (mm)
ΔU SIO (mm)
Year
95.5
96.0
96.5
97.0
97.5

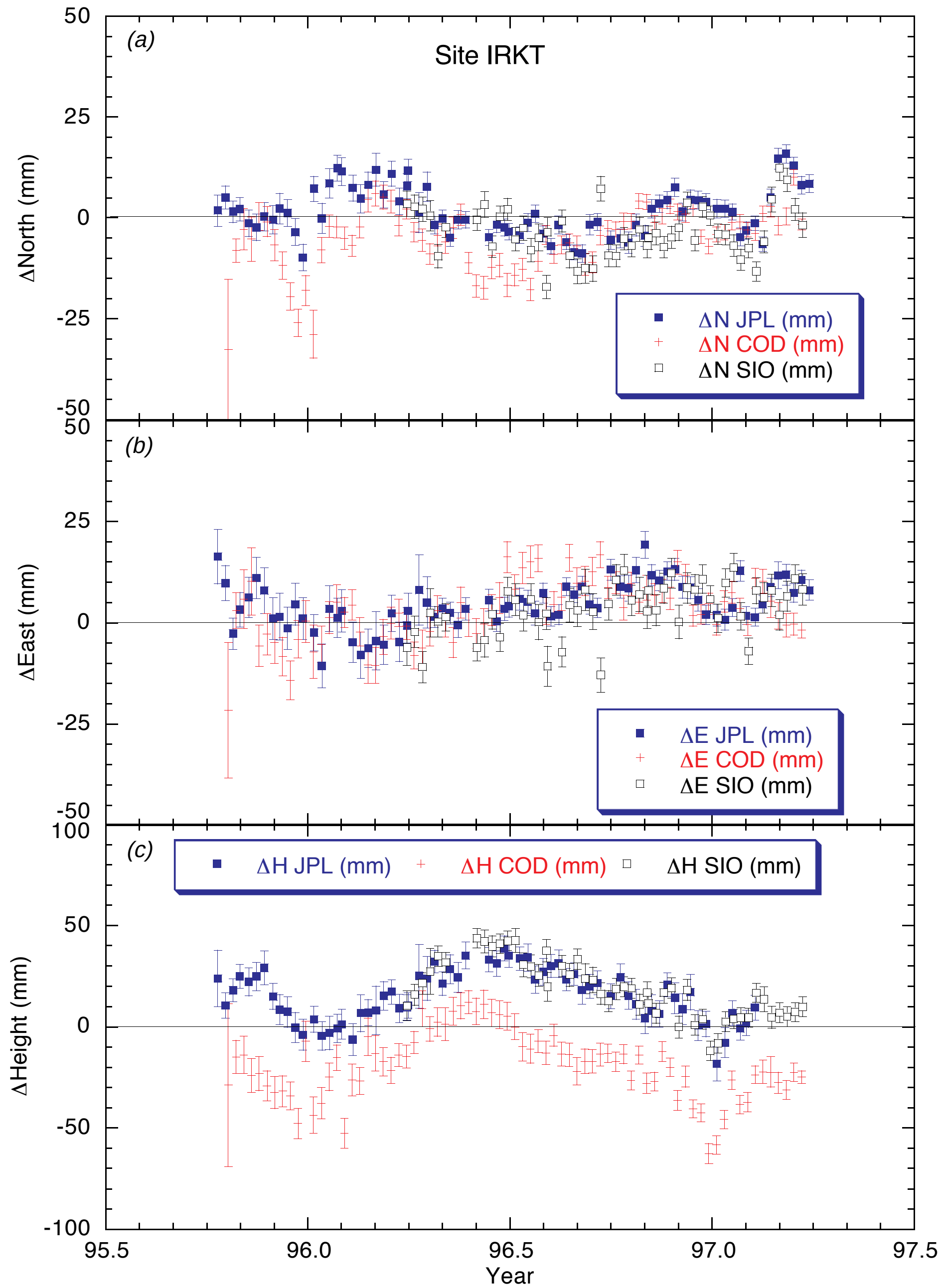
One of the most disturbing aspects of these combinations is the behavior of the SNR-8 Rogues. The most recent example is the MADR site, where the receiver seems to have failed in a mode that still generates usable data, but whose position estimates are clearly corrupted (unless the MADR antenna moved by 50 mm north over the last few months). Similar failures have been seen in the past at WETT, where again the receiver output usable data, but the position estimates from these data are corrupted. (These errors in the WETT receiver are clearly seen (again in the north component) in Figure 5. Even if data after September 1996 when the north component position estimate became erratic are excluded from the combined analysis (which was the case in Figure 5), the position and velocity estimates are still unreasonable, even though the week-to-week scatter is similar to that of other stations. This seems to reflect a subtle failure mode in the SNR-8 receivers, which would seem to need investigation.

2 Conclusions

The greatest difficulty in G-SINEX and P-SINEX file generation has been incorrect antenna height information used by the ACs. There have also been problems with site eccentricity information which is "pasted" into the SINEX files rather than derived from the files actually used in the analysis. This practice is very problematic since it is not possible to reliably correct any errors in this case.

The use of phase center models is not consistent in the IGS at the moment. AUS, JPL, SIO, and SIR do not seem to be using a phase center model; EMR and PGC do not report a phase center model, but these centers use only Dorne-Margolin antennas, which for the IGS01 phase center model have zero corrections. Non-use of a phase center model results in height differences of over 10 cm for sites with non-Dorne-Margolin antennas.

Figure 3: Deviations of the YELL position estimates from the secular motion (position and velocity) determined from the combined analysis of all the AC and AAC SINEX files given in Table 1. Results from only three centers are shown. Systematic deviations are common to all three centers; however, there are times during which the three centers deviate by amounts that are comparable to the systematic deviations themselves. At the beginning of the series, the heights from COD fall midway between those from SIO and JPL, and later, in September 1996, the JPL analysis is low by 10 mm compared to those for SIO and COD. At this same time, the North component for COD does not show the same deviation as those from SIO and JPL analyses


(a)
Site IRKT
ΔNorth (mm)
50
25
0
-25
-50
ΔN JPL (mm)
ΔN COD (mm)
ΔN SIO (mm)
(b)
ΔEast (mm)
50
25
0
-25
-50
ΔE JPL (mm)
ΔE COD (mm)
ΔE SIO (mm)
(c)
ΔHeight (mm)
100
50
0
-50
-100
ΔH JPL (mm)
ΔH COD (mm)
ΔH SIO (mm)
95.5
96.0
96.5
97.0
97.5
Year

Earth orientation results in weekly SINEX files pose particular problems for us for two reasons: (a) each center's treatment is not the same, which makes it difficult to combine SINEX files with and without Earth orientation estimates, and when the parametrization is different, it is difficult to combine these; (b) we use a Kalman filter in our analysis and parameters such as those for Earth orientation are treated stochastically, and therefore the intermediate values after the combination of several days of data are not available in the final state vector of the filter. The way to best represent Earth-orientation parameters, especially when multiyear SINEX files are generated, is not clear at the moment.

References

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[3] P. Elosegui, J. L. Davis, T. K. Jaldehag, J. M. Johansson, A. E. Niell, and I. I. Shapiro, "Geodesy Using the Global Positioning System: The Effects of Signal Scattering on Estimates of Site Positions," *J. Geophys. Res*., 94, 9921–9934, 1995.

Figure 4: Deviations of the IRKT position estimates from the secular motion (position and velocity) determined from the combined analysis of all the AC and AAC SINEX files given in Table 1. Results from only three centers are shown. In this figure, all of the centers show a similar annual signal in the height variations, but COD, which uses a 20° elevation-angle cutoff, is clearly displaced from SIO and JPL, which use 15° elevation-angle cutoffs. We have corrected the 35.9-mm height error in the JPL analysis by assuming that the currently reported height of 92.1 mm has been used for all the analyses (the actual height of the site is 128 mm). The sign of this correction is such that, if it is not applied, the deviation between JPL and COD is even larger than shown

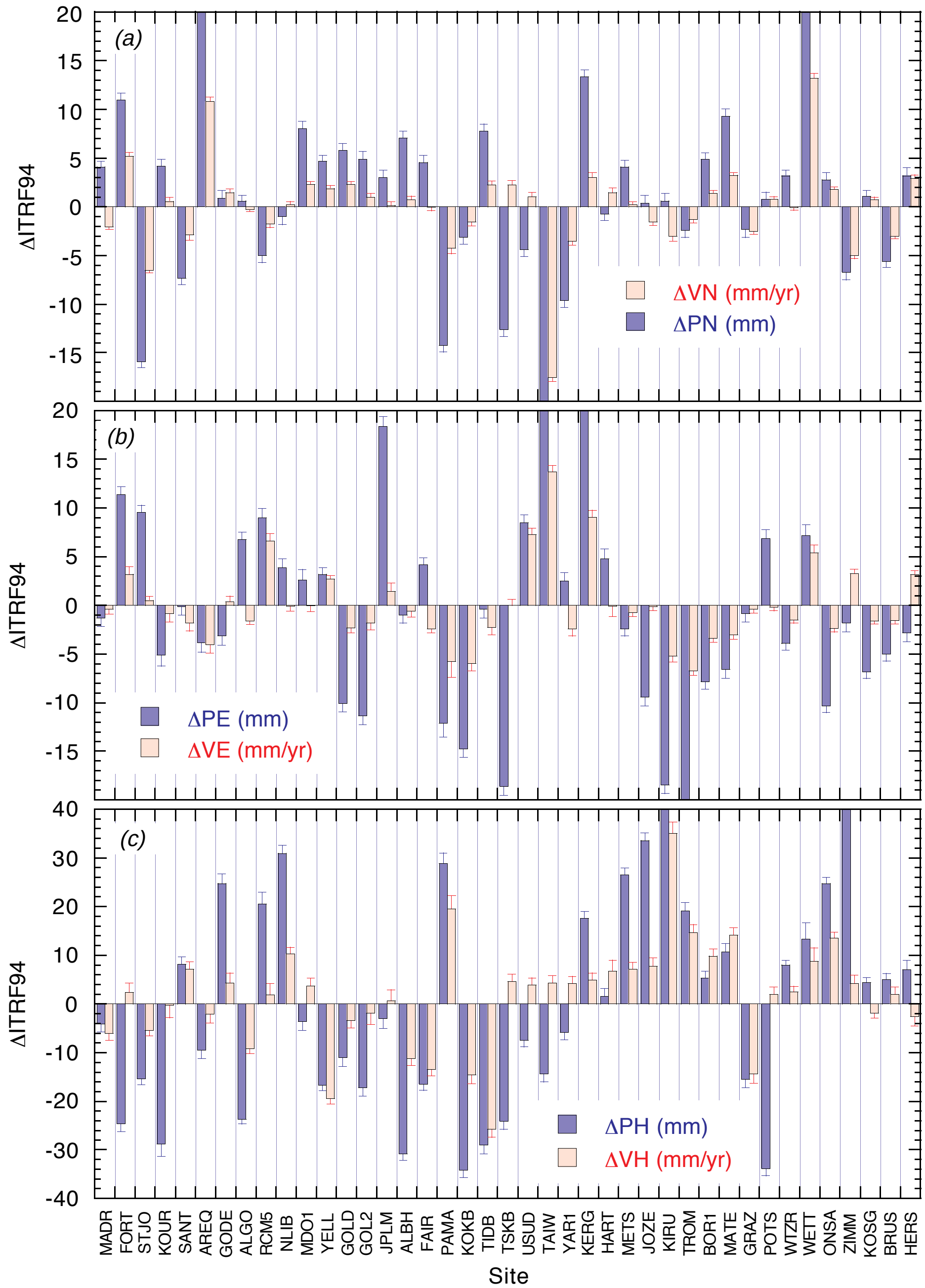
(a)
(b)
(c)
ΔITRF94
ΔVN (mm/yr)
ΔPN (mm)
ΔPE (mm)
ΔVE (mm/yr)
ΔPH (mm)
ΔVH (mm/yr)
Site
MADR FORT STJO KOUR SANT AREQ GODE ALGO RCM5 NLIB MDO1 YELL GOLD GOL2 JPLM ALBH FAIR PAMA KOKB TIDB TSKB USUD TAIW YAR1 KERG HART METS JOZE KIRU TROM BOR1 MATE GRAZ POTS WTZR WETT ONSA ZIMM KOSG BRUS HERS

Figure 5: Differences between the ITRF94 positions (referenced to 1997.25) and velocities and those determined from the analysis of the 1.5 years of SINEX files listed in Table 1. The dark-shaded boxes are positions, and the light-shaded boxes are velocity. One-standard-deviation error bars (based on individual center rescaling) are shown. Position and velocity differences are shown for (a) North; the values off scale are AREQ, ΔN 30.5 ±0.7 mm; TAIW, ΔN –50.8 ±0.7 mm; and WETT, ΔN 23.0 ±0.8 mm. (b) East; the values off scale are TAIW, ΔE 26.2 ±1.0 mm; KERG, ΔE 38.4 ±0.9 mm; and TROM, ΔE –20.1 ±0.7 mm. (c) Height; the values off scale are KIRU, ΔH 43.0 ±2.3 mm; and ZIMM, ΔH 47.8 ±1.7 mm

IGS

REGIONAL NETWORK ASSOCIATE ANALYSIS CENTER REPORTS

The EUREF Associate Analysis Center: 1996 Annual Report

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1 Introduction

The EUropean REference Frame (EUREF) Subcommission was founded in 1987 at the XIXth General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Vancouver. The main task of this IAG subcommission is the establishment, maintenance, and enhancement of a three-dimensional European reference frame. By definition, the European Terrestrial Reference System (ETRS) is fixed to the stable part of the European plate and coincides with the International Terrestrial Reference System (ITRS) at epoch 1989.0 (Resolution No 1 of the EUREF Symposium in Florence, 1990).

A first step towards the realization of the ETRS was taken in 1989 with the observation of the EUREF89 GPS campaign, which covered Western Europe. The EUREF89 campaign involved more than 100 stations and was substantially initiated by the EUREF steering committee set up in October 1988. Fiducials used for this campaign were SLR/VLBI sites fixed to their ITRF89 coordinates at epoch 1989.0, which gave a straightforward realization of the ETRS. Since this first EUREF campaign, several other EUREF campaigns were carried out ameliorating the results of previous campaigns and enlarging the territory covered to the outer parts of Europe.

In 1993, one of the resolutions of the EUREF symposium in Budapest, recognizing the establishment of the IGS, recommended the use of the IGS sites as fiducials for the processing of GPS campaigns to be integrated in EUREF. At the same time, the discussion to establish a densified network of permanent stations in Europe was initiated.

A year later at the EUREF symposium in Warsaw, the use of the European permanent stations for the maintenance of the European Reference Frame was recognized [1]. All organizations operating permanent GPS sites in Europe were invited to make their observations available, and analysis centers were invited to process European subnetworks of those permanent stations. The coordination of these activities with the IGS was recommended.

In May of 1995, one of the resolutions of the EUREF symposium in Helsinki, proposed to the IGS, was to consider the EUREF network as the European densification of the global IGS network. At the same time, guidelines for a EUREF permanent GPS Network were set up by W. Gurtner [2]. In October of the same year, a EUREF network coordinator (C. Bruyninx) was designated at the EUREF Technical Working Group meeting in Paris in order to coordinate the activities related to the European permanent network.

In March 1996, EUREF responded to the IGS "Call for Densification of the ITRF Through Regional GPS Analyses as IGS Network Associate Analysis Center." The EUREF proposal was based on the principle of distributed processing: Five EUREF analysis centers submit weekly solutions to the CODE Analysis Center, which combines these solutions to include a weekly combination of the routine Global Network CODE solution using the Bernese GPS software. The EUREF proposal was officially accepted by the IGS in May 1996.

2 Implementation of the EUREF Permanent Network

The EUREF permanent GPS network consists of permanent GPS tracking stations, Data Centers where the data from the EUREF network are made available to the EUREF community, and Analysis Centers that process the data from (a part of) the EUREF network [3].

2.1 GPS Tracking Stations

The EUREF network of tracking stations consists of all the European permanent sites included in the IGS Network, plus additional sites accepted by the EUREF Technical Working Group following similar rules as set up by and for IGS.

The EUREF network was extended in 1996 from 34 permanent stations to nearly 60 sites, covering 21 countries (Figure 1 and Table 1). Forty percent of the EUREF stations are not included in the IGS network.

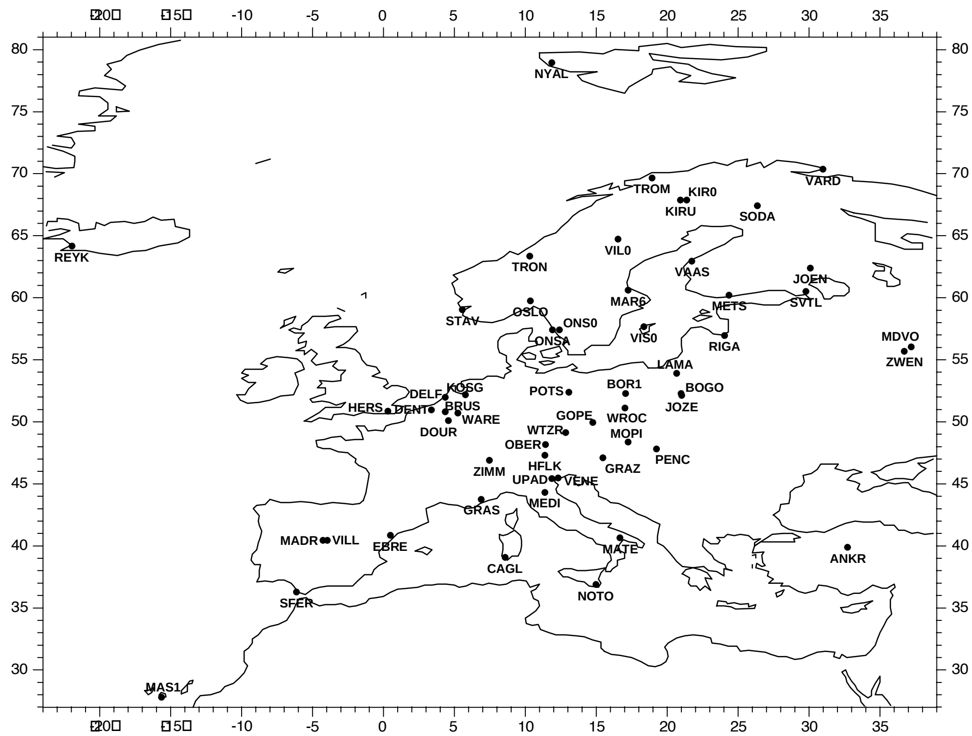


Figure 1: Stations included in the permanent EUREF GPS network

Table 1: Permanently Operating Stations of the EUREF network. Stations with an asterisk are part of the IGS network

No.	Stations	Char ID	Country	Lon (E)	Lat (N)	Agency[a]
1	Ankara*	ANKR	Turkey	32.83	39.92	IfAG
2	Borowa Gora	BOGO	Poland	21.02	52.28	ICG
3	Borowiec*	BOR1	Poland	17.07	52.27	ALO
4	Brussels*	BRUS	Belgium	4.36	50.80	ROB
5	Cagliari*	CAGL	Italy	8.58	39.08	ASI
6	Delft	DELF	Netherlands	4.39	51.98	DUT
7	Dentergem	DENT	Belgium	3.40	50.93	ROB
8	Dourbes	DOUR	Belgium	4.59	50.09	ROB
9	Ebre*	EBRE	Spain	0.49	40.82	ICC
10	Pecny*	GOPE	Czech Republic	14.79	49.91	RIG
11	Grasse*	GRAS	France	6.92	43.75	CNES
12	Graz*	GRAZ	Austria	15.49	47.07	ISR
13	Herstmonceux*	HERS	England	0.33	50.87	RGO
14	Innsbruck*	HFLK	Austria	11.39	47.31	ISR
15	Joensuu	JOEN	Finland	30.10	62.39	FGI
16	Jozefoslaw*	JOZE	Poland	21.03	52.08	WUT
17	Kellyville*	KELY	Greenland	–50.94	66.99	NOAA
18	Kiruna	KIR0	Sweden	20.97	67.88	OSO/NLS
19	Kiruna*	KIRU	Sweden	20.97	67.88	OSO/NLS
20	Kootwijk*	KOSG	Netherlands	5.80	52.17	DUT
21	Lamkowko*	LAMA	Poland	20.67	53.89	OUAT
22	Madrid*	MADR	Spain	–4.25	40.42	NASA/JPL

Table 1: (continued)

No.	Stations	Char ID	Country	Lon (E)	Lat (N)	Agency[a]
23	Maartsbo	MAR6	Sweden	17.26	60.60	OSO/NLS
24	Maspalomas*	MAS1	Spain	–15.63	27.77	ESA/ESOC
25	Matera*	MATE	Italy	16.70	40.63	ASI
26	Mendeleevo*	MDVO	Russia	37.22	56.03	DUT
27	Medicina*	MEDI	Italy	11.38	44.31	ASI
28	Metsähovi*	METS	Finland	24.38	60.22	FGI
29	Modra-Piesok	MOPI	Slovak Republic	17.27	48.37	SUT
30	Noto*	NOTO	Italy	14.99	36.88	ASI
31	Ny-Alesund*	NYAL	Norway	11.85	78.92	SK
32	Oberpfaffenhofen*	OBER	Germany	11.45	48.14	GFZ
33	Onsala	ONS0	Sweden	11.92	57.38	OSO/NLS
34	Onsala*	ONSA	Sweden	11.92	57.38	OSO/NLS
35	Oslo	OSLO	Norway	10.37	59.75	SK
36	Penc*	PENC	Hungary	19.28	47.78	SGO
37	Potsdam*	POTS	Germany	13.07	52.38	GFZ
38	Reykjavik*	REYK	Iceland	–21.51	64.09	IfAG
39	Riga	RIGA	Latvia	24.05	56.95	AIUL
40	San Fernando*	SFER	Spain	–6.12	36.28	ROA
41	Sodankylä	SODA	Finland	26.39	67.42	FGI
42	Stavanger	STAV	Norway	5.59	59.02	SK
43	Svetloe	SVTL	Russia	29.78	60.53	IAA
44	Thule*	THU1	Greenland	–68.73	76.56	JPL
45	Tromsø*	TROM	Norway	18.93	69.67	SK
46	Trondheim	TRON	Norway	10.32	63.37	SK
47	Padova*	UPAD	Italy	11.88	45.41	UP
48	Vaasa	VAAS	Finland	21.77	62.96	FGI
49	Vardo	VARD	Norway	31.02	70.34	SK
50	Venezia	VENE	Italy	12.33	45.43	ASI
51	Vilhelmina	VIL0	Sweden	16.56	64.70	OSO/NLS
52	Villafranca*	VILL	Spain	–3.95	40.44	ESA/ESOC
53	Visby	VIS0	Sweden	18.37	57.65	OSO/NLS
54	Waremme	WARE	Belgium	5.25	50.69	ROB
55	Wroclaw	WROC	Poland	17.03	51.06	AUW
56	Wettzell*	WTZR	Germany	12.88	49.14	IfAG
57	Zimmerwald*	ZIMM	Switzerland	7.45	46.87	FOT
58	Zwenigorod*	ZWEN	Russia	36.54	55.46	GFZ

[a]Agency acronyms:

AIUL	Astronomical Institute, University of Latvia, Latvia
ALO	Astronomical Latitude Observatory, Poland
ASI	Agenzia Spaziale Italiana, Italy
AUW	Agricultural University of Wroclaw, Poland
CNES	Centre National d'Etudes Spatiales, France
DUT	Delft University of Technology, the Netherlands
ESA	European Space Agency, Germany
ESOC	European Space Operations Center, Germany
FGI	Finnish Geodetic Institute, Finland
FOT	Federal Office of Topography, Switzerland
GFZ	GeoForschungsZentrum Potsdam, Germany
IAA	Institut of Applied Astronomy, Russia
ICC	Institut Cartografic de Catalunya, Spain
ICG	Institute of Geodesy and Cartography, Poland
IfAG	Institute for Applied Geodesy, Germany
ISR	Institute for Space Research, Austria
JPL	Jet Propulsion Laboratory, USA
NASA	National Aeronautics and Space Administration, USA
NLS	National Land Survey, Sweden
NOAA	National Oceanic and Atmospheric Administration, USA
OUAT	Olsztyn University of Agriculture and Technology, Poland

OSO	Onsala Space Observatory, Sweden
RGO	Royal Greenwich Observatory, England
RIG	Research Institute of Geodesy, Czech Republic
ROA	Real Instituto y Observatorio de la Armada, Spain
ROB	Royal Observatory of Belgium, Belgium
SGO	FOMI Satellite Geodetic Observatory, Hungary
SK	Statens Kartverk, Norwegian Mapping Authority, Norway
SUT	Slovak University of Technology, Slovak Republic
UP	University of Padova, Italy
WUT	Warsaw University of Technology, Poland

2.2 Data Centers

In addition to the Global IGS Data Center at IGN France and the Regional IGS Data Center at IfAG Germany (making available the data of four-fifths of the EUREF network), six EUREF local data centers (listed in Table 2) give access to the data from a particular EUREF subnetwork.

Table 2: EUREF/IGS data centers in Europe

Function[a]	Abbr.	Operated By	Location
IGS GDC	IGN	Institut Géographic National	Paris, France
IGS RDC	IfAG	Institute for Applied Geodesy	Frankfurt, Germany
EUREF LDC	ASI	Italian Space Agency	Matera, Italy
EUREF LDC	DUT	Delft University of Technology	Delft, The Netherlands
EUREF LDC	GRAZ	Institute of Space Research	Graz, Austria
EUREF LDC	OSO	Onsala Space Observatory	Göteborg, Sweden
EUREF LDC	ROB	Royal Observatory of Belgium	Brussels, Belgium
EUREF CB	ROB	Royal Observatory of Belgium	Brussels, Belgium

[a]Acronyms:
GDC: Global Data Center
RDC: Regional Data Center
LDC: Local Data Center
CB: Permanent Network Central Bureau

2.3 Analysis Centers

The processing scheme for the EUREF Permanent Network allows for distributed processing. EUREF assures that the data from all the stations in its network are processed by at least one analysis center. The EUREF Local Network Associated Analysis Centers (LNAACs) (listed in Table 3) process routinely the data from a particular EUREF subnetwork including the data from at least three geographically well-distributed EUREF stations processed by other LNAACs to enable the merging of the LNAACs' subnetwork with the remaining part of the EUREF network.

Table 3: EUREF local network analysis centers

Agency	Location	Software
Italian Space Agency (ASI)	Matera, Italy	Microcosm
Institute for Applied Geodesy (IfAG)	Frankfurt, Germany	Bernese 4.0
Bayerische Akademie der Wissenschaften (BEK)	München, Germany	Bernese 4.0
Observatory Lustbühel Graz (OLG)	Graz, Austria	Bernese 4.0
Bundesamt für Landestopographie (LPT)	Wabern, Switzerland	Bernese 4.0
Geodetic Observatory Pecny (GOP)	Pecny, Czech Republic	Bernese 4.0
Royal Observatory of Belgium (ROB)	Brussels, Belgium	Bernese 4.0
Warsaw University of Technology (WUT)	Warsaw, Poland	Bernese 4.0
Center for Orbit Determination in Europe (CODE)	Berne, Switzerland	Bernese 4.1
Nordic Geodetic Commission (NKG)	Onsala, Sweden	Bernese 4.0

In addition to the contribution to EUREF, the LNAACs' processing isused for local geophysical or geodetic applications, such as deformation monitoring, ionospheric analysis, and determination of national transformation formulas.

The EUREF data analysis follows IGS standards as much as possible and uses the precise IGS (or CODE) orbits and Earth rotation parameters. Taking into account that no specific data analysis recommendations were available to the EUREF analysis centers until very recently, the processing strategy used at most of the analysis centers is similar.

The LNAACs deliver weekly free-network solutions in the SINEX format to the IGS/EUREF Regional Data Center. Taking the time delay of the availability of the precise orbits into account, the products from the EUREF analysis centers are available within 2 to 3 weeks. The CODE Analysis Center combines all partial solutions into the official weekly EUREF solutions.

2.4 The EUREF Permanent Network Central Bureau

The EUREF permanent network coordination is performed at the Royal Observatory of Belgium; a fully documented information system (including descriptions of the permanent GPS stations, Local Data Centers, Local Analysis Centers, and their subnetworks) is operational and maintained (ftp `ftpserver.oma.be` or 193.190.249.203, `cd pub/astro/euref` or the Web site `http://www.oma.be//KSB-ORB/EUREF/eurefhome.html`).

The consistency between the headers of the RINEX data files and the station description files in the database are weekly checked and station personnel are contacted if necessary. The product availability is monitored and reports on the combined EUREF solution are made available as feedback to the contributing analysis centers.

3 The EUREF Local Network Associate Analysis Centers

3.1 The ASI/CGS Analysis Center

3.1.1 Introduction

The Matera Space Geodesy Center (CGS) operates four GPS permanent stations in Italy (Cagliari, Medicina, Noto, Venezia) since 1995, apart from the Matera GPS receiver, which was installed in 1991. In 1996, efforts were made to perform continuous data processing of the Italian network and data quality control. Automatic procedures were developed to reduce user interactions.

In response to a call for participation (January 1996), CGS joined the IGS pilot project for densification of ITRF through a regional GPS analysis network as IGS AAC, which provides weekly solutions of the Italian GPS Fiducial Network (IGFN) (Figure 2) since the start of the IGS commitment (June 30, 1996—GPS week 0860). At present, since September 1996, CGS gives its contribution within the EUREF as a Local Analysis Center, according to the IGS recommendations.

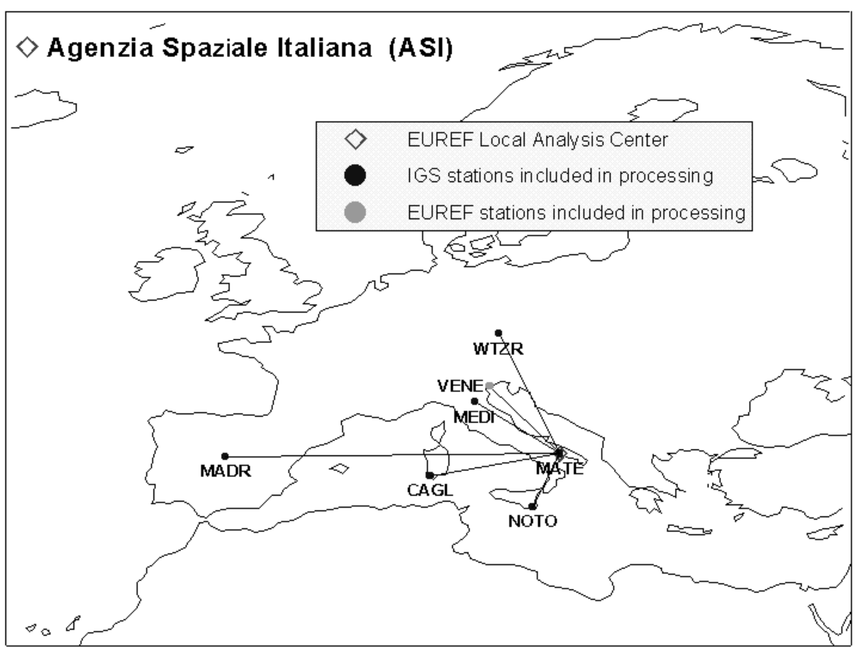


Figure 2: Italian GPS Fiducial Network

3.1.2 EUREF Activities at CGS

CGS provides continuous analysis of the IGFN since June 30, 1996. Beside the IGFN stations, the analyzed network includes also Madrid and Wettzell. The network, apart from the benefit of a densification of reference points in the area, has a remarkable tectonic interest in investigating the behavior of the Eurasian and African boundary and the supposed independent motion of the Adriatic microplate.

Data processing is performed on a HP755 workstation connected to the Internet and can be subdivided into two main steps:

- Data/IGS final-orbit retrieving.
- Data processing.

IGFN data are retrieved from the CGS geodetic data bank—GeoDAF (`http://geodaf.mt.asi.it`)—while the data from IGS anchor stations are generally retrieved from IfAG. IGS final orbits and ERP are taken from the CDDIS.

The second step consists of a main process producing a combined weekly solution by managing slave processes for daily data editing and formatting (double-difference construction), orbit estimation, and data reduction. The "core" of the data reduction procedure is based on the MicroCosm S/W, version 9408, produced by Van Martin System, Inc. (VMSI).

The whole automatic procedure starts usually on Wednesday night (data retrieval) and ends on Friday morning (final solution in SINEX format). At this point, the user has to check only the SINEX and summary files and send them to IfAG.

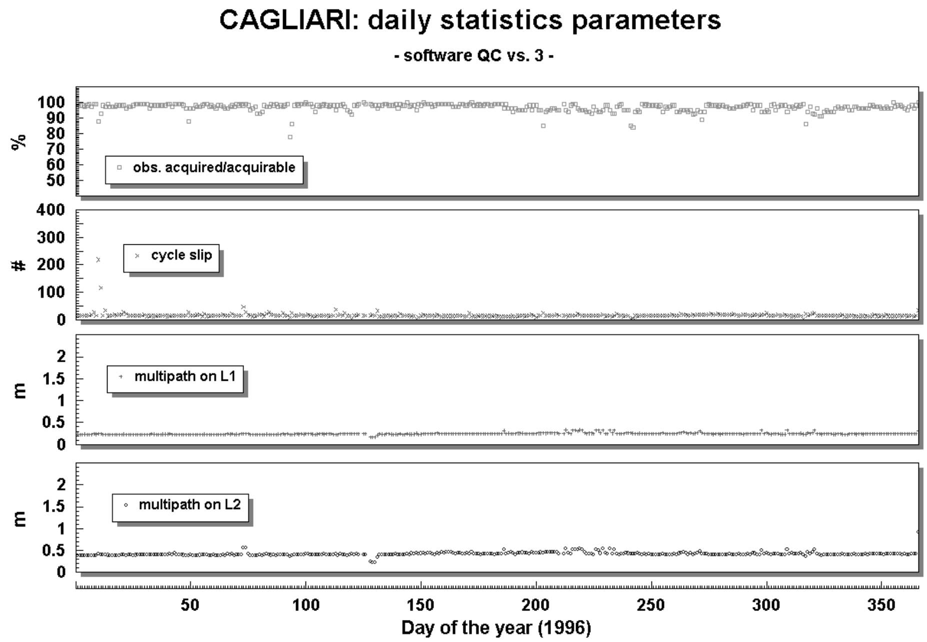
3.1.3 Some Features of Data Analysis Performed at CGS

Daily IGS precise orbits and ERP values act as input for a process providing the best-fit initial satellite state vectors and dynamic parameters (Y-bias and solar radiation pressure coefficients). All these parameters are kept fixed in the geodetic daily solutions, where double differenced ambiguities, tropospheric scale factors, and station coordinates are estimated. Daily solutions, as well as the final combined weekly solution, are constrained to ITRF94 by fixing Matera coordinates to those model predictions.

3.1.4 First Results

First results obtained by analyzing 9 months of data show a daily rms of coordinate residuals with respect to ITRF94 of 1 cm for horizontal components and 2 cm for height. In the case of Venezia and Madrid, these values are 1 cm higher due to specific site problems (respectively, interferences with the GPS signal and data acquisition problems in 1997) (Figures 3 and 4).

In spite of the short data span, Noto and Cagliari already show a good agreement with the predicted tectonic motions (Figure 5).



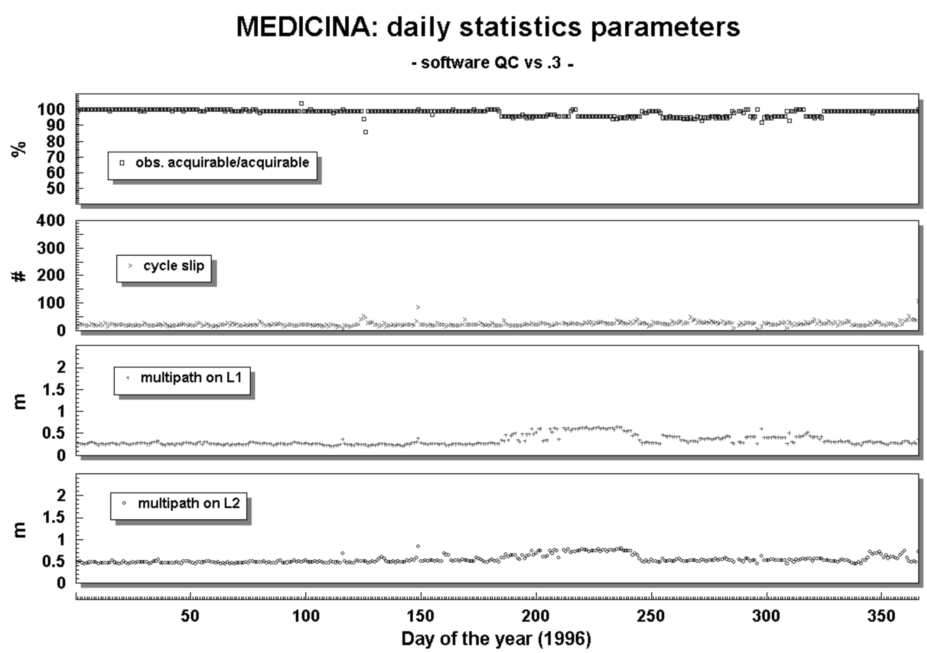
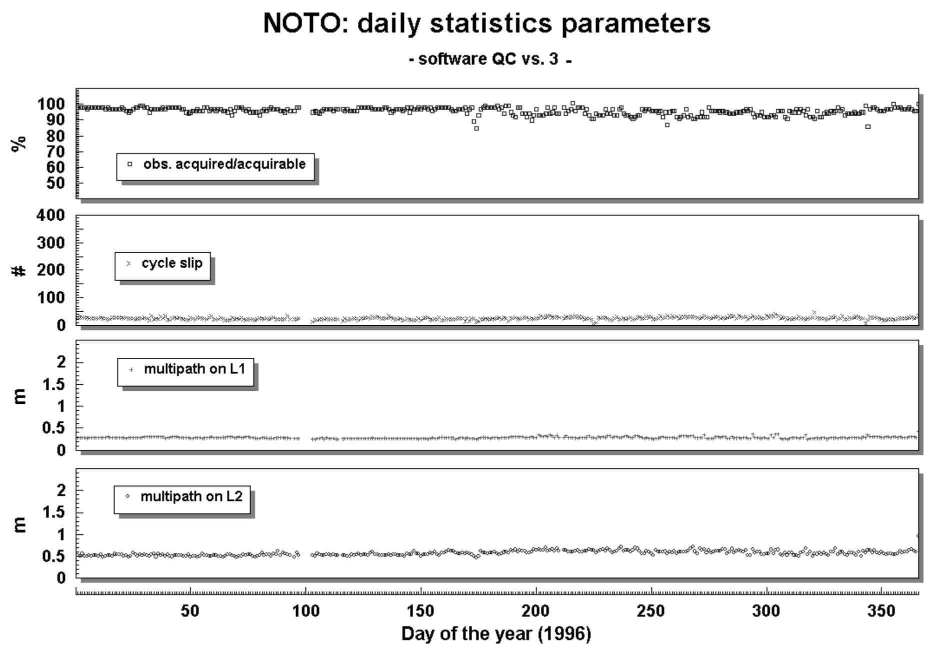


Figure 3: Check of data quality for Cagliari and Medicina



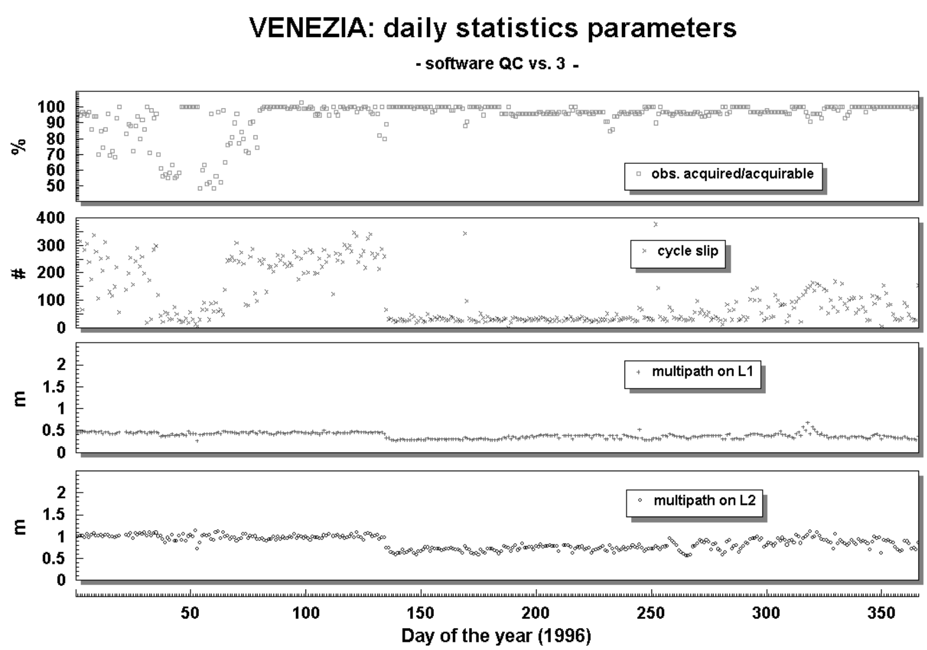


Figure 4: Check of data quality for and Noto and Venezia

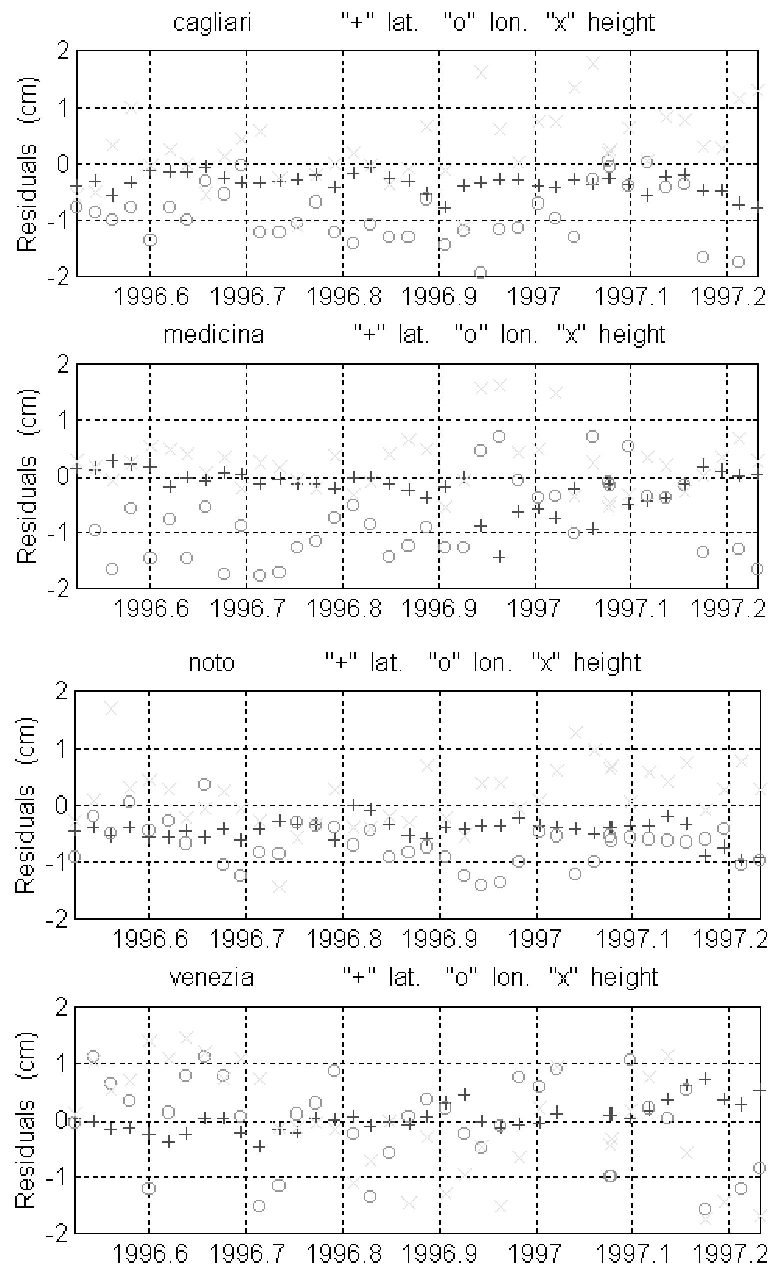


Figure 5: Coordinate residuals with regard to ITRF94 for Cagliari, Medicina, and Noto, and with regard to Nuvel1A for Venezia

3.2 The BEK Analysis Center

Since October 29, 1995, the Bayerische Akademie der Wissenschaften (BEK) analysis center permanently processes the following nine stations: ANKR, GRAS, MADR, MASP, MATE, NOTO, UPAD, VILL, and ZIMM. Two new stations have been included since January 22, 1996: CAGL and MEDI. The station EBRE has been processed since February 8, 1996, and the station SFER since March 17, 1996. The last station, VENE, has been processed since October 20, 1996. All processing has been done with the Bernese software v.4.0, which was installed by Dr. Leos Mervart in November 1995. Mr. Jan Dousa from Prague wrote some additional scripts to facilitate the computation work. A first inspection of the quality of the data shows that there are some problematic stations, whereas the plurality is excellent.

3.3 The CODE Analysis Center

3.3.1 Introduction

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

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

The CODE is located at the AIUB and uses a cluster of six DEC Alpha processors for the GPS processing. The analysis is performed with the Bernese GPS Software Version 4.1 [4].

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

- The European region is over-represented in the global CODE solutions. This should guarantee that the quality of the CODE orbits are as good as possible over Europe.
- A special solution for some 30 European sites is routinely computed to monitor the European sites and reference frame.

In the following discussion, we will focus on the European solution. More information about CODE can be found in [5].

3.3.2 The European Solution at CODE

The special European solution is generated on a daily basis with a delay of 11 days. This processing delay is chosen to allow for data from remote sites to make it to the IGS data centers in time.

The goals of the European solution were to

- Monitor all permanent European sites.
- Verify CODE orbit quality for large regional networks.
- Test different/new processing strategies.
- Monitor the European reference frame by combining the European solution with CODE's global solution.
- Find the optimal processing strategy for regional networks, which is important in view of the IGS densification project.

However, since the start of the weekly EUREF combination in the beginning of 1996 [6], the need to monitor all permanent European sites at CODE has disappeared, because the processing is now distributed amongst several (currently 10) LNAACs. It is no longer necessary to combine CODE's European solution with its global solution since this task taken over by the EUREF combination and/or the Global Network Associated Analysis Centers (GNAAC) combination.

3.3.3 Processing Strategies

The European solution is used to verify the quality of CODE's final orbits. The use of polar motion values, which are consistent with the orbits, is mandatory if the orbits have to be transformed from the Earth-fixed reference frame, used for the SP3 orbit files, to the inertial reference frame, normally used for orbit integration. The effect of an orbit error dR on baseline length L is given by the following rule of thumb:

$$dL = 0.25 * dR * L/R$$

where

L, dL are baseline length and baseline length error
R, dR are satellite distance and orbit error

The regional European network has a diameter of approximately 6000 km, and CODE's orbit quality is believed to be of the order of 50 mm. The effect (dL) on the baseline length would thus be of the order of 3 mm, only! So with the current orbital precision, it will be hard to see an orbit-induced effect in this network! Note that the stations on the edge of the network are Thule

(Greenland), Ny-Alesund (Norway), Maspalomas (Canari Islands), Ankara (Turkey), and Moscow (Russia).

Five different European solutions are generated at CODE for each day using different estimation strategies. The solutions are characterized as follows:

EGB: Baseline-wise processing without ambiguity fixing using an elevation cutoff angle of 20 degrees. The normal equations of the individual baselines are combined to create a full network solution. Because for large networks it is very expensive (in terms of CPU time) to correctly correlate all double-difference observations, this solution is used to study the effect of neglecting the correlations.

EG_: Full network solution without ambiguity fixing using a cutoff angle of 20 degrees. As opposed to the previous EGB, the correlations are treated correctly.

EQ_: Same as previous EG_ solution, but with ambiguities fixed to their integer values. On the average, 90% to 95% of the ambiguities are resolved. The ambiguity fixing is performed using the so called Quasi-Ionosphere-Free (QIF) ambiguity resolution strategy [7]. This solution is performed to study the impact of ambiguity fixing.

ET_: Same as previous EQ_ solution, but here the troposphere estimates from the CODE global solution are used for those stations that are common to both solutions. The idea is that in regional networks it may be difficult, or even impossible—depending on the size of the network, to correctly estimate the absolute troposphere delays. Therefore, it could be advantageous to introduce troposphere estimates, stemming from a global solution, for at least one of the regional sites.

EQB: Same as EQ_ solution, but using a cutoff angle of 15 degrees. Here we study the effect of lowering the cutoff elevation. A lower elevation angle should give a better decorrelation of the station height and troposphere estimates. However, lower elevation data will probably have more noise, cycle slips, and multipath effects.

Table 4 shows the internal consistency of these five solutions based on the first 80 days of 1997. The results were generated by combining the daily normal equations of the 80 consecutive days estimating only the station coordinates (no velocities). The coordinate rms error is computed using the daily station residuals with respect to the estimated solution after applying a seven-parameter Helmert transformation. Note that all five solutions were performed in exactly the same way except for the difference in estimation strategy as outlined above.

Table 4: Internal consistency of the CODE European solutions

SOL ID	DD COR	AMB FIX	Cutoff	Coordinate rms, mm N	E	Up	Remarks
EGB	No	No	20	2.4	3.3	8.5	
EG_	Yes	No	20	2.1	2.9	7.3	
EQ_	Yes	Yes	20	1.9	1.7	7.2	CODE EUREF contribution up to week 0898
ET_	Yes	Yes	20	1.9	1.7	6.7	Global Troposphere estimates used
EQB	Yes	Yes	15	1.9	1.7	5.7	CODE EUREF contribution from week 0899

Based on these results the following conclusions are drawn:

- Correct correlation of the double-difference (DD COR) observations is important.
- Fixing the ambiguities (AMB FIX) to their integer values gives a significant improvement for the "East" component of the coordinate estimates. The improvement for the "North" and "Height" components are insignificant.
- Introduction of the troposphere estimates from the CODE global solution improves the "Height" component of the coordinate estimates. This is remarkable considering the size of the network (6000 km), which should allow for the accurate recovery of the absolute troposphere! We expect that for small networks, the improvement will even be (much) larger.
- Changing the cutoff angle from 20 to 15 degrees gives a very significant improvement for the "Height" component. Apparently the lower elevation data is of good quality so the solution can profit fully from the decorrelation of the troposphere estimates from the height estimates.
- Furthermore, the consistency of all series shows that there are no visible orbital effects. The quality of the series is at least as good as the quality of (the European network in) CODE's global solution.

3.3.4 Outlook

Based on the experiences gained from CODE's European solutions, it is clear that a lower cutoff angle should be used in GPS data processing. However, at this time it is known only that a cutoff angle of 15 degrees gives better repeatabilities than a cutoff angle of 20 degrees. This does not tell what the optimal cutoff elevation is; it might be as low a 0 degrees or somewhere between 15 and 20 degrees. Furthermore, if lower elevations are used, the mapping function used to map the tropospheric zenith delay estimates to different elevations will become important too. Weighting of data should be studied as well. It is clear that lower elevation data are noisy; therefore, a downweighting scheme should be used.

Based on these considerations, CODE added four new solutions to its European processing. These new solutions address the following problems:

- Impact of different mapping functions.
- Impact of elevation dependent weighting.
- Impact of the minimum elevation.

In this way we hope to find a (much) improved estimation strategy for both our regional and global IGS activities in the near future.

3.4 The IFG Analysis Center

The EUREF Analysis Center IFG is located at the Institute for Applied Geodesy in Frankfurt (IfAG). in January 1996, the IfAG started to routinely process a subnet of the EUREF Permanent Network. A selection of 13 stations, consisting of 10 IGS stations and 3 IGS CORE stations covering Germany and a substantial part of Europe (see Figure 6), is currently included in a daily analysis. More stations in Germany will be integrated during the next months (see Figure 7). The GPS observations of these permanent stations are uploaded to Frankfurt on a daily basis. The files are transferred in the compressed RINEX format.

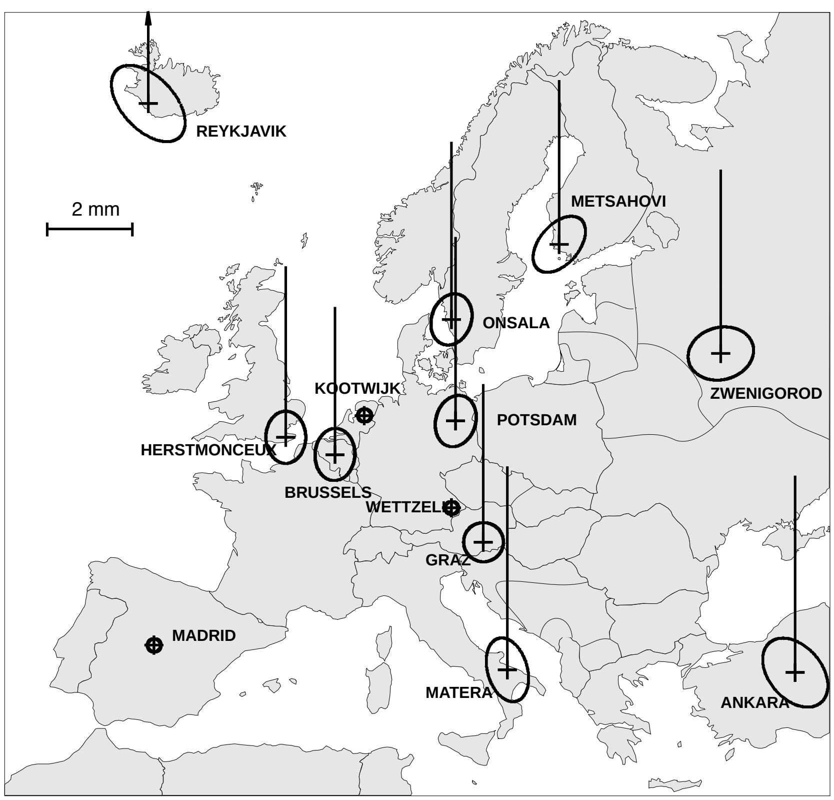


Figure 6: GPS Permanent Network processed by the IfAG, 2D error ellipses, internal accuracy, example day 96/117

Figure 7: Planned GPS permanent network densification for Germany

The data analysis is carried out using the Bernese GPS Software Version 4.0, running on HP-UNIX workstations. The IfAG generates weekly SINEX and Summary files from daily solution. Weekly solutions are transferred to the CODE Analysis Center. Daily solutions were also computed backwards beginning in January 1995. A total number of more than 5000 sets of station coordinates has been made available.

Based on the fixing of the IGS CORE stations, time series for coordinates of 10 European GPS permanent stations could be derived. The daily repeatability varies between ±2 mm and ±10 mm for horizontal components and ±8 mm and ±40 mm for height components (see examples, Figures 8 and 9).

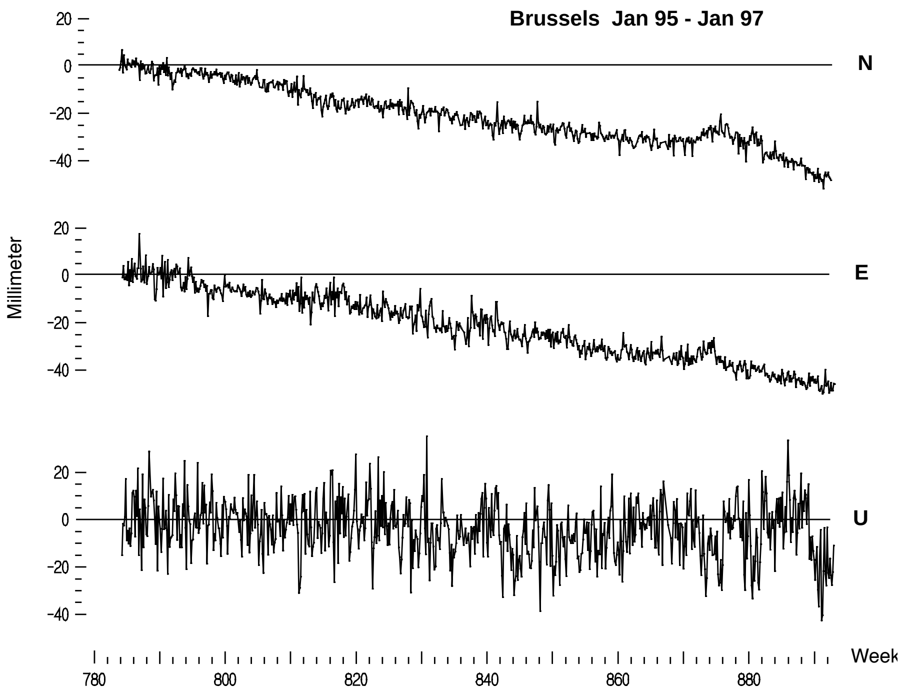


Figure 8: Time Series of coordinates for Station Brussels

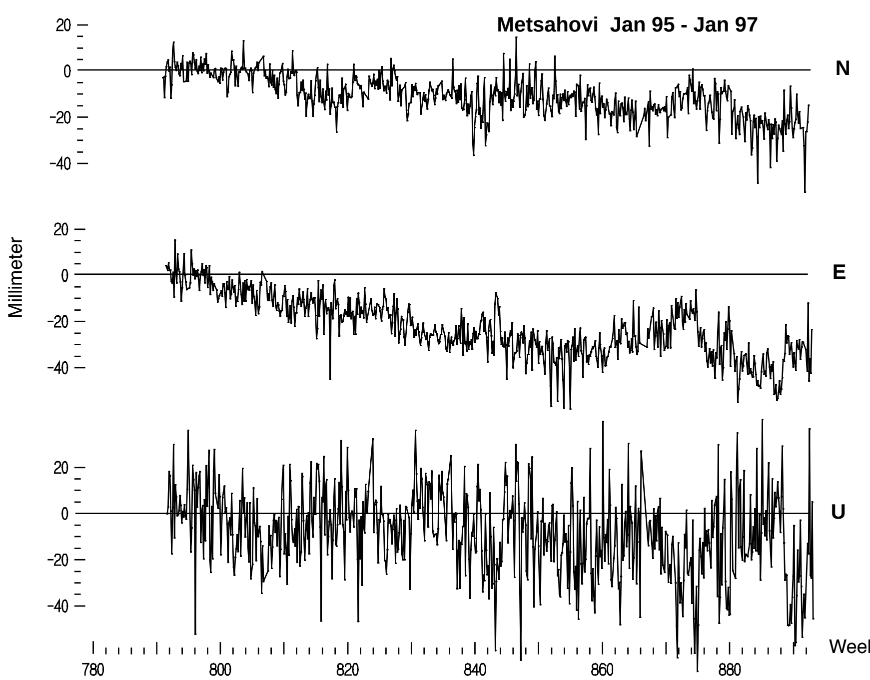


Figure 9: Time Series of coordinates for Station Metsähovi

The applied data analysis is based on the following principles:

<u>Measurement Model</u>

Preprocessing:	Phase preprocessing in a baseline-to-baseline mode using triple differences.
Basic observable:	Carrier phase, code only used for receiver clock synchronization, elevation angle cutoff 20 degrees, sampling rate 180 seconds.
Modeled observable:	Double-differences, ionosphere-free linear combination.
Troposphere:	Saastamoinen a priori model.
Ionosphere:	Not modeled (ionosphere-free linear combination of L1 and L2).

<u>Estimated Parameters</u>

Adjustment:	Weighted least square algorithms.
Rejection criteria:	No rejection during parameter estimation procedure. Outliers are marked during preprocessing step.
Station coordinates:	Three stations (MADR, WETT, and KOSG) heavily constrained (0.1 mm) to ITRF94 positions and velocities, the remaining stations estimated. The ITRF94 velocities are used for monthly coordinates updates.
Troposphere:	Zenith delays estimated once per 2 hours for each station. Corrections to a priori model constrained to 5 m (absolute) and 0.1 m (relative).
Ionosphere:	Not estimated.
Ambiguity:	Following QIF strategy to resolve ambiguities for each baseline. Resolved ambiguities introduced to final solution.
Satellite clock bias:	Satellite clock biases are not estimated but eliminated by forming double differences.
Receiver clock bias:	Receiver clock corrections are estimated during the preprocessing using code measurements.

Main results of the IFG are available from the GPS Information and Observation System (GIBS, see `http://gibs.leipzig.ifag.de`).

3.5 The GOP Analysis Center

The Geodetic Observatory Pecny (GOP) Local Network Associate Analysis Center is a collaboration between the GOP of the Research Institute of Geodesy, Topography, and Cartography (RIGTC) and the Czech Technical University (TU Prague) in Czech Republic. The GOP EUREF Local Analysis Center was officially adopted by the EUREF Network Coordinator at the end of 1996, and 11 sites (BOGO, GOPE, GRAZ, JOZE, MDVO, METS, MOPI, OBER, ONSA, WTZR, and ZWEN) of the northeastern part of the EUREF permanent GPS network were included in the processing.

The facilities available at GOP to process the EUREF permanent network are Pentium WS (100 MHz, Mem 48 MB), OS Debian Linux 1.1, Bernese GPS software version 4.0, Bernese Processing Engine (BPE), and a specially developed superstructure of Unix-shell scripts for full automation of processing.

3.6 The LPT Analysis Center

3.6.1 Introduction

LPT equals L+T and stands for the abbreviation of the German name of the Federal Office of Topography ("Bundesamt für Landestopographie"), Wabern, Switzerland.

The Federal Office of Topography intends to set up a network of permanent reference stations for real-time applications. The project is called Active (or Automated) GPS Network in Switzerland (AGNES). The current activities as an Analysis Center are to be seen in this context and mainly have two goals:

- The monitoring of the permanent site Zimmerwald (ZIMM) within the European reference frame.
- To become familiar with automated routine processing of a network of reference stations.

3.6.2 The EUREF Solution at LPT

The analysis is performed with the Bernese GPS Software Version 4.0 [5] on an IBM RS6000. Routine processing was started in GPS week 0880 (1996 day 322).

The current network includes the IGS stations of Grasse (F), Graz (A), Kootwijk (NL), Padua (I), Wettzell (D), and Zimmerwald (CH). These sites were chosen to

- Include IGS Core stations (WTZR, KOSG).
- Enable collocation with SLR (GRAZ, WTZR, KOSG, ZIMM).
- Include at least one station of the neighbouring countries.

The LPT solution is generated on a daily basis with a delay of 7 days. The X3 type solution produced by the CODE is used as orbits. Basic observables are carrier phase data only, with an elevation cutoff of 20 degrees and a sampling rate of 180 seconds. Modeled observables are the double differences in a ionosphere-free linear combination. Receiver clock corrections are estimated during the pre-processing using code measurements. Elevation-dependent antenna phase center corrections are applied to model the differences between different antenna types using the IGS_01 model. The Saastamoinen model is used as a priori model for the troposphere, estimating zenith delays in 2-hour intervals for each station with the mapping function: 1/cos(zenith angle). An ionosphere model is estimated from $L_2 - L_1$ double-difference observations, helping to increase the number of fixed ambiguities for the so-called QIF ambiguity resolution strategy. The coordinates of the two IGS CORE stations WTZR and KOSG as well as of ZIMM are heavily constrained (to 0.1 mm).

Two solution types are generated:

AG_: Full network solution using the ionosphere-free linear combinations without ambiguity fixing; the correlations are treated correctly.

AQ_: Same as previous AG_ solution, but with ambiguities fixed to their integer values. On the average 90% to 95% of the ambiguities are resolved. The ambiguity fixing is performed using the QIF ambiguity resolution strategy [7].

A weekly combined solution of the AQ_ type using the ADDNEQ program [8] is delivered in SINEX-format to the EUREF data center at IfAG.

The processing is basically identical to that of the CODE Analysis Center. For more details, see the CODE Analysis Center report, Section 3.3.

3.6.3 Outlook

The next station to be included in LPT network is the station Pfaender (A) (PFAN), jointly set up by IfAG Frankfurt, the Austrian Institute for Space Research, and the Swiss Federal Office of Topography (operated by our Austrian colleague, Dr. P. Pesec).

Based on the experiences gained by CODE, some of the processing parameters (e.g., cutoff angle) might be changed and improved in the near future.

3.7 The NKG Analysis Center

3.7.1 Introduction

The Nordic Geodetic Commission (NKG) Local Analysis Center for EUREF was formed as a response to the invitation from the EUREF Technical Working Group to establish an Analysis Center with the task of routinely processing the GPS data from the sites in Northern Europe for the extension and densification of the European reference frame. The NKG analysis center is currently located at the Onsala Space Observatory and coordinated by the NKG working group on permanent geodetic stations.

Permanent networks of GPS stations in the Nordic countries have been established during the last 5 years. By the end of 1996, approximately 50 permanent stations were established in this area. The Nordic GPS network is based on several nationwide clusters of permanent GPS stations. These networks are designed for continuous measurements of the contemporary vertical and horizontal crustal deformations. They provide data to many national and international geodetic and geodynamic research projects such as the Baltic Sea Level project [9] and the BIFROST (Baseline Inferences For Rebound Observations, Sea Level, and Tectonics) [10] investigation on Fennoscandian postglacial rebound. The permanent network also provides data for real-time applications and atmospheric research.

3.7.1.1 FinnNet—the Finnish Permanent GPS Network

The Finnish Geodetic Institute (FGI) is maintaining the Finnish permanent GPS network, *FinnNet*, comprising 12 GPS stations. Most sites are established with a 2.5-m-tall steel-grid tower for the GPS antenna. Beneath the tower is a hut housing the Ashtech Z-12 geodetic GPS receiver. The data are transferred by modem and a dial-up telephone line to the data-bank at the FGI. Subsets of the data are distributed to international data archives via Internet. The stations at Joensuu, Metsähovi, Sodankylä, and Vaasa are members of the EUREF permanent network (see Figure 10).

3.7.1.2 SATREF—the Norwegian Permanent GPS Network

The Norwegian Mapping Authority (Statens Kartverk, SK) is responsible for the establishment and operation of the permanent GPS network in Norway, *SATREF*. The network consists of 11 stations including the IGS sites Tromsø and Ny Ålesund. Station monitoring and data transferring are carried out at the SK headquarters in Hønefoss by direct TCP/IP-connection to all stations. SK also acts as data archive both for SATREF and all IGS stations in Northern Europe. As indicated in Figure 10, six Norwegian stations are included in the EUREF permanent GPS network.

3.7.1.3 SWEPOS—the Swedish Permanent GPS Network

A network of 21 permanent GPS reference stations for GPS—*SWEPOS*—has been established by the National Land Survey of Sweden (NLS) and the Onsala Space Observatory (OSO) [11]. The purposes of the network are to provide dual-frequency data for relative GPS measurements, provide differential correction for broadcasting to real-time users, provide data for studies of crustal dynamics, act as high-precision control points for Swedish GPS users, and support the development and densification of national and international reference systems. All stations are connected to the operational center and data archive at the NLS via TCP/IP computer networks.

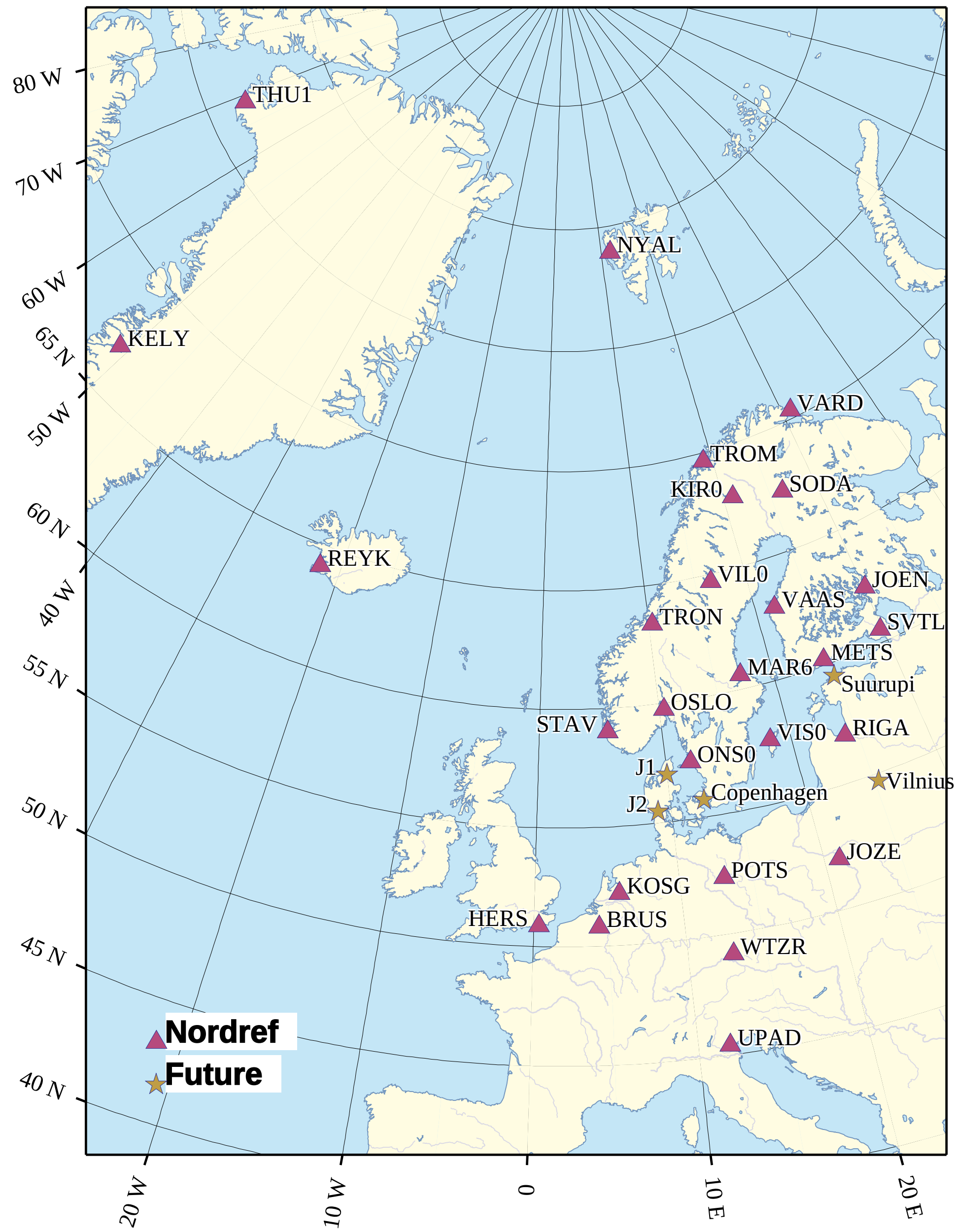


Figure 10: Stations included in the daily processing at the NKG local data analysis center. Also stations currently being established are shown

Starting in 1993 at the OSO analysis center, all SWEPOS data have been analyzed using the GIPSY software package [12]. Five SWEPOS sites are also submitted to the EUREF permanent network (namely Kiruna/Esrange, Vilhelmina, Mårtsbo, Onsala, and Visby (see Figure 10)) and consequently included in the daily processing.

3.7.1.4 Other stations

The station in Riga, Latvia, is operated by the Astronomical Institut at the University of Latvia. The establishment of the permanent GPS site was a collaborative effort by the University of Latvia, FGI, and OSO. The Russian station in Svetloe is operated by the Institute of Applied Astronomy, St. Petersburg. Data from both Riga and Svetloe are available via the FGI. Other stations of interest for the NKG processing center are stations on Greenland (Danish projects), Iceland, and a number of European IGS stations for reference frame issues.

3.7.2 Future Stations

The National Survey and Cadastre in Denmark (Kort-og Matrikelstyrelsen, KMS) is currently establishing a three-station network in Denmark (see Figure 10). The stations will have similar setups and functions as FinnNet and SWEPOS. Data from all stations will be submitted to the EUREF processing centers. National organizations in Lithuania and Estonia are collaborating with the FGI and OSO to establish permanent GPS tracking stations in Vilnius and Suurupi (near Tallinn).

3.7.3 Goals of the NKG Activity in EUREF

The NKG Analysis Center was established in late summer 1996 as a joint effort by members of the NKG Working Group on Permanent Geodetic Stations. The intention is to take an active part in the development of the EUREF permanent network, the EUREF processing strategies, and the products combined with a high degree of involvement in the development of the European and International Terrestrial reference frames. This may help facilitate integration of other Nordic permanent stations and GPS campaign sites into the EUREF/IERS and national reference systems in the region, aiming towards future extension and densification of the such reference systems.

The NKG also actively supports the establishment and integration of new GPS stations in the Baltic countries and Russia into EUREF and IGS. The intention is also to provide information for daily and weekly routine use of the EUREF/IGS and NKG both to NKG members and other Nordic and Baltic area organizations.

Furthermore, using the results of the daily/weekly analysis of GPS data, GPS estimates are compared to results obtained from other techniques, other GPS software, and other analysis centers. This activity is carried out basically using the same method as that used for daily processing within the project BIFROST

[10]. This project now has more 1000 days of continuous data flow and daily processing. Studies of the station time series and their auto- and cross-correlations are undertaken (see, e.g., [13] and [14]). Furthermore, the Power Spectral Density of all time-series are used to detect periodic effects and the problems associated with the mechanical and electromagnetic stability of the sites [15].

3.7.4 Present Activities and Resources

The GPS data acquired at each site are automatically downloaded daily and archived by the agencies responsible for each national network. The data are transferred to the OSO–NKG analysis center for extensive data analysis. Data from European IGS stations are accessed via computer networks from CDDIS. The daily analysis of the 30 permanent GPS sites are handled using a cluster of HP-700 work-stations and a PC-Pentium Pro system running LINUX. The full system includes disc capacity of about 30 Gbytes (another 20 Gbytes are available as CD-rom).

All processing is performed automatically, i.e., noninteractively, using the Bernese Software 4.0 and the Bernese Processing Engine (BPE) [4]. The Bernese Software was chosen in view of the fact that most NKG member agencies use it, as do a majority of the EUREF analysis centers. The exchange of intermediate products can be easily facilitated. For the standard data analysis, an elevation cutoff angle of 15 degrees is used for all sites giving the lowest uncertainties in the estimation of horizontal and vertical baseline components (20 degrees was used until April 1997). There are several different GPS antennas used in the subnet processed by the NKG. Elevation-dependent phase-center corrections are used according to Mader and MacKay [16] and Rothacher and Schär [17].

At the Norwegian SATREF stations, the Trimble antennas currently in use will soon be replaced by Dorne Margolin antennas. Improved satellite orbits and Earth orientation parameters are readily available from the IGS processing centers. The NKG solutions are produced using the IGS combined orbits and Earth orientation parameters. Data processing utilizes a regional free-network technique wherein the coordinates of site position have only weak a priori constraints. The coordinates of the sites are estimated as bias terms. Constraints are thereafter applied to transfer the results into a terrestrial reference frame. The zenith values of the propagation delay due to water vapor (often referred to as the wet delay) are estimated as bias terms with a new parameter for each site every second hour. Investigations on the use of the continuously observing GPS network for ionospheric and tropospheric research are undertaken. The possibility of using data from space geodetic techniques, such as GPS, to estimate atmospheric water vapor content has opened up new applications in association with weather forecasting and climate studies. The continuously operating networks serve also as a data bank for detailed investigations of sources of errors in space geodesy.

The processing functions as a quality evaluation and delivers valuable data for geophysical investigations. Furthermore, it addresses the fundamental question of uncertainties and error sources in space geodetic techniques. The official activity at the NKG local analysis center started in October 1996, and the times series are still very short. However, in parallel, many of the stations are processed within the framework of project BIFROST, using the GIPSY software package. The time series for this project began in August 1993. Figure 11 demonstrates the kind of results we can expect from the routine processing of data from the EUREF permanent network. The repeatability is about 2 mm in the horizontal components and about 6 mm in the vertical component. In Figure 11, problems associated with the GPS antenna and its environment are demonstrated. Jumps in the time series indicate changes of the protective covers (radome) at the site. At the time of inclusion of the Swedish sites in the EUREF permanent network, all conical-shaped radomes were replaced by hemispheric covers. The advantage being that the satellite signals are equally affected (delayed) independent of satellite elevation. We can also notice slightly increased scatter in the time series during the winter periods. This higher noise level seems to be related to snow accumulating on top of the antenna [18]. This is a serious problem that most likely will affect the results obtained from several of the Finnish and Swedish sites during wintertime.

3.7.5 Acknowledgments

This section is based on material from the NKG—Working Group on Permanent Geodetic Stations. Valuable contributions have been made by Martin Vermeer, Markku Poutanen, Matti Ollikainen, and Hannu Koivula (FGI), Torbjørn Nørbech, Olav Haugen, and Lars Brockmann (SK), and Bo Jonsson and Gunnar Hedling (NLS), Bo Madsen and Peter Skjellerup (KMS). The research at Onsala Space Observatory was in part supported by the Swedish Natural Research Council, and the Swedish National Space Board.

3.8 The OLG Analysis Center

The EUREF Analysis Center OLG is situated at the Observatory Lustbühel. It is run by the Austrian Academy of Sciences, Institute of Space Research, Department of Satellite Geodesy (ISR) with assistance of the Federal Office of Metrology and Surveying (BEV).

The hardware presently used for EUREF computations consists of two Intel PCs (Pentium 90 and Pentium Pro 200) with external storage devices. Connections to Internet are provided by the Graz University of Technology.

The analysis software combines the Bernese Software (BSW), version 4.0, with AUTOBERN, written by N. Fachbach. AUTOBERN replaces the Bernese Processing engine and provides additional features. AUTOBERN starts every Saturday morning, processes 7 days, and finishes its task Monday morning.

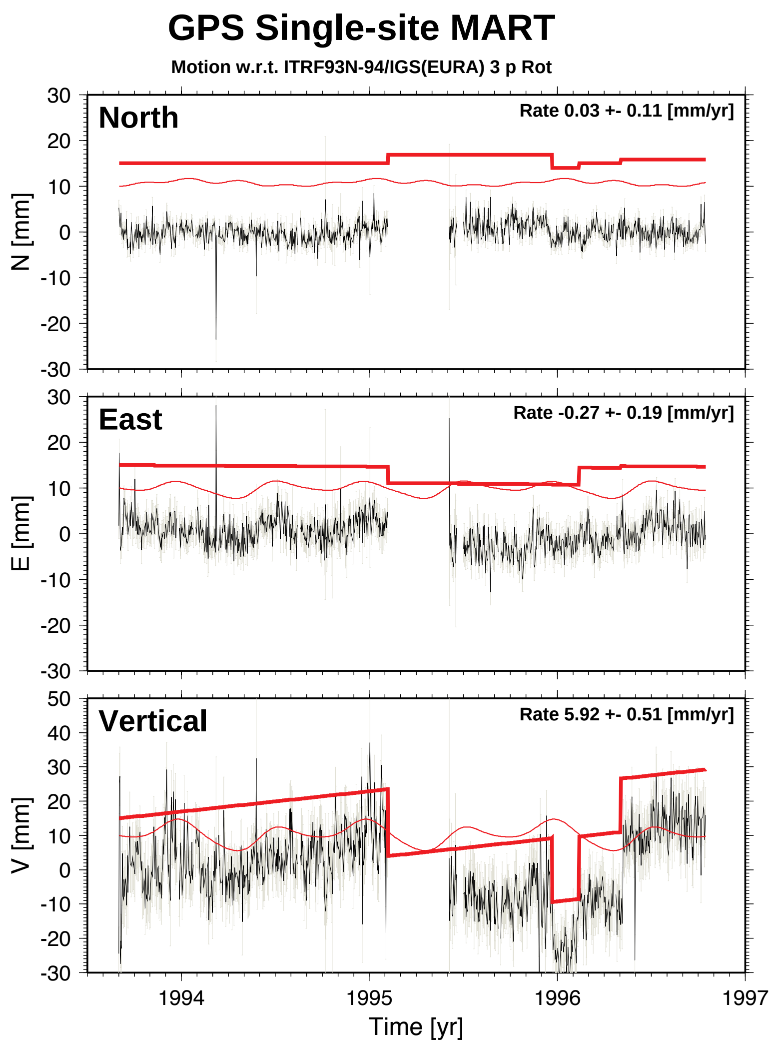


Figure 11: North, East, and Vertical time series for the Mårtsbo site in mid-Sweden. The MART site is identical to the station MAR6 in the EUREF/IGS permanent network. The results are obtained from daily processing, using the GIPSY software. The solid thick line represents a best-fit straight line to the respective data sets in a least-square sense. The offsets in the time series, most obvious in the vertical component, reflect changes around the antenna at the site. In this case the cover protecting the antenna has been changed several times. The results obtained during winter months appears to have more noise. This is most likely associated with snow accumulation on top of the antenna/pillar system. The thin solid line in all panels describes seasonal trends in the data

The part of EUREF stations to be analyzed at OLG was selected for investigating geodynamic and meteorological patterns in Central Europe. The main interest concentrates on monitoring secular tectonic movements among the Mediterranean region, the Alps, the Bohemian Massif, and the Northern Lowlands, and on investigations of the fluctuations of the troposphere in these areas. The network contains baselines running across the tectonic zones; control baselines connect the different branches (see Figure 12).

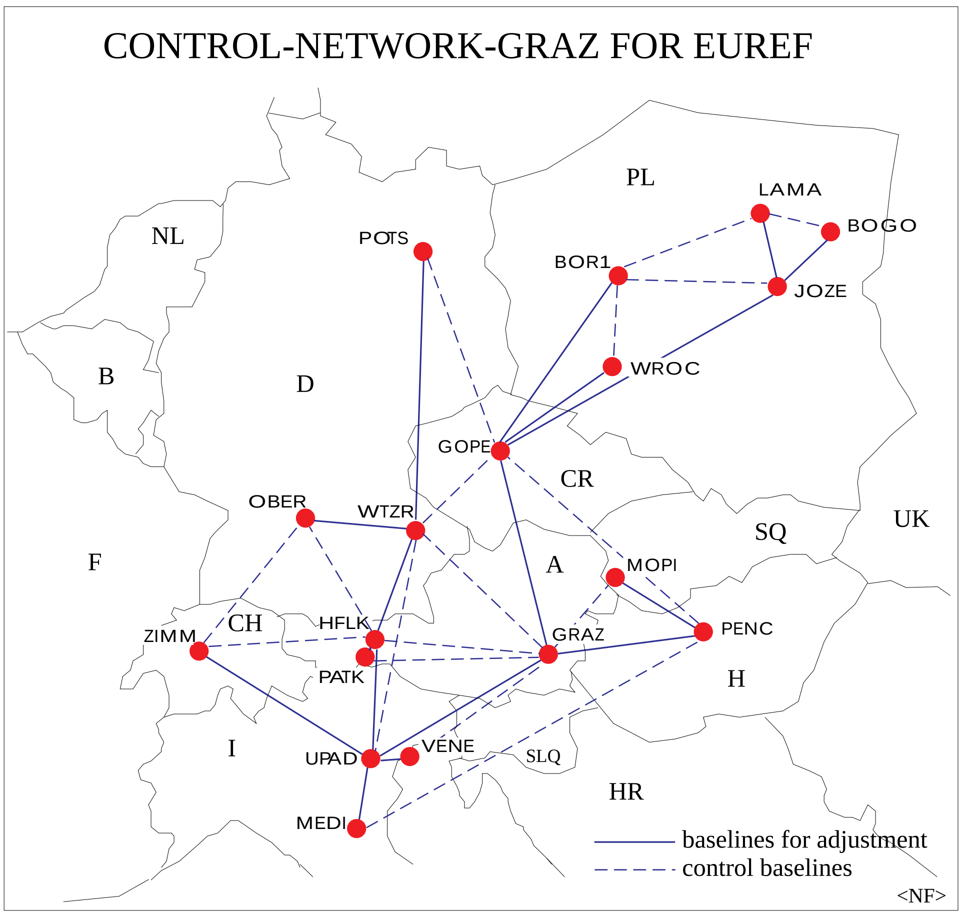


Figure 12: Stations and baselines included in the OLG processing

As of April 1997, the computed network consists of 17 stations (16 baselines) and a total of 35 control baselines.

The OLG EUREF solution in SINEX format is only one part of the results; daily solutions of the networks and several daily coordinate differences are stored also. Control baselines serve to localize errors (e.g., wrong ambiguity fixing in one baseline) and net deformations (caused, e.g., by a priori constraints).

Coordinate differences of several "independent" baselines check the validity of detected movements between tectonic units in the future.

Apart from the EUREF subnetwork, some other networks designed for different investigations will be computed from the bulk of RINEX files. The permanent CERGOP stations form a net for investigating tectonic movements in Central Europe. The number of Austrian stations will increase and will form an Austrian subnet for Geodesy and Navigation computed with the shortest time delay possible. The Adriatic microplate, up to now monitored by special GPS-campaigns, will be monitored regularly by permanent stations, hopefully extending to the east-Adriatic coast. Finally, a network covering the whole Alpine region is under consideration.

3.9 The ROB Analysis Center

3.9.1 Introduction

The Royal Observatory of Belgium (ROB) operates since January 1994 four permanent GPS stations in Belgium. All stations are equipped with TurboRogue receivers and Dorne Margolin T antennas. Principal goals of this network are the study of the long-term stability of the coordinates, monitoring of the ionosphere, and the link to the European and global reference frame for local applications.

3.9.2 Contribution to EUREF Processing

Routine processing of the Belgian network including neighboring IGS sites has been done at the ROB since September 1994 using the Bernese Software, mainly for the monitoring of the Belgian permanent network. Ionosphere monitoring using ROB software was initiated in April 1993.

The daily EUREF processing started at the ROB in January 1996 using, at that time, the Bernese 3.5 Software on a cluster of HP Unix workstations. Since November 1996, the Bernese 4.0 and Bernese Processing Engine, including some additional scripts to allow for fully automated processing, have been used.

The ROB processing includes all present and future EUREF and IGS stations in Belgium, Great-Britain, France, and the Netherlands. Presently a subnetwork of 11 stations is processed: Brussels (BRUS), Dentergem (DENT), Dourbes (DOUR) and Waremme (WARE) are all part of the Belgian permanent GPS network; Kootwijk (KOSG) and Delft (DELF) are both part of the Dutch Active GPS Reference System (AGRS); and the IGS stations are Herstmonceux (HERS), Grasse (GRAS), Potsdam (POTS), Wettzell (WTZR) and Zimmerwald (ZIMM).

The main characteristics of the ROB EUREF analysis are

(1) Use of IGS phase eccentricity variation tables.
(2) Minimal elevation cut-off angle of 10 degrees.
(3) Use of CODE orbits and ERP parameters. The internally generated orbit files fit the CODE orbits at the 1-cm level.

(4) Estimation of 12 tropospheric zenith delay parameters/day with respect to the a priori Saastamoinen model. Stations included in CODE's global solution have tropospheric parameters constrained to CODE's R3-series (introduced as artificial meteo data); for the remaining stations, 10-cm absolute constraints and 5-m relative constraints are applied.
(5) No correction for ocean loading and atmospheric loading.
(6) Solid-earth tides modelling following IERS standards 1992.
(7) Computation of local TEC model.
(8) Ambiguity resolution using the quasi-ionospheric free strategy.

Although the contribution of the ROB analysis to EUREF started in January 1996, solutions were saved since March of that year. From March 1996 to November 1996, weekly solutions were saved, and from November 1996 (since the switch to version 4.0 of the Bernese) daily solutions were saved. The internal consistency of the ROB solution is checked by combining these weekly/daily ROB normal equations and estimating only station coordinates. The coordinate rms error is computed using the station residuals with respect to the estimated solution after applying a seven-parameter Helmert transformation:

$$\begin{cases} rms_N = 1.5 \text{ mm} \\ rms_E = 1.7 \text{ mm} \\ rms_U = 4.2 \text{ mm} \end{cases}$$

3.9.3 Outlook

Future plans of the Royal Observatory of Belgium include

- Software developments:
  - — Include ocean loading and atmospheric loading corrections in the Bernese 4.0 software.
  - — Update the solid-earth tides model to the IERS96 conventions.
- The recomputation of the EUREF subnetwork since January 1994 is under consideration.
- Extension of the Belgian permanent GPS network including
  - — One GPS permanent station at a tide gauge site at the Belgian coast.
  - — Two semipermanent GPS stations in the Feldbiss fault zone near the town of Bree (Belgian Limburg) to assess any ground displacements.
  - — One GPS permanent station at Membach in collocation with a superconducting gravimeter to compare changes in the station heights observed by the two independent instruments.

3.10 The WUT Analysis Center

3.10.1 Introduction

Since January 1995, the CODE Processing Center and the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology have entered into cooperation aimed at testing different processing methods for the Polish network, which consists of three permanent IGS stations: Jozefoslaw, Borowiec, and Lamkowko. The connection to the global reference frame was realized by processing four additional European IGS sites: Wettzell, Kootwijk, Metsähovi, and Onsala. The results of four different processing strategies were compared with the results obtained by CODE from the global network [19]. The experiment was a practical test of the idea of IGS regional data processing expected for the IGS Regional Network Associated Analysis Center. The report of 100 day-to-day solutions has been presented at the XXth IUGG General Assembly in Boulder, Colorado [20]. Of the four solution strategies tested, one was selected.

Since January 1996, the WUT Processing Center located at the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology (accepted as an EUREF Local Analysis Center—WUT EUREF LNAAC) has started the systematic processing of a selected number of Central European sites, consisting of 15 sites: Borowiec, Jozefoslaw, Lamkowko, Borowa Gora, Wroclaw (Poland), Penc (Hungary), Innsbruck (Austria), Pecny (Czech Republic), Mendeleevo (Russia), Wettzell (Germany), Kootwijk (the Netherlands), Metsähovi (Finland), Onsala (Sweden), Matera (Italy), and Modra Piesok (Slovak Republic). The results from 1996 are presented in this paper. So far, many Central European GPS campaigns have been processed at the Center, e.g.,

- EXTENDED SAGET 1992, 1993, 1994, 1995, and 1996, organized by the Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology (presently consisting of more than 50 European stations).
- Central European Regional GPS Geodynamic Reference Network (CEGRN) 1994, 1995, and 1996, realized in the frame of CERGOP CEI Project.

3.10.2 Characteristics of the Methods and Computation Strategies Used in the Test Campaign and Permanent Processing

3.10.2.1 The Test Campaign

For the test campaign, the Warsaw University of Technology (WUT) Processing Center performed an automatic processing of the Polish Regional Network of the IGS (Jozefoslaw, Borowiec, and Lamkowko) using the Bernese v.3.5 GPS software, including four IGS sites (two IGS core sites—Wettzell and Kootwijk—and two IGS global sites—Metsähovi and Onsala). WUT used the same naming conventions and the same phase center corrections as the CODE Center. The vectors between IGS fiducial sites were excluded from the regional data analysis.

For the combination of the normal equations obtained by the different centers, the following common processing options were used:

- The same SATELLIT. file.
- The same SATCRUX. file.
- The same number of troposphere parameters, per day and per station (12 per day).
- The same a priori troposphere model (Saastamoinen).
- Estimation of tropospheric zenith delay parameters for all stations (except for method W4).
- Use of BASELINE mode.
- Use of pre-eliminated ambiguities.
- Use of constraints of 0.0001 m on all Core and Global IGS stations.

Four computation methods were defined and tested:

Method W1: Coordinates and troposphere were estimated. CODE's orbit solution and ERP were used. Coordinates and troposphere parameters were saved in the NEQ (normal equations) file for combination.

Method W2: Coordinates and troposphere were estimated. CODE's orbit solution and ERP were used. Only coordinates were saved in NEQ file.

Method W3: Coordinates and troposphere were estimated. IGS orbits and CODE ERP were used. Only coordinates were saved in the NEQ file.

Method W4: Coordinates and troposphere were estimated. Troposphere parameters were estimated only for the regional sites. The orbit solution, ERP, and troposphere parameters estimated by CODE were used for all IGS Core and Global sites. Only coordinates were saved in NEQ file.

3.10.2.2 The Permanent Processing

At present, the WUT Processing Center uses the Bernese software version 4.0 with the automatic data processing machine modified at WUT. This software is installed on the new HP Workstation J-200. Daily processing includes five Polish stations (Borowiec, Jozefoslaw, Lamkowko, Borowa Gora, and Wroclaw), one Hungarian station (Penc), one Austrian station (Innsbruck), one Czech station (Pecny), one Russian station (Mendeleevo), one Slovak station (Modra Piesok), and five IGS fiducial stations (Wettzell, Kootwijk, Metsähovi, Onsala, and Matera) as quasi-fix stations (not fixed, but the constraint 0.0001 m is used for each station). The processing of the local EUREF GPS permanent network was executed using the modified method W1: CODE orbits and CODE Earth rotation parameters are used in the WUT solution.

Automatic processing at the WUT Processing Center consists of the following steps:

- Check the RINEX data files.
- Prepare single-difference files (baselines) using ObsMax strategy (form baseline with maximum observations) and delete baselines between IGS Core and Global stations.
- Phase preprocessing in a baseline-by-baseline mode using triple differences. In most cases, cycle slips are fixed by looking simultaneously at different linear combinations of L_1 and L_2. If a cycle slip cannot be fixed reliably, bad data points are removed, or new ambiguities are set up. The a posteriori residuals of the observations are checked for outliers, too. These observations are marked for the final adjustment.
- Resolve ambiguities for all baselines using the QIF strategy.
- Estimate network using resolved ambiguities and save normal equations.
- Send results (SINEX file version 1.0 and processing summary file) to IfAG.

3.10.3 Results

3.10.3.1 The Test Campaign

For all tested methods, the same result was obtained, and it was decided to use method W1 for local data processing. The results of the data processing for the stations Jozefoslaw, Borowiec, and Lamkowko for the period January 1—June 30, 1996, obtained by CODE and WUT are used for further analysis. The differences between CODE's “R3” solutions, CODE's “EQ” solutions (combination of normal equation files from Local Processing Centers and CODE's global normal equations) and the solution obtained by WUT for JOZE, LAMA, and BOR1 were analyzed. The mean values of the differences between CODE's R3 solution and the WUT solution are presented in Table 5.

Table 5: Mean values of differences between CODE R3 and WUT W1 solutions

Station	North [mm]	East [mm]	Up [mm]
Lamkowko	4.2	0.3	–6.0
Jozefoslaw	6.1	–0.7	–4.3
Borowiec	6.6	–1.4	–3.1

The data processing of GPS observations performed at the Penc, Pecny, Mendeleevo, Wroclaw, Borowa, Gora, and Modra Piesok stations has been conducted since March 1, 1996, or later, so these solutions were not included in this report.

3.10.3.2 Permanent Processing of Central European Subnetwork Performed by WUT EUREF LNAAC

The results of the data processing contain observations performed in 1996 and 60 days of 1997. The solutions for GPS weeks 854 to 860 were excluded from analysis, for reason of data processing errors caused by changes of reference system and computation strategies. Since GPS week 860, the ITRF93 reference frame was replaced by the ITRF94 reference frame. The mean number of observations per day used in data processing is approximately equal to 12000. The mean number of resolved ambiguities is equal to 90 to 93%.

The estimated values of the parameters of the Lagrange harmonic function for the modeling of ionosphere are used as a priori data for the QIF ambiguity resolution strategy.

3.10.4 Conclusions

Generally, satisfactory results for the data processing of the local EUREF network using the BERNESE v.4.0 software were obtained. However, there are some jumps in the height. The WUT and CODE solutions are not significantly different. The results of the daily computations are accessible 4 days after the precise orbits become available. Taking into account the results of the data processing obtained during the last 2 years as well as the combination of results of the different EUREF LNAAC Centers performed by the CODE analysis center, it can be stated that the computation strategy used in WUT EUREF LNAAC is not different from computation strategies used in the other LNAAC Centers.

4 The EUREF Combined Solution

4.1 Introduction

Since mid-1996, weekly SINEX contributions of different European LNAACs are combined into an official weekly EUREF solution. This EUREF solution is then submitted to the IGS for inclusion into the IGS densification pilot project performed by the GNAACs. Currently (April 1997), there are 10 different European LNAACs. The combination is performed at the CODE processing center situated at the Astronomical Institute of the University of Berne (AIUB), which is also one of the EUREF LNAACs.

The combination of regional solutions is performed using the sequential least-squares adjustment. The combination is statistically correct (equivalent to a common least-squares adjustment using all original GPS observations in one step) if there are no correlations between the observations of each of the sequential solutions. This assumption is true if, e.g., daily network solutions to weekly, monthly, or annual solutions are combined. If there are correlations between the observations of different sequential solutions, this independence is not given. The anchor-site concept (common sites in the different solutions) tries to account for these neglected correlations, but the procedure is not absolutely correct from a statistical point of view because the observations of these anchor sites are introduced into the combined solutions at least twice.

The estimation of the variance–covariance components is essential for a combination of results of different processing centers. Thanks to the fact that most European Analysis Centers (except ASI) process the data using the Bernese GPS Software (version 3.5 or 4.0) and very similar processing options, the variance-covariance factors for each solution can be derived directly from the data sampling rate. For ASI, the factor had to be estimated. Because in 1996 all centers agreed to use 180-second data the scaling could be set to 1 for all centers, except ASI which still uses 30-second data.

4.2 Combination Scheme

The results of all the EUREF LNAACs are received in the SINEX format, which is subsequently converted into normal equation files (NEQ-files). These NEQ-files can be input directly into the Bernese GPS Software program ADDNEQ [8], which is used to generate the EUREF weekly combinations. Note that all individual LNAACs using the Bernese GPS Software also use the ADDNEQ program to combine the NEQ-files of their daily solutions into a weekly (SINEX) solution.

ADDNEQ first removes all constraints from the individual solutions and then applies the covariance rescaling, which is based on the data sampling. Two different combinations are made subsequently, one using a free-network solution and one using fiducial sites. In both solutions, the same stations are used to define the reference frame. In the free-network solution, the geodetic datum is defined by specifying six no-net constraints (translation and rotations) for the selected reference sites. The free solution is performed since it helps to identify problems with the combination. The fiducial solution gives the official EUREF weekly solution.

After successful combination of the week considered, the combinations of the last 7 weeks are combined with the new week to see whether the new solution agrees with the old solution. A jump in the coordinates of individual sites is easily detected in this step.

Finally, the combined solution is made available at the anonymous ftp servers at AIUB (EUREF Combination Center, Switzerland), CDDIS (IGS global data center), IfAG (IGS regional data center), and ROB (EUREF Central Bureau, Belgium).

4.3 Outlook

Currently, the use of different scaling factors is studied in order to make sure that the combined solution has a realistic covariance matrix and to monitor and account for processing differences between Centers. Furthermore, CODE is in the process of redoing all EUREF weekly combinations due to some inconsistencies introduced in the past. Also, there will be a separate EUREF contribution to the IERS to be included into the new realization of the International Terrestrial Reference Frame.

5 A Last Remark

In April 1997, a first EUREF Analysis Workshop was organized in Brussels [21] with, as a main goal the discussion of the optimization of the EUREF processing :

- Data analysis recommendations for EUREF analysis centers have been set up.
- A redistribution of the EUREF subnetworks was discussed in order to work towards a more smooth number of analysis centers that process a specific EUREF station. EUREF analysis centers have agreed that
  - — When adding stations to their subnetwork, priority will be given to new EUREF stations or existing EUREF stations that are processed by only one LNAAC.
  - — When eliminating stations from their subnetwork, priority will be given to those stations that are processed a minimum of four LNAACs.
- It was recognized that one of the main problems for the correct interpretation of the coordinate time series is undocumented changes of the antennas or their environment at the EUREF stations (e.g., snow on the antenna and the use of randomes). EUREF therefore encouraged a closer contact between the analysis centers and the station managers through the EUREF Central Bureau.

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Report of the Regional Network Associate Analysis Center for South America (RNAAC SIR)

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1 Introduction

The continuously increasing number of permanently operating GPS stations led the International GPS Service for Geodynamics (IGS) to the concept of distributed data processing in its operational services. In order to prove the feasibility of this concept, a pilot project aimed at analyzing the performance of Regional Network Associate Analysis Centers (RNAACs) was initiated in early 1996. In response to IGS's call for participation, Deutsches Geodätisches Forschungsinstitut, Abt.I (DGFI/I) is acting on behalf of the SIRGAS project as the RNAAC for South America (RNAAC SIR) since June 1996. Since then, weekly solutions of the South American regional network are delivered to IGS. This brief report summarizes the RNAAC activities at DGFI/I.

2 Processed Network

At the beginning of the pilot project, the SIR network consisted of 12 stations; due to the sparse coverage of South America with permanent GPS stations, all these stations were also processed by at least one of the global analysis centers. Presently, the data of 18 stations are processed (Figure 1). Stations exclusively included in the RNAAC-SIR network are the new Brazilian permanent stations Curitiba, Presidente Prudente, and Bom Jesus Lapa. A further extension of the South American network, in particular in Brazil, can soon be expected.

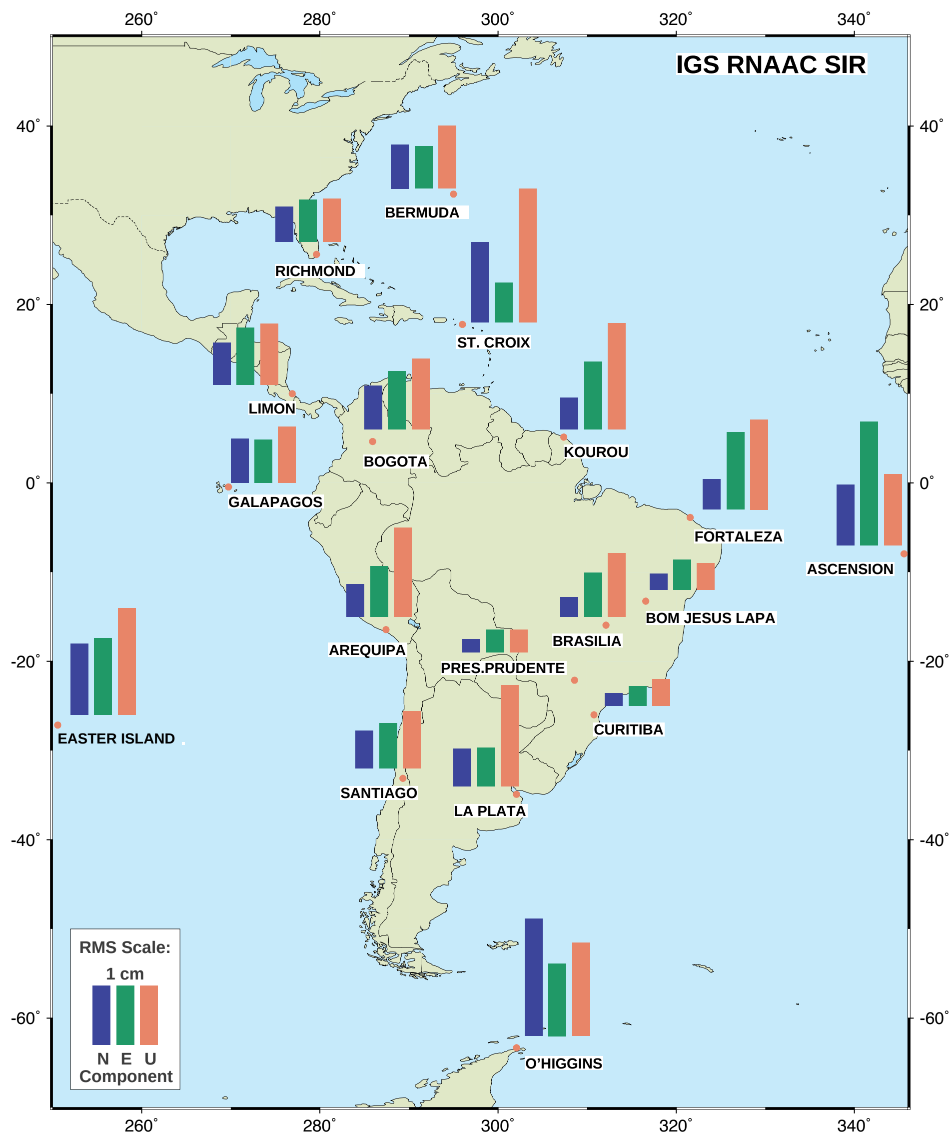

Figure 1: Rms deviations of the RNAAC weekly solutions from the GNAAC combined polyhedron solution derived from the first 15 weeks in 1997

3 Processing Characteristics

Weekly coordinate solutions are generated using the automated Bernese software version 4.0, the so called Bernese Processing Engine (BPE) [1]. Up to the end of 1996, a HP workstation was used; since early 1997, the software is running on an IBM AIX workstation. Characterizing features of the performed solutions are

- Final IGS orbits and Earth orientation parameters applied.
- Measurement elevation angle cutoff 15 degrees, sampling rate 2 minutes for single-day adjustments.
- Residual tropospheric zenith delays every 4 hours; a priori sigmas applied with respect to the prediction model: first parameter ±5 m absolute, following parameters ±10 cm relative.
- Ambiguities partly resolved according to statistical tests; remaining ones estimated as real numbers.
- Station coordinates estimated in the IGS orbits frame, applying a priori sigmas of ±1 m.

4 Discussion of Results

A rough analysis of processing results is demonstrated in Figures 1 and 2. Figure 1 shows the rms deviations of weekly RNAAC SIR solutions (R SINEX) from the GNAAC NCL (combined) polyhedron solution (P SINEX) in North, East, and Up components. They are typically in the subcentimeter level for horizontal components and in the 1- to 2-centimeter level for the vertical. The small deviations of stations Bom Jesus Lapa, Curitiba and Presidente Prudente are due to the fact that no other Analysis Center is processing these data, i.e., only the RNAAC SIR solution is included in the “combination.”

Figure 2 shows the internal stability of the weekly RNAAC SIR solutions for some selected stations. The coordinate variations are in the centimeter level. Some deviations similar in all stations are obviously due to reference frame effects.

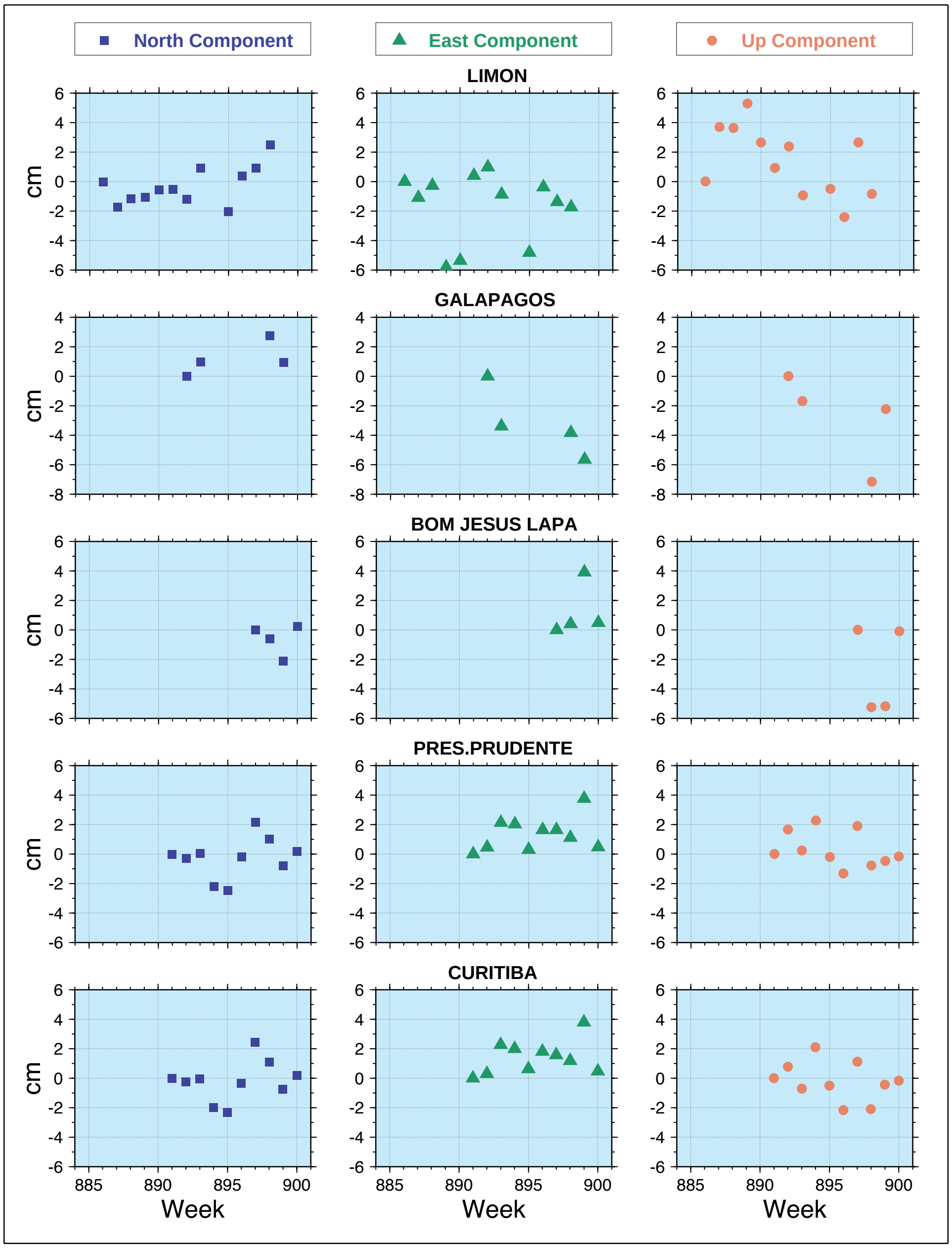

Figure 2: Stability of weekly RNAAC-SIR solutions. Variations of coordinates are plotted with respect to the solution of the first given week

5 Conclusion

The first analysis of RNAAC SIR processing demonstrates satisfying results. The South American network has grown rapidly in a short time interval. The number of stations will further increase in the near future. Thanks are due to the contributing countries, in particular to the Instituto Brasileiro de Geografia & Estatistica (IBGE/DEGED) for its efforts in providing the data of the Brazilian network with highest reliability.

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IGS

DATA CENTER REPORTS

IGN Global Data Center Report

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1 Introduction

The Institut Géographique National (IGN) has operated a Global Data Center of the IGS since the Test Campaign of 1992. The precise definition of the tasks involved can be found in the IGS Terms of Reference [1]. A Global Data Center is committed to archive and make available the IGS data and products. The activity is, in fact twofold: gather and distribute the files needed by the analysis centers of the IGS; and collect and distribute the whole set of products, data, and ancillary information to GPS users. The IGS officially started in 1994 and even earlier in pilot mode. The historic information accumulated since then, along with the current data, are archived at the Global Data Center and available to the GPS user community.

This paper gives a description of the computer and network architecture and provides details about the IGS data handling and users access setup at IGN. Miscellaneous statistics about the activity of the Center have been extracted from our operational database and will be presented below.

2 Computer System Configuration

The IGS activities at IGN are supported by a mixed computer environment, consisting of a VAX cluster with the VMS operating system and a HP server running HP's UNIX incarnation, HP-UX. The most active systems in 1996 were the VAXes, the UNIX box being a backup and providing additional short-term and long-term storage space.

There are two VAX stations in the cluster, totaling 6 Gbytes of hard-disk space (Figure 1). This system is running Oracle in order to deal with the database that stores the most significant information about the routine operations of the center. The database has been setup to assess the quality and performance of the service provided by the data center and to help locate the historic and current data archived at IGN.

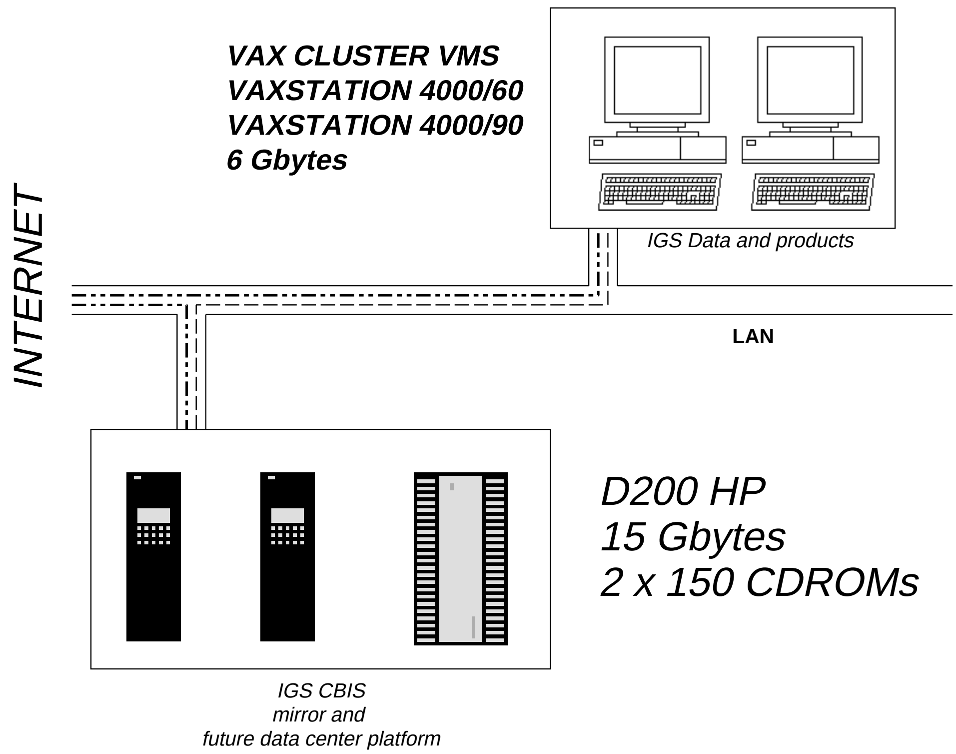

Figure 1: Computer architecture

The archiving media is a two-sided, 5.25-inch rewritable magneto–optical disk. The capacity is 325 Mbytes per side. The writing unit is connected to a VAX, and a VMS file system format is used to generate the archives. There are now more than 200 of these at IGN.

The UNIX server is an HP D200, soon to be upgraded to a biprocessor configuration. Out of its total disk space, this system has 15 Gbytes dedicated to the IGS activities and pilots 2 CD ROM jukeboxes containing 4 reading units and 150 CDs each. It stores the mirror of the IGS CB Information System and provides access to the disks of the VAX cluster. This is progressively becoming the main computer for the data center; the VAXes will be less and less active until the migration is complete. Then all the IGS procedures will be run on the D200, the archives will be stored on CD ROMs, and the VAXes will be maintained and operated just to restore the historic data archives.

Both VMS and UNIX systems are available through TCP/IP protocols; the access is provided by ftp, non-anonymous as well as anonymous. A web server is in construction, it is already up, but it is really basic. The local network is connected to the Internet by a 2-Mbps dedicated line.

3 Archive Access

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

- Anonymous ftp on `mozart.ensg.ign.fr` (195.220.92.11).
- Non-anonymous ftp on `mozart.ensg.ign.fr`, username/password given by `igsadm@ensg.ign.fr`; this is mainly used by other IGS centers.
- Anonymous ftp on `igs.ensg.ign.fr` (195.220.92.14); the archive seen from this host is exactly the same as that on `mozart.ensg.ign.fr`, with an additional delay of 24 hours.

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

The directory structure on `mozart.ign.fr` is based on a root named `IGS$FTPDEV`, which is a pseudo-device that accumulates the full set of magnetic disks. This is a practical way to refer to a particular IGS file without needing to know on which physical device it is stored.

The directory structure on `igs.ensg.ign.fr` (Table 1) is basically the same as that on `mozart.ign.fr`, the difference being the root, which is `/pub/igs`. The naming conventions are those of UNIX, i.e., the compression suffix is translated from `_Z` to `.Z`. There is actually no data on this computer; all the files are symbolic links to physical locations on the VAXes accessed by NFS. Most of the users get data through this server.

The off-line archived files are provided to the users on request, either by restoring them on-line or on tape when the volume is too large to fit on-line. In the future , the archiving will be done on CD ROMs, which will then be stored in the jukeboxes. This will enable full autonomous access to the historical data with no action needed by the IGN staff.

4 Data Handling

The daily operations of the Data Center (Figure 2) are automatic, where all the data transfers are done via the Internet. Basically, according to a list of sources of data and a schedule, a dispatcher module runs the necessary tasks to get the data and redistribute it. In addition, miscellaneous maintenance and check routines are submitted daily in order to generate reports, keep the database sane, and issue warnings when something is wrong.

Table 1: Directory structure on mozart.ensg.ign.fr

Directory	File names	Description
IGS$FTPDEV:[CORE.*ddd*]	0STAT*ddd*.	IGN data flow summary file for day *ddd*
	*SSSSddd*0.*yy*O_Z	Compressed RINEX obs files for stations *SSSS*, day *ddd*, year *yy*
	*SSSSddd*0.*yy*D_Z	Same, in new RINEX compressed format
	*SSSSddd*0.*yy*M_Z	Meteorological data
	*SSSSddd*0.*yy*S_Z	Status data (result of QC run)
	IFAG*ddd*0.*yy*N_Z	Global European compressed RINEX nav file
	BRDC*ddd*0.*yy*N_Z	Global compressed RINEX nav file (all stations)
IGS$FTPDEV:[CALC.*wwww*]	0STAT*wwww*.	IGN data-flow summary file for week *wwww*
	CCCwwwwd.EPH	Orbits produced by center CCC for GPS week *wwww* and day *d* in SP3 format. *d* = 7: full week.
	CCCwwwwd.SP3	Same
	CCCwwwwd.SP1	Same in SP1 format
	CCCwwwwd.ERP	Earth Rotation Parameter file produced by center *CCC* for GPS week *wwww* and day *d*
	CCCwwwwd.SNX	Network coordinates solution in SINEX format
	CCCwwwwd.SUM	Summary file

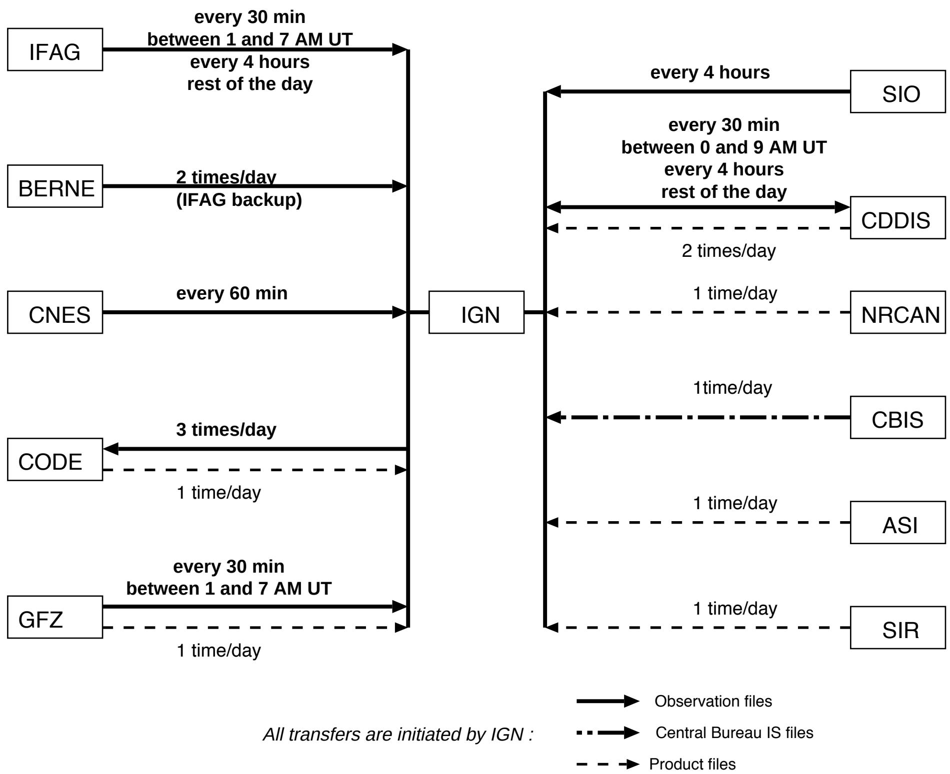

Figure 2: Data-flow schedule

Every day, one day of observation is deleted from the system after a check that the files are actually archived. The archiving of new data is done every day on magneto–optical disk and every month on tape.

5 Archive Statistics

The nominal on-line capacity is 150 days of observation files and 50 weeks of product files. There are more than 80 stations in the average daily set, representing a volume of about 45 Mbytes. The actual on-line capacity is currently reduced to 100 days because we, as some other data centers, are in the process of testing the new RINEX compressed format. The data files are duplicated; the new format requires about 2.5 times less space.

There is a partial mirror of the IGS Central Bureau Information System (CBIS) on `igs.ensg.ign.fr`; it is updated once per day. All the CBIS information files are mirrored; the IGS product files are not because they are part of the IGN Global Data Center holdings.

5.1 IGS Products

The products come from the Analysis and Associate Analysis Centers. The precise ephemerides and related parameter files are collected from seven centers; the combined IGS ephemerides are generated by NRCAN, which is also one of the centers producing an individual ephemeris. In 1996, the IGS began providing a rapid combined ephemeris, which is based on rapid solutions from the Analysis Centers that we do not archive at IGN (this is referenced as IGR in Figure 3). This rapid product is available within 2 days, while the availability of individual ephemerides takes 6 to 8 days; it takes 2 days more to get the IGS precise ephemeris.

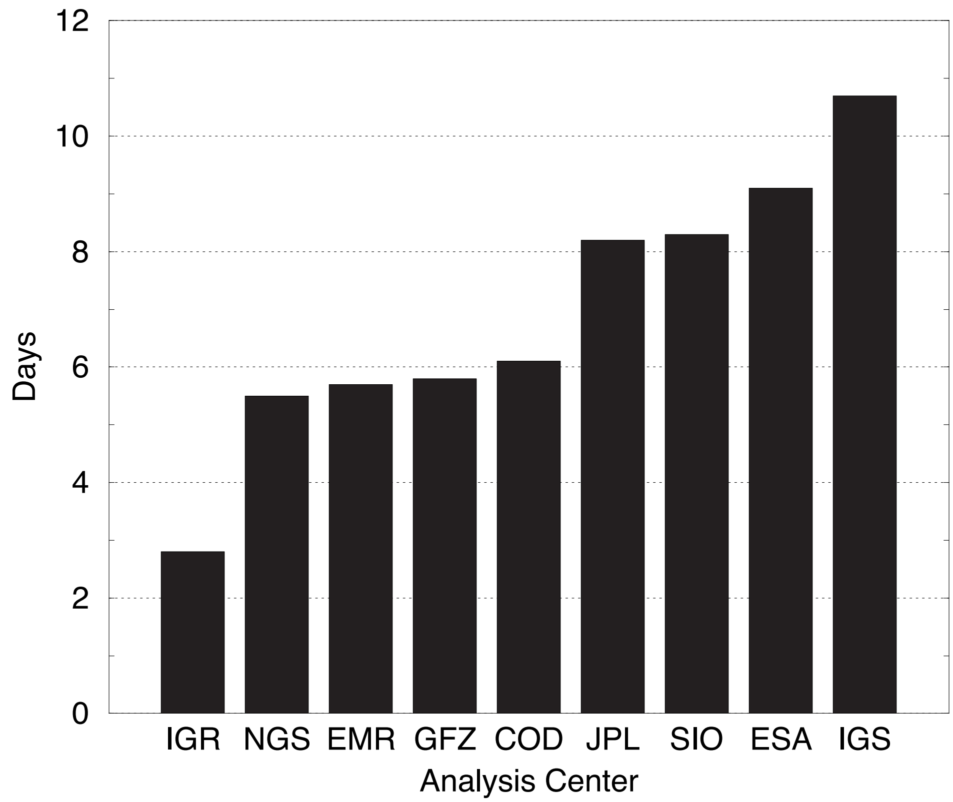

Figure 3: Ephemerides-file availability

The station-coordinate solutions come from 17 different sources. Among these, several types of solutions are provided: the 7 Analysis Centers that compute the precise orbits of the GPS satellites also deliver an estimate of the station coordinates of the core network of the IGS, 10 centers provide regional coordinate solutions, and 3 centers compute combined solutions (JPL, MIT, and NCL). For clarity in Figure 4, the combined solutions provided by JPL are referenced as JPLG, while the others are referenced as JPL.

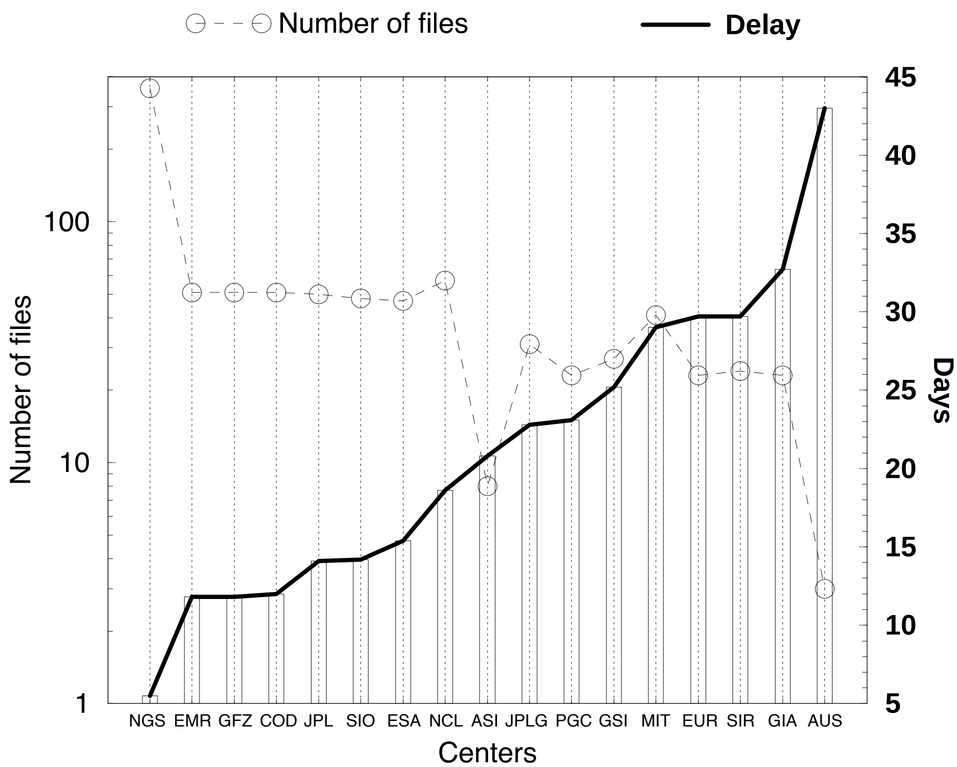

Figure 4: Coordinate-file availability (SINEX)

5.2 Tracking Network Data

In 1996, the data from 82 stations were collected and archived at IGN; roughly 70% of these are available with less than a 24-hour delay (Figure 5). Hidden behind this value is the fact that a very small part of the data files has been available within less than 5 hours during 1996, and this is inadequate for the Analysis Centers that want to generate rapid products. Since then, the data retrieval schedule and procedures have been significantly enhanced to increase this availability and also to comply with a refined objective of a few hours of delay. This will hopefully show up in our next year's report.

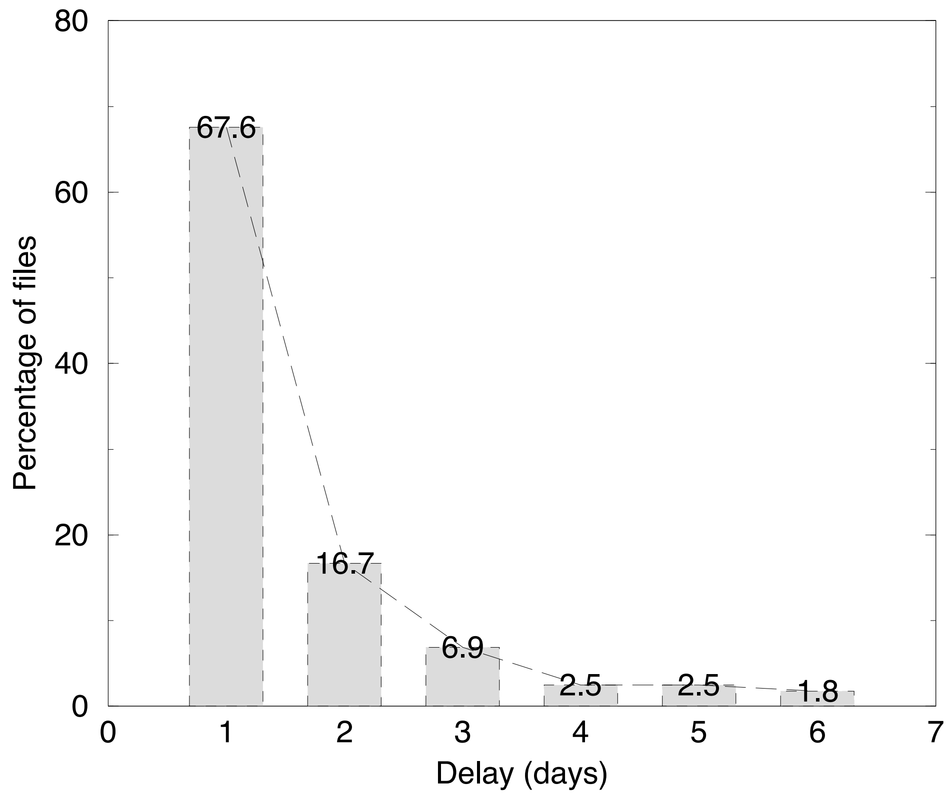

Figure 5: Observation-file availability

Figures 6 and 7 show the total days of data available by IGS site. They are roughly the same as a graphical view of the "quantity" parameter of the igsnet report generated by the Central Bureau, except that Figures 6 and 7 are extracted from our data base. Only 30% of these stations have operated more than 360 days in 1996.

The observation files come from six different sources. Most of the non-European data files are downloaded from the Crustal Dynamics Data Information System (CDDIS) because they are available sooner there than at SIO or because our connection to CDDIS is better. We get some European files directly from some operational centers like CNES and GFZ and get the rest from IfAG—or BERNE when IfAG has a problem. As can be seen in Figure 8, CDDIS and IfAG are the main data providers of IGN.

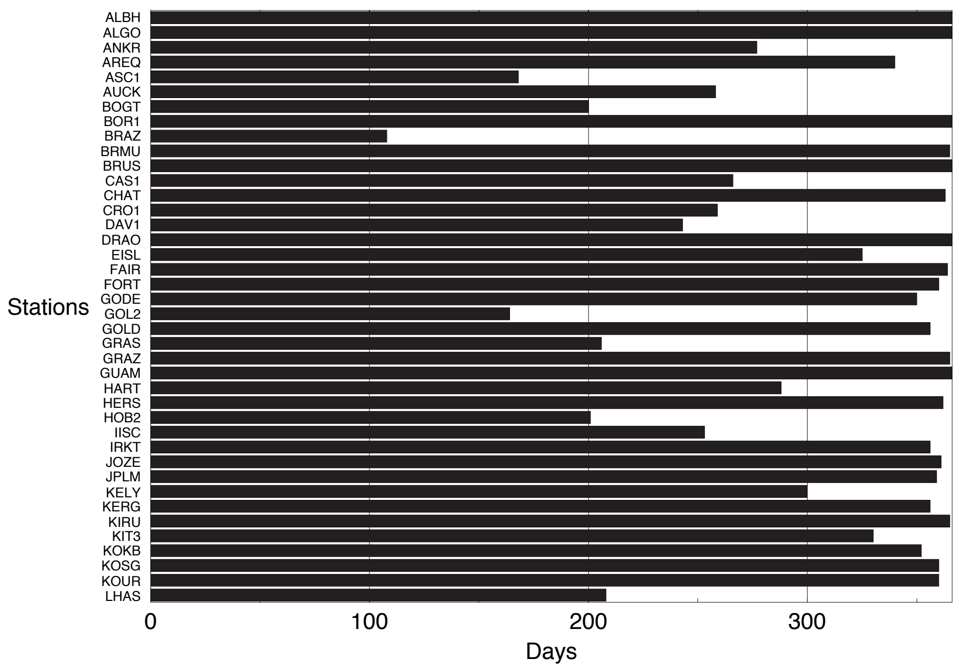

Figure 6: IGS-site data availability at IGN (part 1)

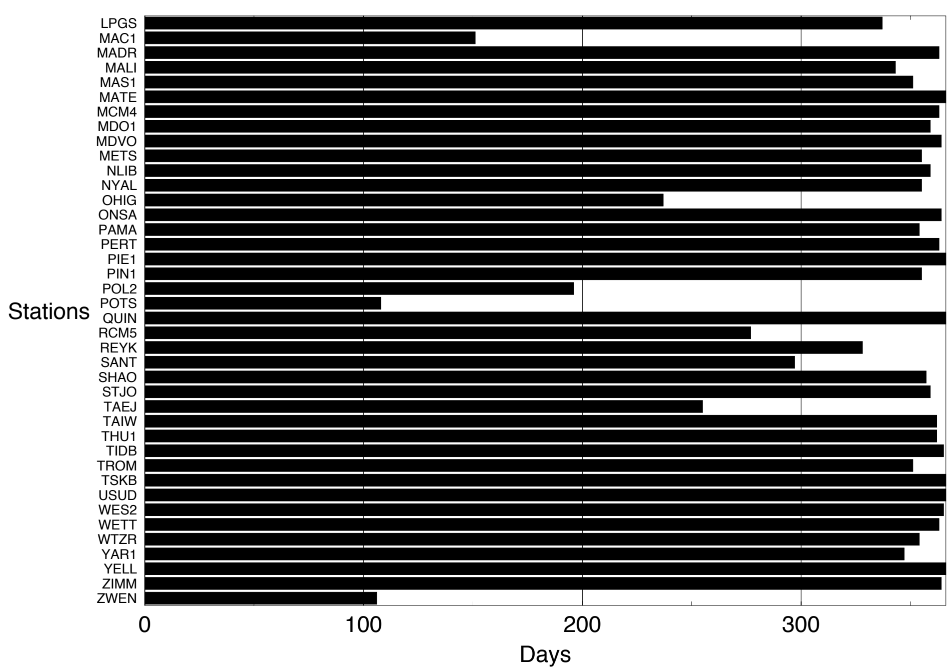

Figure 7: IGS-site data availability at IGN (part 2)

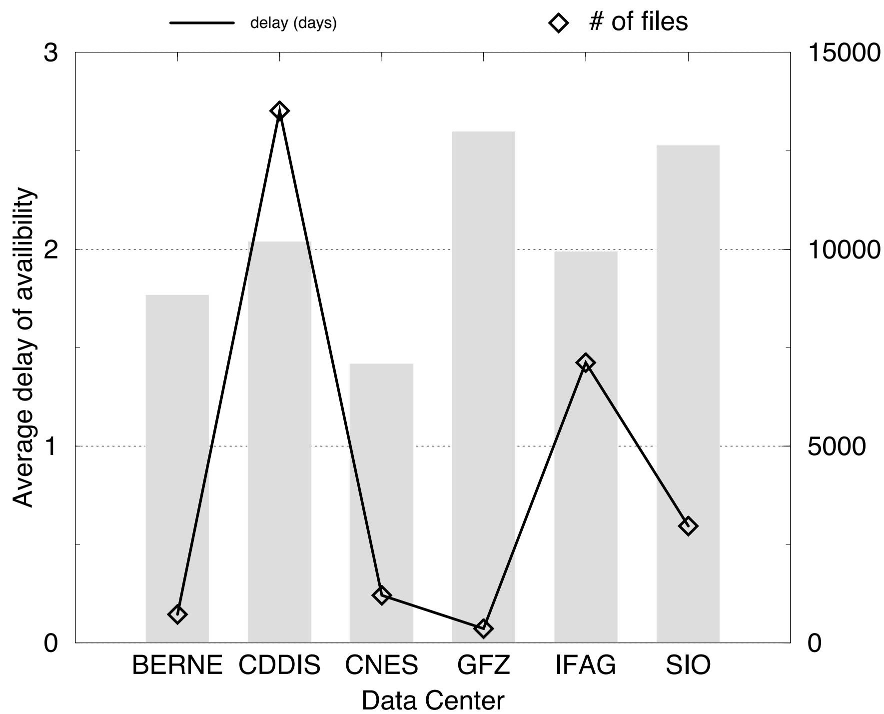

Figure 8: Observation availability by source

6 User Activity

In 1996, there was a total of 50,000 files retrieved from the on-line archive by users of the IGN Global Data Center, amounting to a total volume of 20 Gbytes. The average is 1.7 Gbytes per month. Overall, the increase in activity compared to 1995 is estimated to be 40%. The off-line volume requested by the users amounted to 5 Gbytes. Of the files retrieved, 80% were GPS observations, 15% were product files—almost all of which were precise ephemerides, and the rest were files of ancillary information.

The ftp hits on the server originated from 225 different networks, most of which were universities or educational sites. Of the transfers (Figure 9), 73% were made from a European site; more than 10% of these sites were not referenced in the Internet DNS system and have been marked "unresolved" in Figure 10.

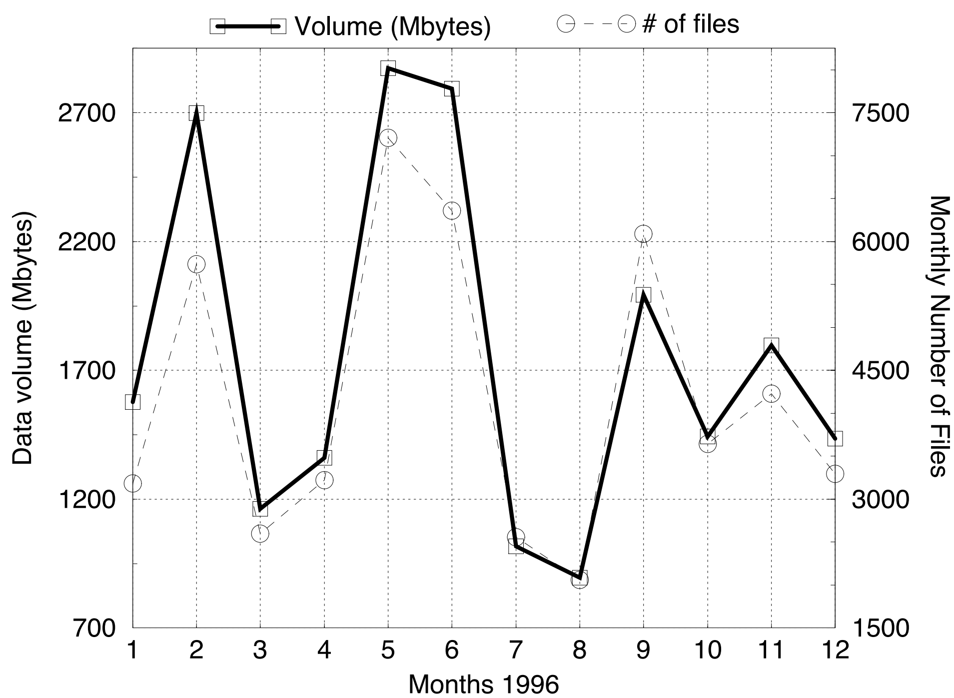

Figure 9: Volume of data transferred by users

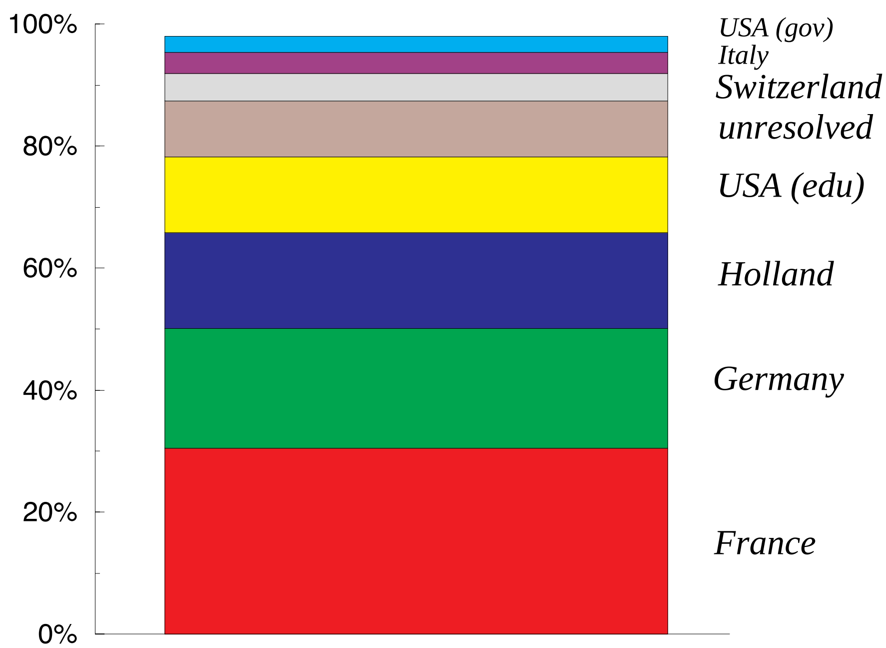

Figure 10: User access to on-line data by country

In addition to this, 5000 files have been transferred to 100 different networks from the CBIS ftp mirror on the UNIX system.

7 Plans

The migration to UNIX is progressing. When the first step is complete, all the active routines will be shut down on the VAXes and run on the UNIX server.

The second step will be the switch to the new archiving architecture. The sole media will be the CD ROM and all of the CDs will be directly available to users through the jukeboxes. The actual operations of the jukeboxes will be hidden; the users will be able to browse directories and get files, and the jukebox software will take charge of moving the CDs in the readers (an example of this can be seen at the anonymous ftp server `bach.ensg.ign.fr` in `/pub/igs`, with four CDs).

In the third step, the web site will be developed and we will provide a search engine interfaced with the database. The last step could be to rewrite the current archive from magneto-optical disks to CDs; this option is still under study. This is a heavy task that requires a significant amount of human intervention, so for the moment the priority is low on this.

As usual, we will do some enhancements on the hardware: more disks (maybe RAID, if funding permits) and memory and a new processor to get a biprocessor configuration.

A GLONASS data center has been set up in test mode at IGN; currently it is basically a directory structure. A disk space of 1 Gbyte has been opened to centers that wish to put their observation files there. The address is `bach.ensg.ign.fr` in `/pub/glonass` . This will be developed and set up according to the IGS standards.

8 Contact information

To obtain more information or make a request please contact :

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ftp	`igs.ensg.ign.fr:/pub/igs`
http	`http://igs.ensg.ign.fr/`

9 Reference

[1] *International GPS Service for Geodynamics, 1995 Annual Report*, edited by J. F. Zumberge, M. P. Urban, R. Liu, and R. E. Neilan, JPL Publication 96-18, Jet Propulsion Laboratory, Pasadena, California, 1996.

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 1996 are summarized below; this report also includes any changes or enhancements made to the CDDIS during the past year. General CDDIS background and system information can be found in the CDDIS data center summary included in the IGS 1994 Annual Report [1].

2 System Description

The CDDIS archive of IGS data and products is accessible worldwide 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

The CDDIS is operational on a dedicated Digital Equipment Corporation (DEC) VAX 4000 Model 200 running the VMS operating system. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is accessible to users 24 hours per day, 7 days per week. The CDDIS is available to users globally through electronic networks using TCP/IP (Transmission Control Protocol/Internet Protocol) and DECnet (VAX/VMS networking protocol), through dial-in service (currently, up to 9600-baud) and through the GTE SprintNet system. During 1996, two additional disk drives were installed, bringing the current on-line magnetic storage capacity of the system to nearly 30 Gbytes.

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 4 days of GPS tracking data can be stored on a single side of one of these platters. The older data continue to be stored on these optical disks and can easily be requested for mounting and downloading remotely by the user. Alternatively, if the request for older data is relatively small, data are downloaded to magnetic disk, providing temporary on-line access. A 4.3-Gbyte magnetic disk drive is devoted to the on-line storage of IGS products, special requests, and supporting information.

3 Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to both GPS data from the global IGS network and 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 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 1996; Table 2 presents detailed information on the sites whose data were archived in the CDDIS during the past year.

Table 1: Sources of GPS data transferred to the CDDIS

Source	Sites								No. Sites
AUSLIG	CAS1	COCO	DAV1	HOB2	MAC1				5
NOAA/GL	BRMU	FORT	HNPT	KELY	RCM5/6	SOL1	USNA	WES2	9
	WUHN								
NRCan	ALBH	ALGO	CHUR	DRAO	DUBO	FLINN	STJO	WHIT	9
	YELL								
ESA	KIRU	KOUR	MALI	MAS1	PERT	VILL			6
GFZ	KIT3	LPGS	OBER	POTS	ZWEN				5
GSI	TAIW	TSKB							2
IGN	ANKR	BOR1	BRUS	EBRE	GRAS	GRAZ	HART	HERS	25
	IRKT	JOZE	KERG	(KIRU)	(KIT3)	KOSG	LHAS	(LPGS)	(31)
	(MAS1)	MATE	MDVO	METS	NYAL	OHIG	ONSA	PAMA	
	(POTS)	REYK	TROM	WETT	WTZR	ZIMM	(ZWEN)		
JPL	AOA1	AREQ	ASC1	AUCK	AZU1	BOGT	BRAZ	CARR	56
	CASA	CAT1	CHAT	CICE	CIT1	CRO1	CSN1	DGAR	
	EISL	FAIR	GALA	GODE	GOL2	GOLD	GUAM	HARV	
	HRAO	IISC	JPLM	KOKB	KRAK	KWJ1	LBCH	MADR	
	MCM4	MDO1	MKEA	MOIN	NLIB	OAT2	PIE1	QUIN	
	SANT	SEY1	SHAO	SNI1	SPK1	THU1	TID2	TIDB	
	UCLP	USC1	USUD	WHC1	WHI1	WLSN	XIAN	YAR1	
NIMA	BAHR								1
KAO	TAEJ								1
SIO	MONP	PIN1	PVEP	SIO3	VNDP				5
UNAVCO	POL2								1
Totals:								125 sites from 12 data centers	

Note: Sites in () indicate backup delivery route

Table 2: 1996 GPS data holdings of the CDDIS

Site Name	N. Lat.	E. Long.	Mon. Name	Data Center Source	Receiver Type	Start Date	End Date	No. Days
Albert Head	48° 23’	-123° 29’	ALBH	NRCan	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Algonquin	45° 57’	-78° 04’	ALGO	NRCan	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Ankara	39° 53’	32° 45’	ANKR	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	267
Annapolis	38° 36’	76° 18’	USNA	NOAA	ROGUE SNR-8000	13-Jan-96	31-Dec-96	354
AOA, Westlake	34° 10’	-118° 50’	AOA1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	350
Arequipa	-16° 28’	-71° 38’	AREQ	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	339
Ascension Island	-07° 58’	-14° 49’	ASC1	JPL	ROGUE SNR-8000	21-Apr-96	31-Dec-96	247
Auckland	-35° 33’	174° 28’	AUCK	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	360
Azusa	34° 07’	-117° 54’	AZU1	JPL	ROGUE SNR-8000	26-Jul-96	31-Dec-96	97
Bahrain	26° 13’	50° 37’	BAHR	NIMA	ASHTECH Z-XIID	23-Jun-96	31-Dec-96	181
Bangalore	12° 59’	77° 40’	IISC	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	254
Bermuda	32° 21’	-64° 39’	BRMU	NOAA	ROGUE SNR-8000	01-Jan-96	31-Dec-96	365
Bishkek	42° 32’	74° 28’	POL2	UNAVCO	ROGUE SNR-8000	01-Jan-96	31-Dec-96	292
Bogotá	04° 38’	-74° 05’	BOGT	JPL	ROGUE SNR-8000	19-Feb-96	12-Dec-96	230
Borowiec	52° 17’	17° 05’	BOR1	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	363
Brasília	-15° 57’	-47° 53’	BRAZ	JPL	ROGUE SNR-8000	29-Aug-96	31-Dec-96	108
Brussels	50° 18’	04° 13’	BRUS	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	354
Carr Hill	35° 53’	-120° 26’	CARR	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	361
Casey	-66° 16’	110° 32’	CAS1	AUSLIG	ROGUE SNR-8100	01-Jan-96	31-Dec-96	295
Catalina Island	32° 13’	-118° 12’	CAT1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	364
Chatham Island	-43° 58’	-176° 34’	CHAT	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	365
Churchill	58° 27’	-94° 00’	CHUR	NRCan	ROGUE SNR-8000	18-Jun-96	31-Dec-96	184
CIT, Pasadena	34° 09’	-118° 08’	CIT1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Cocos Island	-12° 12’	96° 50’	COCO	AUSLIG	ROGUE SNR-8100	13-Jun-96	31-Dec-96	147
Davis	-68° 34’	77° 58’	DAV1	AUSLIG	ROGUE SNR-8100	02-Feb-96	29-Dec-96	266
Diego Garcia	-07° 12’	72° 15’	DGAR	JPL	ROGUE SNR-8000	09-May-96	31-Dec-96	235
Easter Island	-27° 09’	-109° 23’	EISL	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	342
Ensenada	31° 15’	-116° 09’	CICE	JPL	ROGUE SNR-8000	03-Jan-96	31-Dec-96	348
Fairbanks	64° 58’	-147° 29’	FAIR	JPL	ROGUE SNR-8	01-Jan-96	16-Apr-96	106
					ROGUE SNR-8000	17-Apr-96	31-Dec-96	258
Flin Flon	54° 44’	-101° 59’	FLIN	NRCan	ROGUE SNR-8000	08-Jun-96	31-Dec-96	206
Fortaleza	-03° 45’	-38° 35’	FORT	NOAA	ROGUE SNR-8000	01-Jan-96	31-Dec-96	363
Galapagos Island	00° 54’	-89° 03’	GALA	JPL	ROGUE SNR-8000	29-Mar-96	31-Dec-96	218
Goldstone	35° 15’	-116° 47’	GOL2	JPL	ROGUE SNR-8000	29-May-96	31-Dec-96	214
			GOLD	JPL	ROGUE SNR-8	01-Jan-96	30-Dec-96	342
Grasse	43° 45’	06° 55’	GRAS	IGN	ROGUE SNR-12 RM	03-Oct-96	31-Dec-96	78
					ROGUE SNR-8100	01-Jan-96	06-May-96	127
Graz	47° 04’	15° 30’	GRAZ	IGN	ROGUE SNR-8	01-Jan-96	24-Jun-96	175
					ROGUE SNR-8000	25-Jun-96	31-Dec-96	189
Greenbelt	39° 01’	-76° 50’	GODE	JPL	ROGUE SNR-8100	01-Jan-96	31-Dec-96	350
Guam	13° 28’	144° 45’	GUAM	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	365
Hartebeesthoek	-25° 53’	27° 42’	HART	IGN	ROGUE SNR-8	01-Jan-96	03-Mar-96	61
					ROGUE SNR-8000	29-Apr-96	31-Dec-96	220
			HRAO	JPL	ROGUE SNR-8000	27-Sep-96	19-Nov-96	53
Harvest Platform	34° 28’	-120° 41’	HARV	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	358
Herstmonceux	50° 52’	00° 20’	HERS	IGN	ROGUE SNR-8C	01-Jan-96	31-Dec-96	361
Hobart	-42° 48’	147° 26’	HOB2	AUSLIG	ROGUE SNR-8100	06-Feb-96	31-Dec-96	236
Horn Point	38° 36’	-76° 08’	HNPT	NOAA	ROGUE SNR-12 RM	01-Jan-96	31-Dec-96	366
Irkutsk	52° 18’	104° 15’	IRKT	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	354
Jozefoslaw	51° 02’	21° 30’	JOZE	IGN	TRIMBLE 4000SSE	01-Jan-96	31-Dec-96	360

Table 2: (continued)

Site Name	N. Lat.	E. Long.	Mon. Name	Data Center Source	Receiver Type	Start Date	End Date	No. Days
Kellyville	66° 59’	-50° 57’	KELY	NOAA	ROGUE SNR-8000	01-Jan-96	31-Dec-96	298
Kerguelen	-49° 21’	70° 16’	KERG	IGN	ROGUE SNR-8C	01-Jan-96	31-Dec-96	357
Kiruna	67° 32’	20° 09’	KIRU	ESA	ROGUE SNR-8100	01-Jan-96	31-Dec-96	365
Kitab	39° 08’	66° 53’	KIT3	GFZ	ROGUE SNR-8000	01-Jan-96	30-Dec-96	333
Kokee Park	22° 08’	-159° 40’	KOKB	JPL	ROGUE SNR-8000	11-Jan-96	31-Dec-96	353
Kootwijk	52° 11’	05° 49’	KOSG	IGN	ROGUE SNR-12	02-Feb-96	31-Dec-96	333
					ROGUE SNR-8	01-Jan-96	01-Feb-96	27
Kourou	05° 08’	-52° 37’	KOUR	ESA	ROGUE SNR-8C	01-Jan-96	31-Dec-96	360
Kwajalein	09° 24’	167° 29’	KWJ1	JPL	ROGUE SNR-8000	17-Mar-96	31-Dec-96	280
L'Ebre	40° 82’	00° 49’	EBRE	IGN	TRIMBLE 4000SSE	29-Jan-96	30-Dec-96	160
La Plata	-34° 31’	-57° 33’	LPGS	GFZ	ROGUE SNR-8000	01-Jan-96	31-Dec-96	338
Lac du Bonnet	50° 16’	-95° 52’	DUBO	NRCan	ROGUE SNR-8000	18-Oct-96	31-Dec-96	75
Lhasa	29° 25’	91° 07’	LHAS	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	303
Limon	09° 59’	-83° 06’	MOIN	JPL	ROGUE SNR-8000	25-Feb-96	30-Dec-96	54
Long Beach	33° 28’	-118° 09’	LBCH	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	364
Macquarie Island	-54° 30’	158° 56’	MAC1	AUSLIG	ROGUE SNR-8100	01-Jan-96	31-Dec-96	193
Madrid	40° 26’	-04° 15’	MADR	JPL	ROGUE SNR-8	01-Jan-96	31-Dec-96	362
Malindi	-03° 14’	40° 08’	MALI	ESA	ROGUE SNR-8C	01-Jan-96	31-Dec-96	343
Mammoth Lakes	37° 38’	-118° 57’	CASA	JPL	ROGUE SNR-8000	01-Jan-96	29-Dec-96	333
			KRAK	JPL	ROGUE SNR-8000	25-Jul-96	25-Dec-96	141
Maspalomas	27° 46’	-15° 38’	MAS1	ESA	ROGUE SNR-12 RM	18-Apr-96	31-Dec-96	253
					ROGUE SNR-8100	01-Jan-96	17-Apr-96	96
Matera	40° 39’	16° 42’	MATE	IGN	ROGUE SNR-8	01-Jan-96	08-Jul-96	190
					ROGUE SNR-8100	09-Jul-96	31-Dec-96	176
Mauna Kea	19° 48’	-155° 28’	MKEA	JPL	ROGUE SNR-12 RM	10-Oct-96	31-Dec-96	82
					ROGUE SNR-8000	27-Sep-96	09-Oct-96	13
McDonald	30° 41’	-104° 01’	MDO1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	359
McMurdo	-77° 51’	166° 40’	MCM4	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	361
Mendeleevo	37° 14’	56° 02’	MDVO	IGN	TRIMBLE 4000SSE	01-Jan-96	31-Dec-96	363
Metsahovi	60° 13’	24° 24’	METS	IGN	ROGUE SNR-8100	01-Jan-96	31-Dec-96	345
Monument Peak	32° 53’	-116° 25’	MONP	SIO	ASHTECH LPZ-XII	01-Jan-96	30-Dec-96	355
Mount Wilson	34° 13’	-118° 04’	WLSN	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	337
North Liberty	41° 46’	-91° 34’	NLIB	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	356
Northridge	34° 15’	-118° 31’	CSN1	JPL	ROGUE SNR-8000	02-May-96	31-Dec-96	243
Ny Ålesund	78° 56’	11° 52’	NYAL	IGN	ROGUE SNR-8	01-Jan-96	31-Dec-96	348
O'Higgins	-63° 19’	-59° 54’	OHIG	IGN	ROGUE SNR-8000	12-Jan-96	31-Dec-96	347
Oatt Mountain	34° 20’	-118° 36’	OAT2	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Oberpfaffenhofen	48° 05’	11° 17’	OBER	GFZ	ROGUE SNR-8000	27-Oct-96	31-Dec-96	62
Onsala	57° 24’	11° 56’	ONSA	IGN	ROGUE SNR-8000	01-Jan-96	31-Dec-96	362
Palos Verdes	33° 45’	-118° 24’	PVEP	SIO	TRIMBLE 4000SSE	01-Jan-96	31-Dec-96	360
Pamate	-17° 34’	-149° 34’	PAMA	IGN	ROGUE SNR-8100	01-Jan-96	31-Dec-96	354
Pasadena	34° 12’	-118° 10’	JPLM	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	357
Penticton	49° 19’	-119° 37’	DRAO	NRCan	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Perth	-31° 58’	115° 49’	PERT	ESA	ROGUE SNR-8100	01-Jan-96	31-Dec-96	362
Pie Town	34° 18’	-108° 07’	PIE1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Pinyon Flat	33° 37’	-116° 27’	PIN1	SIO	ASHTECH Z-XIID	01-Jan-96	31-Dec-96	347
Potsdam	52° 23’	13° 04’	POTS	GFZ	ROGUE SNR-8000	01-Jan-96	31-Dec-96	363
Quincy	39° 58’	-120° 56’	QUIN	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	364
Reykjavík	64° 09’	-22° 00’	REYK	IGN	ROGUE SNR-8000	12-Jan-96	31-Dec-96	348
Richmond	25° 37’	-80° 23’	RCM5	NOAA	ROGUE SNR-8000	01-Jan-96	03-Nov-96	276
			RCM6	NOAA	ROGUE SNR-8000	01-Nov-96	31-Dec-96	58

Table 2: (continued)

Site Name	N. Lat.	E. Long.	Mon. Name	Data Center Source	Receiver Type	Start Date	End Date	No. Days
Saddle Peak	34° 04’	-188° 39’	SPK1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	355
Saint John's	47° 36’	-52° 41’	STJO	NRCan	ROGUE SNR-8000	01-Jan-96	31-Dec-96	359
San Nicolas Isl.	33° 15’	-119° 31’	SNI1	JPL	ROGUE SNR-8000	01-Jan-96	28-Jul-96	58
Santiago	-33° 09’	-70° 40’	SANT	JPL	ROGUE SNR-8	01-Jan-96	18-May-96	132
					ROGUE SNR-8000	17-Jul-96	10-Sep-96	50
					ROGUE SNR-8100	11-Sep-96	31-Dec-96	112
Scripps	32° 52’	-117° 15’	SIO3	SIO	ASHTECH Z-XII3	01-Jan-96	31-Dec-96	357
Seychelles	-04° 41’	55° 30’	SEY1	JPL	ROGUE SNR-8000	03-Jan-96	11-Feb-96	20
Shanghai	31° 11’	121° 26’	SHAO	JPL	ROGUE SNR-8100	01-Jan-96	31-Dec-96	355
Solomons Island	38° 19’	-76° 27’	SOL1	NOAA	ROGUE SNR-8000	06-Mar-96	31-Dec-96	300
					TRIMBLE 4000SSE	01-Jan-96	05-Mar-96	59
St. Croix	17° 45’	-64° 35’	CRO1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	364
Taejon	36° 12’	127° 16’	TAEJ	KAO	TRIMBLE 4000SSE	01-Jan-96	01-Jan-97	357
Taipei	25° 01’	121° 32’	TAIW	GSI	ROGUE SNR-800	01-Jan-96	31-Dec-96	362
Thule	76° 21’	-68° 18’	THU1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	363
Tidbinbilla	-35° 24’	148° 59’	TID2	JPL	ROGUE SNR-8000	26-Jul-96	31-Dec-96	159
			TIDB	JPL	ROGUE SNR-8	01-Jan-96	31-Dec-96	365
Tromsø	69° 40’	18° 56’	TROM	IGN	ROGUE SNR-8	01-Jan-96	31-Dec-96	344
Tsukuba	36° 06’	140° 05’	TSKB	GSI	ROGUE SNR-8100	01-Jan-96	31-Dec-96	366
UCLA, Los Angeles	34° 04’	-118° 27’	UCLP	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
USC, Los Angeles	34° 01’	-118° 18’	USC1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	357
Usuda	36° 08’	138° 22’	USUD	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	366
Vandenberg	34° 34’	-120° 30’	VNDP	SIO	ASHTECH LPZ-XII	01-Jan-96	31-Dec-96	353
Villafranca	42° 11’	-01° 27’	VILL	ESA	ROGUE SNR-8100	01-Jan-96	31-Dec-96	365
Westford	42° 37’	-71° 29’	WES2	NOAA	ROGUE SNR-8000	01-Jan-96	31-Dec-96	364
Wettzell	49° 09’	12° 53’	WETT	IGN	ROGUE SNR-800	01-Jan-96	31-Dec-96	363
			WTZR	IGN	ROGUE SNR-8000	10-Jan-96	31-Dec-96	354
Whitehorse	60° 43’	-135° 05’	WHIT	NRCan	ROGUE SNR-8000	07-Jun-96	31-Dec-96	201
Whittier College	33° 59’	-118° 02’	WHC1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	351
Whittier Library	33° 59’	-118° 02’	WHI1	JPL	ROGUE SNR-8000	01-Jan-96	31-Dec-96	363
Wuhan	30° 35’	114° 19’	WUHN	NOAA	ROGUE SNR-8000	03-Jan-96	30-Dec-96	272
Xi'an	34° 22’	109° 13’	XIAN	JPL	ROGUE SNR-8000	18-May-96	31-Dec-96	178
Yaragadee	-29° 03’	115° 21’	YAR1	JPL	ROGUE SNR-8	01-Jan-96	31-Dec-96	343
Yellowknife	62° 29’	-114° 29’	YELL	NRCan	ROGUE SNR-12	20-Dec-96	31-Dec-96	12
					ROGUE SNR-8000	01-Jan-96	18-Dec-96	353
Zimmerwald	46° 53’	07° 28’	ZIMM	IGN	TRIMBLE 4000SSE	01-Jan-96	31-Dec-96	364
Zvenigorod	55° 24’	36° 30’	ZWEN	GFZ	ROGUE SNR-8000	01-Jan-96	31-Dec-96	348
138 occupations at 125 sites								38,343

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. During 1996, these procedures were modified to increase their execution frequency. 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 1996, the CDDIS archived data on a daily basis from an average of 105 stations; toward the end of the year, this number increased to nearly 120 stations. Under the current 120 station network configuration, about 120 days worth of GPS data are available on-line to users at one time. Each site produces approximately 0.6 Mbytes of data per day; thus, one day's worth of GPS tracking data, including the summary and meteorological data files, totals nearly 70 Mbytes. For 1996, the CDDIS GPS data archive totaled over 26 Gbytes in volume; this figure represents data from over 40k observation days. Of the 120 or more sites archived each day at the CDDIS, not all are of "global" interest; some, such as those in Southern California, are regionally oriented. The CDDIS receives data from these sites as part of its NASA archiving responsibilities.

The majority of the data delivered to and archived on the CDDIS during 1996 was available to the user community within 24 hours after the observation day. As shown in Figure 1, nearly one quarter of the data from all sites delivered to the CDDIS was available within 6 hours of the end of the observation day; over 50 percent were available within 12 hours. These data delivery statistics are comparable, as shown in Figure 2, for the current set of nearly seventy "global stations" processed by three or more IGS Analysis Centers on a daily basis. Figure 3 presents the data availability information by global station; a few of the sites were not operational for a majority of 1996 and the statistics could reflect delays due to the initiation of the new data flow. These statistics were derived from the results of the daily archive report utilities developed by the IGS Central Bureau and executed several times each day on the CDDIS.

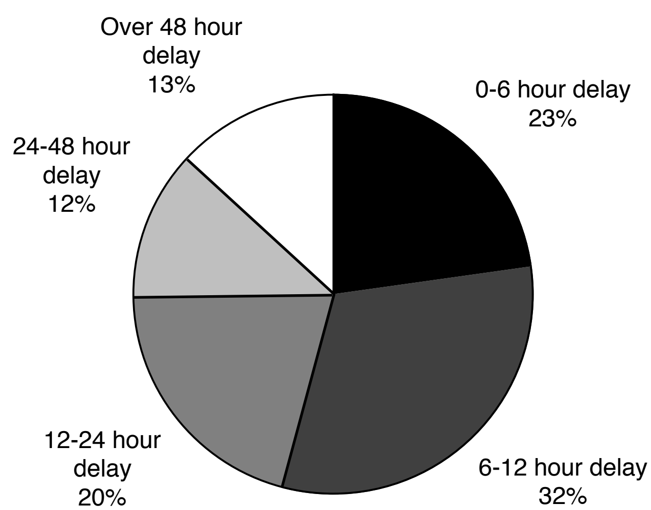

Figure 1: Median delay in GPS data delivery (all sites) to the CDDIS in 1996

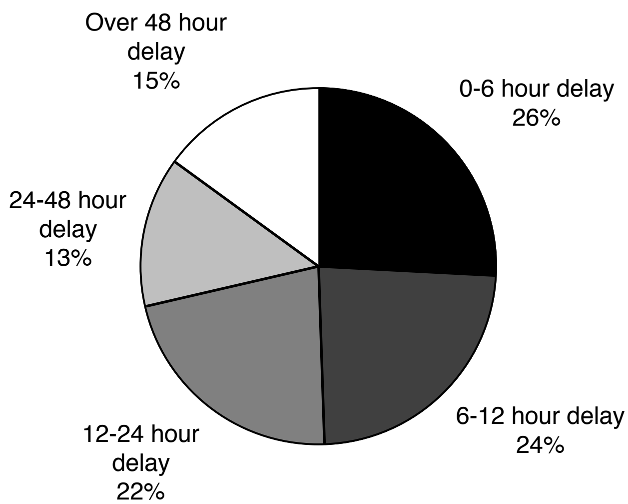

Figure 2: Median delay in GPS data delivery (global sites) to the CDDIS in 1996

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 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.

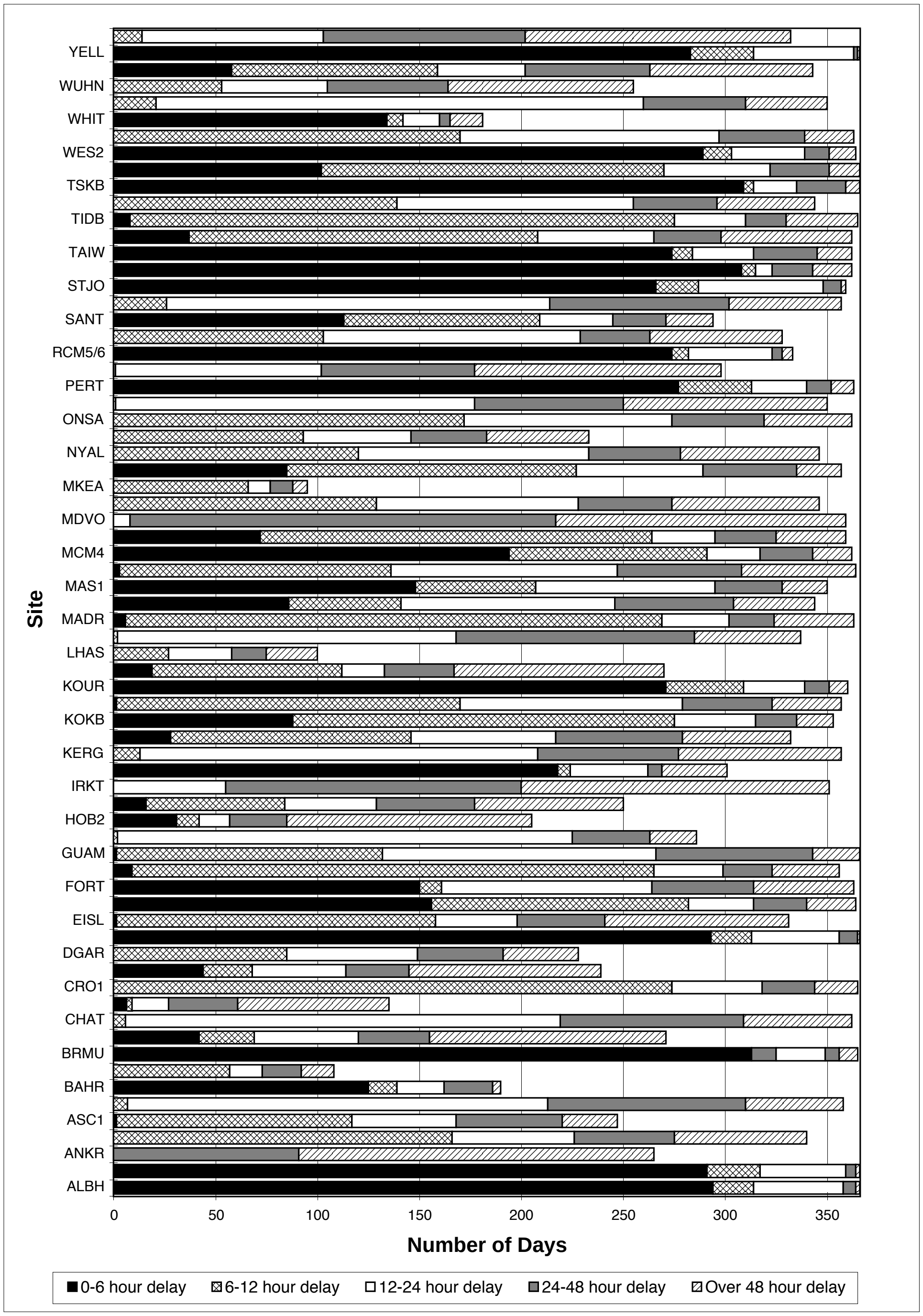

Figure 3: Median delay in GPS data delivery (by global site) to the CDDIS in 1996

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 1996 and submitted the resulting SINEX files to the CDDIS. The current set of RNAACs participating in the IGS are:

- AUSLIG
- EUREF through the Center for Orbit Determination (CODE), Astronomical Institute of Berne (AIUB), Switzerland
- Geophysical Institute, University of Alaska in Fairbanks, Alaska
- GSI
- Pacific Geoscience Centre, NRCan in Sidney, British Columbia, Canada
- Deutsches Geodätisches ForschungsInstitute (DGFI) in Munich, Germany

The three participating GNAACs are:

- JPL
- Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts
- University of Newcastle upon Tyne in Newcastle, Great Britain

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 10 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 average delay during 1996, in days and by source, of products delivered to the CDDIS, including the AACs operational during 1996. 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 1 to 2 days of receipt of data from all analysis centers and is typically available to the user community within 10 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.

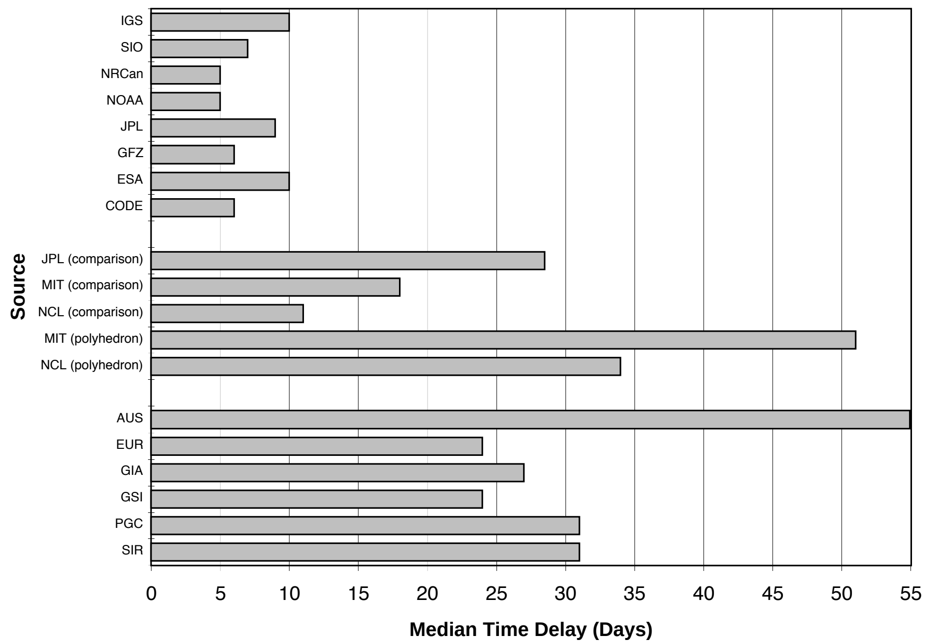

Figure 4: Median delay in GPS product delivery to the CDDIS (by source) in 1996

3.3 Meteorological Data

In 1995, the CDDIS and GSFC's Very Long Baseline Interferometry (VLBI) group began providing meteorological data from selected global GPS stations collocated with VLBI antennas. Meteorological data from the Greenbelt, MD; Fairbanks, AK; Kokee Park, HI; Westford, MA; and Wettzell, Germany, VLBI stations have been sent to the CDDIS routinely. These data are extracted from VLBI logs and converted into RINEX format at the CDDIS. The meteorological data provided are dry temperature, relative humidity, and barometric pressure at 30-minute sampling intervals. The data are acquired and downloaded by the VLBI site personnel on a best effort basis with typically a 1- to 3-day delay. In 1996, additional IGS sites began providing meteorological data from collocated sensors; these stations are: Bahrain; Kitab, Uzbekistan; Lhasa, Tibet; Oberpfaffenhofen and Potsdam, Germany; and Reykjavík, Iceland. These data are stored on CDDIS with the daily GPS observation and navigation data files in parallel subdirectories.

3.4 Supporting Information

In early 1996, the CDDIS staff developed software to create and maintain daily status files of GPS data holdings. The automated CDDIS archiving procedures were modified to execute the UNAVCO QC program, which analyzes the daily observation file and generates a summary file containing various statistics on these data. Routines then browse these summary files and update the daily status file with statistics on the number of data points, cycle slips, and multipath. Furthermore, information from the RINEX header, such as receiver and antenna type, antenna height, and marker name and number, are extracted to provide checks against the system configuration information available through the IGS Central Bureau Information System (CBIS). Data latency (in hours) is also computed and provided for each station. Replacement data are processed and reflected in this file by way of a version column. The summary files created by the QC program are also stored on the CDDIS in lieu of the previously generated CDDIS summary file. The daily status files are loaded into the CDDIS data base for reporting purposes. The staff can then easily generate reports on the timeliness of data deliveries and data quality of the IGS stations. The user community can receive a quick look at a day's data availability and 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://cddis.gsfc.nasa.gov/gpsstatus/`

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://cddis.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 5 through 7 summarize the monthly usage of the CDDIS for the deposit and retrieval of GPS data during 1996. These figures were produced daily by automated routines that peruse the log files created by each network access of the CDDIS. Figure 5 illustrates the amount of data retrieved during 1996. Over one million files were transferred in 1996, 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 6 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 7 illustrates the profile of users accessing the system during 1996; these figures represent the

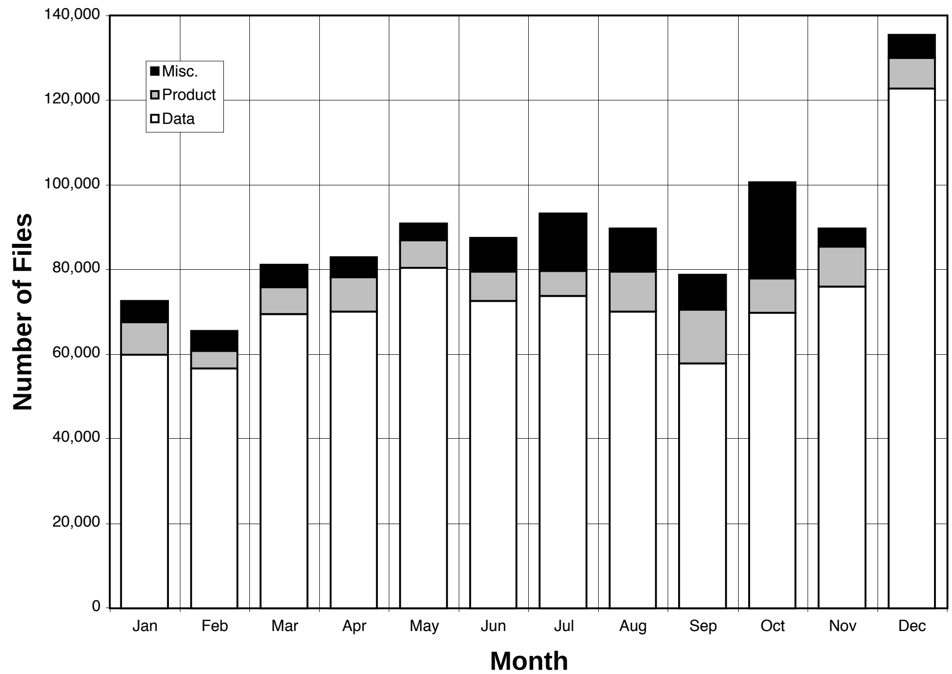

Figure 5: Number of GPS-related files transferred to/from the CDDIS in 1996

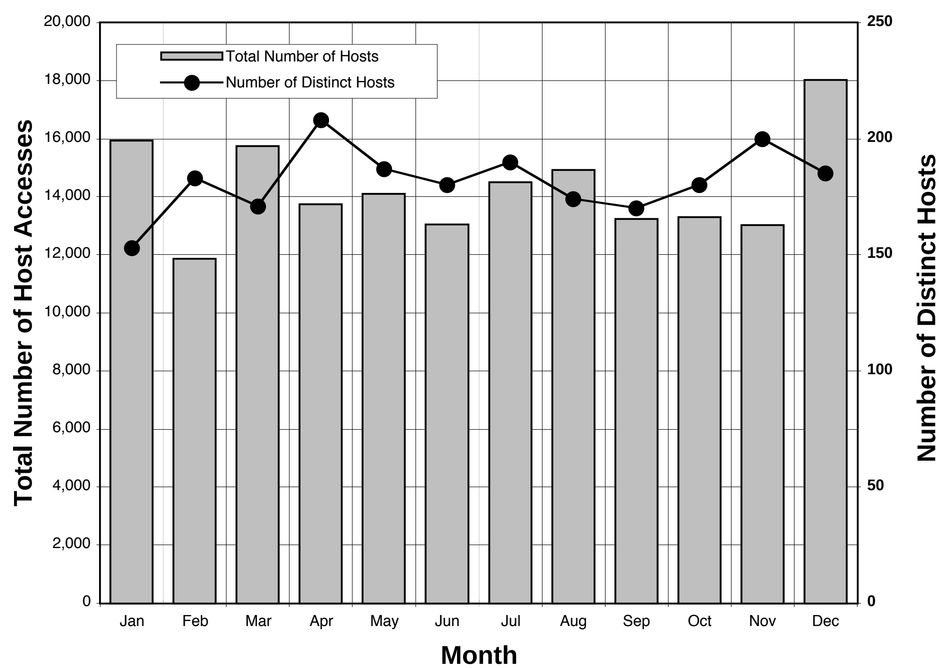

Figure 6: Number of hosts accessing GPS data and products on the CDDIS in 1996

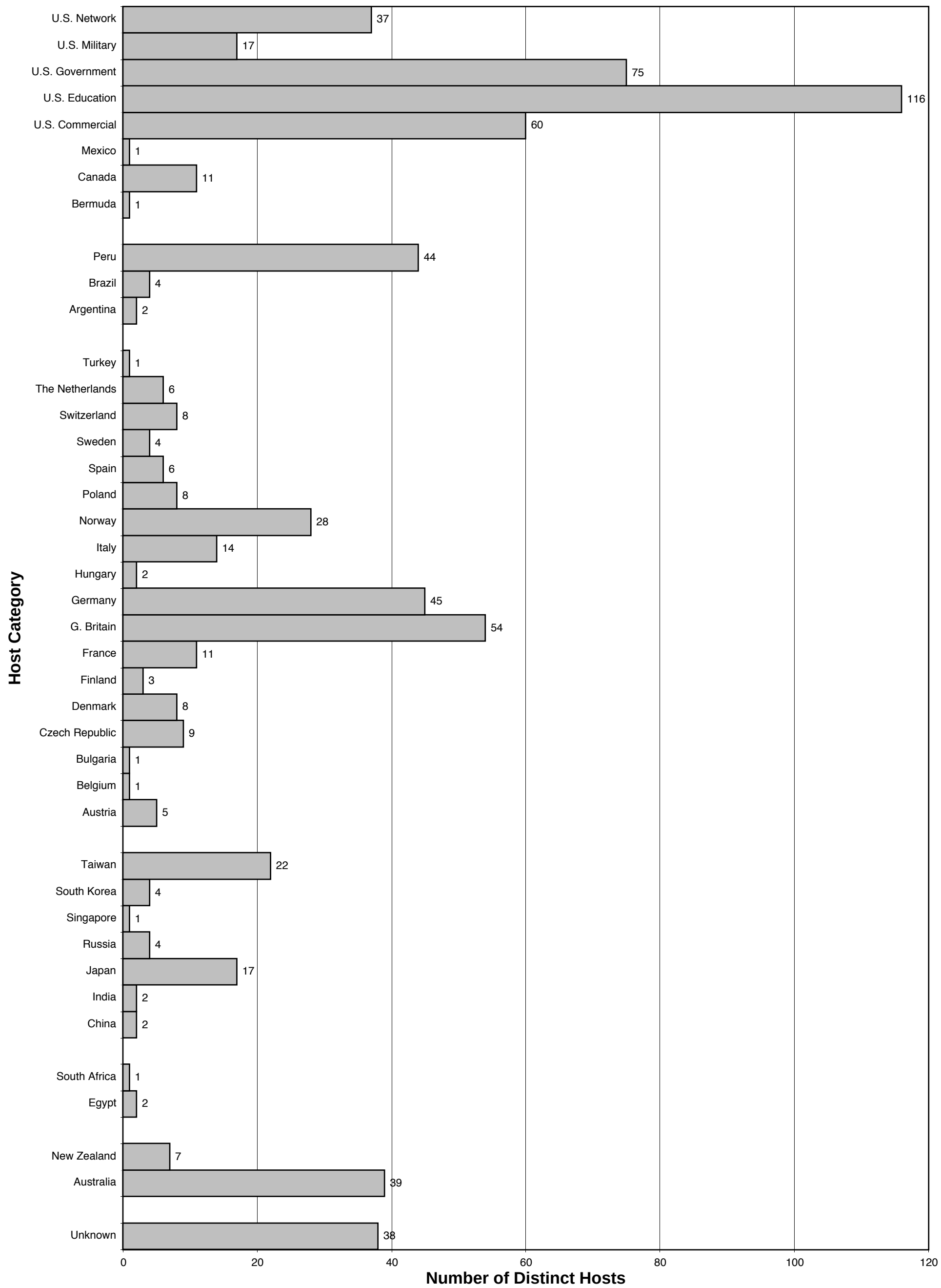

Figure 7: Distribution of IGS users of the CDDIS in 1996

number of distinct hosts in a particular country or organization. Nearly half of the users of GPS data available from the CDDIS come from U.S. government agencies, universities, or corporations.

The figures referenced above 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 3 summarizes the type and amount of special requests directed to the CDDIS staff during 1996. 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 3: Summary of special requests for GPS data and information in 1996

Type of Request	Totals
General IGS/CDDIS information	~115 requests (phone, fax, e-mail)
Off-line GPS data	~120 requests (phone, fax, e-mail)
Amount of off-line data requested	~50,150 station days†
Volume of off-line data requested	~30 Gbytes
Note: †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 1996 and presented papers on or conducted demos of their activities within the IGS, including:

> "Flow, Archiving, and Distribution of Global GPS Data and Products for the IGS and the Role of the Crustal Dynamics Data Information System (CDDIS)" (Carey E. Noll and Maurice P. Dube) was presented at the Workshop on Improving the DGPS Infrastructure for Earth and Atmospheric Science Applications in March 1996.

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

`http://cddis.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 initially have 30 Gbytes of on-line magnetic disk storage, but will soon be augmented with as much as an additional 60 Gbytes. A significant amount of the CDDIS staff time will be 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 late 1997.

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 and a procurement of a CD recordable system will be undertaken in 1997. This system will have 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. The data will most likely be written to CD-ROM by GPS week. Furthermore, purchase of a CD-ROM jukebox will be investigated in the hopes of delivery in late 1997.

6.2 Changes in the Data Archive

Tests are currently underway to incorporate a "compact RINEX" into the IGS data flow. This software, developed by Yuki Hatanaka (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). Plans are for testing at the IGS data centers to commence in early 1997.

An area of continual concern for the IGS community is that of the timeliness of the RINEX data deliveries to the global data centers. The CDDIS along with all groups involved in data flow will focus heavily in 1997 in improving the speed at which data flows through various levels of data centers to reach the global data center. As can be seen in Figure 1, more data need to be available within 6 hours than current statistics show in order to reliably generate predicted and rapid orbits required by an ever-increasing user community, particularly for new applications such as atmospheric analyses. Improvements in automated data downloading procedures as well as RINEX compression software will greatly aid in the reduction of these time delays.

The CDDIS staff will also install new procedures to check the RINEX header information, ensuring that it conforms to information reported in the site logs stored at the IGS Central Bureau. This information is currently extracted as part of the QC routines; data base software will be developed to further validate selected RINEX header fields.

As stated earlier, in 1995 the CDDIS began archiving meteorological data from VLBI and GPS collocated sites. These sites are equipped with sensors utilized during VLBI experiments. During 1997, however, a new field system will be installed in many of the VLBI sites; this system will automate data handling, including data from these meteorological sensors. It is hoped that this capability will enable more VLBI/GPS collocated sites to submit meteorological data to the IGS data stream.

At a business meeting in March 1997, the IGS Governing Board recommended that efforts begin to make GLONASS data available to the IGS user community. A minimal data flow will be established initially, with a more formal, data-center-oriented flow to follow as user needs and data volume are assessed. The CDDIS plans to establish on-line directories for these data and to incorporate GLONASS data in normal data processing procedures.

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 will be established in early 1997 (GPS3:[GPSDATA.BRDC.yyyy]) to store the historic BRDC files.

6.3 Changes in the Product Archive

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. 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.

7 Contact Information

To obtain more information about the CDDIS or a user name 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://cddis.gsfc.nasa.gov/cddis.html`

8 Acknowledgments

The author would once again like to thank members of the CDDIS staff, Dr. Maurice Dube and Ms. Ruth Kennard (Hughes-STX). They continue to enthusiastically support the high standards of the CDDIS and are constantly striving to improve our capabilities.

Reference

[1] C. E. Noll, “CDDIS Global Data Center Report” in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

IGS

IGS STATION REPORTS

The LAMA IGS Station

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Institute of Geodesy, Olsztyn University of Agriculture and Technology
Olsztyn, Poland

1 Introduction

In the IGS 1994 Annual Report [1] a short history of the Satellite Observatory of the Olsztyn University of Agriculture and Technology, founded in 1960, was presented. This report presents information about 2 years of work at the LAMA IGS Station. At this station, located at Lamkowko near Olsztyn, observations and research on GPS measurements are conducted.

2 Permanent GPS Observations 1995–1996

The LAMA IGS Station is one of three Polish stations taking part in the International GPS Service for Geodynamics. Permanent observations began in Lamkowko on December 1, 1994, using a TurboRogue SNR-8000 GPS receiver. Permanent observations in 1995 were conducted without perturbations. Results were transferred by INTERNET, mostly at regular intervals, to the IGS Data Centre in Graz. The first break in permanent observations was caused by damage to the receiver on February 26, 1996. Because the TurboRogue SNR-8000 was damaged, the Ashtech Z-XII receiver was installed on April 18, 1996, at the main point of the IGS Station in Lamkowko. Permanent GPS observations were performed with this equipment in the period April 18 to July 22, 1996. Since April 23, 1996, the Ashtech Z-XII receiver was controlled with an outer Rubidium Frequency Standard.

After repair, the TurboRogue SNR - 8000 was installed again on July 23, 1996, at the main point of IGS network.

3 Monitoring the Vector Lamkowko–Borowiec

GPS observations at the Borowiec IGS Station (BOR1) are performed using TurboRogue SNR-8000 with an outer Cesium Frequency Standard.

The vector Lamokowko–Borowiec is orthogonal to the direction of the Teisseyre–Tornquist Zone, passing across Poland and dividing the East European Platform from the Paleozoic Platform. The obtained day-by-day coordinates of this vector, computed using the Bernese Software Program and GPS satellite precise orbit elements from the Jet Propulsion Laboratory in Pasadena, confirm on the one hand high accuracy of the GPS observations and, on the other hand, the length of the vector stability. The average length of the Lamkowko–Borowiec vector computed on the basis of 22 days in January 1995 is

$$\overline{D}_{JAN} = 300575.6589 \text{ m}$$

The same length calculated on the basis of 24 days in February 1995 is

$$\overline{D}_{FEBR} = 300575.6588 \text{ m}$$

A deviation of weekly averages from the global average, calculated for the period of 859 to 883 GPS weeks, 1996, is presented in Figure 1. The global average length of the vector is

$$\overline{D}_{1996} = 300575.6592 \text{ m}$$

and differs from the February 1995 average by only about 0.3 mm.

4 The Use of GPS for Ionospheric Studies

The studies of the ionosphere have been carried out since 1995, in cooperation with the West Department of the Institute of Geomagnetism, Ionosphere and Wave Propagation of the Russian Academy of Sciences in Kaliningrad. The instrumental biases and total electron content (TEC) have been computed from GPS observables using the ionospheric model for diurnal variation of ionospheric delays. It has been shown that accurate results of instrumental bias determination can be achieved only if the ionosphere is not disturbed. During storms, the error in TEC determination, because of incorrect bias, may be more than 2×10^{16} el/m^2 [2].

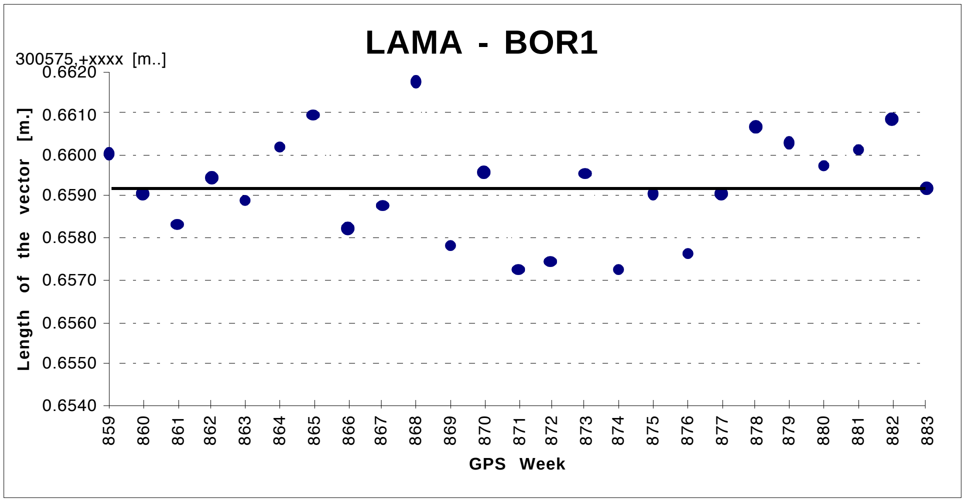

Figure 1: Weekly averages of the vector lengths repeatability

References

[1] L. W. Baran, "Lamkowko Satellite Observatory," in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

[2] L. W. Baran, I. I. Shagimuratov, N. J. Tepenitzina "The Use of GPS for Ionospheric Studies," *Artificial Satellites*, Vol. 32, No. 1, Warsaw, Poland, 1997.

IGS Stations Operated by the Institute of Geological and Nuclear Sciences, New Zealand

John Beavan

Institute of Geological and Nuclear Sciences Limited
Lower Hutt, New Zealand

1 Introduction

Since October 1995, the Institute of Geological and Nuclear Sciences (GNS), with cooperation from JPL and Land Information New Zealand (LINZ), has operated two stations contributing data to the IGS. These are (Figure 1)

AUCK Whangaparaoa Peninsula, north of Auckland (Australian plate)

CHAT Chatham Island (Pacific plate)

The stations are equipped with permanently installed TurboRogue SNR-8000 receivers supplied by JPL and the University Navstar Consortium (UNAVCO) under NASA's Dynamics of the Solid Earth project. The GPS instruments are collocated with stations of the New Zealand Meteorological Service.

2 Operations at GNS

Both stations are downloaded by phone to GNS using JPL's GNET software. A copy of the raw data is transferred by Internet to JPL, where the data are RINEXed and forwarded to IGS. The data are RINEXed independently at GNS and are processed daily along with those from other New Zealand stations.

The stations are inspected on an approximately annual basis (or as needed if maintenance is required) and local ties checked. Remeasurements of the AUCK and CHAT local ties in early 1997 showed no significant change from the 1995 values.

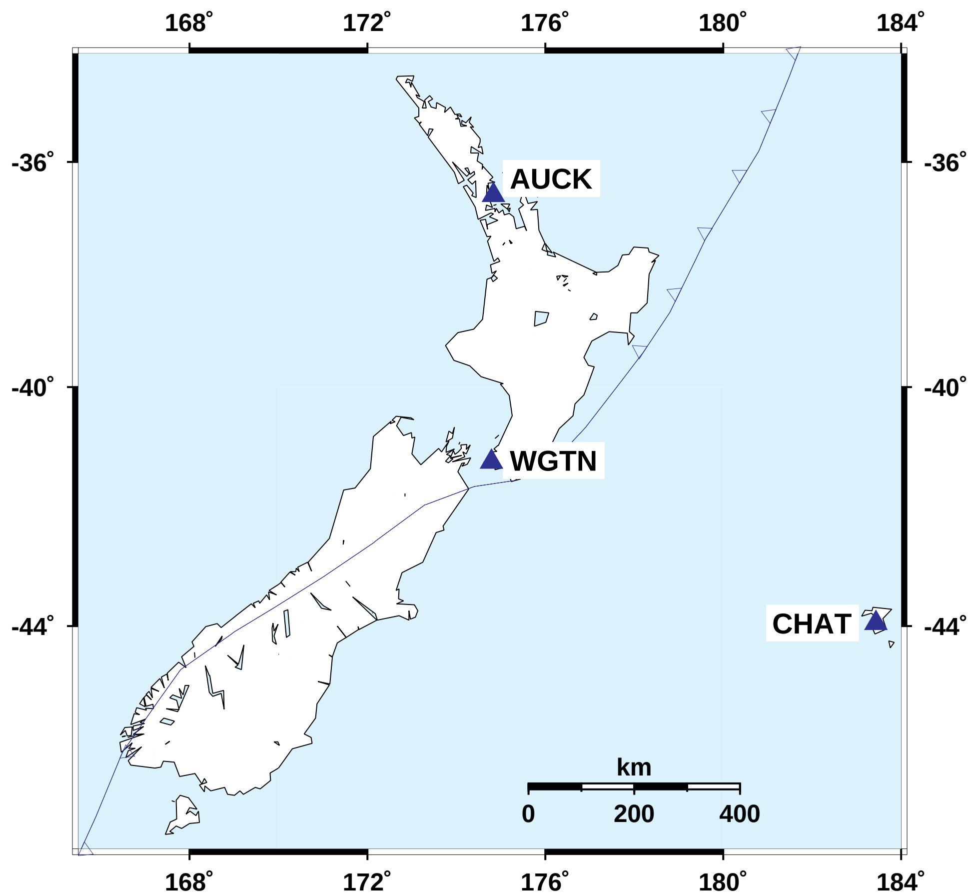

Figure 1: Existing (AUCK, CHAT) and planned (WGTN) IGS stations in New Zealand

With the assistance of JPL and the University of Auckland, the AUCK downloading was upgraded at the end of 1996 from daily to hourly. The data are downloaded by phone to the University of Auckland, then transferred by Internet to JPL and GNS. During the first few months of operation, more than 99% of the hourly downloads have been on time; the remainder have been delayed by phone problems but none have been lost.

3 Monumentation

Both sites are installed on reinforced concrete pillars with a small stainless-steel plate set horizontally in the top surface of the concrete. The plate has a welded 0.625-in. stainless-steel threaded stud onto which the antenna is firmly screwed. Stainless shims are inserted between the plate and the antenna to ensure that the antenna is correctly oriented. The top surface of the stainless plate serves as the vertical reference. Additional monumentation details can be found in the IGS site logs.

4 Meteorological Data

Both AUCK and CHAT are collocated at New Zealand MetService automatic weather stations (AWS). The AWS report hourly to MetService, and GNS receives the hourly data once per day to use for research purposes. The AWS instruments are calibrated annually. The pressure accuracy is better than 0.3 hPa, temperature accuracy better than 1°C, and humidity accuracy a few percent.

Details of the AWS are

> CHAT has a Sutron data acquisition unit with a Vaisala pressure sensor, Rotronic humidity sensor, and YSI temperature sensor.
>
> AUCK is an EG&G AWS with a KDG pressure sensor, Rotronic humidity and YSI temperature.

5 Future Plans

During the first half of 1997, in a joint project between Australian Survey and Land Information Group (AUSLIG), LINZ and GNS, an Ashtech Z-12 with a Dorne Margolin choke-ring antenna will be installed at station WGTN in Wellington, New Zealand. We propose to submit the data to IGS, on an hourly or daily basis, as preferred.

This station is of some historical interest as it is only a few km from station WELL, which ran as a CIGNET site from 1990-1992 and has operated with an AUSLIG TurboRogue SNR-8100 from 1994-1996. We have an extensive set of simultaneous data between WELL and WGTN from which to generate an interstation tie.

The new WGTN station is also collocated with a MetService AWS. In addition, we plan to install a Paroscientific MET-3 instrument at this site, logging directly to the Z-12. This instrument has characteristics as good or better than the MetService AWS.

The possibility of collocating a DORIS station at CHAT is being discussed with colleagues at Institut Geographique National, Paris, France.

CNES 1996 IGS Annual Report

H. Burger

Centre National d'Etudes Spatiales
Toulouse, France

1 Introduction

Since 1991, Centre National d'Etudes Spatiales (CNES), the French Space Agency, has contributed to the International GPS Service for Geodynamics. Through its Toulouse Operational Center, CNES currently manages five stations, which are part of the International Network:

- Grasse, France
- Toulouse, France
- Hartebeesthoek, Republic of South Africa
- Kerguelen Islands, Southern Indian Ocean
- Tahiti Island, French Polynésia

CNES sites are equipped with permanently installed receivers, which are dedicated to continuous GPS satellite tracking.

2 Toulouse Operational Center

An Operational Center at CNES in Toulouse performs Network management, which includes tasks such as data management, network maintenance, and users' interface.

The five CNES stations have access to direct communication links with the Toulouse Operational Center. GPS raw data are transmitted daily to Toulouse. The data are also stored at each site for backup. CNES personnel in Toulouse

- Overview data transfer from the stations to Toulouse.
- Assess performance of the data taking by the stations of the network.
- Ensure data are available to the users within the proper time delay.

- Respond to special requirements of the users in terms of data availability.
- Manage data storage at the Toulouse Operational Center.

At the Toulouse Operational Center, data are uncompressed and converted to the RINEX format, data completeness is verified, and a quality control check is performed. RINEX files are then stored on a workstation to be retrieved by users. Every day, data are transferred from Toulouse to the IGN Global Data Center in Paris, which provides on-line access to the community. Besides data formatting and validation, the Toulouse Operational Data Center

- Assists station personnel in first-level maintenance.
- Performs diagnosis on GPS receivers in case of an anomaly.
- Directs and coordinates equipment shipment if maintenance cannot be performed on-site.
- Provides the interface between the network and the industrial maker when maintenance is required.
- Ensures that the necessary equipment to perform first-level maintenance is available or can be secured for each station.

3 Grasse Station

In February 1995, a GPS receiver (Figure 1) was installed near Grasse, southeast of France, at the Calern Observatory, which is part of the "Observatoire de la Côte d'Azur" (OCA). It is collocated with SLR/LLR and the VLBI system. The GPS antenna is mounted on a dedicated concrete pillar on bedrock with a forced-centering plate.

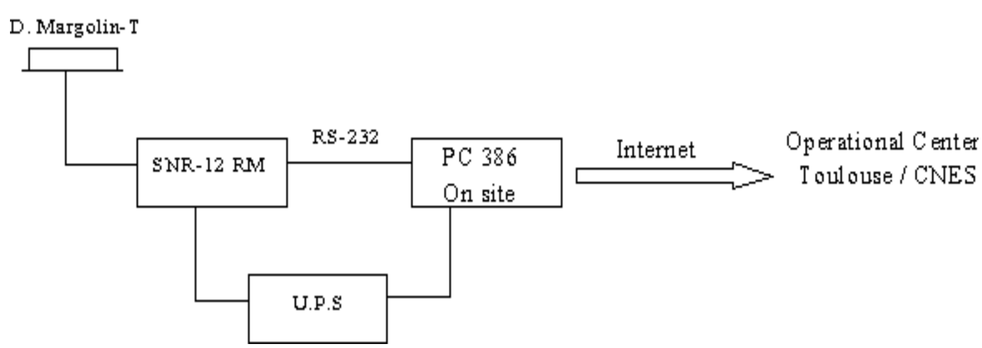

Figure 1: GPS System Configuration—Grasse

The GPS receiver is monitored by OCA personnel. Data are downloaded daily and automatically to the PC and retrieved by the Toulouse Operational Center through Internet.

At the end of May 1996, the receiver was damaged by a storm. The receiver's downtime lasted 130 days. In October 1996, a new receiver (TurboRogue SNR-12 RM) was installed at Grasse in place of the damaged Rogue SNR-8000.

4 Hartebeesthoek Station

The GPS receiver at Hartebeesthoek, Republic of South Africa, (Figure 2) has tracked GPS satellites continuously since January 1991. The receiver is set up at the CNES satellite tracking station, near the radio-observatory of Hartebeesthoek, which provides a VLBI reference point. It is collocated with DORIS and VLBI system. This GPS station was a part of the six-station Global Network for the Topex–Poseidon project.

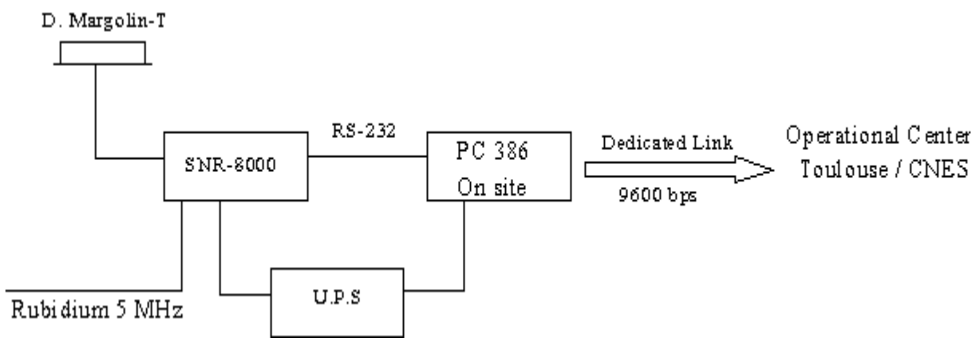

Figure 2: GPS System Configuration—Hartebeestoek

The GPS receiver is monitored by Satellite Applications Center personnel from CSIR. Data are downloaded daily to the PC and transferred automatically to the Toulouse Operational Center through a permanent link (9600 bps) set up for satellite tracking applications.

At the beginning of March 1996, the receiver was damaged by a storm. The receiver's downtime lasted 50 days. In April, a new Rogue (SNR-8000) receiver was installed at Hartebeesthoek in place of the Rogue SNR-8.

5 Kerguelen Station

A Rogue SNR-8C (minirogue) (Figure 3) has been operational since mid-November 1994, in the Kerguelen islands in the southern Indian Ocean. The site is located on the main island, at Port-aux-Français, in Institut Français pour la Recherche et la Technologie Polaire (IFRTP) facilities and close to a CNES satellite tracking station.

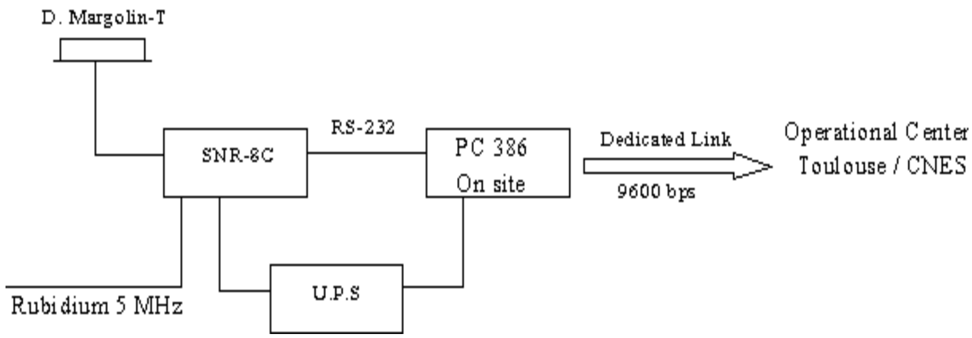

Figure 3: GPS System Configuration—Kerguelen

The receiver is operated and monitored by IFRTP personnel from the Geophysics Laboratory. Data are downloaded daily to the PC and transferred automatically to the Toulouse Operational Center through a permanent link (9600 bps) set up for satellite tracking applications.

6 Tahiti Station

The GPS receiver at Pamataï on the French Polynesian island of Tahiti (Figure 4) has been tracking GPS satellites continuously since January 1992. The receiver is set up in the facilities of the Commissariat à l'Energie Atomique (CEA) Geophysics Laboratory (LDG).

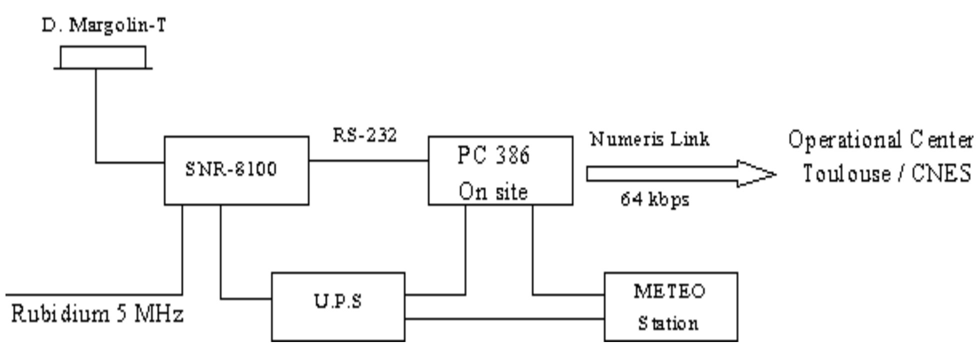

Figure 4: GPS System Configuration—Tahiti

The GPS receiver is monitored by LDG personnel. Data are downloaded daily and automatically to the PC and transferred to the Toulouse Operational Center through a NUMERIS type link (64 kbps). NUMERIS is a service for data transfer offered to general customers by France Telecom.

The Tahiti station is also equipped with weather equipment (pressure/humidity /temperature).

(Remark: At the beginning of 1997, the GPS station of Pamataï will be moved to the site of the Université Française du Pacifique (UFP) at Punauïaa.)

7 Receiver Tracking Performance

For 1996, The overall tracking success rates are

Hartebeesthoek	82%
Kerguelen	100%
Pamataï	98%
Grasse	63%

The Permanent GPS Station at the University of Padova

Alessandro Caporali

University of Padova, Italy

1 Introduction

The GPS station of the University of Padova (UPAD) operates since 1994 as a permanent installation in support of the International GPS Service for Geodynamics (IGS).

The UPAD station serves the scientific and tutorial needs of the Departments of Geology, Paleontology, and Geophysics, for applications of GPS data to Earth Sciences, and of the Centro Interdipartimentale di Studi e Attivita' Spaziali (CISAS) "G. Colombo" for applications of GPS techniques to Space Engineering, Space Communication, and Navigation. The station (Figure 1) is located downtown Padova, on the roof of the University Main Building, near a Geodetic Dome formerly used for astrolabe observations (Figure 2) . The line of sight is unobstructed except on the northern side, because of the geodetic dome. However, the orbital geometry of the GPS satellites is such that this obstruction is harmless.

Figure 1: The UPAD station

Figure 2: The antenna of the UPAD station

2 Station Equipment

The equipment consists of

- TRIMBLE 4000SSE geodetic receiver 9+9 channels, L1/L2.
- Geodetic antenna dual frequency with ground plane.

- PC 386 Hewlett Packard RS25C running DOS 6.22.
- Streamer Colorado for backup on magnetic cassette.
- High-speed modem.
- Ethernet connection.

3 Procedures

The station is designed to work unattended and autonomously, following a pre-programmed schedule on the PC and on the receiver. For IGS activities, data logging starts daily at 00:05 UTC and ends at 23:59 UTC, with a sampling time of 30 seconds. The data logging is done on the receiver both as a caution against blackouts (the receiver is provided with two batteries) and to keep the PC available during the day for offline work.

At the end of a daily session, a scheduler on the PC activates a batch procedure that does the following:

(1) Connects via serial port to the GPS receiver; downloads the datafile and memory cleanup. This is done with the Trimble's TRIM4000 program driven by a binary command file.

(2) Converts data from Trimble binary to RINEX ASCII format, using the University of Bern programs TRRINEXO and TRRINEXN for observation and navigation data, respectively.

(3) Checks data by means of the program QC developed by UNAVCO for the following:

  (a) Total number of acquired data.

  (b) Percentage acquired/acquirable data.

  (c) Number of edited data.

  (d) Rms of the position differences between the QC values and the RINEX value.

  (e) Rms (dispersion) of code multipath on L1 and L2, for all satellites.

  (f) Total number of cycle slips on zero-difference data.

  (g) Receiver clock drift.

(4) Compresses the RINEX files using the IGS program COMPRESS.

(5) Compresses the raw Trimble binary files using the PKZIP program and backup on magnetic cassette.

(6) Sets up the DOS command file for file transfer via ftp to the following Data Centers:
   (a) GEODAF in Matera, of the Italian Space Agency: `geodaf.mt.asi.it`; subdirectory: `GEOD/GPSD/RAW/.`

   (b) Graz Observatory, Austria: `flubiw01.tu-graz.ac.at;` subdirectory: `cei/indata/rinex.`

   (c) University of Padova ftp public area: `ipdunidx.unipd.it;` subdirectory: `/pub/incoming/GPS-UPAD.`

(7) Sends data files via Internet/ftp to Data Centers.

The above procedure requires approximately 15 minutes on the local PC. The remaining time is dedicated to offline operations. Of these, the most important is the "host mode," where a remote user logs on the local PC using modem connection for interactive access to the receiver or just file transfer.

4 Data Statistics

The statistics of the GPS data at UPAD are given in Figure 3. The basic features can be summarized as follows:

(1) Data acquisition statistics: on average, 99% of the acquirable data are acquired.

(2) Code multipath: on average, <0.5 m on L1 and <0.7 m on L2. In 1995, low multipath periods are strongly correlated with periods when A/S (Anti-Spoofing) was off.

(3) Number of cycle slips: <100/day; higher number in 1995, when A/S was off.

(4) Clock drift: -4 msec/hour, implying a reset of 1 msec every 15 minutes. Marked seasonal component in summer, probably related to increase in room temperature.

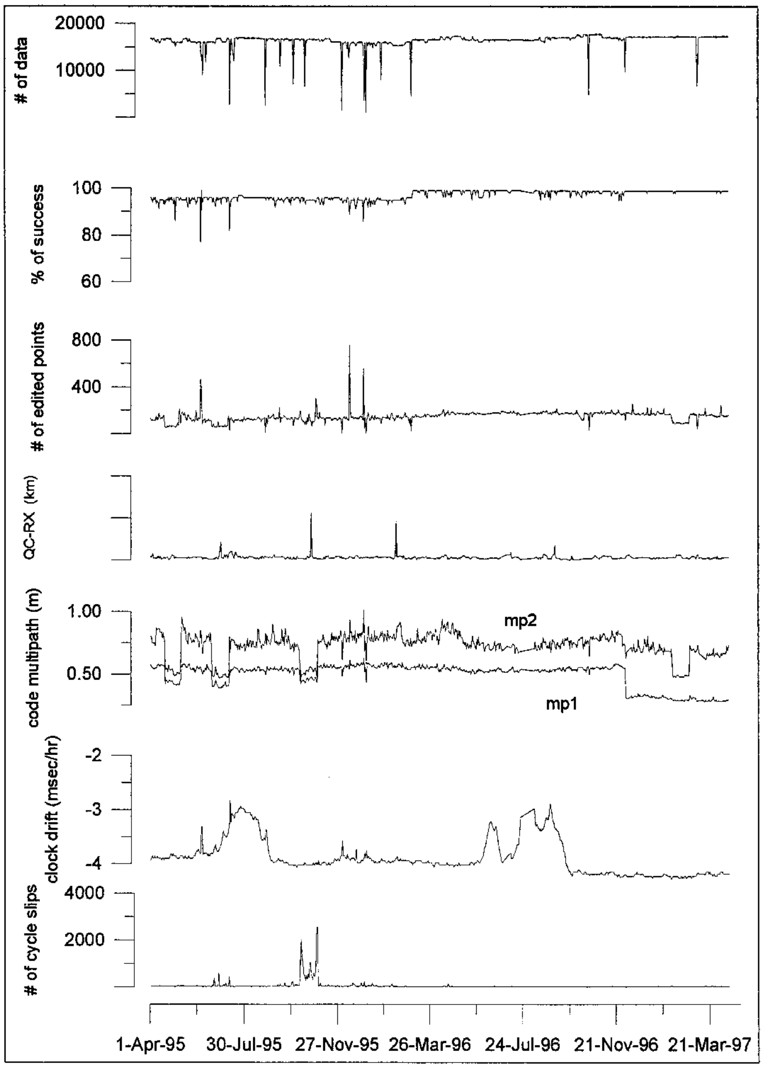

Figure 3: Data statistics of UPAD from April 1995 to April 1997

5 Science and Applications

5.1 Crustal Deformation in the Eastern Alps

A number of Austrian, French, and Italian permanent GPS stations have joined in a network comprising the Eastern Alps, dedicated to the measurements of relative displacements (Figure 4).

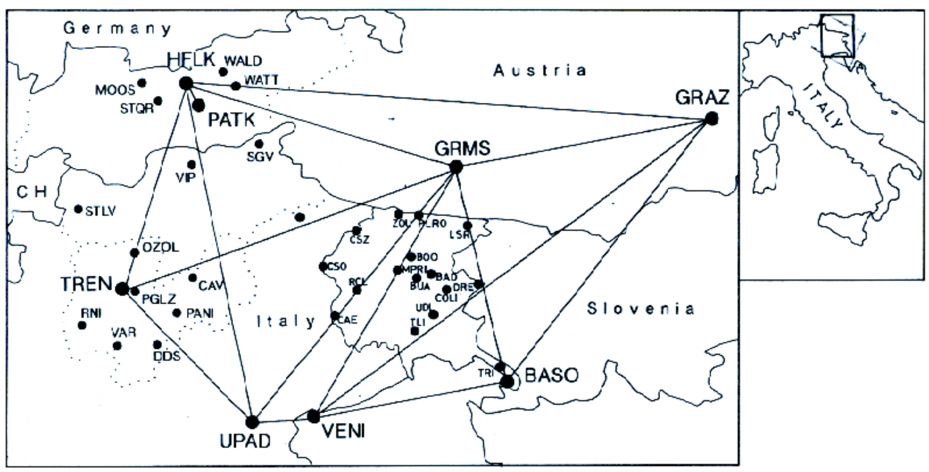

Figure 4: GPS and seismic network in the Eastern Alps

The computation of the baselines is based on the BERNESE Program Vers. 4.0 of the Astronomical Institute of the University of Berne. The processing scheme is based on the following steps:

(1) Create directory structure appropriate for the campaign of day nnn.

(2) Upload from the Data Centers compressed RINEX files for day nnn and store in the appropriate directory area.

(3) Upload from Center for Orbit Determination in Europe (CODE) precise ephemeris file, satellite clock file, ionospheric file, updated ERP file, satellite problem file and store into the appropriate directory area(s).

(4) Setup BERNESE's -N, -I, -F files as appropriate for the campaign.

(5) Run in batch mode the basic modules of BERNESE.

(6) On a weekly basis, combine daily free-network solutions.

(7) Archive weekly solutions in SINEX format.

(8) Generate updated plot files of changes in baseline length and station coordinates.

5.2 Support to Positioning and Navigation

The UPAD station routinely supports post-processed positioning of mobile units. UPAD data can be downloaded via modem or ftp and combined with user data files to reconstruct trajectories in differential mode. Our software DDGPS employs double differences of pseudoranges smoothed with L1 carrier phase, and decimetric accuracies have been demonstrated if at least 5 satellites are simultaneously tracked. The UPAD coordinates are known in the ITRF system and relative to local trigonometric vertices. Thus the coordinates of the mobile unit can be represented either in the ITRF reference system on the WGS84 ellipsoid or in a local datum on the ED50 ellipsoid oriented consistently with the national cartography.

Coordinates of UPAD in the local datum (Gauss Boaga System) are

UTM East (m)	1725243.94 m
UTM Nord (m)	5032183.60 m
height of ground marker	40.71 m

The most important applications and products are

(1) Production of vectors of 3-D coordinates, in support of Geographic Information Systems (GIS) applications.

(2) Positioning of aircraft for geo-reference of the focal center of the camera in aerial-photogrammetric flights.

(3) Precision computation of coordinates of landmarks occupied in static mode with a GPS receiver.

(4) Integration of vector data (arrays of coordinates of surveyed sites) and raster/vector maps.

Establishing a New IGS Station at Kumasi, Ghana

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Collins Fosu

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Currently at:
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Neubiberg, Germany

In 1993, the International GPS Service for Geodynamics (IGS) was established by the International Association of Geodesy (IAG); it began formal operation in January 1994. This multinational service provides a number of products in support of geodetic and geophysical research, in particular precise GPS satellite ephemerides, Earth rotation parameters, IGS tracking station coordinates and velocities, as well as GPS satellite and IGS tracking station clock information. The products support scientific activities such as improving and extending the International Earth Rotation Service (IERS) International Terrestrial Reference Frame (ITRF), monitoring deformations of the solid Earth and variations of the liquid Earth (e.g., sea level and ice sheets) and, in Earth rotation, determining orbits of scientific satellites, and monitoring the ionosphere.

Under the guidance of a Governing Board and a Central Bureau and based on the Terms of Reference, a structure of about 50 tracking stations worldwide, three Global Data Centers, several Regional Data Centers, and currently seven Analysis Centers are operating to provide the products. Information on the status of the IGS is provided by the Central Bureau Information Service (CBIS), e.g., over the Internet via ftp (`igscb.jpl.nasa.gov`) or WWW (`http://igscb.jpl.nasa.gov`).

A global tracking network overview map is shown in Figure 1. The map reveals that in the African region, current IGS sites are at only Maspalomas, Malindi, and Hartebeesthoek. Up to now, there is no station in West Africa.

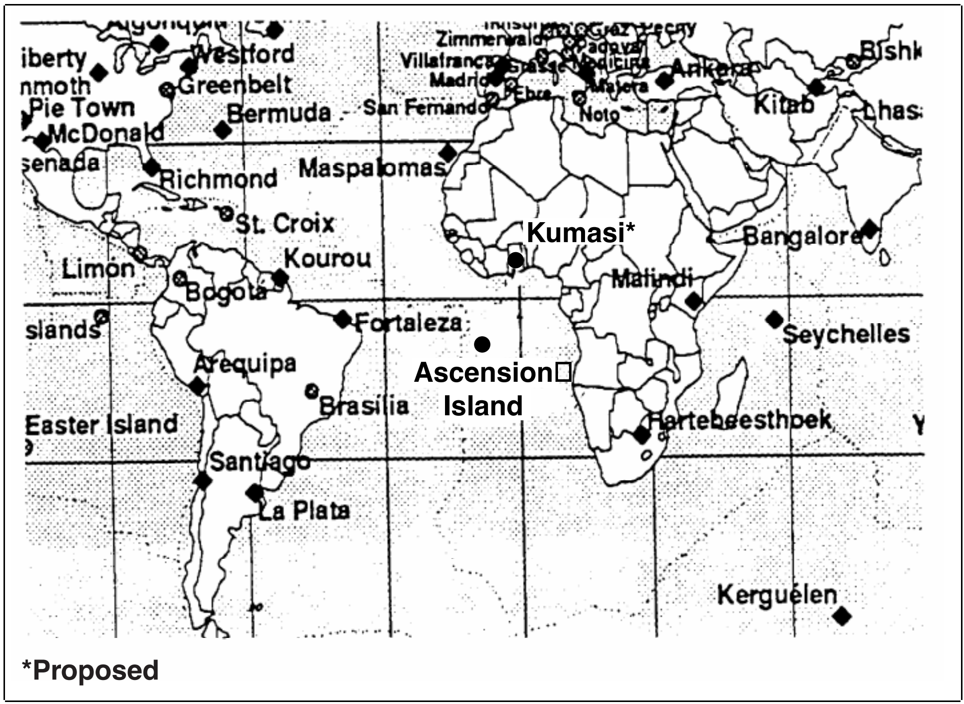

Figure 1: Global IGS Network as of April 1996

The poor regional station coverage may affect orbit determination. Current GPS orbit precision is of the order of 10 cm. It is evident that the quality of these orbits depends on the distribution of tracking stations; hence, an even distribution of IGS stations is important, and furthermore, a station in a certain region helps to improve the orbit in that region.

One goal of the International GPS Service for Geodynamics is investigating and monitoring plate tectonic motion, earthquakes and other disaster related activities. It is clear that this can be done only if sufficient receivers are located on each plate to be monitored. A look at the map makes clear that in Africa this requirement is not fulfilled. So far, there have been only two permanent IGS stations at Hartebeesthoek ($\varphi = -25° 53'$, $\lambda = 27° 42'$) and at Malindi ($\varphi = -3° 13'$, $\lambda = 40° 07'$) in South Africa and Kenya, respectively.

A permanently operated GPS station tied into a global system is also a prime candidate to serve differential GPS (DGPS) activities and to improve GPS positioning, navigation, and other services in this region.

In the framework of cooperation between Bayerische Akademie der Wissenschaften (BEK) and University of Science and Technology (Ghana) (UST), it was proposed that the situation in West Africa should be improved by establishing an IGS station at Kumasi (φ = 6° 41´, λ = -1° 34´). This is supported by the Chairman of BEK, em. o. University Professor Dr.-Ing., Dr.-Ing. E.h. Rudolf Sigl, the Dean of the School of Engineering, UST, and Prof. Dr. M. K. Kumapley, the Head of the Department of Geodetic Engineering, UST. Dr.-Ing. Gerd Boedecker had the idea for establishing this station and gave initial support, Dipl.-Ing. Werner Wende of BEK assisted with data transfer problems, while Mr. Duker currently manages the station in UST Kumasi, Ghana. This support is gratefully acknowledged.

In the fall of 1995, the BEK lent a Rogue SNR-8000 receiver to the UST; the receiver has been used by Collins Fosu to establish the experimental IGS station. The antenna of the receiver has been mounted on top of the architecture studio building of UST (see Figure 2), while the receiver itself, connected by a cable with the antenna, is in the room below the top. More details on the station can be found in the IGS station log (see the appendix).

Figure 2: GPS antenna on top of the architecture building at UST

Since the end of 1995, the receiver has been recording GPS data that has been transmitted by e-mail to Munich. Despite the fact that the University of Kumasi had to pay a lot of money for the transmission of the data, the data could not be processed due to frequent transmission errors. Therefore, both the transmission and the recording had to be amended. This was the state until April 1996 when this problem was resolved.

Meanwhile, the records of 163 days have been transmitted by diskettes (using ordinary mail) to the BEK. They comprise the days from April 16, 1996, to October 29, 1996. All of these could be easily transformed into the RINEX format and also evaluated by the Bernese Software.

The first 15 days had been evaluated with respect to only three IGS stations in Europe:

	φ	λ
Maspalomas	27° 46´	–15° 38´
Madrid	40° 26´	–4° 15´
San Fernando	36° 28´	–6° 12´

The following 148 days have been evaluated using the stations

	φ	λ	Distance to Kumasi, km
Ascension I.	-7° 57´	-14° 25´	2146
Fortaleza	-3° 53´	-38° 26´	4181
Maspalomas	27° 46´	-15° 38´	2745
Madrid	40° 26´	- 4° 15´	3695
Villafranca	40° 27´	- 3° 57´	3694

The adjusted coordinates for the station Kumasi in the IGS system (ITRF93) has been computed in the geocentric system as

$$x = 6\,333\,145.04 \quad \pm 0.04 \text{ m}$$

$$y = -172\,977.01 \quad \pm 0.04 \text{ m}$$

$$z = 736\,412.30 \quad \pm 0.04 \text{ m}$$

and in the geographical system as

$$\varphi = 6° \, 40' \, 27.6389'' \quad \pm 0.001''$$

$$\lambda = -1° \, 33' \, 52.3044'' \quad \pm 0.001''$$

$$h_{ellipsoidal} = 311.48 \quad \pm 0.04 \text{ m}$$

This is the first time that precise coordinates in the global IGS network have been determined for a station in West Africa.

The next step should be to upgrade the test station to an operational IGS station. The problem is to establish an operational and fast data-transfer facility to transmit the data from Kumasi for orbit determination. For this purpose, the recorded data of any day should be available at the analysis centres in the morning of the next day. This means that every night about 0.5 megabyte of data must be forwarded to the analysis centres, for instance by the Internet. UST is currently being linked to the Internet. It is uncertain when a regular data transmission will be working.

Nevertheless, in the framework of the cooperation between UST and BEK, it is expected that Kumasi (Figure 3) will be an important IGS station in the near future and may develop several functions for the international scientific community and particularly for national scientific and practical needs.

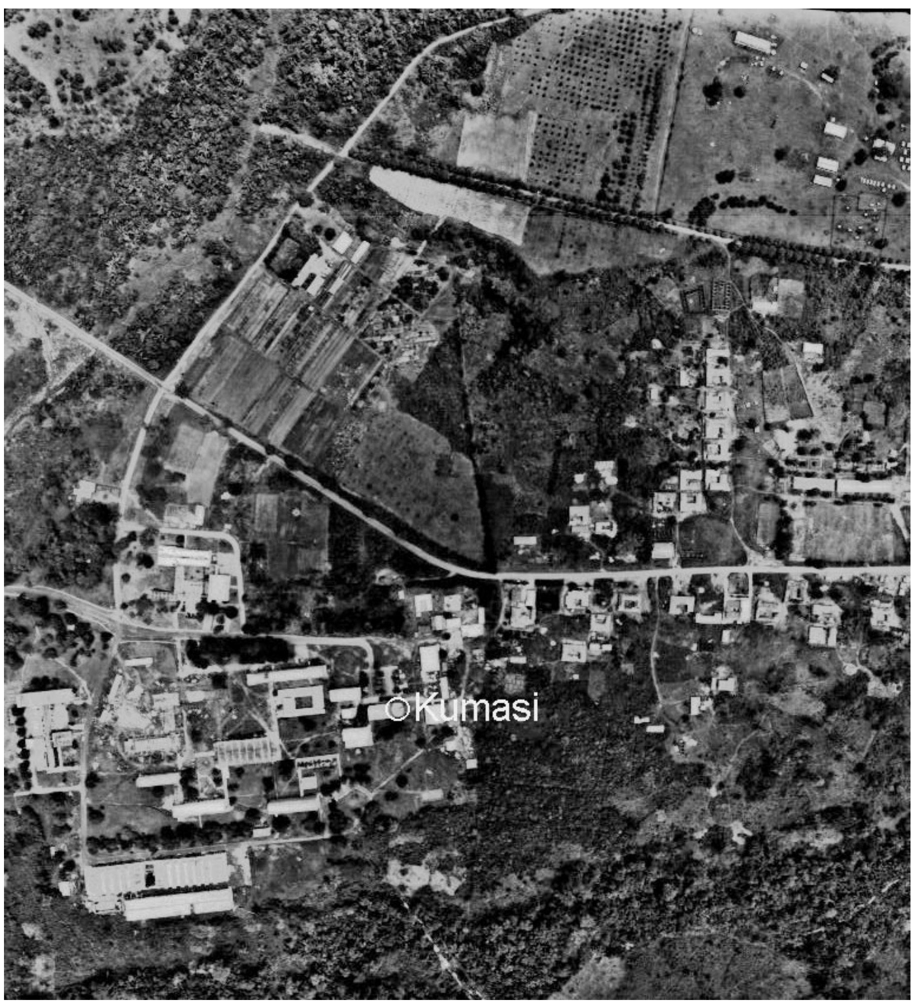

Figure 3: Aerial photo of Kumasi, scale ≈ 1:8000

Appendix: Kumasi Log

KUMA Site Information Form
International GPS Service for Geodynamics

0. Form

Prepared by (full name):	Alfred A. Duker
Date Prepared:	28-Aug-1996
Report Type:	NEW
Prepared Using:	

1 Site Identification of the GPS Monument

Site Name:	UST/Kumasi Station
Four Character ID:	KUMA
Monument Inscription:	
IERS DOMES Number:	329001M01
CDP Number:	
Date Installed:	before 1995
Geologic Characteristic:	bedrock
Bedrock Type:	igneous
Bedrock Condition:	fresh/jointed/weathered
Fracture Spacing:	
Notes:	
Additional Information:	Site is on top of a very stable building

2 Site Location Information

City or Town:	Kumasi
State or Province:	Ashanti region
Country:	Ghana
Tectonic Plate:	African Plate
Approximate Position	
X coordinate (m):	6 333 145
Y coordinate (m):	–172 977
Z coordinate (m):	736 412
Latitude (deg):	06.6743 N
Longitude (deg):	001.5645 W
Elevation (m):	311
Additional Information:	University campus

3 GPS Receiver Information

3.1	Receiver Type:	TurboRogue TM (Survey & Navigation)
	Serial Number:	SNR 8000 (243)
	Firmware Version:	Version 3 Release 2
	Date Installed:	09-Mar-1995
	Date Removed:	
	Additional Information:	

3.x	Receiver Type:	no second receiver
	Serial Number:	
	Firmware Version:	
	Date Installed:	
	Date Removed:	
	Additional Information:	

4 GPS Antenna Information

4.1	Antenna Type:	Dorne Margolin T
	Serial Number:	304
	Antenna Height (m):	(m)
	Antenna Reference Point:	ARP
	Degree Offset from North:	no offset
	Antenna Radome Type:	
	Date Installed:	Nov 1995
	Date Removed:	
	Additional Information:	cf. sketch

4.x	Antenna Type:	no second antenna
	Serial Number:	
	Antenna Height (m):	
	Antenna Reference Point:	
	Degree Offset from North:	
	Antenna Radome Type:	
	Date Installed:	
	Date Removed:	
	Additional Information:	

5 Local Site Ties

5.x Monument Name:
Site Ref CDP Number:
Site Ref Domes Number:329001M01
Differential Components from GPS Mark to Site Reference (ITRS)
dx (m):
dy (m):
dz (m):
Accuracy (mm):
Date Measured:
Additional Information: Tripod centered above trig. point
Architecture UST1/68/35

6 Frequency Standard

6.1 Standard Type: no
Frequency:
Effective Dates:
Notes:

6.x Standard Type: no
Frequency:
Effective Dates:
Notes:

7 Collocation Information

7.x Instrumentation Type: no
Status:
Effective Dates:
Note:

8 Meteorological Instrumentation

8.1 Humidity Sensor Model: no humidity sensor
Manufacturer:
Data Frequency:
Accuracy (% rel h):
Effective Dates:
Notes:

8.2	Pressure Sensor Model:	no pressure sensor
	Manufacturer:	
	Data Frequency:	
	Accuracy (mbar):	
	Height Diff to GPS (m):	
	Effective Dates:	
	Notes:	
8.3	Temperature Sensor Model:	no temperature sensor
	Manufacture:	
	Data Frequency:	
	Accuracy (deg C):	
	Effective Dates:	
	Notes:	
8.4	Water Vapor Radiometer:	no water vapor radiometer
	Manufacturer:	
	Distance to GPS (m):	
	Elev Diff to GPS (m):	
	Effective Dates:	
	Notes:	
8.5	Other Instrumentation:	nothing

9 On-Site, Point of Contact Agency Information

Agency:	Geodetic Engineering Dept., UST.
Mailing Address:	Geodetic Engineering Dept., UST, Kumasi
Primary Contact	
Contact Name:	Alfred A.Duker
Telephone (primary):	++233 51 60227
Telephone (secondary):	
Fax:	++233 51 60137 (or ...60232)
E-mail:	ustlib@ust.gn.apc.org
Secondary Contact	
Contact Name:	Head of department
Telephone (primary):	++233 51 60227
Telephone (secondary):	
Fax:	++233 51 60137 (or ...60232)
E-mail:	ustlib@ust.gn.apc.org
Additional Information:	

10 Responsible Agency (if different from 9.)

Agency:	Bavarian Commission for Global Geodesy
Mailing Address:	Marstallplatz 8, D-80539 Muenchen, Germany
Primary Contact	
Contact Name:	Dr. Walter Ehrnsperger
Telephone (primary):	++49 89 23031 111
Telephone (secondary):	++49 89 23031 112
Fax:	++49 89 23031 100
E-mail:	a2101aa@bek.badw-muenchen.de
Secondary Contact	
Contact Name:	Werner Wende
Telephone (primary):	++49 89 23031 111
Telephone (secondary):	++49 89 23031 112
Fax:	++49 89 23031 100
E-mail:	wende@bek.badw-muenchen.de
Additional Information:	

11 More Information

URL for More Information:	
Hard copy on File	
Site Map:	A photograph with site marked by a circle
Site Diagram:	See sketch on antenna description
Horizon Mask:	No obstructions. The Architecture building, on the roof of which the antenna is placed, is higher than all surroundings.
Monument Description:	Concrete pillar with nail in the middle
Site Pictures:	aerial photo available on MS-WORD
	Additional Information:

UTM coordinates of the surroundings: survey done between 17 and 31 July 1989; UST1 is the GPS-site

Monument Name	North (m)	East (m)	Height (m)
ARCHITECTURE UST1/68/35	221409.0506	211535.4107	311
UNITY HALL UH1/74/1	222025.5473	210695.6675	
AFRICA HALL UST1/68/558	222142.9952	210386.9959	
INDEPENDENCE HALL UST1/68/5512	221849.9147	210768.1981	
REPUBLIC HALL UST1/68/556	221911.6224	210574.2710	
QUEEN'S HALL	221790.2315	210419.3798	
UNIVERSITY HALL UST1/68/5510	221159.0524	210649.3370	
GP2 (AYEDUASG.)	221661.5717	211949.9279	

Antenna Graphics with Dimensions:

```
           TurboRogue:  DORNE MARGOLIN T

<--        0.19          -->

                         -----
                     /     +     \                        <--  0.988  L2
                    |      +      |                       <--  0.970  L1
  +--------------------------------------------------+    <--  0.962  TCR
  |                                                  |
  |                                                  |
  |                                                  |
  |                                                  |
+-+--------------------------------------------------+-+  <--  0.898
+-------------------+-------------+--------------------+  <--  0.895  BCR
                    |             |
                   =|             |
                    +------x------+                       <--  0.860  ARP

<--                      0.381                       -->









 -------------------------------------------------------  <--  0.000 top:
              \            +             /                    level of pillar
                -------------------------
```

```
ARP: antenna reference point
L1 : L1 phase center                L2 : L2 phase center
TCR: top of choke ring              BCR: bottom of choke ring
```

```
       +----------------------------------------------+
       |                                              |
       |                                              |
North  |                                 +----------+ |
  |    |                                 |          | |
  |    |                                 |      O<--|-|--site of antenna on
  |    |                                 |          | |  ARCHITECTURE main
  |    |                                 +----------+ |  building
  |    |                                              |  (circled on
  |    |                                              |  aerial photograph)
  |    +----------------------------------------------+
  |
  |
  +----------------> East
```

The UNAVCO Boulder Facility Contribution to the IGS

S. Fisher[1]*, C. Meertens, B. Perin, and W. Shiver*

University Corporation for Atmospheric Research/
University NAVSTAR Consortium

The University NAVSTAR Consortium, Boulder, Colorado, Facility (UNAVCO-Boulder) of the University Corporation for Atmospheric Research (UCAR) is jointly sponsored by the United States National Science Foundation (NSF) and the National Aeronautics and Space Administration (NASA) to support scientific applications of the Global Positioning System (GPS). Since 1984, UNAVCO–Boulder has been helping Earth science researchers carry out complex international measurement campaigns by providing a centralized pool of GPS receivers and other equipment, a data management and archiving system, various software and hardware tools, and staff devoted to ongoing support activities (including technical assistance, project planning, logistics support, purchasing and shipping, training, field engineering, data management, equipment testing and repair, data processing assistance, and software and hardware development). More recently, several UNAVCO constituents have begun programs involving the integration of continuous GPS monitoring for cost effectiveness and other technical reasons. As such, UNAVCO–Boulder has been emphasizing support for the implementation and operation of permanently operating GPS networks and associated technology development. Through the end of 1996, UNAVCO–Boulder has helped to establish 41 new permanently operating GPS stations in support of solid-Earth science research projects, many of which supply data to the IGS, and has supported JPL in establishing and maintaining several of the NASA Global GPS Network (NASA/GGN) stations (see Table 1).

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[1] Also at the Jet Propulsion Laboratory via Sterling Federal Systems, Inc., Pasadena, California, USA.

Table 1: UNAVCO supported permanent GPS station installations through 1996

*Site or Network Name	Country	Sponsor/ Investigator(s)	**Date Established	Data Available to IGS	IGS Global Station Designation	Data Available Via	UNAVCO Role Supporting or Primary
Regional Project Permanent Station and Array Installations							
Northern Baja 1 Station	Mexico	NASA T. Dixon	Mar-95	Yes	No	JPL	Primary
Central Asia Array 3 Stations	Kyrgyzstan Kazakhstan	NASA B. Hager, M. Hamburger, P. Molnar, R. Reilinger	May-95	Yes 1 station daily Others with delay	Yes POL2	UNAVCO	Primary
New Zealand Array 2 Stations	New Zealand	NASA J. Beavan	Oct-95	Yes	Yes CHAT and AUCK	GNS/JPL	Supporting
Eastern Mediterranean Array 2 Stations	Armenia Egypt	NASA R. Reilinger	May-96	Pending Both will be available once stabilized	No	UNAVCO	Primary
Kangerlussuak 1 Station	Greenland	NOAA T. Van Dam	May-96	Yes	No	NOAA	Supporting
SW Pacific 3 Stations	N. Caledonia Vanuatu Fiji	NSF M. Bevis	May-96	Yes with delay	No	U. Hawaii	Primary
CASA Array 5 Stations	Costa Rica Colombia Ecuador	NASA J. Kellogg, P. Lundgren	Aug-96	Yes Some stations sporadic	Yes BOGT	UNAVCO and JPL	Primary
Basin and Range Array Phase I 9 Stations	USA	NSF B. Wernicke	Aug-96	Pending, at least 1 station	No	TBD.	Primary
Yellowstone 1 Station	USA	NSF C. Meertens	Aug-96	Yes	No	UNAVCO	Supporting
Wasatch 1 Station	USA	USGS C. Meertens	Aug-96	Yes	No	UNAVCO	Supporting
Can. West Coast Def. Array 2 Stations	Canada	NASA/NRCan E. Pavlis, A. Lambert	Oct-96	Yes	No	NRCan	Supporting
Global GPS Network Station Installations							
Shanghai	PRC	NASA	Jan-95	Yes	Yes	JPL	Supporting
Bangalore	India	NASA	Sep-95	Yes	Yes	JPL	Primary
Irkutsk	Russia	NASA	Sep-95	Yes	Yes	JPL	Supporting
Thule	Greenland	NASA	Nov-95	Yes	Yes	JPL	Supporting
Xi'an	PRC	NASA	May-96	Yes	No	JPL	Primary
*Does not include 11 volcano monitoring station installations supported by UNAVCO to date.							
** Some individual array stations may have become operational earlier.							
Does not include maintenance activities.							

Beginning in 1997, in addition to providing continued support to NSF and NASA researchers, UNAVCO–Boulder will undertake an expanded role in assisting JPL with operating the NASA/GGN. While JPL will remain responsible for the overall operation of the network and data retrieval, UNAVCO-Boulder will take responsibility for some of the network monitoring, troubleshooting, station maintenance, and configuration management activities and will provide field engineering support to new station installations. UNAVCO–Boulder will also work in cooperation with JPL to refine data communication and management capabilities by helping to integrate and extend the functionality of existing software systems to include remote control capabilities for all commonly used receiver types, more efficient file translation subroutines, more sophisticated quality assurance capabilities, more reliable automated data transfers, and support for additional communication configurations. By implementing such software in support of NASA, NSF, and other permanent GPS stations, UNAVCO–Boulder hopes to help improve overall capabilities, performance, and data return to the IGS.

Also beginning in 1997, UNAVCO–Boulder will begin a support role on behalf of NASA to assist the IGS Central Bureau with organizing, maintaining and updating information related to IGS station operations. UNAVCO–Boulder will help document site and data-flow characteristics and points of contact for key IGS network stations, and will help to monitor and maintain updates to station configuration records. An improved on-line interface will be developed and pertinent network information will be posted on the Central Bureau Information System for access by IGS participants and interested parties. UNAVCO–Boulder will also assist the Central Bureau in monitoring IGS station performance and will support problem solving with the station operators as necessary to maintain reliable data flow from critical stations.

Contact Information

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Status of the IGS Stations Provided by GFZ

R. Galas and Ch. Reigber

GeoForschungsZentrum Potsdam
Potsdam, Germany

1 Introduction

In the previous year, the GeoForschungsZentrum (GFZ) Permanent GPS Network Control Center continued to support IGS activities, providing data from continuously operating stations in South America, Central Asia, and Europa. The Center's tasks are not described here, because [1] already contains this information. This report covers only new activities and the network upgrades.

2 New Site

In 1996, a TurboRogue receiver (SNR-8000) was installed at German Aerospace Research Establishment (DLR) in Oberpfaffenhofen, about 25 km west of Munich (Bavaria). The station is monitored by the GFZ–PRARE staff in DLR. It is equipped with an automatic meteorological sensor and external rubidium clock, both shared with the PRARE-Master station at the same site. A GPS antenna is mounted on a dedicated pillar that is close to the PRARE antenna. The on-site computer that monitors the GPS receiver is a part of DLR-LAN with access to Internet. Raw GPS and meteorological data are automatically transferred daily to Potsdam a few minutes after midnight. The station became an IGS site on October 15, 1996, and delivers GPS files daily to CDDIS via IFAG and IGN.

3 Data Availability

In 1996, GFZ managed 17 continuously operating GPS stations (Figure 1). From five of them—Potsdam, Kitab, Zwenigorod, La Plata, and Oberpfaffenhofen—the data were delivered to the IGS data centers. The overall availability of daily files follows:

Potsdam	100%
Oberpfaffenhofen	97% (since October 15)
Zwenigorod	96%
Kitab	94%
La Plata	94%

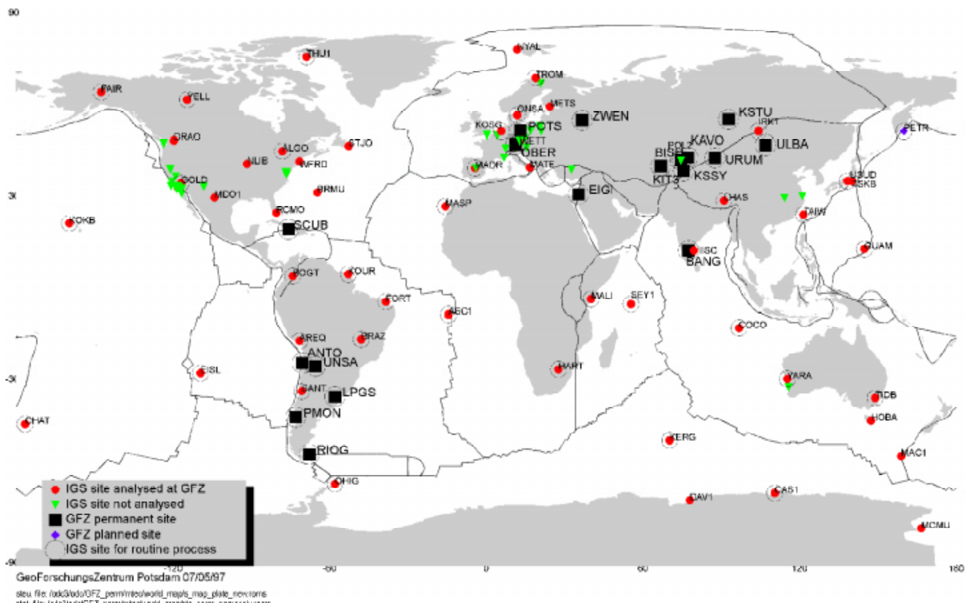

Figure 1: IGS and GFZ permanent sites

4 Upgrades and Improvements

4.1 Meteorological Surface Measurements

Three stations now record meteorological surface data: Pots (since day 253), Ober (since day 281), and Kit3 (since day 323 of 1996). Temperature, humidity, and air pressure are measured by automatic meteorological sensor TM200, manufactured by TimeTech/Stuttgart (Figure 2). The accuracy of the measurements is

pressure:	better than 0.5 hPa (drift 0.1 hPa/year)
temperature:	0.25°C
humidity:	1 %

Figure 2: Meteorological sensor TM200

In Oberpfaffenhofen, Kitab, and Potsdam, the sensors were already available. They are standard equipment of the PRARE systems there. However, the PRARE Earth station records meteorological parameters only during passes of the ERS-2 satellite that carries the PRARE Space Segment on board. We decided to share the TM200 sensor with GPS equipment and upgrade the software controlling GPS receivers on-site, in order to manage meteorological data in a stand-alone mode. In Potsdam, the distance between the PRARE and GPS receivers does not allow the two systems to share the meteorological sensor. For that reason, an additional TM200 operates there.

On the permanent GPS sites, the available computers have to control GPS receivers and communication devices. The meteorological surface measurements are collected every 10 minutes by the on-site GPS computer. At sites where the GPS and PRARE systems share the TM200 sensor, there are gaps of about 30 minutes. They occur because the sensor is not available to the GPS computer during PRARE sessions. New improved GPS remote control software will circumvent this problem.

Meteorological data files are transmitted to Potsdam daily. From there, after conversion to RINEX m-files, they are sent to the global data centers with the same latency as the observation files.

4.2 Inmarsat/GPS—System Update

The software for control of the Inmarsat Mobile Station has been improved. Because of it, the GPS/Inmarsat system became more efficient in the second half of 1996.

5 Outlook

Future plans include making GPS data from Krasnoyarsk and Urumqi available to the IGS community as soon as the communications problems with those sites are solved.

The next four meteorological sensors are scheduled to be installed in June and July at Krasnoyarsk, Zwenigorod, La Plata, and Urumqi.

Reference

[1] R. Galas, "Status of the IGS Stations Provided by GFZ," in *International GPS Service for Geodynamics, 1995 Annual Report*, edited by J. F. Zumberge, M. P. Urban, R. Liu, and R. E. Neilan, JPL Publication 96-18, Jet Propulsion Laboratory, Pasadena, California, 1996.

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

C. Garcia-Martinez and P. Bernedo

Grupo de Mecanica de Vuelo at European Space Operations Centre

J. M. Dow, T. Martin-Mur, and J. Feltens

European Space Operations Centre

The European Space Operations Centre (ESOC) is currently involved in the establishment of a network of high-precision geodetic receivers on European Space Agency (ESA) ground sites. So far, six installations have been completed at Malindi, Maspalomas, Kourou, Kiruna, Perth, and Villafranca. The establishment of this network is one of the objectives of the ESA GPS–Tracking and Data Analysis Facility (TDAF). Figure 1 shows the geographical distribution of the receivers.

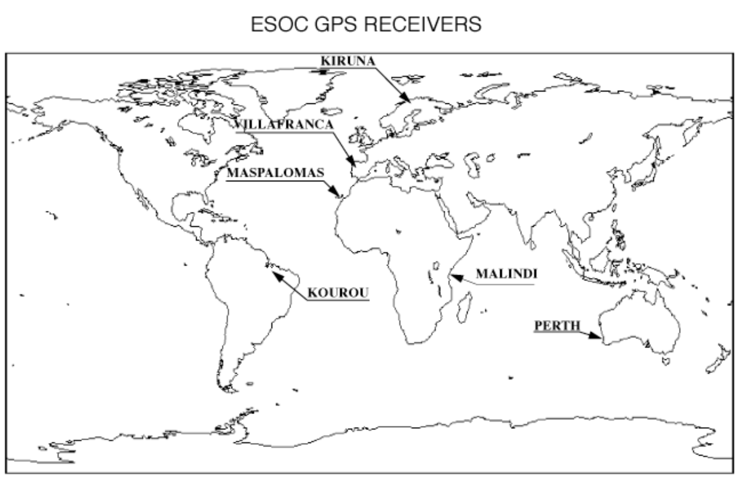

Figure 1: ESOC receiver locations

1 Location of the Receivers

The ESOC receivers are being installed at the ESA ground stations. In this way, they can take advantage of the facilities that the stations provide. They are integrated in racks in rooms with temperature and humidity control, connected to the frequency standards of the stations and to the permanent communication links between the stations and the control centre at ESOC. They 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.

1.1 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.

1.2 Maspalomas

The GPS receiver is installed at the Maspalomas ground station, which 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 m from the coast.

1.3 Kourou

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

1.4 Kiruna

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

1.5 Perth

The receiver is located at the ESA Perth station approximately 20 km north of the city of Perth on the western coast of Australia. The station is situated on the Perth International Telecommunications Centre Complex, which is operated by Telstra Corporation Limited.

1.6 Villafranca

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

2 History and Evolution

The development of the network started at the beginning of 1992 when two MiniRogues SNR-8C, the most advanced receiver then, were ordered from Allen Osborne Associates (AOA). After a period of testing in ESOC, the first installation was completed in the week before the start of the IGS campaign at Maspalomas. Data were available from June 22, 1992. The antenna was mounted on a monument belonging to the Spanish Instituto Geographico Nacional (IGN), that participated in several geodetic campaigns with the marker name MPA1. For IGS, the selected marker name was MASP.

ESOC constructed another monument and on April 11, 1994, installed a new GPS system with a TurboRogue SNR-8100. Both systems 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 1996, shortly after the delivery and testing in ESOC, one of the new units was installed in Maspalomas.

The second of the MiniRogues was installed in late July 1992 at Kourou. Initially, the data were downloaded directly from the receiver to ESOC using Telebit modems. Unfortunately, the quality of the public telephone lines between Europe and French Guiana were very irregular. The data were obtained for a period of 10 days in August, and sporadically thereafter. Attempts made from Pasadena to dial up the Kourou modem were also unsuccessful. The low transfer rates and the irregular quality of the telephone lines made very problematic the completion of the file transfers using XMODEM. A new solution had to be implemented. It was based on the permanent links between the station and the control centre ESOC; the links are shared by several ESA projects. The regular operation of the receiver started on October 18, 1992, when the connection to the new data link was completed. During the period when communications were not possible, a permanent concrete monument was constructed for the antenna there (see IGS mail No. 144). The antenna was moved by about –3.0, –1.1, and 1.1 m in longitude, latitude, and height, respectively, from its previous position. The software of the MiniRogue was upgraded to version 7.8 on October 6, 1994. The receiver has been operated permanently without hardware problems for almost 4 years.

A set of five receivers, model TurboRogue SNR-8100, was ordered at the end of 1992. After the testing period in ESOC, the first receiver was dispatched to

Kiruna and installed on July 1993. The receiver was placed in a building several meters away from the main building of the station. From here the distance to the monument is shorter. The monument is on top of a slope surrounded by trees. The antenna was replaced in May 1995.

The second TurboRogue SNR8100 installation was performed on August 13, 1993, at Perth. Unfortunately, a few days after the beginning of the operation, the receiver was damaged during a lightning storm on September 3, 1993. A new receiver was immediately delivered. The grounding of the antenna has been improved to try to avoid the same problem happening again. The original receiver and antenna were repaired and reinstalled on April 27, 1994.

Villafranca was set up on November 12, 1994. At this site, the cabling from the monument to the racks of the main building, where the receiver is integrated, is about 150 m long. This is 50 m longer than the standard setup of the receiver. This made necessary the installation of an additional line amplifier close to the antenna. With this modification, the signal level has nominal values.

The last installation has been Malindi. A MiniRogue SNR-8C was deployed 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 kbit/s digital circuit. Because other ESA projects depend on these facilities, our use of them will be discontinued. A test with dial up modems using the recently improved Public Switched Telephone Network (PSTN) at Malindi has been carried out successfully in May 1996. The receiver is connected to an external 5-MHz quartz reference.

3 Monumentation

Figure 2 shows the monument specially developed for the GPS-TDAF. It is basically a reinforced concrete cylinder of 50-cm diameter that is situated over a foundation. On top of the cylinder there is an embedded horizontal metal plate. The marker is the centre of this plate, on the upper surface.

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

4 Equipment

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

The remote stations are continuously tracking the GPS satellites. The antenna is connected to the receiver normally with a standard 91-m (300-ft) RG-214 coaxial cable. Only Villafranca has a cable 137 m (450 ft) long, as remarked in Section 2.

The timing system of the stations are used as a 5-MHz reference frequency. They are cesium timing systems manufactured by OSCILLOQUARTZ with long-term drift controlled by a timing GPS system.

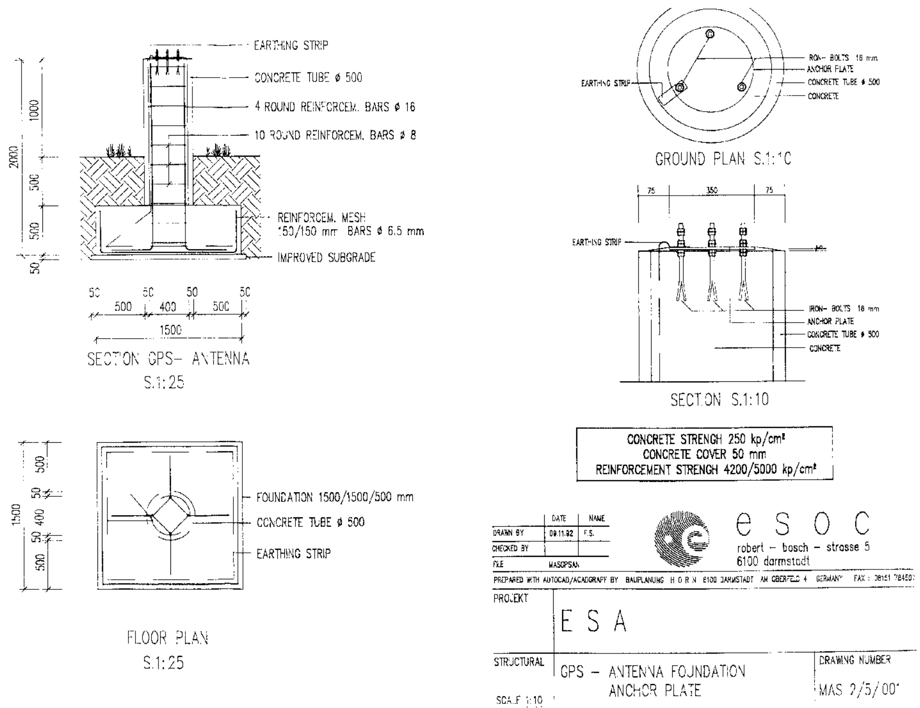

Figure 2: GPS–TDAF monument

There are three different receivers in the ESA stations. The MiniRogue SNR-8C, currently in Kourou and Malindi; the TurboRogue SNR 12 RM at Maspalomas; and the TurboRogue SNR8100 at the rest of the stations. An effort is made to update them with the latest well tested software releases. The TurboRogues SNR 8100 are running software version 3.2.32.1 since the middle of 1996, when software and processors were upgraded. The MiniRogues of Kourou and Malindi run Meenix 7.8 and Ruse 4.2. The TurboRogue SNR 12 of Maspalomas runs firmware 3.2.32.1.

One of the serial ports of the receivers is connected to a device that provides for communications and optionally for data storage. This device is a PC that runs a script of a communications package. Shortly after 00:00 UTC, the PC downloads the data from the receiver with the XMODEM protocol, waits the remainder of the day for the call from the control centre ESOC, and allows the remote control of the computer.

There are two main reasons 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 data communication equipment (DCE).

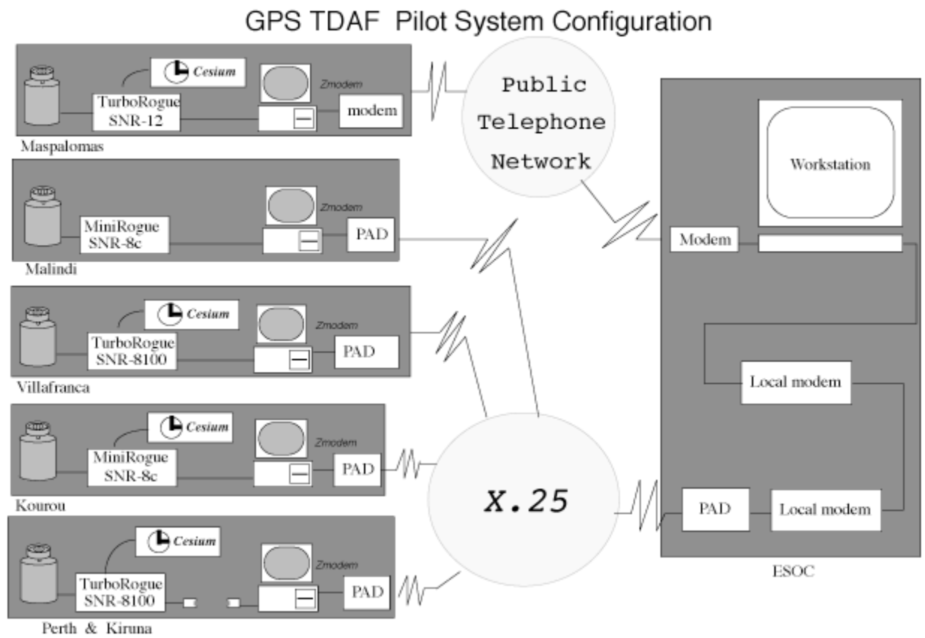

Figure 3: GPS–TDAF plot system configuration

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 communication port to the one connected to the receiver, sends them, waits for the answer, and stores it. The active port is swapped again to the one connected to the communication device and the answer of the receiver is echoed. Several attempts have been made with a secondary line (Packet Assembler–Disassembler (PAD) or modem) connected to the free port of the receiver for interaction with it in terminal mode, but the system has been shown to be more reliable without this secondary link.

For the communications with ESOC, the permanent links between ESOC and the stations are used whenever possible. They are very reliable and do not introduce additional costs due to the small amounts of data involved.

At ESOC, there is one workstation with two serial ports. One is attached to a Telebit modem and the other to an internal LAN of ESOC that gives access to the ESA ground station via X.25/PAD. This workstation retrieves, decompresses, reformats, validates, archives, recompresses, and distributes every day the data automatically. The nominal time when all the processes are finished is 02:00 UTC.

The data are available to the IGS community in RINEX format via the official data centres.

At Malindi, the receiver is a MiniRogue SNR-8C. The antenna is Dorne Margolin B with a height of 0.222 m and is located at the centre of the station. 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 meters east of the Main Equipment Room. The antenna height is 0.033 m. The data retrieval is performed with a Telebit T2500 modem. A PAD that runs over a 64-kbit/s line has been used in the past.

Kourou is equipped with a MiniRogue SNR-8C. The antenna is Dorne Margolin B with a height of 0.132 m and is located about 25 m from the MCR (Main Control Room) building.

Kiruna has a TurboRogue SNR-8100 and a Dorne Margolin T antenna with a height of 0.062 m. The communications are performed using a PAD that runs over a permanent circuit between ESOC and Kiruna Station.

The TurboRogue of Perth is connected to a Dorne Margolin T antenna which has a height of 0.0595 m. The communications are carried out by means of a PAD that is situated in a different building of the station. To overcome this problem, two local modems had to be used. They provide for communications between PC and PAD.

Villafranca has also a TurboRogue with a Dorne Margolin T antenna. The antenna height is in this case 0.0437 m.

5 Plans for the Future

There are currently two ESA sites that offer possibilities for future installations. They are Odenwald (Germany) and Redu (Belgium). They are really more interesting for other projects than for IGS. The baseline of the plans for the future, concerning IGS, is more than new installations; it includes improvements of the current installations with the latest hardware and software available and provides for even more robust communications that tend to the real-time data availability at ESOC.

We are working on a Real Time Infrastructure project that will replace the software currently running in the remote station PCs with more versatile software that will provide for continuous data downloading to the control centre at ESOC and will enhance the data analysis capabilities.

Additional Reading

GPS TDAF Stations Configuration Manual. Version 1.1, December 1995, ESOC.

C. Garcia-Martinez, J. M. Dow, T. Martin-Mur, J. Feltens, M. A. Bayona-Perez, “The GPS Receiver Network of ESOC: Maspalomas, Kourou, Kiruna, Perth and Villafranca,” in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

C. Garcia-Martinez, J. M. Dow, T. Martin-Mur, J. Feltens, and M. A. Bayona-Perez, "The GPS Receiver Network of ESOC: Maspalomas, Kourou, Kiruna, Perth and Villafranca," in *International GPS Service for Geodynamics, 1995 Annual Report*, edited by J. F. Zumberge, M. P. Urban, R. Liu, and R. E. Neilan, JPL Publication 96-18, Jet Propulsion Laboratory, Pasadena, California, 1996.

AUSLIG 1996 IGS Annual Site Report

M. R. Hendy

Australian Surveying & Land Information Group
Canberra, Australia

1 Introduction

The Australian Surveying and Land Information Group (AUSLIG) commenced a national fiducial GPS network in 1993. TurboRogue GPS receivers were installed at three Antarctic stations: Casey, Davis & Mawson; the sub-Antarctic station at MacQuarie Island; and Hobart during 1993. All stations operate automatically and are controlled remotely from AUSLIG's office in Canberra in southeast Australia.

2 1996 Improvements

Since June 1996, AUSLIG has also provided data from Cocos Island to the IGS network.

The GPS data are RINEXed upon receipt in Canberra and the RINEX format files on the ftp server are updated every half hour. Thus users of the AUSLIG ftp site can get the latest data at any time of the day. With current performance, which is limited by the capacity on the internet links and the quality of the phone lines, data are RINEXed and available on the AUSLIG ftp server within 2 hours of observation throughout each day.

3 AUSLIG Data Centre

The AUSLIG GPS data centre operates continuously providing the IGS community with data from the following sites:

Casey	Hobart
Davis	Cocos Island
MacQuarie Island	

The AUSLIG data centre comprises a Sun Sparc10 workstation, a DEC AlphaStation 250, and a DEC AlphaServer 400. The AlphaServer is the data archive and has 24 Gb of disk space and a RAID controller. The data acquisition is done by the Sun workstation, and another DEC workstation is the anonymous ftp server, which is located outside the AUSLIG firewall.

The data are available by anonymous ftp on Internet from ftp.auslig.gov.au. Data from some sites are retrieved via Internet and from other sites by using dialup phone lines and ppp protocol. The data are received into the centre continuously throughout each day.

4 Remote GPS Installations

At each site, the TurboRogue GPS receivers are logged continuously in real time using an Intel based personal computer running the Linux operating system. Custom software logs the data and sends it back to AUSLIG in Canberra. The full system at each site comprises

(1) GPS receiver.
(2) Computer.
(3) Multiplexer.
(4) Modem.
(5) Power controller.
(6) UPS.
(7) Batteries.

The system is powered by ac electricity and the PC is supported by the UPS. The GPS receiver is supported by the batteries, which are trickle charged by the power controller. This unit also acts as a UPS to the GPS. In the event of a power failure, the power controller switches to dc battery power without interruption to the operation of the GPS receiver. The batteries are sufficient to power the GPS for about 2 weeks. The power controller also contains a microprocessor that monitors the state of the GPS receiver and batteries and ac power. The status of the system is logged by the PC and warning messages are sent back to Canberra in the event of failure. The multiplexer allows all components of the system to be monitored remotely from Canberra.

5 GPS Configurations

The configurations of the GPS receivers and antennae as of April 1997 at the sites are given in Table 1.

Table 1: GPS receiver and antenna configurations

Site	Gps Rx	Gps Vers.	Antenna	Monument	Dome	Cable length, m
Casey	TurboRogue	3.2.33.1	Dorne Margolin T	Concrete pedestal on rock	Yes	250
Cocos Island	TurboRogue	2.8.33.2	Dorne Margolin T	Concrete pillar	Yes	70
Davis	TurboRogue	3.2.33.1	Dorne Margolin T	Steel rods in rock	Yes	70
Hobart	TurboRogue	3.2.33.1	Dorne Margolin T	Concrete pillar	No	130
MacQuarie Island	TurboRogue	3.2.33.1	Dorne Margolin T	Concrete pillar	Yes	60

6 Future Plans

Due to the remoteness of these sites, installation of a second backup receiver at some sites is being investigated, and other receivers that show the potential to provide more reliable performance for real-time downloads will be considered.

The equipment at the remote sites will be regularly reviewed and upgraded as necessary to provide improved performance.

The data communications strategies are being monitored and our goal is to have the data on our ftp server in RINEX format ready for processing within half an hour of observation.

JPL-Supported Permanent Tracking Stations

D. Stowers, A. Moore, B. Iijima, U. Lindqwister,
T. Lockhart, M. Marcin, and R. Khachikyan

Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California

1 Introduction

JPL currently operates more than 55 permanent, continuously operating GPS ground stations for NASA, many in conjunction with international and regional agencies (Figure 1). The data are automatically uploaded from the remote stations, processed, and distributed, with a high degree of reliability.

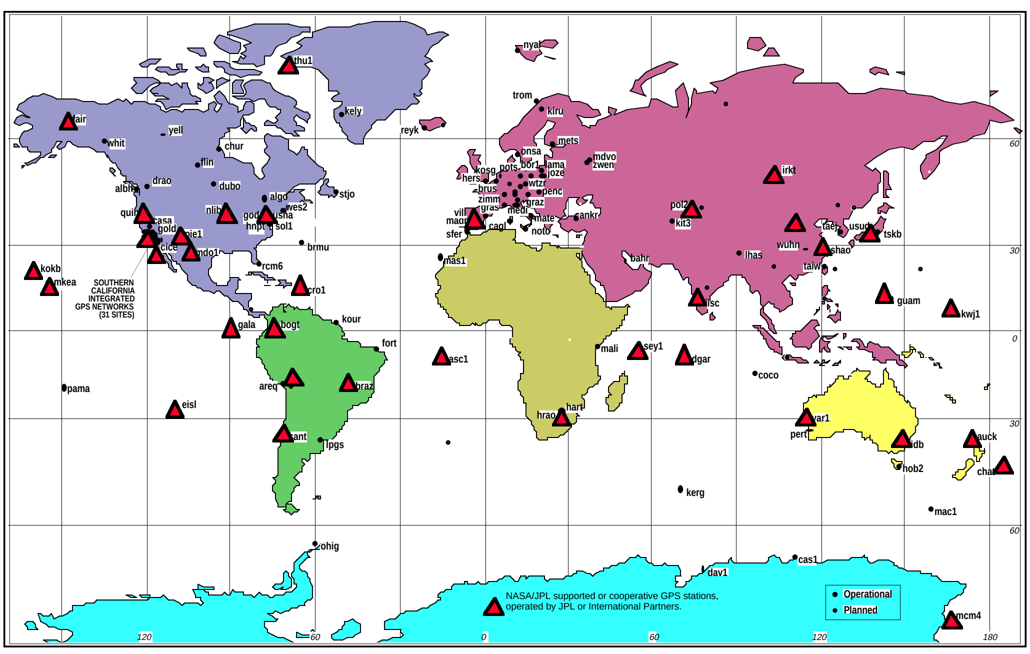

Figure 1: GPS Stations of the IGS Network Supported by NASA

Historically, data collection has been on a daily basis; however, some sites (detailed below) now provide data to JPL hourly. JPL supports ground stations equipped with various combinations of local computers, cabled serial connections, wireless serial connections, and telephone lines, depending on the available local infrastructure. Collection of the raw data files from the receivers falls into three categories according to the configuration of the stations:

- At sites with Internet and a JPL-supplied Macintosh computer, the JPL-developed GNET software (based on Microphone, a commercially available Macintosh communications application) retrieves the data.
- At sites with a PC running the Linux operating system (a freely-distributable implementation of Unix for IBM-PC architectures), the Perl-based GNEX software developed at JPL handles data retrieval.
- At sites with telephone service only, a Macintosh computer at JPL running the GNET software dials the remote modems attached to the receivers and collects the data.

Transfer of the data files to the GPS Data Handling Facility (DEC Alpha computers running the Digital Unix system) occurs via two distinct mechanisms:

- An automated process on the Unix computer collects the data via ftp from the remote Macintosh and PC computers, as well as from the modem-dialing Macintosh computers at JPL.
- A similar automated process collects data files via ftp from external agencies that make data available to JPL.

Once raw data are on board the JPL computers, end-to-end data processing is handled by GPS Network Operating System (GNOS), which automates data inventory, formatting, validation, storage, and distribution in a data-driven manner by utilizing an Ingres relational database. The validation step includes point positioning using range data and velocity calculations that use phase data, as well as computation of multipath and the application of other sanity and outlier checks on each data record. The most visible product of GNOS is the data posted daily in JPL's publicly accessible ftp site.

Data processing on the data handling computers at JPL initially differs slightly for hourly files. These are first processed by a series of Perl scripts designed to deliver GPS-based ionospheric total-electron-content measurements at subhourly turnaround times. Following this specialized handling, the hourly files are submitted to GNOS to undergo the same processing as daily files.

All phases of GPS network operation are evolving rapidly at JPL. The GNEX receiver control software is poised to afford flexibility in communications options as well as receiver types. The hourly data processing scripts are the impetus for development of Generalized Near-Real Time (GNRT) software, which can be configured by a user to provide rapid-turnaround, data-driven, queued processing of any type of data, including GPS data from subsets of the Global Network. The validation portion of GNOS will be upgraded to more proactively influence the storage and distribution phases. Finally, development of our Web page and data browsing utility continues. JPL and the UNAVCO organization have entered into a collaboration wherein UNAVCO will take responsibility for the installation and maintenance of JPL's Global Network sites, and enhance JPL's development of next-generation GPS networks.

In 1996, several sites were added to JPL's global network, and many existing sites enjoyed communication upgrades to Internet. In addition, JPL also began off-loading raw data on an hourly basis from those sites with appropriate communications links.

The following sites are permanent installations currently operated or supported by JPL. Latitude (Lat) and longitude (Long) are in degrees; heights (Ht) are in meters.

2 Global Network Sites

AREQ: NASA Laser Tracking Station, Arequipa, Peru
Lat: -16.4655
Long: -71.4928
Ht: 2488.9455
The station at Arequipa is collocated with the Satellite Laser Ranging station.

ASC1: Ascension Island
Lat: -7.9512
Long: -14.4121
Ht: 105.1508
Date Installed: April 20, 1996
The TurboRogue receiver was installed in April 1996. Communication to the site is via telephone.

AUCK: Whangaparaoa Peninsula, Auckland, New Zealand
Lat: -36.6028
Long: 174.8344
Ht: 132.8184
This station was installed by John Beavan of IGNS with UNAVCO support. Raw data are off-loaded hourly via Internet.

BOGT INGEOMINAS, Bogota, Colombia
Lat: 4.6401
Long: -74.0809
Ht: 2577.0489
Operated locally by INGEOMINAS. Communication was upgraded to Internet in 1996. Raw data are off-loaded hourly.

BRAZ: IBGE, Brasilia, Brazil
Lat: -15.9475
Long: -47.8779
Ht: 1106.0413
Operated locally by IBGE. Communication for this site was upgraded in 1996; data are transferred via telephone from Brasilia to Rio de Janeiro, and then by Internet to JPL.

CHAT: Waitangi, Chatham Island, New Zealand
Lat: -43.9558
Long: -176.5658
Ht: 58.0761
This station was installed by John Beavan of IGNS with UNAVCO support.

CICE: CICESE, Ensenada, Mexico
Lat: 31.8713
Long: -116.6674
Ht: 87.6618
This site was installed by the Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico (CICESE), University of Miami, UNAVCO, and JPL in 1995. In 1996, communications were upgraded to Internet, and hourly off-loading of raw data began.

CRO1: Christiansted, St. Croix NRAO VLBA, United States Virgin Islands
Lat: 17.7569
Long: -64.5843
Ht: -31.8281
Communication was upgraded to Internet in 1996. Raw data are off-loaded hourly.

DGAR: Diego Garcia Island, British Indian Ocean Territory
Lat: -7.2697
Long: 72.3702
Ht: -64.8965
This site was installed in March 1996. Communication is by telephone.

EISL: Easter Island Laser Station, Chile
Lat: -27.1482
Long: -109.3833
Ht: 114.5567
Station assistance is provided by the University of Chile, Santiago. The TurboRogue is collocated with the Satellite Laser Ranging Facility on Easter Island.

FAIR: Gilmore Creek Observatory, Fairbanks, Alaska
Lat: 64.9780
Long: -147.4992
Ht: 318.9963
The receiver at Fairbanks was upgraded to a TurboRogue in April 1996. The new equipment was first used for the former GPS/MET site, FAI2. Raw data are off-loaded hourly via Internet. Local support is arranged through the GSFC VLBI group.

GALA: Darwin Station, Galapagos Island, Ecuador
Lat: -0.7427
Long: -90.3036
Ht: 7.4453
The Galapagos site was installed in January 1996. Internet is available at the Darwin station, and a network upgrade is expected to connect the TurboRogue's local computer in 1997 for timely data retrieval.

GODE: Goddard Space Flight Center, Greenbelt, Maryland
Lat: 39.0217
Long: -76.8268
Ht: 14.5191
Tom Clark of GFSC installed the site; JPL collects the data. Communication was upgraded to Internet in 1996. Raw data are off-loaded hourly.

GOL2: Goldstone Deep Space Tracking Station, Goldstone, California
Lat: 35.4252
Long: -116.8892
Ht: 986.6691
This TurboRogue will become the primary station at Goldstone in 1997. Raw data are off-loaded hourly via Internet. (See the note to GOLD, below.)

GOLD Goldstone Deep Space Tracking Station, Goldstone, California
Lat: 35.4252
Long: -116.8892
Ht: 986.6645
This older Rogue, SNR8, will be retired in 1997 to be replaced by GOL2. Note that both GOLD and GOLD2 operate from the same antenna.

GUAM: Guam Seismic Observatory, Dededo, Guam
Lat: 13.5893
Long: 144.8684
Ht: 201.9220
The receiver is installed at the Seismic Observatory along with an IRIS/USGS seismometer. USGS and JPL share an Internet connection through a local provider at this site. Raw data are off-loaded hourly.

HRAO: Hartebeesthoek, Pretoria, Republic of South Africa
Lat: -25.8901
Long: 27.6870
Ht: 1439.6815
This site was installed at the Hartebeesthoek Radio Astronomy Observatory (HRAO) in September 1996. The local TurboRogue control computer is a Linux PC belonging to the Observatory, running JPL software. Data are off-loaded hourly via Internet.

IISC: Indian Institute of Science, Bangalore, India
Lat: 13.0212
Long: 77.5704
Ht: 842.4943
This site was installed by the Indian Institute of Science, Center for Mathematical Modeling and Computer Simulation (IISC), Bangalore, India, and UNAVCO. Communications are via Internet; however, the connection is insufficient for hourly data transfers.

KOKB: Kokee Park Geophysical Observatory, Waimea, Kauai, Hawaii
Lat: 22.1263
Long: -159.6649
Ht: 1167.3613
This site was upgraded to a TurboRogue in 1996. Raw data are off-loaded hourly via Internet.

KWJ1: Kwajalein Atoll, Marshall Islands
Lat: 8.7222
Long: 167.7302
Ht: 38.2688
This site was installed in March 1996.

MADR: Madrid Deep Space Tracking Station, Robledo, Spain
Lat: 40.4292
Long: -4.2497
Ht: 829.4575

A faulty antenna was replaced in September 1996. This is an older ROGUE SNR8, which will be replaced in 1997.

MCM4: McMurdo GPS Station, Ross Island, Antarctica
Lat: -77.8383
Long: 166.6693
Ht: 97.9202
Raw data are off-loaded hourly via Internet. On-site collaboration with this station through the USGS and the National Science Foundation.

MDO1: McDonald Laser Observatory, Fort Davis, Texas
Lat: 30.6805
Long: -104.0150
Ht: 2004.4950
Communications to the McDonald site were upgraded to Internet in 1996. Raw data are off-loaded hourly.

MKEA: Mauna Kea, Hawaii
Lat: 19.8014
Long: -155.4560
Ht: 3755.6669
This site was installed in August 1996. Raw data are off-loaded hourly via Internet.

NLIB: North Liberty VLBA Site, Iowa
Lat: 41.7716
Long: -91.5749
Ht: 207.0424
Communications were upgraded to Internet in 1996. Raw data are off-loaded hourly.

PIE1: NRAO VLBA Site, Pie Town, New Mexico
Lat: 34.3015
Long: -108.1189
Ht: 2347.7120
Communications were upgraded to Internet in 1996. Raw data are off-loaded hourly.

QUIN: Mobile Laser Tracking Station, Quincy, California
Lat: 39.9746
Long: -120.9444
Ht: 1105.7709
Communications were upgraded to Internet in 1996. Raw data are off-loaded hourly.

SANT: Santiago Tracking Station, Santiago, Chile
Lat: -33.1503
Long: -70.6686
Ht: 723.0702
A faulty antenna was replaced in July 1996. Raw data are off-loaded hourly via Internet.

SEY1: Seychelles Tracking Station, Mahe Island, Seychelles
Lat: -4.6737
Long: 55.4794
Ht: 537.2242

SHAO: Shanghai Observatory, Sheshan station, Sheshan, China
Lat: 31.0996
Long: 121.2004
Ht: 22.0716
The antenna for this station was installed on a solid satellite-camera pier. It was installed in 1994 by the Shanghai Observatory, JPL, and UNAVCO. Data retrieval is by telephone.

THU1: Thule AFB, Greenland
Lat: 76.5373
Long: -68.7880
Ht: 55.0030
Operated in conjunction with National Survey and Cadastre of Denmark (KMS), Denmark, and Statens Kartverk, Norway.

TID2: Tidbinbilla Deep Space Tracking Station, Tidbinbilla, Australia
Lat: -35.3992
Long: 148.9800
Ht: 665.3818
This TurboRogue will become the primary Tidbinbilla site in 1997. (See note to TIDB, below.)

TIDB: Tidbinbilla Deep Space Tracking Station, Tidbinbilla, Australia
Lat: -35.3992
Long: 148.9800
Ht: 665.3818
This SNR8 older equipment will be retired in 1997 and upgraded to TID2. Note that TIDB and TID2 operate on a common antenna.

USUD: Usuda Deep Space Tracking Station, Usuda, Japan
Lat: 36.1331
Long: 138.3620
Ht: 1508.6206
Communications to Usuda were upgraded to Internet in 1996. Raw data are off-loaded hourly.

XIAN: Shaanxi Observatory, Lintong, China
Lat: 34.3687
Long: 109.2215
Ht: 464.5646
This site was installed by Shaanxi Observatory, UNAVCO, and JPL in May 1996. Data retrieval is by telephone.

YAR1: Yaragadee, Near Mingenew in the State of Western, Australia
Lat: -29.0466
Long: 115.3470
Ht: 241.3080
This station is in Western Australia, collocated with the SLR.

3 Southern California Sites

AOA1: Allen Osborne Associates, Westlake, California
Lat: 34.1574
Long: -118.8303
Ht: 246.5566

AZU1: Azusa High School, Azusa, California
Lat: 34.1260
Long: -117.8960
Ht: 145.7474

CAT1: Catalina Island, California
Lat: 33.4458
Long: -118.4830
Ht: 3.9099

CIT1: California Institute of Technology, Pasadena, California
Lat: 34.1367
Long: -118.1273
Ht: 215.3446

CSN1: California State University at Northridge, Northridge, California
Lat: 34.2535
Long: -118.5238
Ht: 261.5188

HARV: Harvest Oil Platform, California
Lat: 34.4694
Long: -120.6821
Ht: 14.9627

JPLM: JPL Mesa, Pasadena, California
Lat: 34.2048
Long: -118.1732
Ht: 423.9831
Raw data are off-loaded hourly via Internet.

LBCH: Long Beach, California
Lat: 33.7878
Long: -118.2033
Ht: -27.5399

OAT2: Oat Mountain, Los Angeles County, California
Lat: 34.3299
Long: -118.6014
Ht: 1112.5756

SNI1 : Saint Nicolas Island, Port Hueneme/Point Mugu, California
Lat: 33.2479
Long: -119.5244
Ht: 239.6859

SPK1: Saddle Peak, California
Lat: 34.0593
Long: -118.6462
Ht: 440.1271

UCLP: University of California, Los Angeles, California
Lat: 34.0691
Long: -118.4419
Ht: 111.5498

USC1: University of Southern California, Los Angeles, California
Lat: 34.0239
Long: -118.2851
Ht: 21.9488

WHC1: Whittier College, Whittier, California
Lat: 33.9799
Long: -118.0312
Ht: 94.3079

WHI1: Whittier Library, Whittier, California
Lat: 33.9738
Long: -118.0345
Ht: 65.7262

WLSN: Mt. Wilson Observatory, Los Angeles County, California
Lat: 34.2261
Long: -118.0559
Ht: 1705.3094

4 Special Regional Sites

CARR: Carrhill- Parkfield, California Ken Hurst
Lat: 35.8883
Long: -120.4310
Ht: 479.7481
Installed by Ken Hurst of JPL.

CASA: Mammoth, California
Lat: 37.6446
Long: -118.8967
Ht: 2390.4416
Installed by Frank Webb of JPL.

KRAK: Krakatoa, California
Lat: 37.7131
Long: -118.8811
Ht: 2367.9687
Installed by Frank Webb of JPL.

5 Data Access Information

Short name: JPL
Institution: Jet Propulsion Laboratory
Function within IGS: Operational, Regional Data Center
Mail address: 4800 Oak Grove Drive Pasadena, CA 91109 USA
Contact: David A. Stowers
Telephone: +1 818 354-7055
Fax: +1 818 393-4965

E-Mail:	dstowers@jpl.nasa.gov (internet)
Telnet access:	none
Ftp access:	bodhi.jpl.nasa.gov (128.149.70.66) anonymous
Computer operating system:	HP9000/715 HP-UX
Amount of data on-line:	120 days
Access to off-line data:	special arrangements

6 Directory Information

Table 2: Directory Structure

(Directory specifications are for the JPL guest computer BODHI)

Directory	Subdirectory	Description
pub		
	/pro	RINEX area indexed by day of year
	/raw	Raw data area indexed by day of year
	/docs	Supporting documentation and IGS MAIL
	/software	Supporting software
	/topex	Topex orbit data

7 Network References

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

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

JPL's contribution to the Southern California Dense Array and the Southern California Integrated GPS Network (SCIGN):
http://milhouse.jpl.nasa.gov/

New Western Canadian Deformation Array Sites: Lac du Bonnet and Flin Flon

Michael Schmidt

Pacific Geoscience Centre
Geological Survey of Canada

1 Introduction

Since the last reporting, two new sites have been added to the Western Canadian Deformation Array. Their locations are given in Table 1.

Table 1: New Western Canadian Array Sites

			Coordinates (m)		
Station	Latitude	Longitude	X	Y	Z
DUBO	N 50 15 31.66670	E 264 08 01.82064	–417602.471	–4064531.610	4881431.964
FLIN (approx.)	N 54.7257	E 258.0220	–766174.6	–3611375.4	5184056.4

2 Lac du Bonnet (DUBO)

DUBO is located on the property of AECL Underground Research Lab, located east of Lac du Bonnet, Manitoba, Canada. DUBO is one of two GPS tracking stations operated in central Canada by the Geological Survey of Canada (GSC). DUBO was established in partnership with the Geodetic Survey Division (GSD) of Geomatics Canada, Manitoba Hydro, and NASA/UNAVCO, specifically to provide geodetic constraints on postglacial rebound in central North America. DUBO is located on the North American Plate.

The GPS station commenced operation in October 1996; absolute gravity measurements are carried out at regular intervals. All markers on site (GPS, and local references) are tied into local vertical control through Special Order levelling surveys carried out by GSD.

2.1 Instrumentation

As of April 1997, DUBO is equipped with a dual frequency, eight-channel AOA SNR-8000 Turbo Rogue GPS receiver on loan from NASA/JPL. The GPS antenna (Figure 1) is mounted on a brass, forced centered plate embedded in a 3-m-tall concrete pier. A 10-cm-high anodized aluminum base provides a constant height above the brass plate and also permits the antenna to be referenced to north. The GPS equipment uses local grid power backed up by an uninterruptible power supply (UPS) capable of sustaining the site for up to 45 minutes. Two high-speed modems are used (1) to access the receiver for instrument control and data recovery and (2) to access the UPS to monitor and control power to the GPS instrumentation.

```
               TurboRogue: DORNE MARGOLIN T (Allen Osborne Design)
                               (not to scale)

                              .     .
                        .                 .
                   .                           .
               .                                    .<-- ACRYLIC DOME
           .                 ----                    .
         .                /    +    \                  .      <-- 0.128m L2
       .                 |     +     |                   .    <-- 0.110m L1
      .     +-----------------------------------------+    .  <-- 0.102m TCR
     .      |                                         |     .
     .      |                                         |     .
     .      |                                         |     .
     .      |                                         |     .
     .   +-+-------------------------------------------+-+  .  <-- 0.038m
    ...  +---------------+------------+----------------+  ... <-- 0.035m BCR
    |========            |            |            ========| FLANGE RING
    |                    |            |                    |
    |                    +-----X------+  <-----            | <-- 0.000m ARP
    |                    *            *       |            |
    |                    *            *       |            |
    |                    *            *       |            |
    |                    *            *     0.100m         |< metal screening
    |                    *            *       |            |   (RF skirt)
    |                    *            *       |            |
    [--------------------*-----#------*--------------------] TOP OF CONCRETE
    [                                                      ]     PIER
    [                                                      ]
    [                                                      ]
    [                                                      ]

                      # ...  Monument Reference Point
                      X ...  Antenna Reference Point (ARP)
      L1 : L1 Phase Center                L2 : L2 Phase Center
      TCR: Top of Chokering               BCR: Bottom of Chokering
```

Figure 1: Antenna Schematic for DUBO GPS Station

2.2 Data Handling

The GPS data from all GSC sites are retrieved automatically from a central data collection and validation platform located at the Pacific Geoscience Centre (PGC) in Sidney, B.C. Data retrieval takes place every 4 hours; each 4-hour data file is validated using two routines developed at GSD, GIMP8, and GPS-PACE. The validation routines issue both warning and error flags. In the event of an error condition, the data are automatically downloaded again and revalidated. The QC Quality Assurance program is run on the RINEXed files. Any warnings or errors are captured in a daily log file along with summaries from all data validation programs. Both native CONAN Binary and RINEX 4-hour data files are available from a public ftp directory. The GSD in Ottawa currently picks up the data from the PGC ftp site, validates and merges them into 24-hour data files, and forwards the RINEX files to CDDIS.

2.3 DUBO Station Summary as of April 1, 1997

GPS Receiver:	96/10/18 (96.292) 16:00UT ROGUE SNR-8000 Rcvr s/n 207 UNAVCO 8765
Firmware:	96/10/18 (96.292) 16:00UT Vers. 3.2 95/02/08 link 95/03/09 12:37:24 G050 JPL
Data Rate:	30 seconds
Antenna:	97/01/08 (97.008) 19:50UT AOA Dorne Margolin T p/n 7490400-2, s/n 236 UNAVCO 8438 (acrylic dome added)
Antenna Height:	vertical distance measured from monument reference point (#) to antenna reference point (X) (ARP) 96/10/18 (96.292) 16:00UT 0.100m
Antenna Dome:	97/01/08 (97.008) 19:50UT acrylic dome added
Antenna RF Skirt:	96/10/18 (96.292) 16:00UT placed aluminum screen around base of antenna such that top of pier covered
Clock:	96/10/18 (96.292) 16:00UT internal clock steering
Status:	96/10/18 (96.292) 16:00UT operational

3 Flin Flon (FLIN)

FLIN is located on the property of CFD Flin Flon, Saskatchewan, located west of the town of Flin Flon, Manitoba, Canada. FLIN is one of two GPS tracking stations operated in central Canada by the Geological Survey of Canada (GSC). FLIN was established in partnership with the Geodetic Survey Division (GSD) of Geomatics Canada, Manitoba Hydro, and NASA/UNAVCO, specifically to provide geodetic constraints on postglacial rebound in central North America. FLIN is located on the North American Plate.

The GPS station commenced operation in June, 1996; absolute gravity measurements are carried out at regular intervals. All markers on site (GPS, and local references) are tied into local vertical control through Special Order levelling surveys carried out by GSD.

3.1 Instrumentation

As of April 1997, FLIN is equipped with a dual-frequency, eight-channel AOA SNR-8000 Turbo Rogue GPS receiver on loan from NASA/JPL. The GPS antenna (Figure 2) is mounted on top of a 1.5-m-high concrete pier. The antenna is attached to a stainless-steel antenna mount (UNAVCO), which provides tilt and azimuth adjustment. The antenna mount in turn is attached to a 4.5-m-long Invar rod anchored at a depth of 3.0 m in solid bedrock. The concrete pier is constructed of a special superplasticized fly ash concrete mix developed by the CANMET laboratory of Natural Resources Canada. Polypropylene fibres are included in the mix to restrain any small cracks. It is expected that the specialized concrete mix in combination with the Invar rod will provide minimal monument expansion/contraction due to the extreme temperature fluctuations in this region. The GPS equipment uses local grid power backed up by an uninterruptible power supply (UPS) capable of sustaining the site for up to 45 minutes. Two high-speed modems are used (1) to access the receiver for instrument control and data recovery and (2) to access the UPS to monitor and control power to the GPS instrumentation.

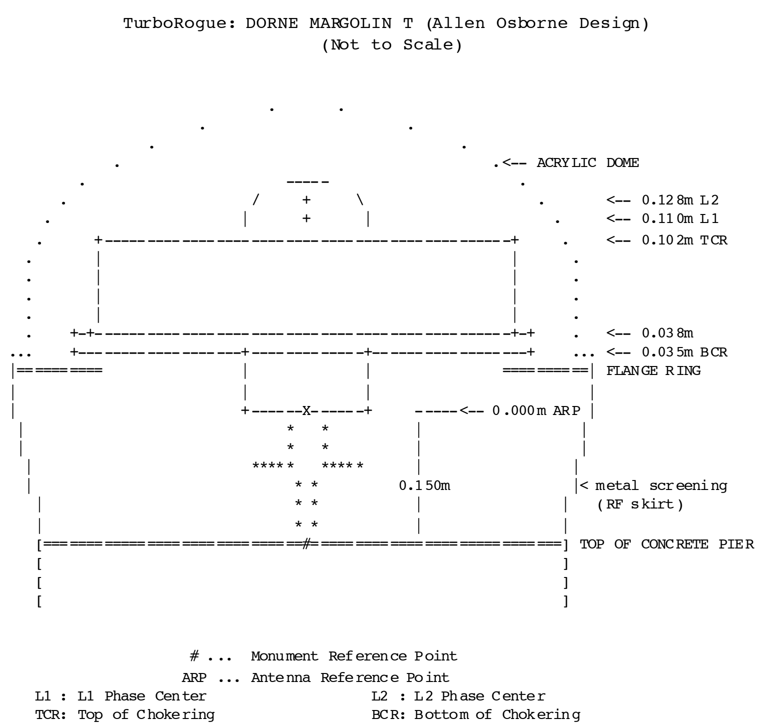

Figure 2: Antenna Schematic for FLIN GPS Station

3.2 Data Handling

The GPS data from all GSC sites are retrieved automatically from a central data collection and validation platform located at the Pacific Geoscience Centre (PGC) in Sidney, B.C. Data retrieval takes place every 4 hours; each 4-hour data file is validated using two routines developed at GSD, GIMP8, and GPS-PACE. The validation routines issue both warning and error flags. In the event of an error condition, the data are automatically downloaded again and revalidated. The QC Quality Assurance program is run on the RINEXed files. Any warnings or errors are captured in a daily log file along with summaries from all data validation programs. Both native CONAN Binary and RINEX 4-hour data files are available from a public FTP directory. The GSD in Ottawa currently picks up the data from the PGC FTP site, validates and merges them into 24-hour data files, and forwards the RINEX files to CDDIS.

3.3 FLIN Station Summary as of April 1, 1997

GPS Receiver:	97/01/07 (97.007) 20:03UT ROGUE SNR-8000 Rcvr s/n 194 UNAVCO 8870
Firmware:	97/01/07 (97.007) 20:03UT Vers. 3.2 95/02/28 link 95/03/09 12:37:24 G050 JPL
Data Rate:	30 seconds
Antenna:	97/01/07 (97.007) 20:03UT AOA Dorne Margolin T p/n 7490400-2, s/n 231 UNAVCO No. 8498
Antenna Height:	vertical distance measured to antenna reference point (ARP) ('X' on Figure 2) 96/06/05 (96.157) 00:00UT 0.150m
Antenna Dome:	97/01/07 (97.007) 20:03UT acrylic dome placed over antenna
Antenna RF Skirt:	96/06/05 (96.157) 00:00UT placed aluminum screen around base of antenna such that top of pier covered
Clock:	96/06/05 (96.157) 00:00UT internal clock steering
Status:	96/06/05 (96.157) 00:00UT operational

4 Contact Information

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Report on IGS Global Station Jozefoslaw (JOZE)

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Warsaw, Poland

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 southward from the Warsaw city center. The Observatory was established in 1959; 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 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. In some periods of 1996 and 1997, other types of GPS receivers were temporarily installed at the station Jozefoslaw. They were Ashtech ZXII-3, No. 03314 (antenna No. 12779 microstrip); Leica SR 9500, No. 1302 (antenna AT 302); and Zeiss RM24, No. 102521 (antenna No. 5595). The observations were performed to study some instrumental effects, and multipath and atmospheric (ionosphere and troposphere) influences.

- Gravimetric permanent tidal observations are carried out using a LaCoste & Romberg, mod. G gravity meter. This service has been maintained since November 1993. The Observatory is incorporated with 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. A 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 changes of the vertical.

- Astrometric latitude observations have been carried out since 1959 in 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 to complement analyses of the time variations of the plumb line.

- Meteorologic service maintained at the station can be supported by the nearby permanent meteo service of the Warsaw airport (Warszawa-Okecie). The station Jozefoslaw is a few kilometers from the Warsaw airport.

- In some periods, observations of atmospheric electricity are made at the Observatory by a team from 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. Since the 1960s, the Observatory has also participated in other astrometric and satellite campaigns (photographic, Doppler, and GPS).

The Institute's Processing Center acts as an IGS Regional Network Associate Analysis Center, the EUREF Local Analysis Center, and the CEI CERGOP Processing Center. 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.

OTHER CONTRIBUTIONS

Status Report on the SIRGAS Project

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1 Introduction

The project for the establishment of a South American Geocentric Reference System (Sistema de Referencia Geocéntrico para América del Sur, SIRGAS) was initiated in October 1993 during an international conference held in Asunción, Paraguay [1]. One of the main objectives defined at this meeting was the installation of a continental reference frame by observing a precise GPS network of about 50 stations covering homogeneously the entire continent. The network design was determined during a workshop held in La Plata, Argentina, in October 1994 (see Figure 1).

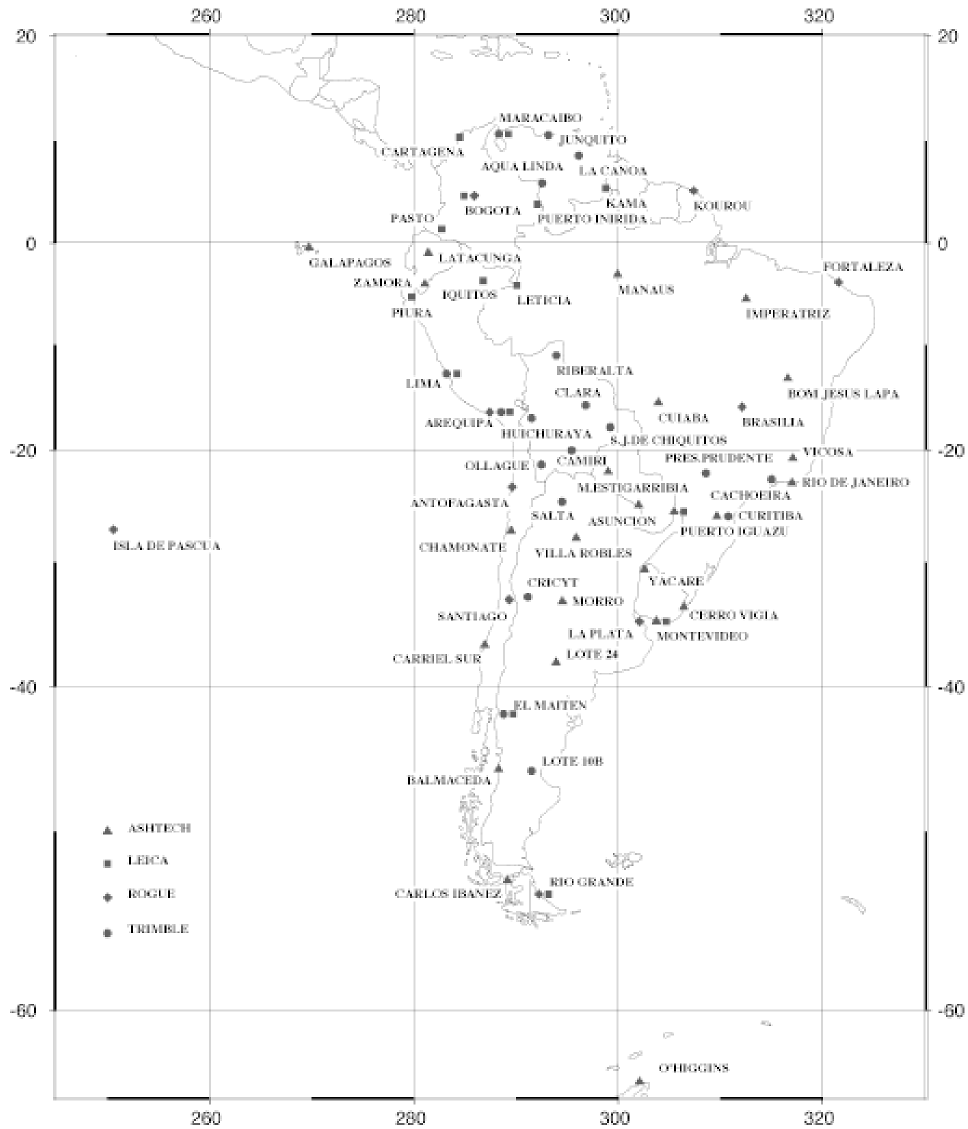

Figure 1: SIRGAS reference frame as observed by the GPS campaign 1995

2 Realization of the SIRGAS Reference Frame

A total of 56 sites on the South American mainland were selected to form the SIRGAS reference frame, 7 of those being IGS stations. In addition, the two IGS stations at Easter Island and O'Higgins were considered part of the SIRGAS network. All these sites were occupied simultaneously during the SIRGAS GPS campaign; the sites observed continuously from May 26, 1995, 0:00 to June 4, 1995, 24:00.

Four different GPS receiver types were employed: Ashtech Z12, Leica 200, Rogue (or TurboRogue), and Trimble SSE. In order to tie receiver-type dependent subnetworks together, collocations of different receivers were performed at nine sites. The local ties were observed by identical receiver types and, in addition, by terrestrial levelling.

3 Data Processing and Results

Two data centers collected and “cleaned” (controlled and corrected RINEX format eccentricities and obscurities) all the data of the SIRGAS GPS campaign; the two centers are Deutsches Geodaetisches Forschungsinstitut (DGFI/I), Munich, Germany, and Instituto Brasileiro de Geografía e Estatistica (IBGE/DEGED), Rio de Janeiro, Brazil. The total amount of data comprises some 1.3 Gbyte in about 700 observation files. Both data centers are identical in structure and in storage due to a permanent data exchange.

The prepared data sets were independently processed by two processing centers: DGFI/I and the National Imagery and Mapping Agency (NIMA), St. Louis, Missouri, USA. The processing characteristics were defined after the discussion of preliminary results during a workshop in Santiago, Chile, in August 1996. DGFI/I used the Bernese Software and IGS precise (combined) orbits, while NIMA used the GIPSY Software with JPL orbits and clock parameters. The two “free” networks (without fiducial stations) differ after a seven-parameter Helmert-transformation and correction for elevation-dependent phase center variations by ±7 mm in X, ±9 mm in Y, and ±6 mm in Z. The combined "free" networks were transformed to the ITRF94 by means of the averaged coordinates of nine IGS stations from CODE and JPL 1996 solutions. The transformed coordinates were adopted as the SIRGAS final reference frame at a workshop held in Isla de Margarita, Venezuela, in April 1997. They have rms errors with an average of ±4 mm in each coordinate component.

4 Future Development

Several South American countries started already with the establishment of new geocentric national networks based on the SIRGAS reference frame. Through identical stations with the existing (terrestrial) networks, transformation parameters are being derived. As the offset to the existing networks is up to hundreds of meters, there will be an effect on cartographic products (maps), too.

The maintenance of the SIRGAS network will certainly lead to an increasing number of permanent GPS stations in South America. Presently, the data of existing permanent stations are processed by the IGS Regional Network Associate Analysis Center for SIRGAS (RNAAC SIR) operated by DGFI/I in Munich. This activity will be continued in close cooperation with IBGE in Rio de

Janeiro. For the rest of the SIRGAS network not occupied by permanent GPS stations, a repetitive observation campaign is foreseen after about 5 years in order to control the stability of the network and eventually derive station velocities.

Reference

[1] L. P. Fortes, M. J. Hoyer, W. H. Subiza, and H. Drewes, "The SIRGAS Project," in *International GPS Service for Geodynamics, 1994 Annual Report*, edited by J. F. Zumberge, R. Liu, and R. E. Neilan, JPL Publication 95-18, Jet Propulsion Laboratory, Pasadena, California, 1995.

The Use of GPS Earth Orientation Data by the International Earth Rotation Service Sub-Bureau for Rapid Service and Predictions

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1 Introduction

Analyses of the orbits of the GPS satellites by participants in the IGS have provided daily observations of high-accuracy polar motion. These data are used routinely by the National Earth Orientation Service (NEOS) in its normal operations. Also, a longer series of GPS Earth orientation information is required to assess the value of the data in maintaining a reference system over a long period of time. In 1996, NEOS began using GPS UT1-UTC determinations in its combination procedure for its Rapid Service solutions.

2 Source of Data

Daily estimates of pole positions have been provided by contributors to the IGS. These contributors include the Scripps Institution of Oceanography (SIO), the Center for Orbit Determination in Europe (CODE) located at the University of Berne, Jet Propulsion Laboratory (JPL), the European Space Operations Center (ESOC), Natural Resources Canada (NRCan), the GeoForschungs-Zentrum (GFZ), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Naval Observatory (USNO). Estimates of UT1-UTC are contributed by CODE, JPL, and NRCan.

3 Analysis of GPS Data

The time series contributed by each of the institutions mentioned above were analyzed by comparing them with the NEOS combination series produced for the International Earth Rotation Service (IERS) Bulletin A. Figures 1 and 2 show plots of recent differences in polar motion after the removal of biases. Table 1 shows the statistical analysis of the polar motion data for a typical 30-day interval.

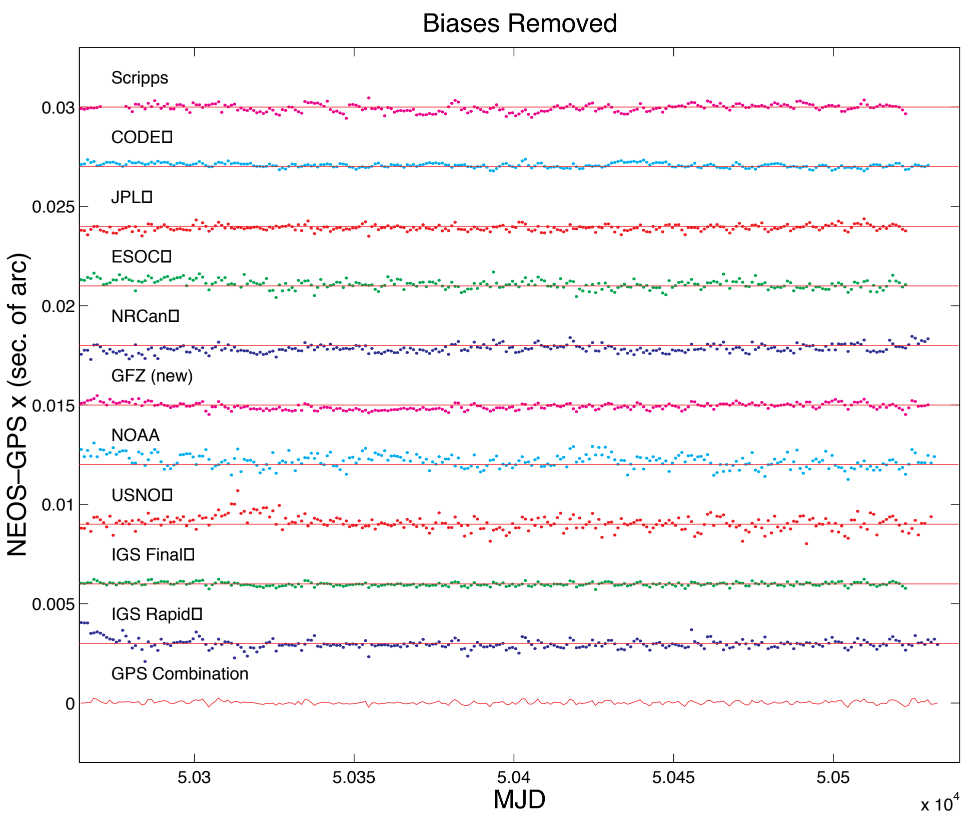

Figure 1: Residuals in x for GPS contributors

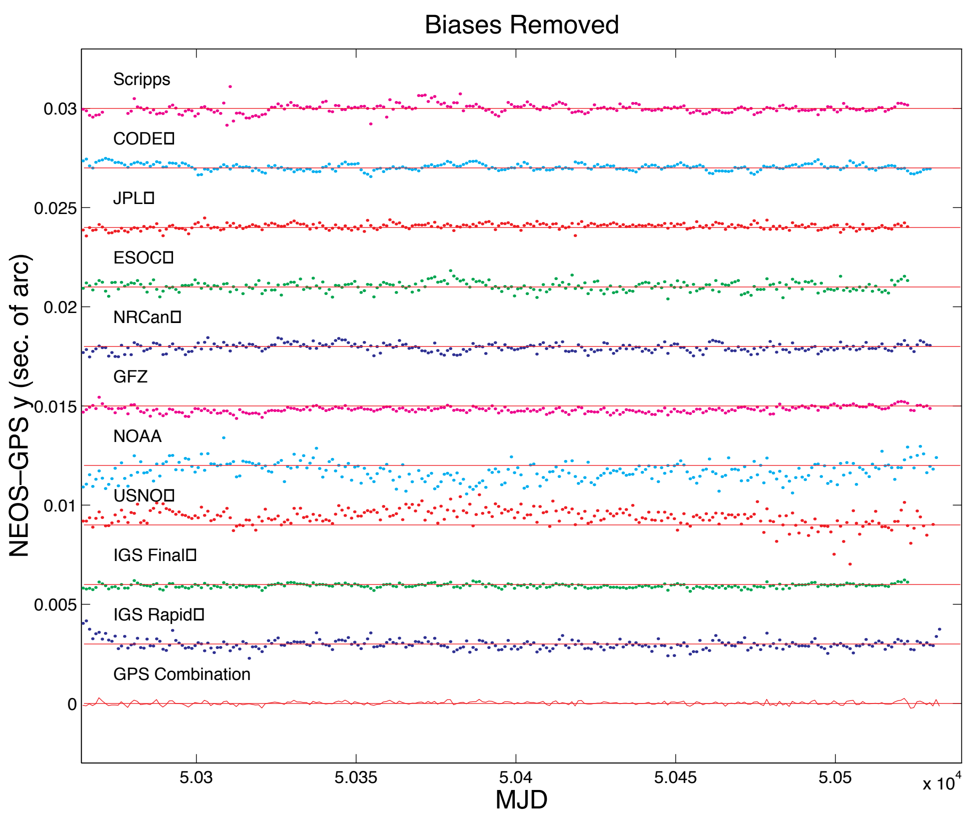

Figure 2: Residuals in y for GPS contributors

4 Use of GPS Data in IERS Bulletin A

The NEOS makes use of GPS data contributed to the IERS in its combination series. This is done by smoothing the contributed data separately using algorithms similar to those used in the procedure to combine the VLBI, SLR, and LLR [1]. Statistical weights are assigned to each of the contributors based on their past agreement with the NEOS combination series. Figures 3 and 4 show the agreement between the smoothed GPS estimates and those derived using data from other techniques for recent times.

Table 1: Statistics for GPS Polar Motion Data

Contributor	Data Span	Mean (NEOS–GPS) x	Mean (NEOS–GPS) y	Mean (NEOS–GPS) UT1–UTC	Standard Deviation x	Standard Deviation y	Standard Deviation UT1–UTC
Scripps	50493.5 –50522.5	–0.34	0.14		0.13	0.14	
CODE	50500.5 –50529.5	0.34	0.04	–19.14	0.10	0.16	0.22
JPL	50493.5 –50522.5	0.14	–0.25	–2.55	0.15	0.12	0.45
ESOC	50493.5 –50522.5	0.35	–0.59		0.20	0.25	
NRCan	50500.5 –50256.5	0.04	0.54	10.49	0.23	0.15	0.07
GFZ	50500.5 –50529.5	0.26	0.20		0.17	0.12	
NOAA	50502.5 –50531.5	–0.61	0.20		0.31	0.45	
USNO	50500.5 –50530.5	0.55	–0.83		0.36	0.58	
IGS Final	50493.5 –50522.5	0.27	–0.25	–0.02	0.11	0.08	0.05
IGS Rapid	50503.5 –50532.5	0.28	–0.28	–0.11	0.19	0.23	0.22

5 Accuracy

Comparison with the other techniques shows that the combined GPS series has a precision of ±0.20 to 0.30 ms of arc in x and y in the Rapid Service combination solution. Figures 1 and 2 show that serious systematic difference between the contributors remain which must be resolved to obtain further improvement.

Reference

[1] D. D. McCarthy and B. J. Luzum,"Combination of Precise Observations of the Orientation of the Earth," *Bull. Geod.*, 65, pp. 22–27, 1991.

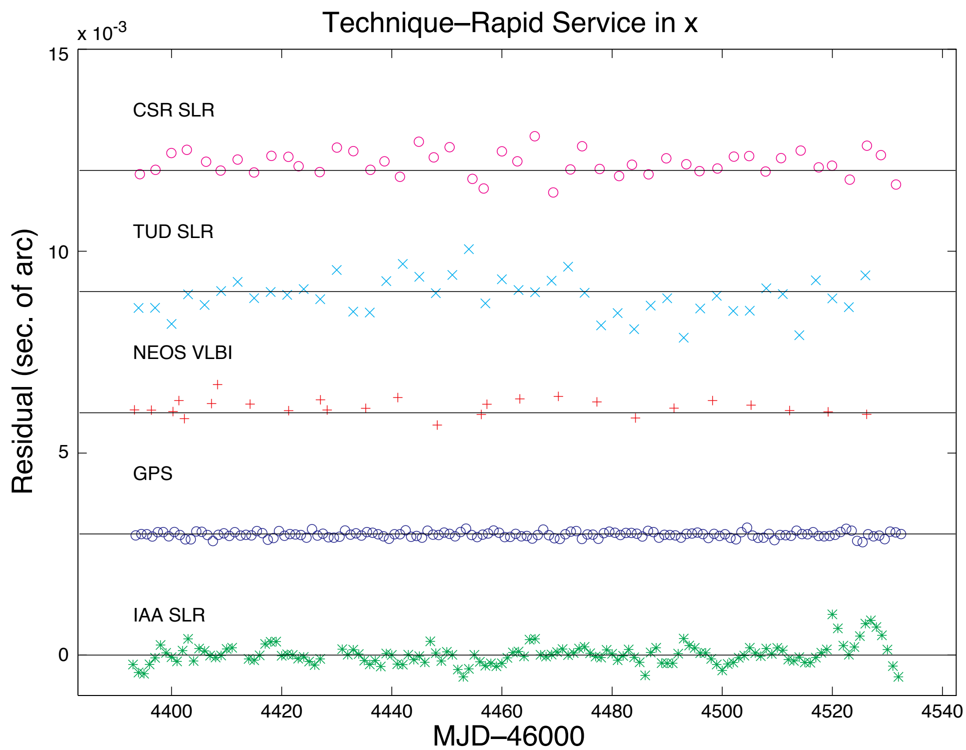

Figure 3: Residuals in x of contributors in combination solution

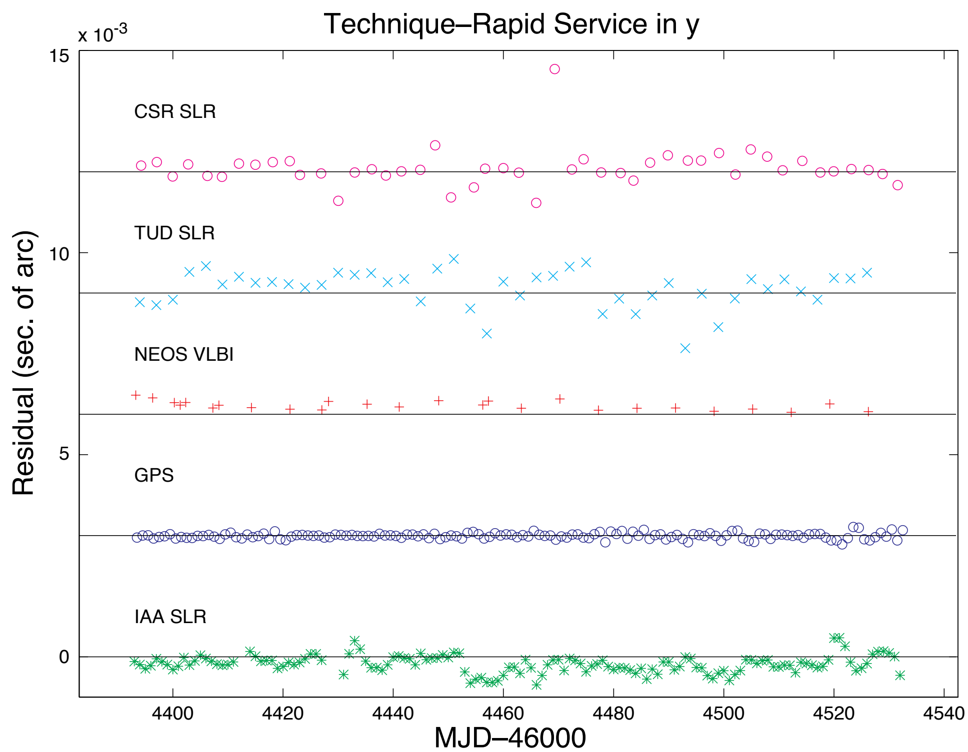

Figure 4: Residuals in y of contributors in combination solution

Acronyms

AAC	Associate Analysis Center
AC	Analysis Center
AECL	Atomic Energy Canada Ltd.
AIUB	Astronomical Institute of the University of Berne, Switzerland
AS	anti-spoofing
ASI	Italian Space Agency
AUCK	existing IGS station in New Zealand
AWS	automatic weather station
BAdW	Bayerische Akademie der Wissenschaften, Germany
BEK	Bayerische Kommission für die Internationale Erdmessung, Germany
BIFROST	Baseline Inferences for Rebound Observations Sea Level and Tectonics (Scandinavian)
BPE	Bernese Processing Engine
BRD	broadcast ephemeris
BSW	Bernese Software
CA	coarse acquisition
CB	Central Bureau
CBIS	Central Bureau Information System
CDDIS	Crustal Dynamics Data Information System, USA
CEA	Commissariat à l'Energie Atomique
CEGRN	Central Europe GPS Reference Network
CEI CERGOP	Central European Initiative, Central Europe Regional Geodynamics Project
CGS	Matera Space Geodesy Center, Italy
CHAT	existing IGS station in New Zealand
CICESE	Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico
CISAS	Centro Interdipartimentale di Studi e Attivita' Spaziali
CLG	Central Laboratory for Geodesy, Sofia
CNES	Centre National d'Etudes Spatiales, France
COD	Centre for Orbit Determination
CODE	Center for Orbit Determination in Europe
COP	Code predicted (orbit)
CPU	central processor unit
CSR	Center for Space Research, USA
DCE	data communication equipment
DEC	Digital Equipment Corporation
DGFI	Deutsches Geodätisches ForschungsInstitut
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite

DUBO	Lac du Bonnet: a new Canadian deformation array site
DUT	Delft University of Technology
EMP	EMR predicted (orbit)
EMR	Energy, Mines, and Resources; now Natural Resources Canada (NRCan)
EOP	Earth orientation parameter
erp	Earth rotation parameter
ESA	European Space Agency
ESOC	European Space Operations Center
ESP	ESA predicted (orbit)
ETRS	European Terrestrial Reference System
EUR	Europe
EUREF	European Reference Frame
FAGS	Federation of Astronomical and Geophysical Data Analysis Services
FGI	Finnish Geodetic Institute
FLIN	Flin Flon: a new Canadian deformation array site
GDC	Global Data Center
GFP	GFZ predicted (orbit)
GFZ	GeoForschungsZentrum, Germany
GIA	Geophysical Institute, University of Alaska
GIBS	GPS Information and Observation System, Germany
GIS	Geographic Information Systems
GL	Geosciences Laboratory
GLOSS	Global Sea Level Observing Systems
GMST	Greenwich mean sidereal time
GNAAC	Global Network Associate Analysis Center
GNO	GPS Networks and Operations Group (also GNOG), JPL
GNOS	GPS Network Operating System, JPL
GNRT	Generalized Near-Real Time, JPL
GNS	Institute of Geological and Nuclear Sciences, New Zealand
GNSS	Global Navigation Satellite System
GODC	Geosciences Laboratory Operational Data Center
GOP	Geodetic Observatory Pecny
GPS	Global Positioning System
GSC	Geological Survey of Canada
GSD	Geodetic Survey Division, Canada
GSFC	Goddard Space Flight Center, USA
GSI	Geographical Survey Institute, Japan
GZ	GEOZUP Company, Kaliningrad, Russia
IAA	Institute of Applied Astronomy, Russia
IAG	International Association of Geodesy
IAPSO	International Association for the Physical Sciences of the Ocean
IAU	International Astronomical Union
IBGE	Instituto Brasileiro de Geografía e Estatistica, Brazil
ICET	International Center for Earth Tides
ICRF	International Celestial Reference Frame

IERS	International Earth Rotation Service
IfAG	Institute for Applied Geodesy, Germany
IfEN	Institut für Erdmessung und Navigation
IFG	EUREF Analysis Center
IFRTP	Institut Français pour la Recherche et la Technologie Polaire
IGFN	Italian GPS Fiducial Network
IGN	Institut Géographique National, France
IGNS	Institute of Geological and Nuclear Sciences, New Zealand (see also GNS)
IGP	IGS predicted (orbit)
IGR	IGS rapid (orbit)
IGS	International GPS Service
IISC	Indian Institute of Science, Center for Mathematical Modeling and Computer Simulation, Bangalore, India
IRKT	GPS station in Irkutsk, Russia
ITRF	International Terrestrial Reference Frame
ITRS	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
JOZE	IGS permanent GPS station Jozefoslaw, Poland
JPL	Jet Propulsion Laboratory, USA
JPP	JPL predicted (orbit)
KMS	National Survey and Cadastre of Denmark
LA	long arc
LDC	Local Data Center
LINZ	Land Information of New Zealand
LLR	lunar laser ranging
LNAAC	Local Network Associate Analysis Center
LODR	length of day (regularized)
LPT	Bundesamt für Landestopographie, Switzerland
MADR	GPS station in Madrid, Spain
MINQE	Minimum Invariant Quadratic Estimate
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration, USA
NAVSTAR	Navigation System Timing and Ranging
NCL	University of Newcastle, UK
NEOS	National Earth Orientation Service
NEQ	normal equation
NGS	National Geodetic Survey
NIMA	National Imagery and Mapping Agency (formerly Defense Mapping Agency), USA
NKG	Nordic Geodetic Commission
NLS	National Land Survey of Sweden
NOAA	National Oceanic and Atmospheric Administration, USA
NRCan	Natural Resources Canada
NUVEL-NNR	Northwestern University velocity model, no net rotation
OCA	Observatoire de la Côte d'Azur
OLG	Observatory Lustbühel Graz, Austria

PAD	Packet Assembler–Disassembler
PGC	Pacific Geoscience Centre, Canada
PM	polar motion
PRN	pseudo random number
PSTN	Public Switched Telephone Network
RDC	Regional Data Center
RIGTC	Research Institute of Geodesy, Topography, and Cartography
RINEX	Receiver-Independent Exchange format
rms	root mean square
RNAAC	Regional Network Associate Analysis Center
ROB	Royal Observatory of Belgium
SA	Selective Availability
SCIGN	Southern California Integrated GPS Network, USA
SGGS	Satellite Geodesy and Geodynamics Systems Group, JPL, USA
SINEX	Software-Independent Exchange format
SIO	Scripps Institution of Oceanography, USA
SIP	SIO predicted (orbit)
SIR	see SIRGAS
SIRGAS	Sistema de Referencia Geocéntrico para América del Sur (South American Geocentric Reference System)
SLR	satellite laser ranging
SSC	Sets of Station Coordinates
TCP/IP	Transmission Control Protocol/Internet Protocol
TDAF	Tracking and Data Analysis Facility
TEC	total electron content
UNAVCO	University NAVSTAR Consortium, USA
UPAD	University of Padova
UPS	uninterruptible power supply
USGS	U.S. Geological Survey
USNO	United States Naval Observatory
UST	University of Science and Technology, Ghana
VLBI	very long baseline radio interferometry
WETT	IGS permanent station in Wettzell, Germany
WGTN	planned IGS station in New Zealand
WRMS	weighted root mean square
WUT	Warsaw University of Technology, Poland
WWW	World Wide Web
YSI	Yellow Springs Instruments, USA

International GPS Service for Geodynamics

Association Internationale de Géodésie

Union Géodésique et Géophysique Internationale

International Association of Geodesy

International Union of Geodesy and Geophysics

The Federation of Astronomical and Geophysical Data Analysis Services

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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