IGS

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SERVICE

2000 TECHNICAL REPORTS

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 and engineering activities. Contributions from the IGS Governing Board and Central Bureau, analysis and data centers, station operators, and others constitute the 2000 Technical Reports. This report has a companion publication, the 2000 Annual Report. Hard copies of each volume can be obtained by contacting the IGS Central Bureau at the Jet Propulsion Laboratory. Electronic versions can be viewed at http://igscb.jpl.nasa.gov/overview/pubs.html.

Preface

This volume documents the technical progress of the International GPS Service in the year 2000. While the detail in this report is generally compiled for the benefit and interest of the internal IGS participants, more often recently, universities, libraries and other organizations request copies of the documentation for reference purposes. Attempts are made by the editors to obtain submissions from the many contributors to the IGS – Analysis Centers, Data Centers, IGS Coordinators (for Analysis, Network and Reference Frame), Network Operators, Projects, Working Groups, and status reports from the Governing Board and the Central Bureau. A companion volume is the 2000 Annual Report which serves as the executive summary of key annual activities for this unique organization.

The year 2000 saw many new technical developments in the IGS, notably the establishment of two new projects, the Low Earth Orbiter Pilot Project and the International GLONASS Pilot Project. During the latter half of the year, the IGS Governing Board was engaged in a strategic planning effort resulting in a renewed mission statement and identified goals and objectives for the period 2002-2007. The final plan document will be available by early 2002.

The Analysis Center Coordinator, Tim Springer at the University of Bern in Switzerland, departed for a new position with very fond farewells from long-time IGS colleagues, The University of Bern succeeded in seamlessly reassigning responsibility for this vital role, and continues to produce the combined IGS products, orbits, clocks, station position and velocities under the leadership of Robert Weber. The IGS through its Analysis Centers collectively produces the most precise GPS orbit products available anywhere. The IGS Network continued to grow, not just in number of stations and affiliated regional arrays, but in functionality as stations become identified as meeting requirements necessary for one or more of the IGS projects. Data Centers are a critical link in the smooth processing of the IGS, and find themselves responding to an increasing user base with decreasing latencies as many groups and applications push towards real-time availability of data and products. The IGS as an organization continues to leverage the resources of over 200 contributing organizations and fosters the evolution of many GPS applications through projects and working groups.

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EXECUTIVE REPORTS

IGS Governing Board in 2000

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Introduction

Over the past year, the IGS again experienced great success in many areas. The IGS continues to thrive as new applications emerge and fundamental IGS systems and processes continually improve. This vitality is due to the concerted effort of each of our contributing organizations and individuals. On behalf of the Governing Board, I would like to sincerely thank each contributor.

The year 2000 was also a new experience for the Board, beginning with important changes in membership. December 1999 saw the departure of Ivan Mueller, Bill Melbourne, Jan Kouba, and Yehuda Bock. Each of these individuals had been members of the Board since the inception of the IGS and their collective talents greatly helped to shape the organization.

The main activities this past year addressed by the Governing Board include the development of a strategic plan for the IGS for the coming years and a focus on IGS working group activities.

IGS Strategic Planning Summary

With the tremendous growth of IGS and an increase in demanding applications, the Board appointed a planning committee in June to coordinate a strategic planning process for the IGS. The IGS is mature and diverse enough to warrant a close look at the organization's focus over the next five years, how to achieve the key goals and objectives that are identified, and how best to continue the success and benefits accomplished to date. The Governing Board is committed to completing the IGS strategic plan in 2001.

The planning group approved by the Board includes:

- Norman Beck, Natural Resources Canada
- Gerhard Beutler, University of Bern, Switzerland
- John Manning, Australian Survey and Land Information Group
- Bill Melbourne, Jet Propulsion Laboratory, California Institute of Technology
- Angelyn Moore, IGS Central Bureau, Jet
  Propulsion Laboratory, California Institute of Technology
- Ivan Mueller, Professor Emeritus, Ohio State University

- Ruth Neilan, IGS Central Bureau, Jet Propulsion Laboratory, California Institute of Technology
- Jim Ray, United States Naval Observatory
- Christoph Reigber, GeoForschungsZentrum Potsdam
- Robert Serafin, National Center for Atmospheric Research

The Central Bureau retained an excellent planning consultant, Haig Bazoian, to facilitate the strategic planning process.

The planning committee was involved in preparation of materials with Bazoian throughout the summer of 2000, and met as a smaller group at Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt during early September. This initial meeting was a two-day session aimed at preparing material for a retreat with the entire Governing Board in December. The main points discussed were the strengths and challenges of the IGS, the three most important strategies that should be adopted, the IGS mission, and long-term objectives. This preliminary material was distributed to the Governing Board in October. Additional input was solicited from each Board member and we met as a large group in Napa Valley, California, on 12–13 December, just prior to the AGU. Additional invitees to this meeting were Werner Gurtner (Astronomical Institute, University of Bern/AIUB), Gordon Johnston (RACAL), David Simpson (Incorporated Research Institutions for Seismology/IRIS), and Pascal Willis (Institut Géographique National/IGN).

This was a very good meeting with refinement of the strategies and identification of actions that need to be taken over the next few years. The next steps are to complete the meeting summary and develop the draft document of the strategic plan by March. The Governing Board plans its next meeting in conjunction with the European Geophysical Society (EGS) in Nice, France, on 25 March 2001. The document will be reviewed and the IGS hopes to make a future presentation to the International Association of Geodesy (IAG) Executive Committee and gain approval of the plan.

The strategic plan discussions resulted in a broadening of the stated missions of the IGS specifying our “long-term commitment to provide the highest quality global navigation satellite systems data and products,” reflecting IGS inclusion of GLONASS and future global navigation satellite systems (GNSS) such as Galileo into the IGS GPS infrastructures.

Much discussion centered on consideration of the establishment of the IGS as an “official” or legal international entity, the benefits of such action, and how this could improve the ability of the IGS to conduct its tasks. Recommitment to IGS participation is envisioned and strategies for stabilizing and acquiring agency sponsorships will be explored.

Two key strategies identified by the Board include that the IGS affirms to continuously provide users with the highest quality, reliable data and products in a readily accessible manner and to achieve worldwide acceptance of IGS products as the “world standard” for data and products — the provider of choice.

These two strategies address the vital interest in keeping the IGS on the leading edge of this technology and encouraging broader recognition and use of IGS data products. This is especially important with regards to the global reference systems and the utility of GPS and GLONASS to provide access to the international terrestrial reference frame. Of course, many other issues and considerations were addressed in addition to these topics. The detailed plan will be will be made available in the next few months.

IGS Governing Board Business Meeting Summary

On 14 December, following the two days of strategy meetings, the Governing Board met for its 15th official meeting. The agenda began with a wrap-up of the two-day strategy session, defining the schedule for completing the documents as described above.

A pivotal event this past year was the decision by Tim Springer to resign his position as Analysis Center Coordinator. Tim was able to attend the Governing Board meeting and provided an excellent report on the state of IGS products. He was presented with the IGS certificate of appreciation, noting his long involvement and commitment to the IGS since pre-IGS days. The IGS is most fortunate that Prof. Beutler and his staff at the University of Bern were able to provide an excellent candidate as Tim’s replacement, Prof. Robert Weber. The Analysis Center representatives and the Governing Board unanimously accepted Robert. This demonstrates Bern’s remarkable commitment to complete the next two years of the Analysis Center Coordinator term. Many thanks again to AIUB for this perfect solution. Robert, in his new position, was also welcomed to the Governing Board and will represent the IGS on analysis issues. Tim was congratulated on his new position with wishes for success being expressed by the Board.

The issue concerning data centers for the IGS was also discussed at length, while noting the increased pressure on the data flow and access as a result of IGS sub-daily “ultra” products and moving closer to real-time processes. It was agreed that a solution must be found to ensure redundant capabilities and provide more efficient and timely access by the Analysis Centers to network data. Carey Noll agreed to work with the Analysis Center Coordinator and the Central Bureau to redefine data center requirements and processes. The IGS components and the Governing Board will review this in 2001 in anticipation of acquiring additional data centers and realizing enhancements at our existing data centers.

The remainder of the time was devoted to the IGS working groups and pilot projects. The current projects of the IGS are:

- IGS/BIPM Precise Time and Frequency Project — Jim Ray, U.S. Naval Observatory and Felicitas Arias, Bureau International des Poids et Mesures, Co-Chairs
- LEO Pilot Project — Mike Watkins, Jet Propulsion Laboratory, Chair

- Ionosphere Working Group — Joachim Feltens, European Space Operations Center, Chair
- Atmospheric Working Group — Gerd Gendt, GeoForschungsZentrum, Chair
- Reference Frame Working Group — Remi Ferland, Natural Resources Canada, Chair
- International GLONASS Service Pilot Project (IGLOS PP) — Jim Slater, National Imagery and Mapping Agency, Chair

According to IGS policy, each working group must be reviewed every two years to determine its status and continuance or dissolution of the activity. The IGS/BIPM timing project had been extended through 2001 previously, and the IGLOS-PP was approved at the June meeting of the Governing Board. All groups provided an update and it was decided to continue the working groups, with additional technical and organizational details to be considered at the next Board meetings. Reports on the progress of these groups are contained in the IGS Annual Report and in the Technical Reports. Progress is described generally in the IGS Report series or details may be obtained via the IGS website (*http://igscb.jpl.nasa.gov*). The organizational meeting of the IGS LEO Project will take place on 6–8 February at GFZ Potsdam; for more information, visit *http://op.gfz-potsdam.de/D1/LEOW/LEOW_index.html*.

The Central Bureau noted that, due to budgetary challenges, the finalization of the 1999 report series had been delayed since midsummer, but should be completed very soon, with electronic versions becoming available first.

Mike Bevis and I discussed the formalization of a working group on sea-level monitoring with continuous GPS measurements at tide gauges and tide gauge benchmarks. This has been a "seed" initiative of the IGS since the joint Permanent Service for Mean Sea Level (PSMSL)/IGS "Workshop on Methods for Monitoring Sea Level" in 1997 (see the proceedings, subtitled GPS and Tide Gauge Benchmark Monitoring and GPS Altimeter Calibration, in the "Publications" section at the IGS website). A proposal will be prepared for the next meeting of the IGS Governing Board. Mike is the responsible chair for the International Association for the Physical Sciences of the Ocean (IAPSO) Commission on Mean Sea Level and Tides and has established a website to further discussion of this activity at *http://www.soest.hawaii.edu/cgps_tg*. The Sea Level Change Project (SEAL), carried out by a number of German research institutions — GeoForshungsZentrum Potsdam (GFZ), GKSS Research Center Geesthacht (GKSS), and Alfred Wegener Institute for Polar and Marine Research (AWI). The project will put a concerted effort into GPS monitoring of global tide gauges. An introduction to the complete program can be found at *http://op.gfz-potsdam.de/seal/*. Additional recommendations at the meeting were to form two additional committees, reinstate the Infrastructure Committee, and create a new IGS Real Time Working Group.

The next meeting of the Governing Board is scheduled for 25 March 2001 in Nice, France, during the 26th General Assembly of the EGS.

One further note — it was decided to plan the next IGS workshop based on a theme as opposed to having separate analysis and network workshops. This is tentatively planned for early in 2002. Proceedings from the Network workshop in Oslo in July 2000 and the Analysis Center workshop at U.S. Naval Observatory in September will be published and available in spring 2001. The Network Workshop proceedings will be published by Elsevier in the peer-reviewed journal publication *Physics and Chemistry of the Earth*; the Analysis Center workshop proceedings will be published by the GPS *Solutions* journal.

Important IGS-related events and influences in 1999 and 2000

1999

9–11 March	Low-Earth Orbiter Workshop, Potsdam, Germany
8–10 June	Analysis Center Workshop, La Jolla, California
July	International Union of Geodesy and Geophysics General Assembly, Birmingham, UK
27 July	12th IGS Governing Board Meeting, Birmingham, UK
August	IGS Adopts ITRF97
15 August	GPS Week Roll-over
13 December	13th IGS Governing Board Meeting

2000

January	Call for Participation in IGS Low-Earth Orbiter Project announced
2 May	Selective Availability – removed!
March	IGS Tutorials in Capetown and Hartebeesthoek, South Africa
27 April	AFREF Planning Meeting, Nice, France
June	14th Governing Board Meeting, USNO, Washington, DC
12–14 July	IGS Network Workshop, joint with COST 716: “Towards Operational Meteorology,” Oslo, Norway
15 July	Successful CHAMP launch
13–14 September	IGS Strategic Planning Committee meets in Frankfurt, Germany
19–22 September	Institute of Navigation GPS2000 Annual Meeting, Salt Lake City, Utah; IGS User Forum conducted
25–29 September	IGS Analysis Center Workshop, USNO; two days devoted to the IGS-BIPM Precise Time Transfer Project

IGS Central Bureau - Status in 2000

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Introduction

After the quiet and uneventful passage of "Y2K," the year 2000 for the Central Bureau was marked by significant outreach for the IGS organization, as described below. The IGS exhibit display and materials were completely redesigned to reflect the continuous IGS technical advancements and growth of projects. The exhibit is easily transportable and quite cost effective. The IGS tutorial, first developed in 1999 for the International Symposium on GPS (GPS99 Tsukuba) was revised, updated, and integrated into a single document available both as hardcopy and via the IGS website. The tutorial is an important tool for promoting the straightforward use of IGS data and products and outlines the IGS conventions as the accepted international standard.

A key task of the Central Bureau was the support for the organization of the IGS strategic planning committee, as addressed by Christoph Reigber in this Annual Report. The Central Bureau worked to prepare materials with the very experienced facilitator, Haig Bazoian, to organize interim documents, as well as managing the logistics for the various meetings of the planning groups and the Governing Board throughout the year. One of the factors resulting from the planning process is a critical consideration of the organization, staffing, and resources of the Central Bureau, and how this should be structured to properly support the IGS in the future. Resource issues of the Central Bureau delayed the publications of the 1999 and 2000 report series; however, the issues have largely been resolved at present and these important annual records should resume normal preparation and publication schedules.

The Central Bureau was very much involved in the preparation of the Call for Participation in the Low-Earth Orbiter (LEO) Pilot Project, as described in the reports by Christoph Reigber and Mike Watkins (this Annual Report). This is an IGS project with appropriate structure involving every component of the IGS (station, data centers, analysis centers, etc.). This activity is expected to have a significant effect on the IGS and to bring substantial enhancements technically and in terms of broadening partnerships.

IGS Outreach and Tutorial

The new IGS booth was first displayed in March 2000 at Capetown, South Africa, at the 28th International Symposium on Remote Sensing of the Environment entitled "Information for Sustainable Development." The IGS sponsored a tutorial during the venue of this symposium hosted by Richard Wonnacott, Director of Survey Services, Chief Directorate of Surveys and Mapping, and Prof. Charles Merry, University of Capetown. The following week, the tutorial was again offered outside of Johannesburg at the Hartebeesthoek Radio Astronomy Observatory (HARTRAO) hosted by Ludwig Combrinck. HARTRAO is recognized as a fundamental station for geodetic positioning, where a number of techniques are collocated: very long baseline interferometry (VLBI), Global Positioning System (GPS), satellite laser ranging (SLR), and precise range and range-rate experiment (PRARE). The tutorial was well received in both locations and there was valuable feedback from attendees for making the IGS products more accessible to the user community. The IGS tutorial and product details were updated after the removal of selective availability on 2 May .

Expanding Partnership of IGS

The Chinese Seismological Bureau (CSB) is the designated project head for the Crustal Motion Observation Network of China (CMONOC), a newly implemented state-of-the-art national GPS network collocated with their existing seismic network. The CMONOC sent a letter to the Governing Board outlining their intention to participate in the IGS. The Governing Board responded very favorably to this with hopes to develop significant collaboration with CMONOC and its contributing organizations, while pursuing an open data policy as advocated by IGS values. Discussions with the CSB took place in China during January, where the U.S. National Science Foundation coordinators delegation negotiated the renewal of the 20-year U.S.–China protocol agreement on earthquake science research.

AFREF

A meeting on developing and implementing an African Reference System (AFREF), was held in Nice, France, organized by Claude Boucher as head of the International Association of Geodesy (IAG) Commission X devoted to Global and Regional Geodetic Networks. About 13 people attended, including representatives from and United Nations Food and Agricultural Organization (UN–FAO), the IGS Central Bureau, the Norwegian Mapping Authority, the European Reference Frame (EUREF), Sistema de Referencia Geocéntrico para América del Sur (SIRGAS), and the U.S. National Imagery and Mapping Agency. Lamentably, none present were African due to the ad hoc nature of the meeting. A meeting is expected to occur in Africa to encourage broad-based African participation in generating a project plan and structure. An e-mail list service was subsequently established by the Central Bureau to facilitate contacts between IAG, IGS, Africans, and people from the global community interested in such an activity. The IGS and International Earth Rotation Service (IERS), as IAG services and with IAG endorsement, have pledged strong support. It was noted that GPS is a truly viable and sustainable technology that can be adopted by the African organizations and maintained in the future for continental and national infrastructures. The Central Bureau has been invited to the Congress on South African Surveyors Meeting (CONSAS) to be held in March 2001 in Capetown where an AFREF planning meeting will be conducted. A regional realization based on IGS conventions may be the more practical approach given the numerous nations within Africa and the extensive infrastructure of the IGS. A previous activity known as ADOS (African Doppler Survey) was initiated in 1981 and based on the TRANSIT satellite system. This was organized within the IAG International Coordination of Space Techniques of Geodesy and Geodynamics (CSTG), in cooperation with the IAG Commission for Geodesy in Africa.

International Geodynamics Research Center in Kyrgyz Republic

In June 2000, a dedication of the International Research Center–Geodynamic Proving Ground (IRC-GPG), took place in Bishkek, Kyrgyz Republic, followed by a four-day workshop on the geodynamics of the Tien Shan. This occasion was to dedicate new facilities collocated with the scientific station research facility of the Institute of High Temperatures, Russian Academy of Sciences (IVTAN). It was well attended by the international science community. The purpose of the new center is to facilitate not only regional but international collaborative research in geodynamics. Since 1992, a GPS network has been established through collaborations with Indiana University and Massachusetts Institute of Technology, consisting of more than 300 stations in the region and an impressive nine-station permanent GPS network. Two of these stations are recognized as global stations of the IGS and therefore of great importance for analysis and global network stability. One of these is located at IRC-GPG and known as the Poligan GPS station, and one is at Selezaschita, Almaty, Kazakhstan. A subsequent geological field trip included exploring various locations, some measured by GPS, revealing the intriguing geology and spectacular beauty of the Tien Shan region. The facility was the vision of Yuri Trapeznikov, former director of the IVTAN scientific station. The IRC-GPG was presented an IGS certificate of appreciation for outstanding contributions. For more information on this center and its activities see *http://tiger.gdirc.ru/irc/* or *http://helios.gdirc.ru/*.

Workshops

Network Workshop

The second major IGS Network Workshop was hosted by the Norwegian Mapping Authority, 10–14 July 2000 in Oslo, Norway. The purpose of this workshop was to focus on aspects of the network targeted at improving the infrastructure and network operations in support of the quality and timeliness of IGS products. Angelyn Moore, IGS Network Coordinator and Deputy Director of the IGS Central Bureau at the Jet Propulsion Laboratory in Pasadena, California, convened this workshop, which was considered a great success by all who attended. The local organization and logistics were excellently managed by the Norwegian Mapping Authority's Hans-Peter Plag, within the Geodesy Division under the direction of Bjorn Engen, a member of the IGS Governing Board. The workshop was held at the beautiful Soria Moria Hotel on a hill overlooking Oslo and provided a unique atmosphere enjoyed by all, which will be long remembered.

This was the first occasion that the IGS Network Workshop was convened as a multidisciplinary meeting. It was co-organized with "COST Action 716"– "European Cooperation in the Field of Scientific and Technical Research." Action 716 is

"Exploitation of Ground-Based GPS For Climate and Numerical Weather Prediction Applications." COST is a framework for scientific and technical cooperation, allowing the coordination of national research on a European level. The main objective of COST 716 is assessment on an international scale of the operational potential for exploiting ground-based GPS networks to provide near real-time observations for numerical weather prediction and climate applications. In parallel, the IGS has a dedicated Tropospheric Working Group estimating total zenith path delays (ZPD) and precipitable water vapor (PWV) at a number of the IGS stations (see Gerd Gendt's report in this Annual Report). Also, a number of the IGS agencies and their networks have either implemented or are moving towards real-time processing activities, many pursuing similar applications in terms of ground-based meteorology.

The Network workshop proceedings were published in the peer reviewed journal publication *Physics and Chemistry of the Earth* by Elsevier.

Analysis Center Workshop and IGS/BIPM Precise Time and Frequency Project

The IGS Analysis Center Workshop 2000 was held in September at the U.S. Naval Observatory, where Jim Ray and his USNO Earth Orientation Department colleagues did an outstanding job in organizing and hosting this superb workshop. This was a very good occasion for many interesting presentations and fruitful discussions. The first two days were devoted to the IGS/BIPM Timing Project (see Jim Ray's account in this Annual Report). The remaining days focused on IGS near-real-time products and their applications, and the potential interactions between the IGS and various Global Navigation Satellite Systems (GNSS, e.g., GPS, Galileo, GLONASS). A subset of the presented papers has been published as a special issue of the journal *GPS Solutions*.

The next IGS workshop will be based on the theme "Towards Real-Time" and will be hosted by the Natural Resources Canada Geodetic Division. This will be a comprehensive IGS workshop addressing all components, projects, and working groups. It is planned for early 2002.

IGS

ANALYSIS CENTER REPORTS

2000 Analysis Coordinator Report

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Introduction

Similar to the year before this report complements the Analysis Activities Report given in the IGS Annual Report 2000 (Weber, Springer, 2001). A summary of the most important changes and topics of the IGS Analysis Activities in 2000 will be presented, complemented by a huge number of figures focusing on the combination statistics of orbits, clocks and ERPs. Most of this figures are freely accessible and can be retrieved from the IGS ACC web-page at http://www.aiub.unibe.ch/acc.html.

Current IGS and AC product quality

The primary objective of the IGS is to provide a Reference System for a wide variety of GPS applications. To fulfil this role the IGS produces a large number of different combined products which constitute the practical realization of the IGS Reference System. Table 1 gives a brief overview of the estimated quality of these different IGS Reference Frame products at the beginning of the year 2001.

Table 1: Quality of the IGS Reference Frame products as of March 2001 (for details see http://igscb.jpl.nasa.gov/components/prods.html)

Products Delay	Predicted Real Time	Ultra-Rapid Real Time	Rapid 17 hours	Final 13 days	Units
Orbit	50.0	25.0	5.0	< 5.0	cm
Clock	150.0	5.0	0.2	0.1	ns
Polar Motion	(note: delivery		0.2	0.1	mas
LOD	of IGP–products		30.0	20.0	μs/d
Stations h/v	terminated in			3.0/6.0	mm
Troposphere	March 2001)			4.0	mm ZPD

The quality improvement of the IGS products since 1994 has been demonstrated in the IGS Annual Report 2000. Figure 1 shows the weighted orbit RMS (WRMS) of the Final Analysis Centre solutions with respect to the combined IGS final orbit products in 2000. Most Analysis Centres and also the IGS rapid orbit products have reached the 3-6 centimeter orbit precision level (Table 2). Similar levels of accuracy are indicated by the IGS 7-day arc orbit analysis and by comparisons with satellite laser ranging observations of the GPS satellites PRN 5 and 6. Figure 3 is related to the IGS rapid orbit combination.

The orbit consistency is about 5-8 cm, which is a quite small number having in mind the latency of only 17 hours and subsequently the lower amount of available tracking data. The yearly averages of weighted orbit RMS values of the Rapid Analysis Centre submissions with respect to the IGS Rapid combination (IGR) are also shown in Table 2.

Table 2: Yearly average weighted orbit RMS (cm) of the Final Analysis Center orbit submissions and the IGS Rapid (IGR) orbit solution with respect to the IGS final orbits + Yearly average weighted orbit RMS (cm) of the Rapid Analysis Center submissions with respect to the IGS Rapid orbit combination.

Year	COD	EMR	ESA	GFZ	JPL	NGS	SIO	IGR
Fin 2000	3	7	6	3	3	9	5	3
Rap2000	5	14	9	6	9	12	7	--

Figures 6-20 illustrate the time series of Helmert Transformation Parameters between the individual center submissions and the combined orbits, both for the Final and the Rapid IGS orbit.

Reference Frame

The most striking change in the implementation of the reference frame was the alignment of the IGS final orbit products to the IGS reference frame realization (based on a set of about 50 stations), starting with GPS week 1051. IGS reference frame products are available in SINEX format and issued by the IGS Reference Frame Coordinator on a weekly basis. The alignment ensures product consistency but delays the calculation and distribution of the combined orbits for an additional day (13 days after end of GPS-week). Detailed information may be inferred from (Kouba, Ray and Watkins, 1998), (Ferland, 2001) or from the weekly IGS Sinex Combination Reports (e.g. Ferland, Hutchison, 2001). The IGS realization of the ITRF97 has been labelled IGS97. An update of the ITRF (ITRF2000) and subsequently for the accompanying IGS realization (IGS00) is planned for end of December 2001.

Ultra Rapid Products

In September 2000 the IGS Analysis Center workshop was held at the U.S. Naval Observatory in Washington D.C. Current progress in carrier phase time transfer and the realization of an internal IGS time scale had been identified as major goals in this meeting. Furthermore, as proposed in a position paper by G.Gendt et al. the year before, IGS products have to move towards real-time availability. Thus this workshop discussed the quality of the recently implemented Ultra-Rapid products as well as their applications, e.g. for the derivation of ground-based GPS meteorological parameters used in numerical weather prediction.

In October 1999 the first Analysis Centre (GFZ) provided the new ultra rapid products. These products, delivered every 12 hours (two times per day), will contain a 48 hour orbit arc from which 24 hours are real orbit estimates and 24 hours are orbit predictions. The latency of this product is 3 hours. The generation of a combined ‘ultra-rapid’ product (IGU) has started in March 2000 based on contributions from up-to five different Analysis Centres. This product has been made available for real-time usage, like the IGS predicted orbits (IGP), but the quality is significantly better because the average age of the predictions was reduced from 36 to 9 hours. The next months the quality and the reliability of the IGS Ultra rapid (IGU) orbits were assessed against the IGS Predicted (IGP) and the IGS Rapid (IGR) products. Figure 5 shows a consistency of the individual orbit submissions at the 25 cm level during the year 2000 and figures 21-27 deliver the related series of Helmert Transformation Parameters with respect to the IGS Rapid orbits. Currently seven different Analysis Centres deliver contributions to the ultra-rapid products.

In November 2000 the IGU products became an official IGS product and subsequently the submission of predicted orbits (IGP) could be terminated in March 2001 (Wk 1105). Figures 28a,b show the year-2000 time series of Helmert Transformation Parameters of the IGS Predicted Orbits with respect to the IGS Rapid orbits.

Clock Combination

A new station and satellite clock combination, which is based on the RINEX clock format, has been implemented in November 2000 (about Wk 1088). This combination provides the regularly combined satellite clocks in the orbit (SP3) format and it also provides both satellite and station clocks in the RINEX clock format. These clock products have a sampling rate of 5 minutes, compared to the 15 minutes in SP3. Some Analysis Centres even provide higher sampled clock products, e.g., JPL provides clocks with a sampling rate of 30 sec. The new clock combination is distinguished by the high quality of the provided clocks and it has improved the robustness of the combination process tremendously by handling clock jumps. Figures 2 (IGS final) and 4 (IGS Rapid) illustrate impressively the considerable improved consistency of the submitted AC clock solutions at the 0.1 nsec level after implementation of the new clock combination in week 1088.

Summary and Outlook

Contrary to widely expressed concerns, the increasing ionospheric activity did not really harm IGS operations in 2000. Nevertheless, the policy of phasing out an old generation of GPS-receivers at the IGS sites and their replacement by updated technology has to be pursued continuously.

Logically the goal of IGS analysis groups is to further improve accuracy and consistency of IGS products. Besides these ongoing efforts there are a few special challenges like the clarification of remaining radial orbital biases with respect to orbit determination of GPS satellites based on SLR tracking data. Another challenge is of course the complete integration of GLONASS tracking data into IGS operations and analysis.

On July 15, 2000 the ‘Challenging Minisatellite Payload for Geophysical Research and Application (CHAMP)’ has been launched. CHAMP and the number of upcoming LEO missions have the potential to fundamentally increase the demands on IGS-products as we know it today. In this context the generation of more frequent IGS products for near real-time use is an urgent need. Near real time products as well as orbit predictions are also a topic in view of the increasing number of RT surveying applications. Therefore the next IGS Analysis workshop in Ottawa is dedicated to real-time requirements and IGS real-time products.

Last but not least its my pleasure to acknowledge my predecessor Tim A.Springer, who left the position of an IGS AC Coordinator in December 2000 for his efforts and his continuous support. He was heavily involved in most of the activities described above, especially in establishing the new clock combination and in launching smoothly the Ultra Rapid Products.

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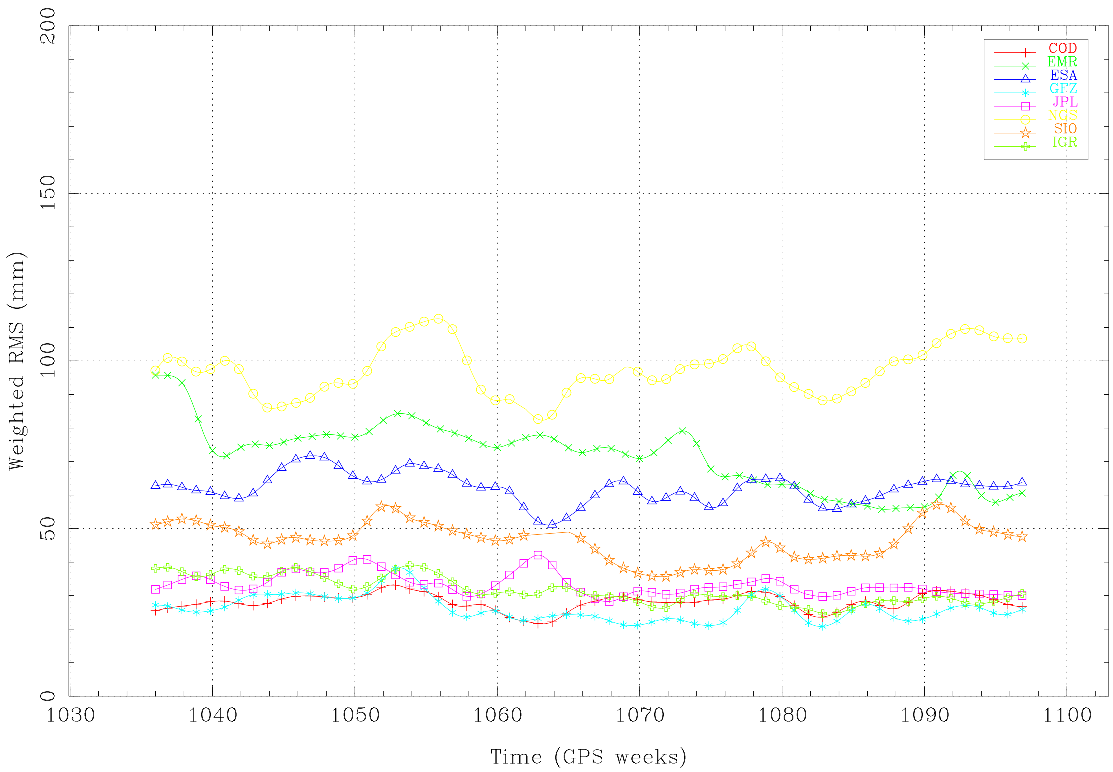


Figure 1: Weighted orbit RMS(mm) of the Final AC submission w.r.t the IGS Final combination.

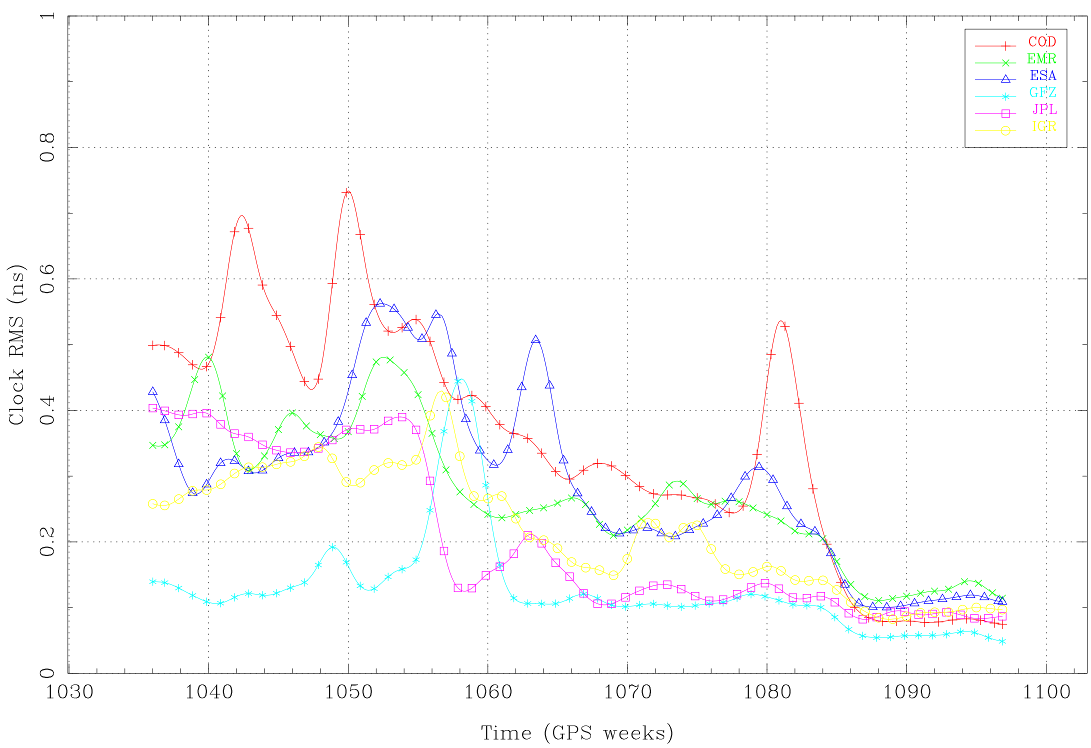


Figure 2: Weighted clock RMS(ns) of the Final AC submission w.r.t the IGS Final combination.

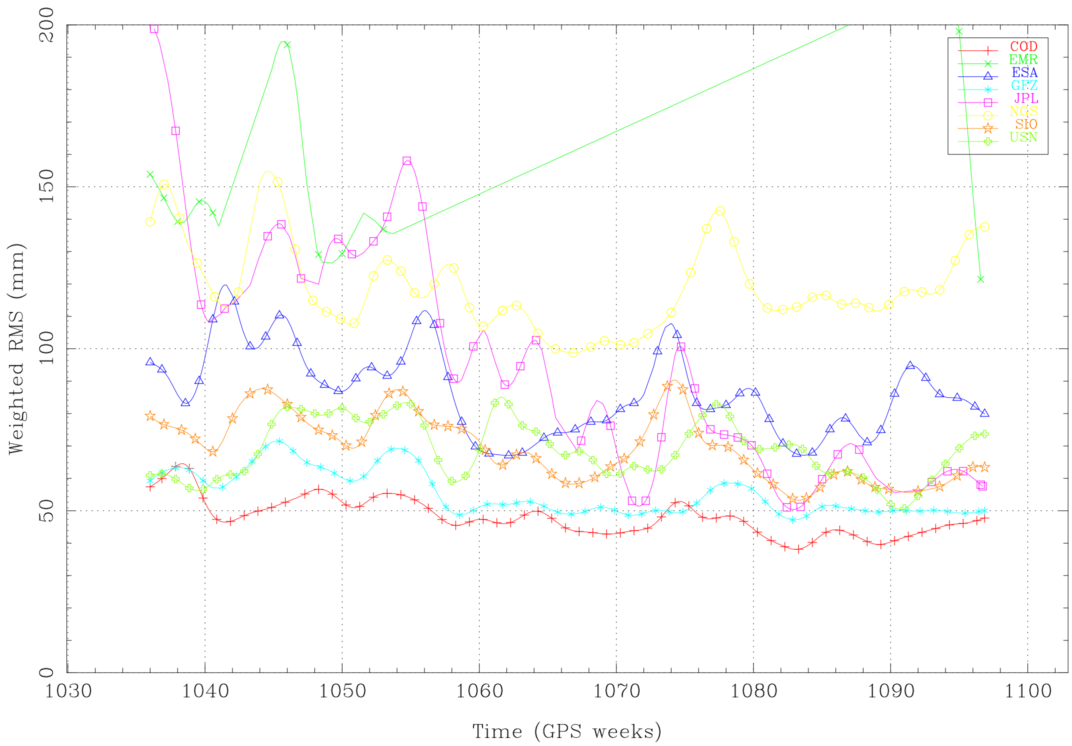


Figure 3: Weighted orbit RMS(mm) of the Rapid AC submission w.r.t the IGS Rapid combination The daily RMS values of the combination summaries were smoothed for plotting purposes, using a sliding 7 day window.

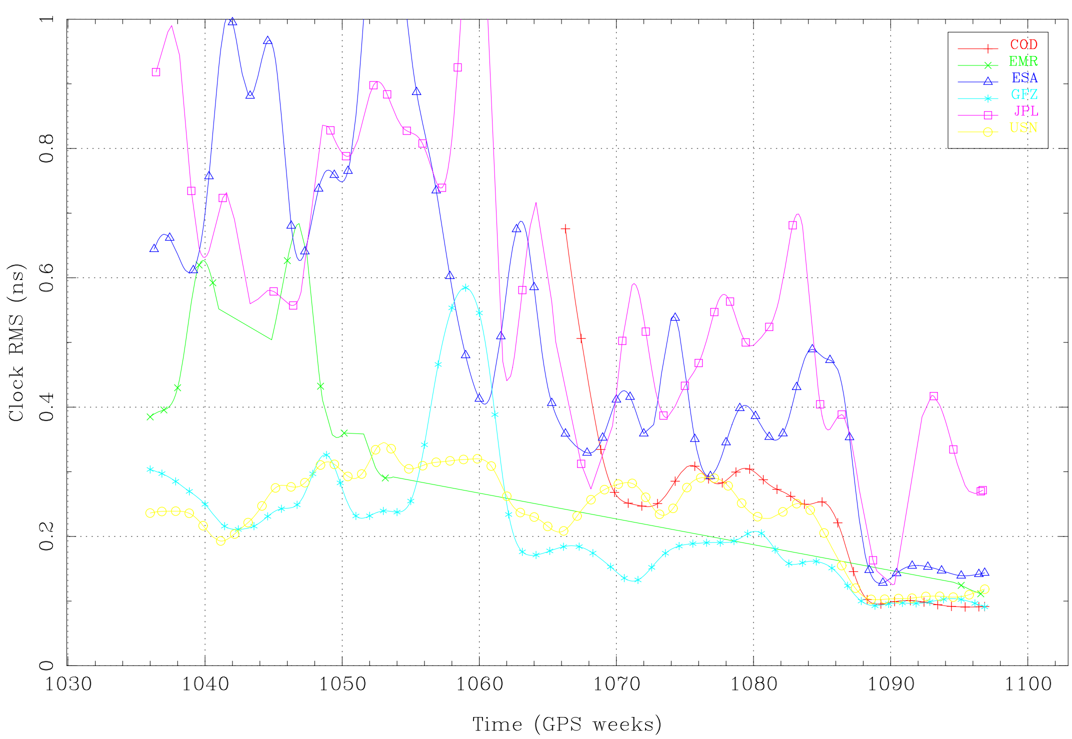


Figure 4: Weighted clock RMS(ns) of the Rapid AC submission w.r.t the IGS Rapid combination. The daily RMS values of the combination summaries were smoothed for plotting purposes, using a sliding 7 day window.

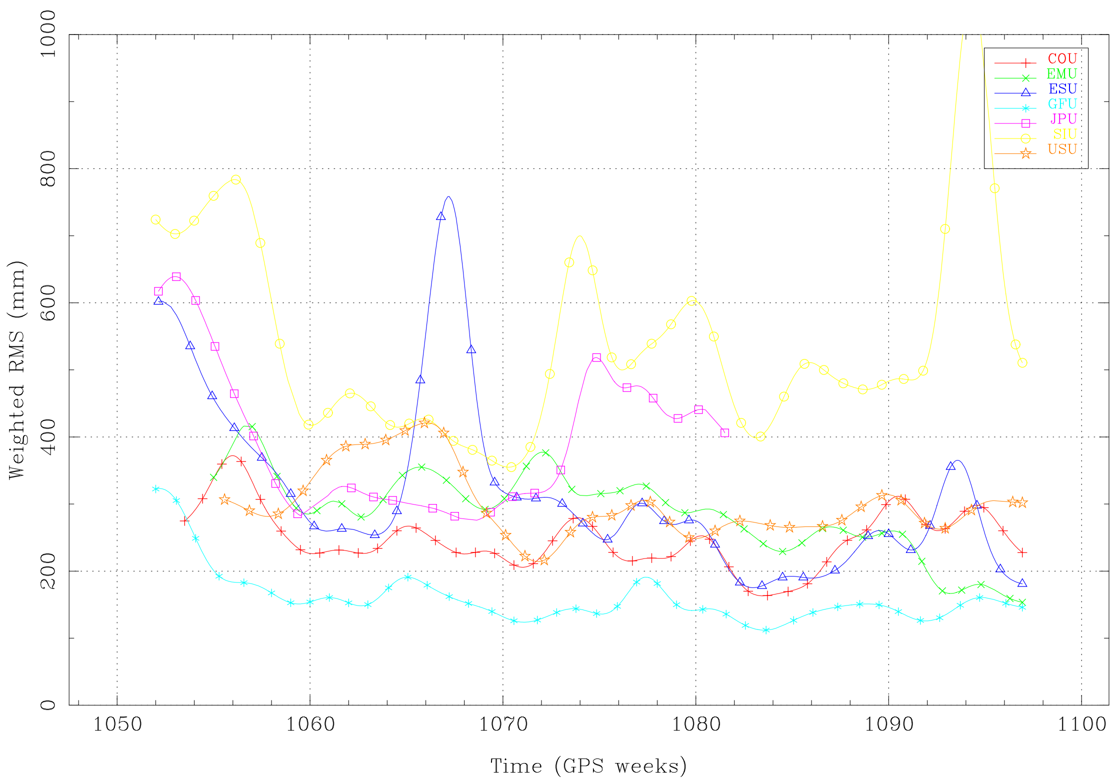
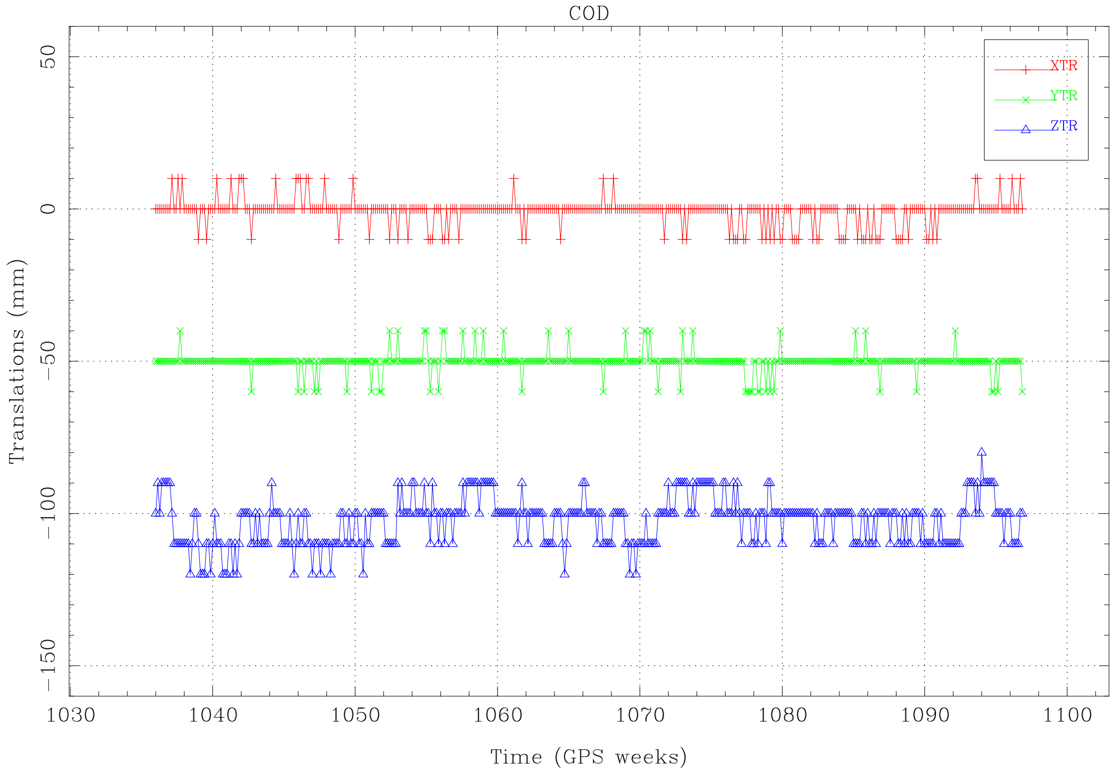
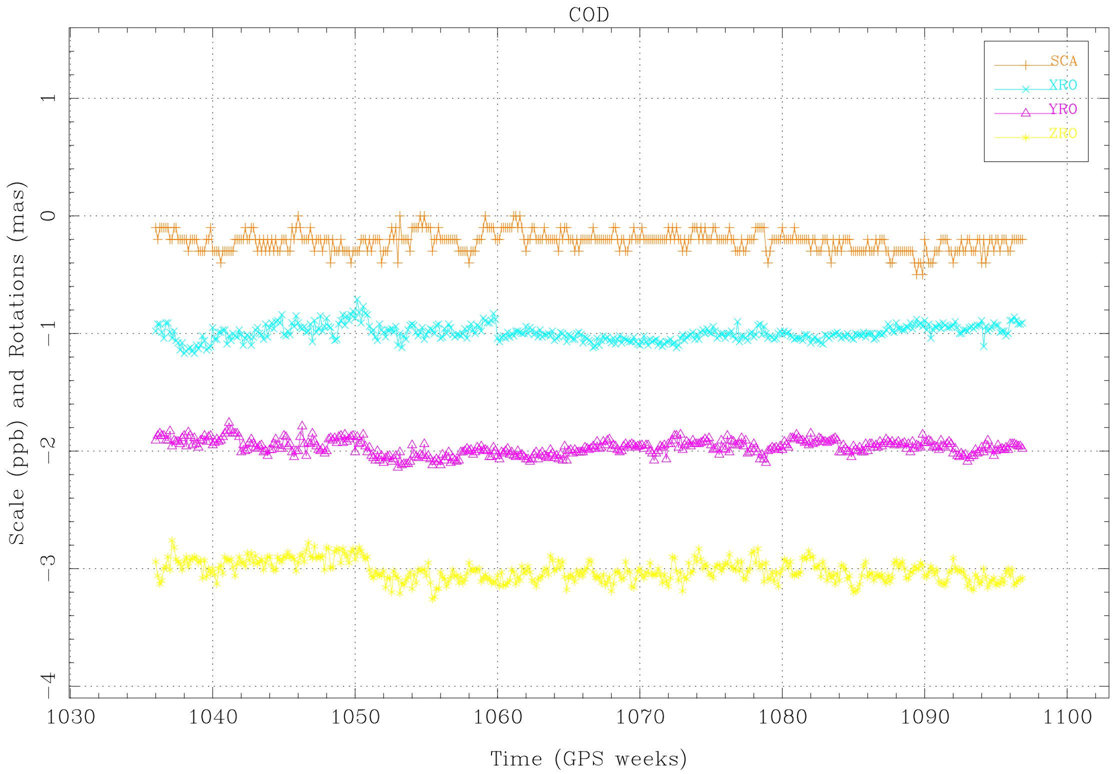
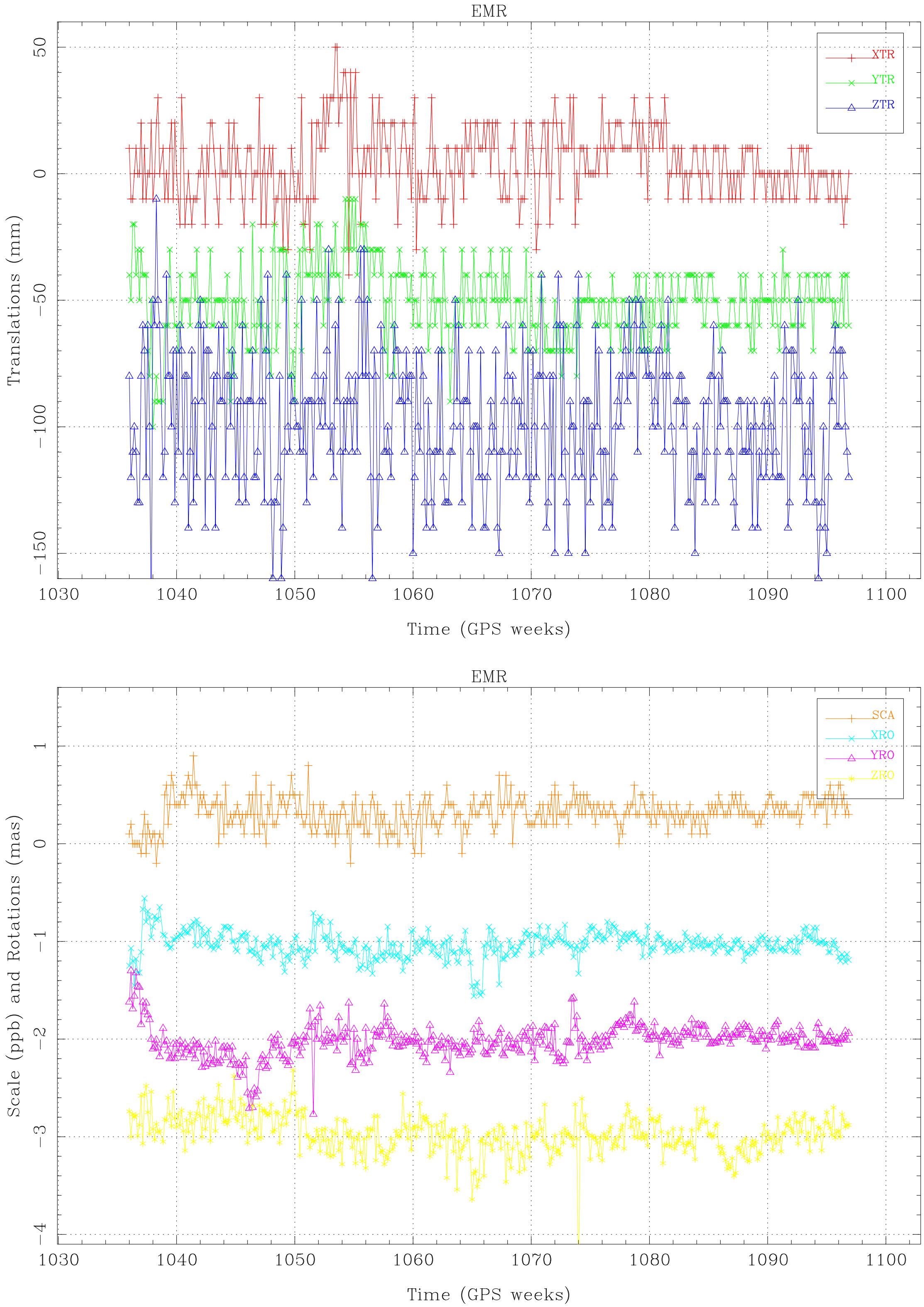


Figure 5: Weighted orbit RMS(mm) of the Ultra Rapid AC submission w.r.t the IGS Ultra-Rapid combination The RMS values of the combination summaries (twice per day) were smoothed for plotting purposes, using a sliding 7 day window.

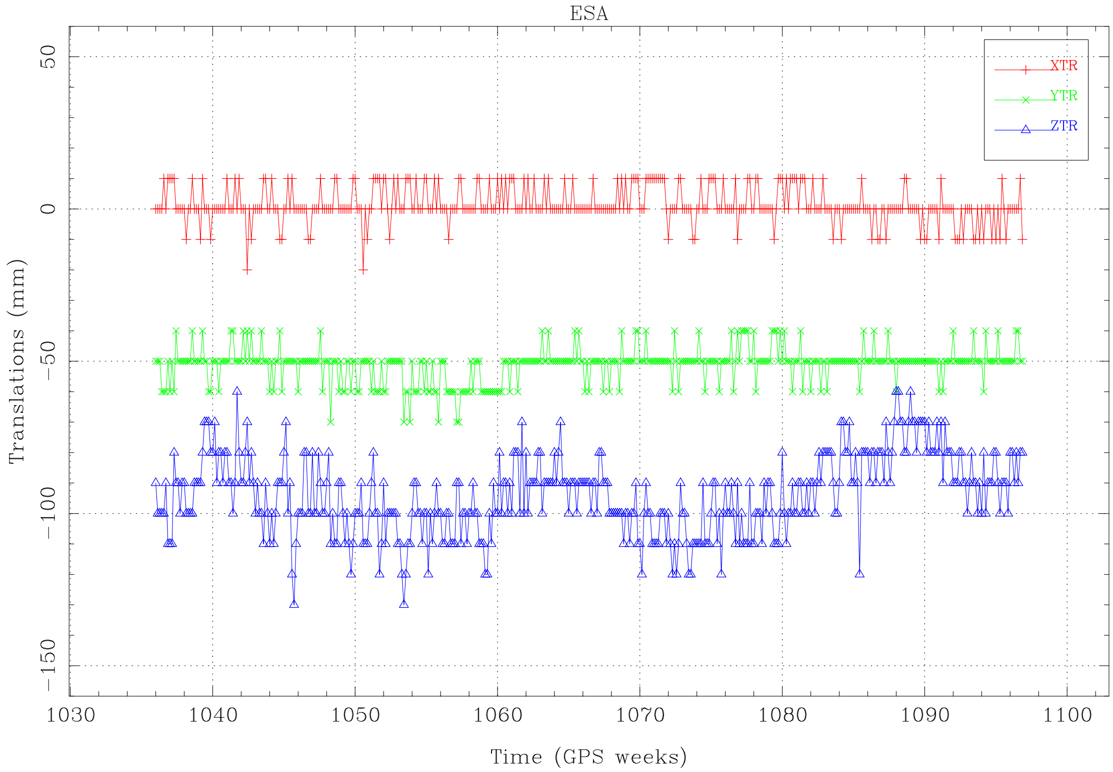


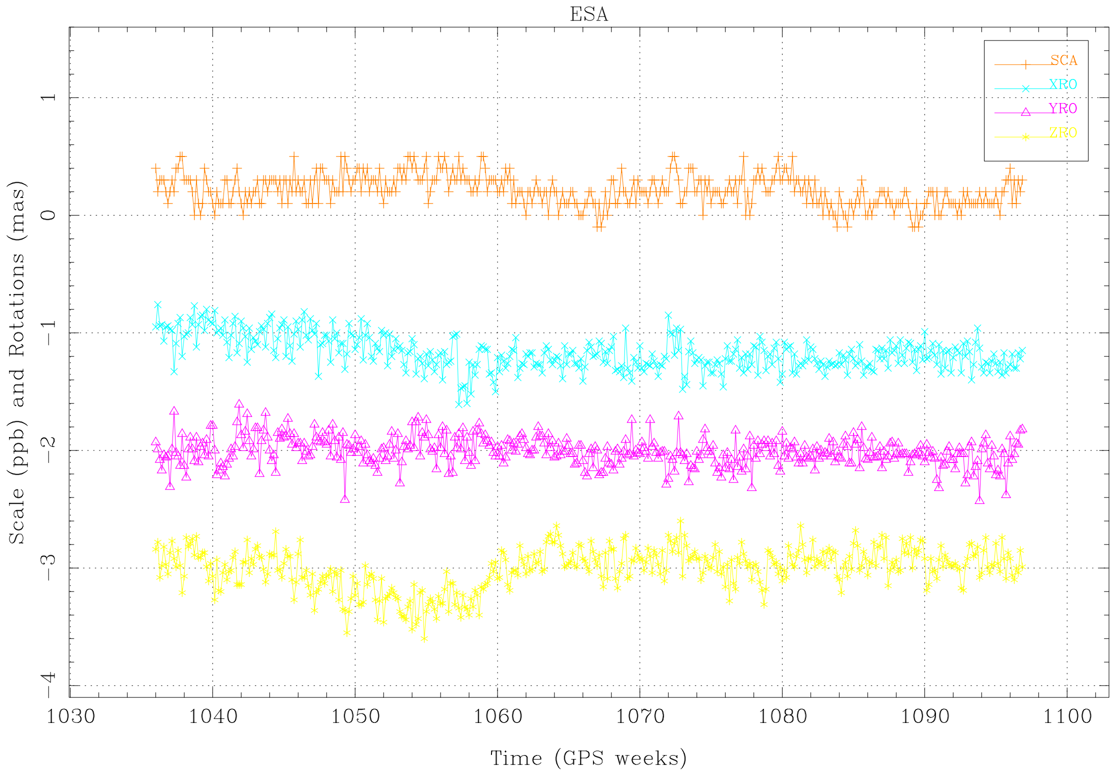


Figures 6a,b: Daily Transformation parameters of the COD Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.

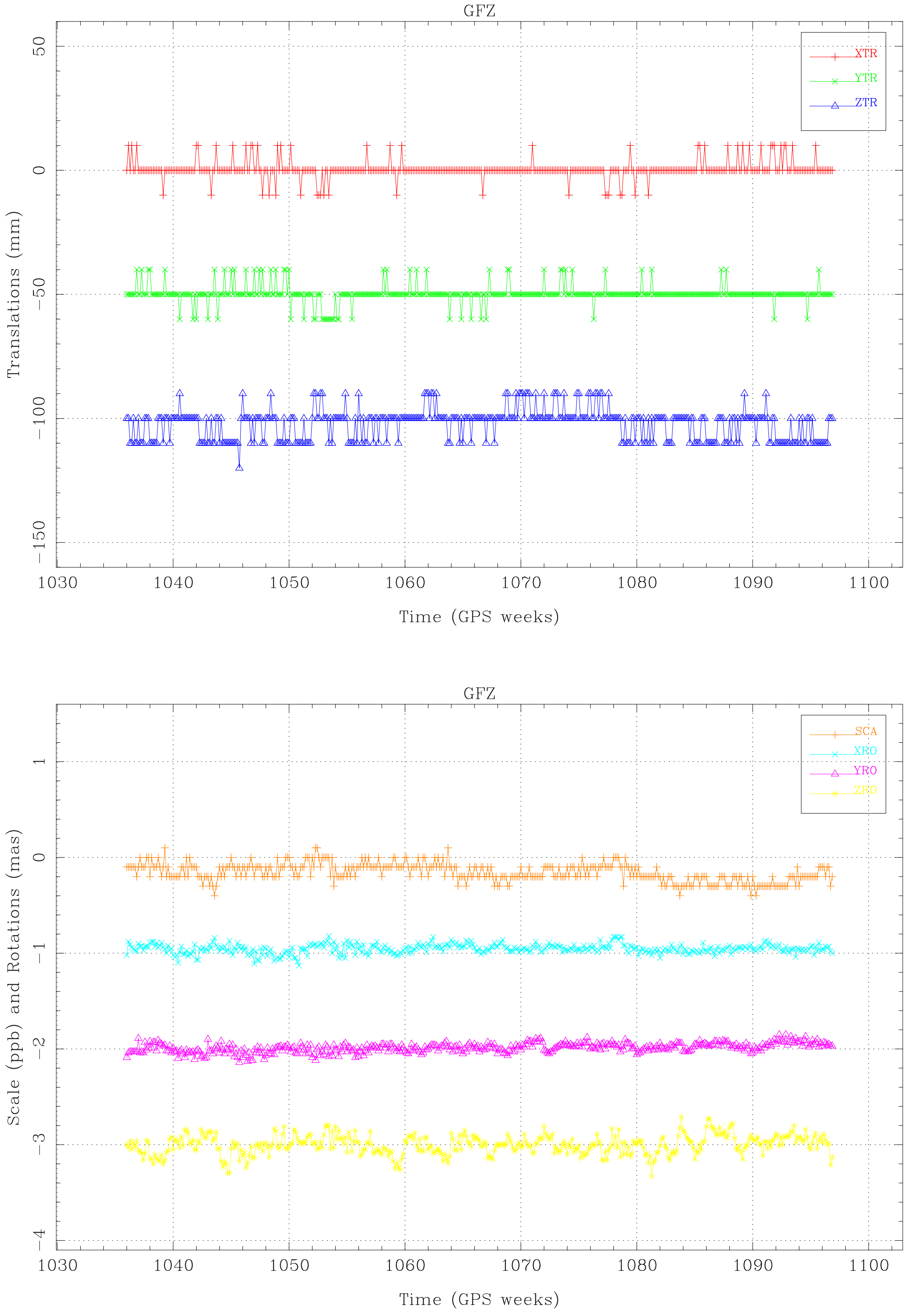


Figures 7a,b: Daily Transformation parameters of the EMR Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.

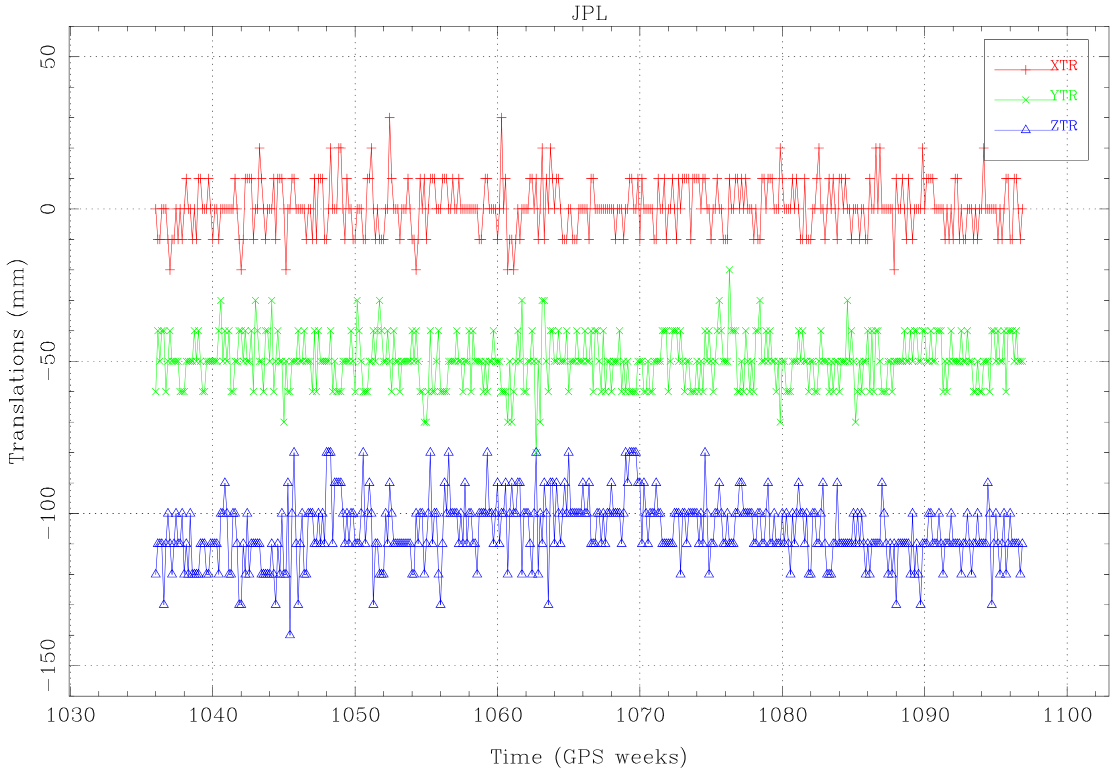


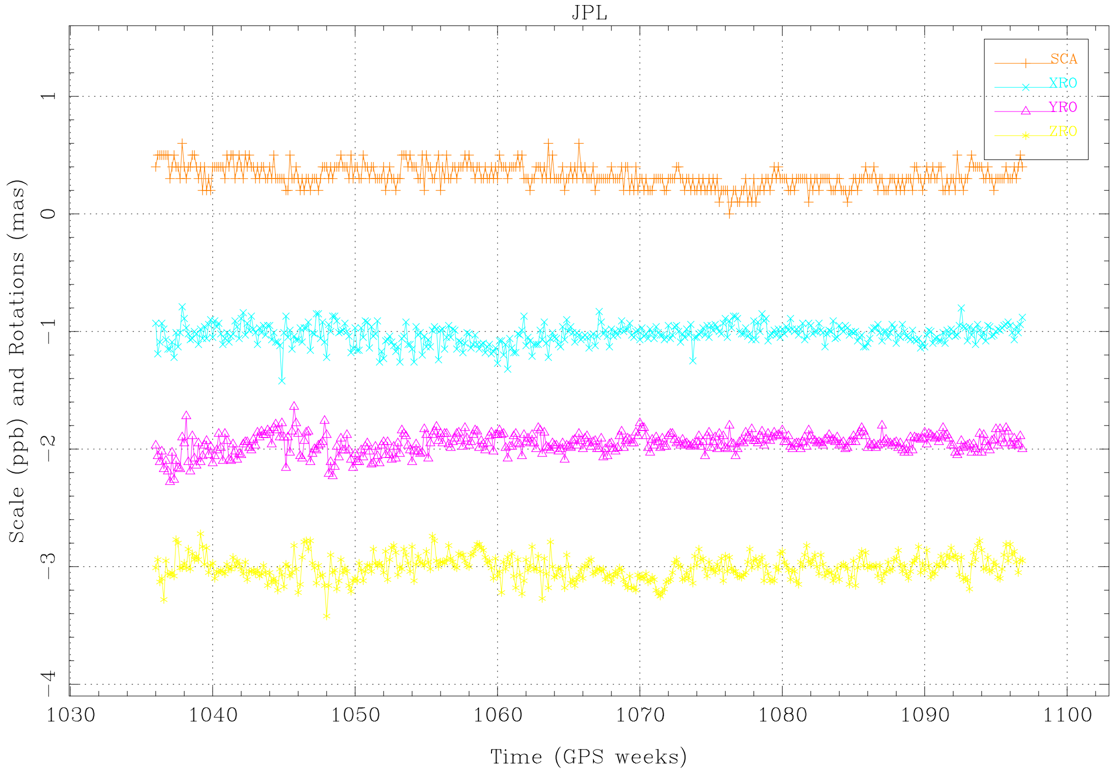


Figures 8a,b: Daily Transformation parameters of the ESA Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.

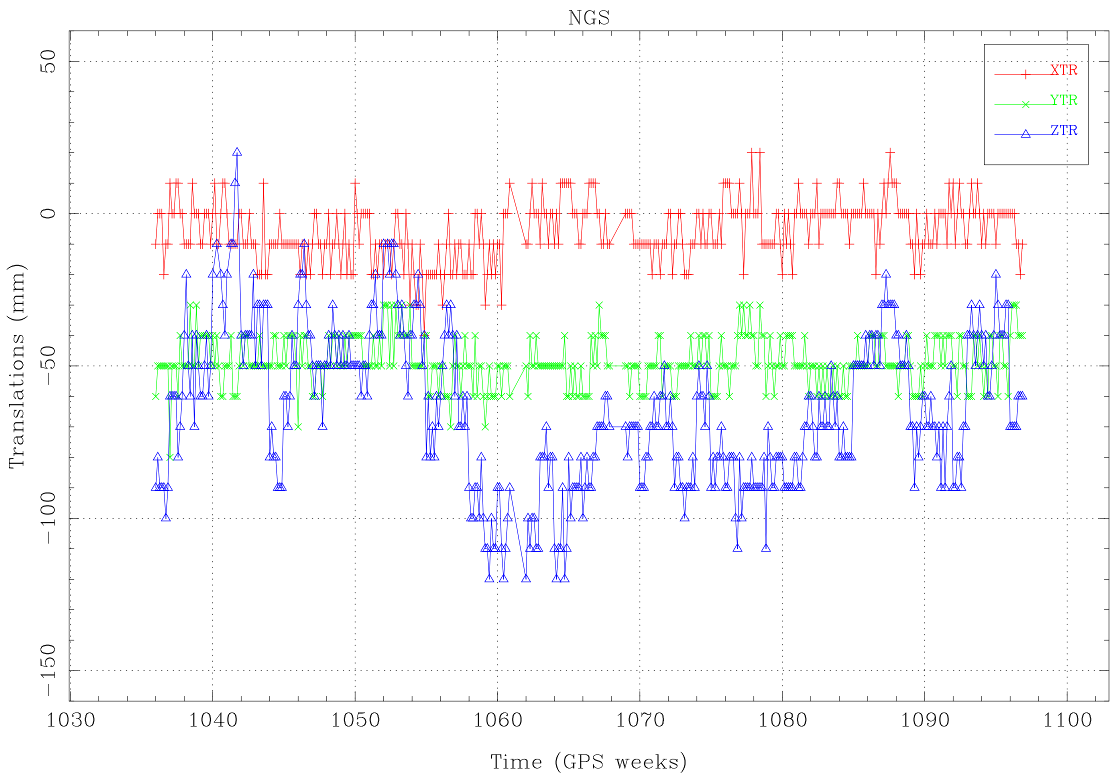


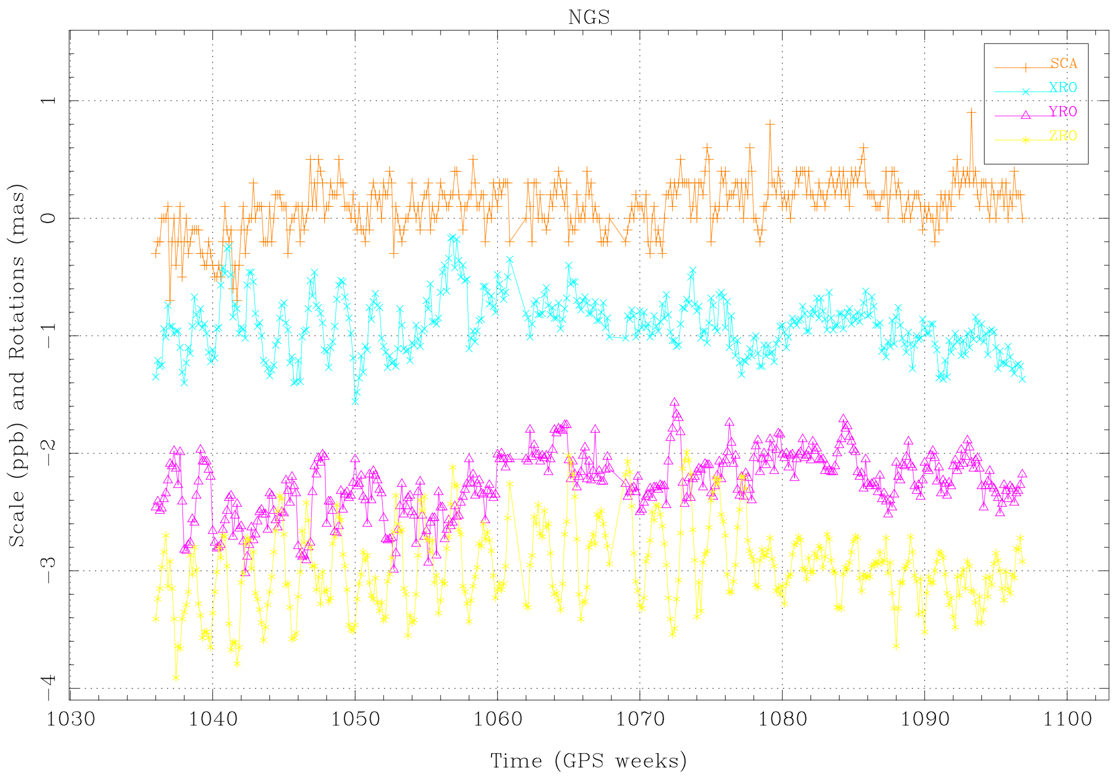
Figures 9a,b: Daily Transformation parameters of the GFZ Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



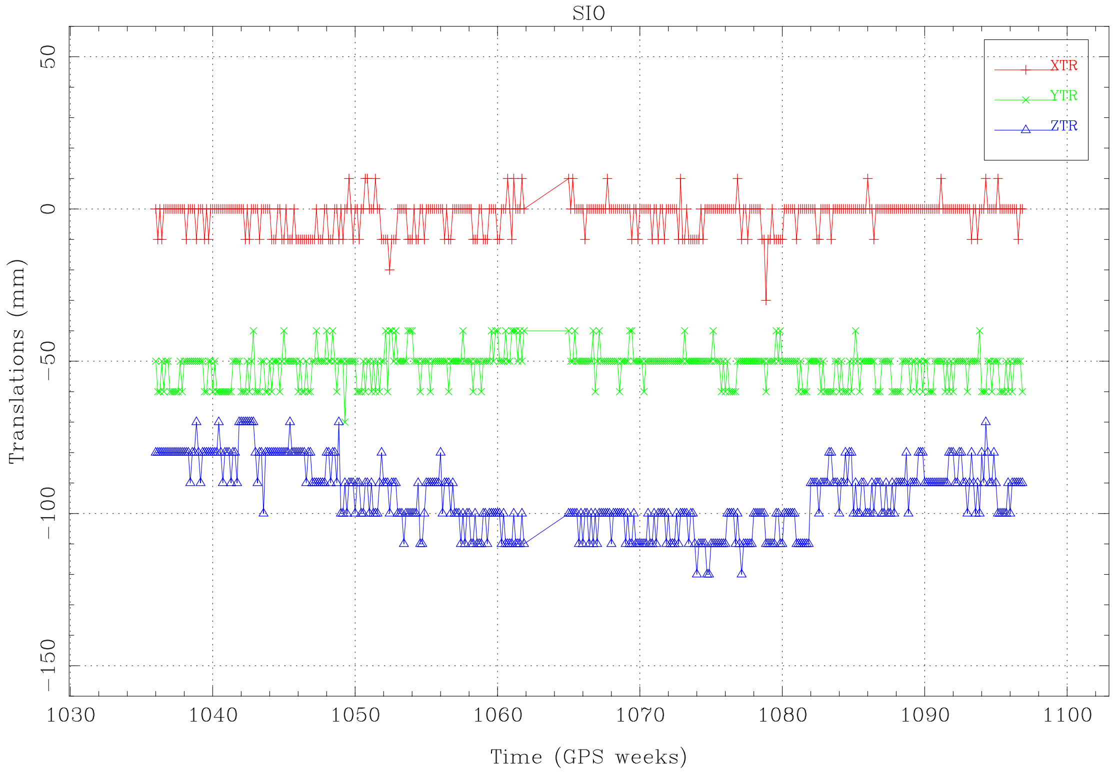


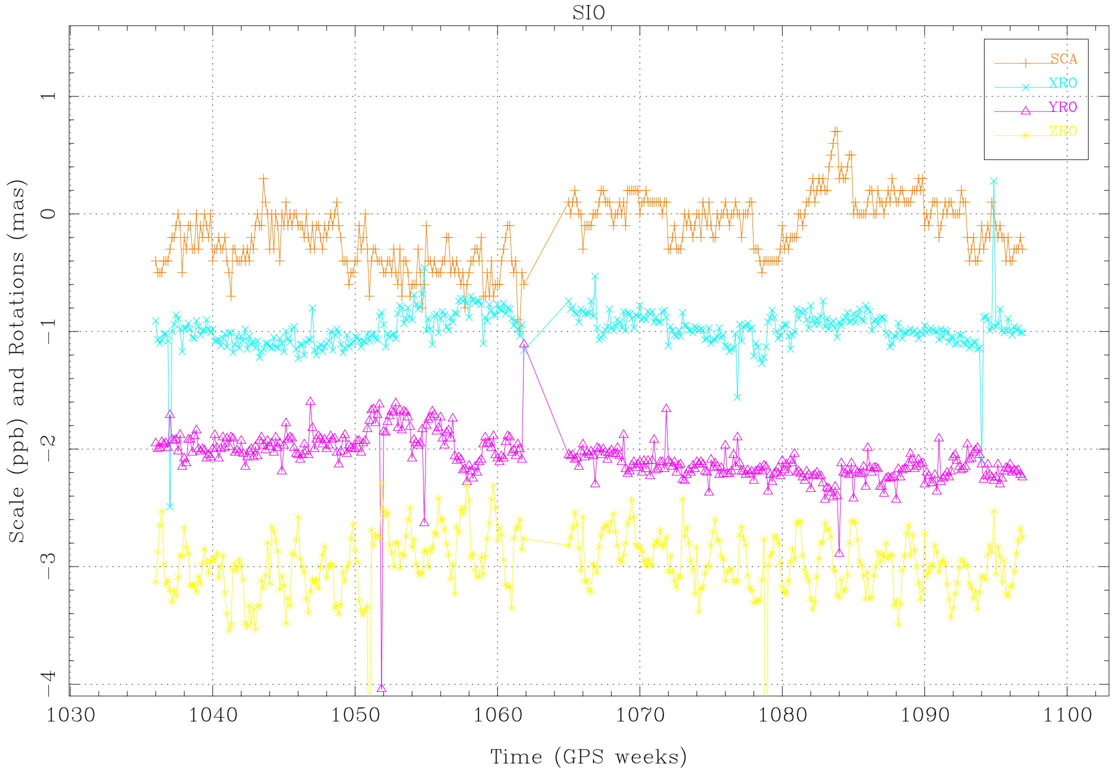
Figures 10a,b: Daily Transformation parameters of the JPL Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



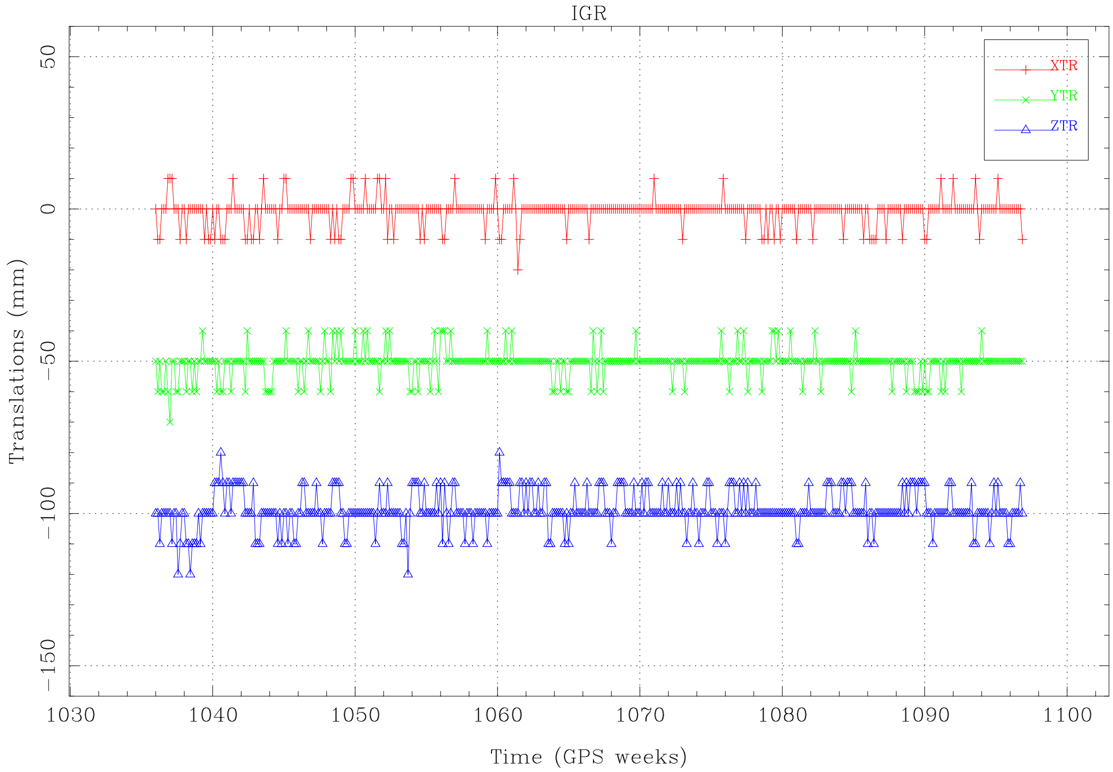


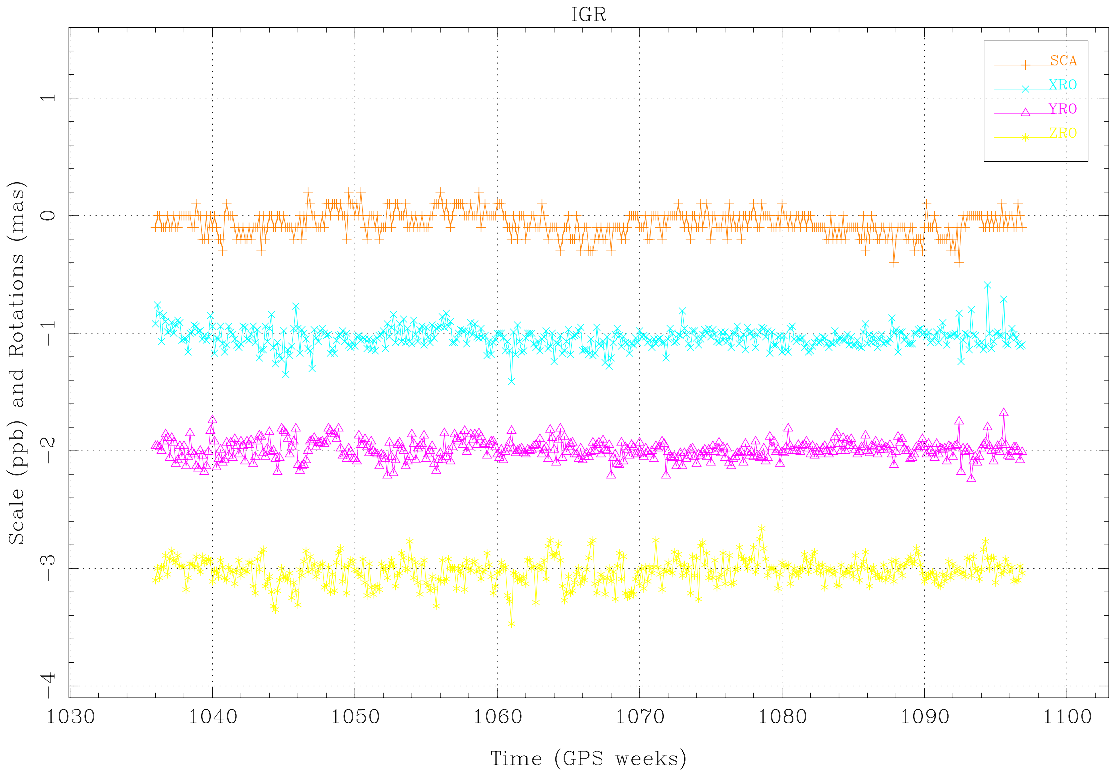
Figures 11a,b: Daily Transformation parameters of the NGS Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



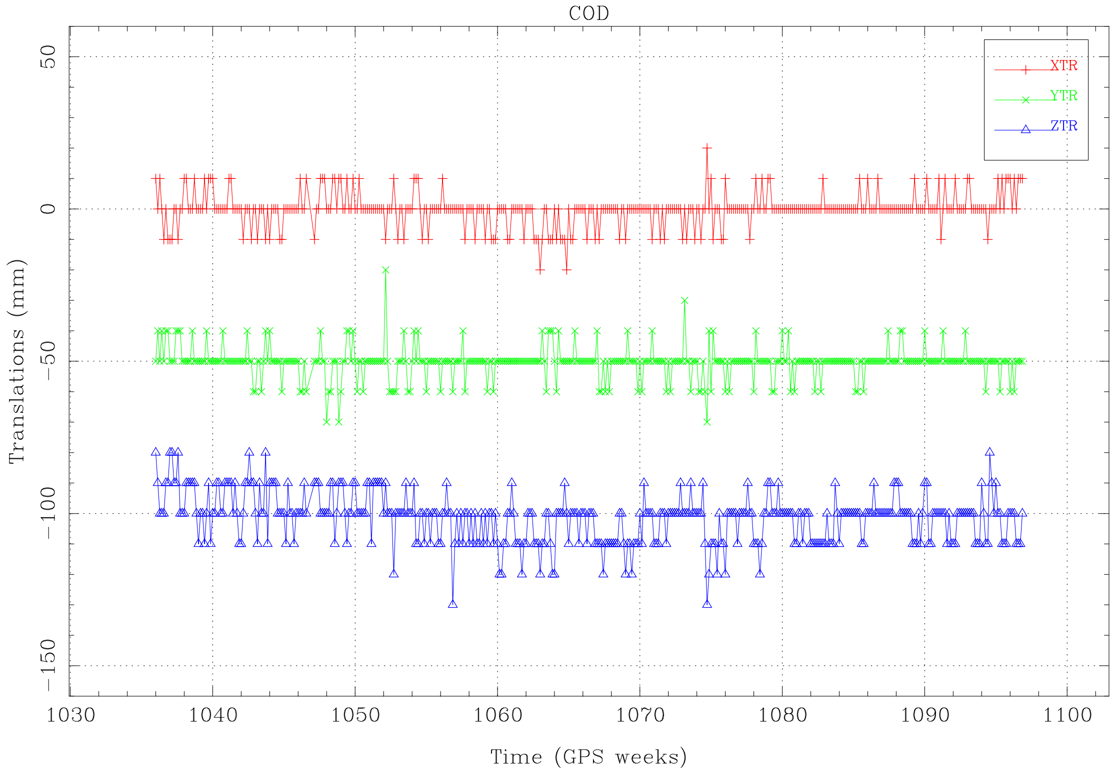


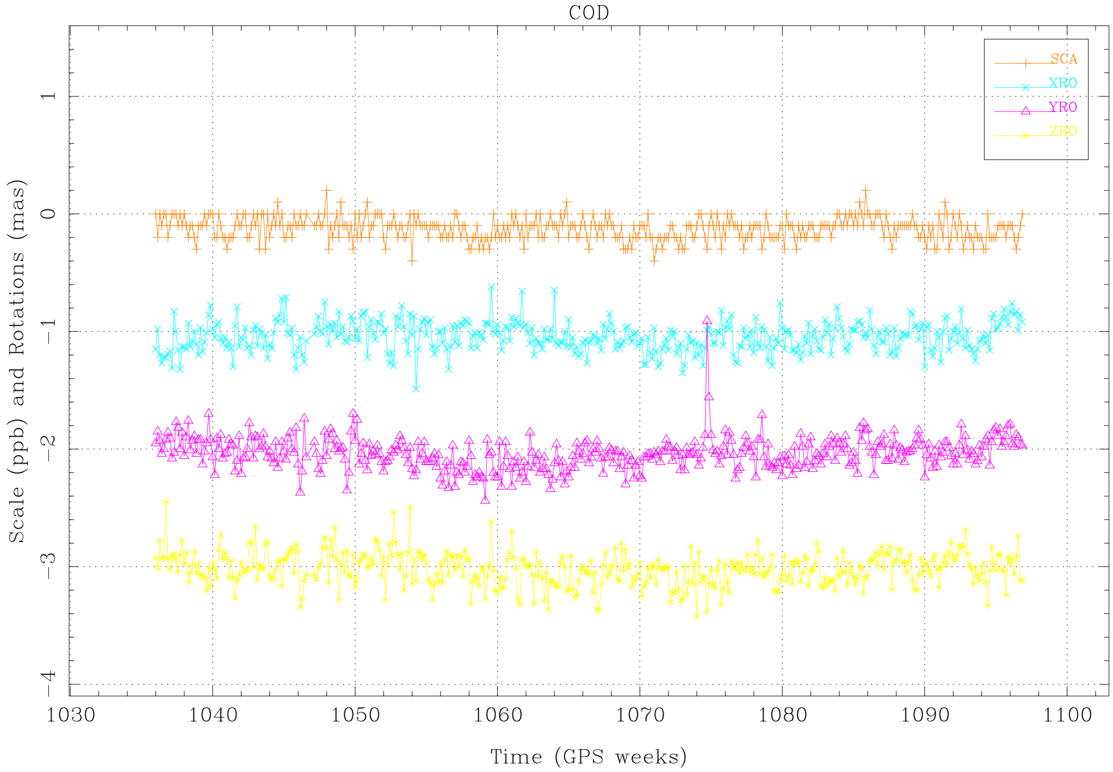
Figures 12a,b: Daily Transformation parameters of the SIO Final orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



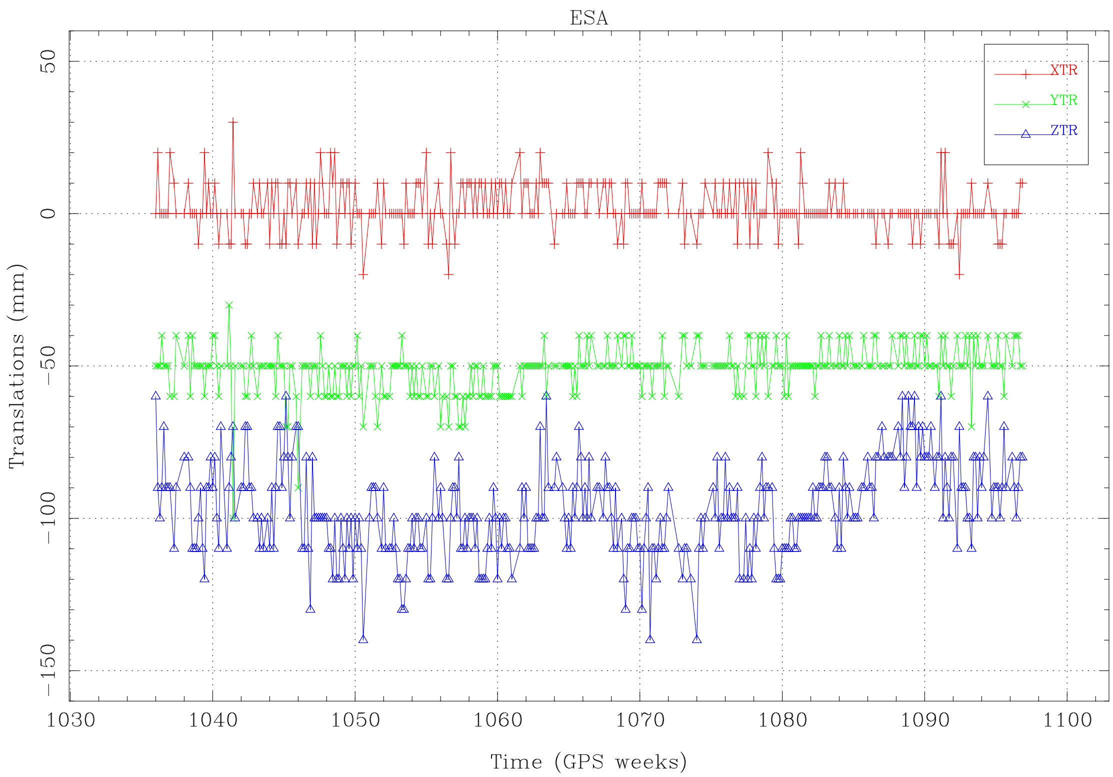


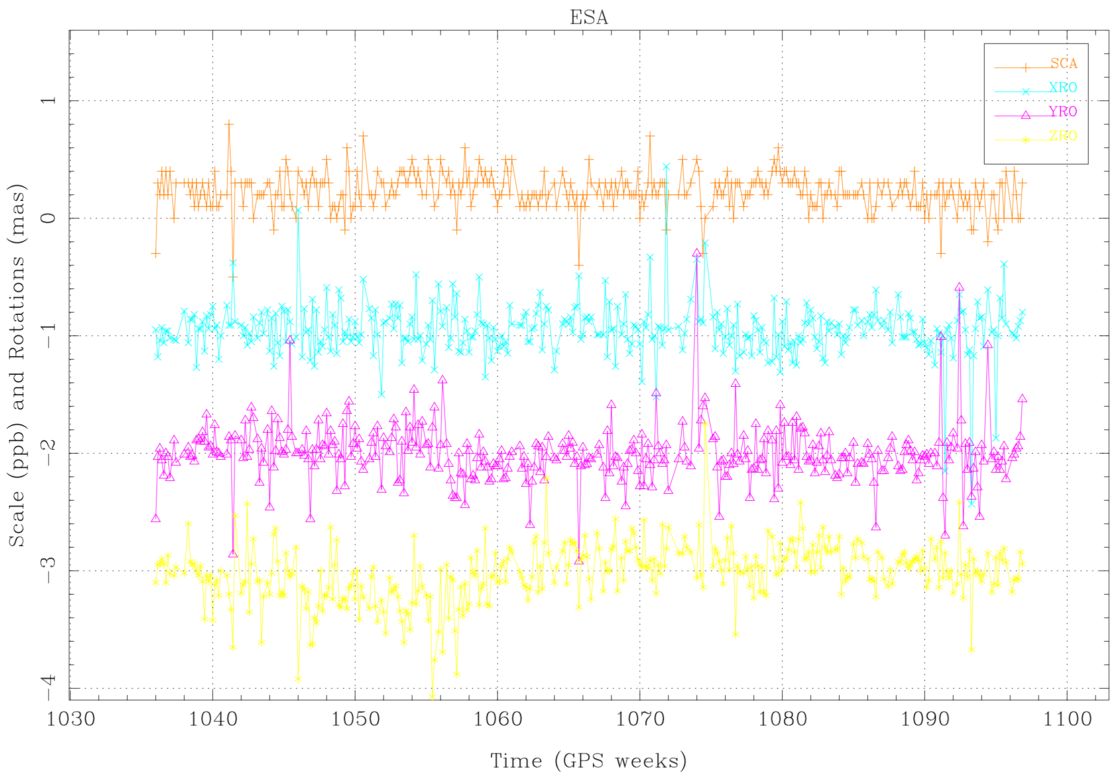
Figures 13a,b: Daily Transformation parameters of the IGS Rapid orbits w.r.t. the IGS Final orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



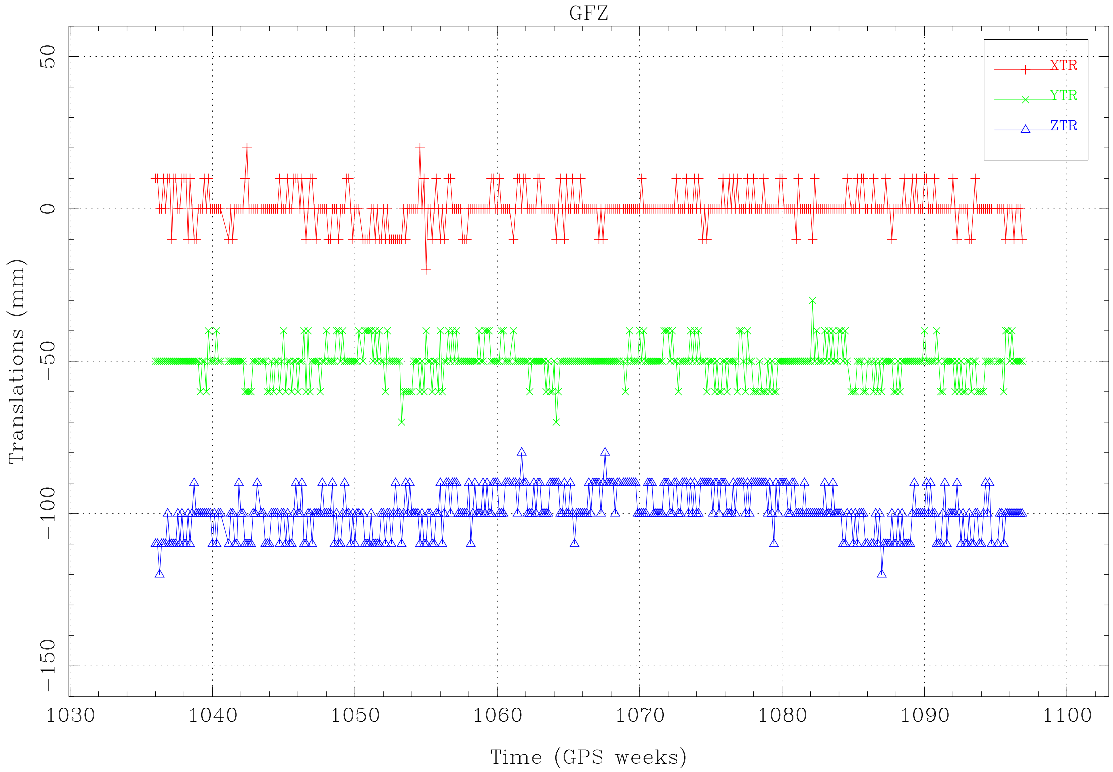


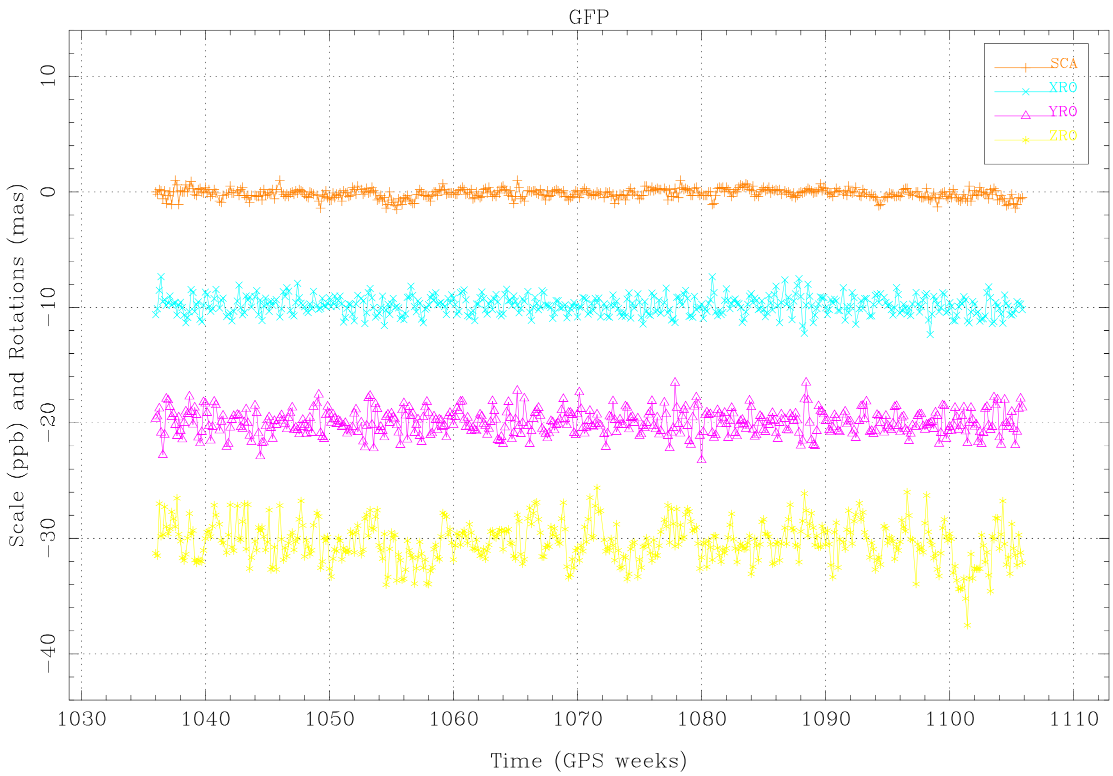
Figures 14a,b: Daily Transformation parameters of the COD Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



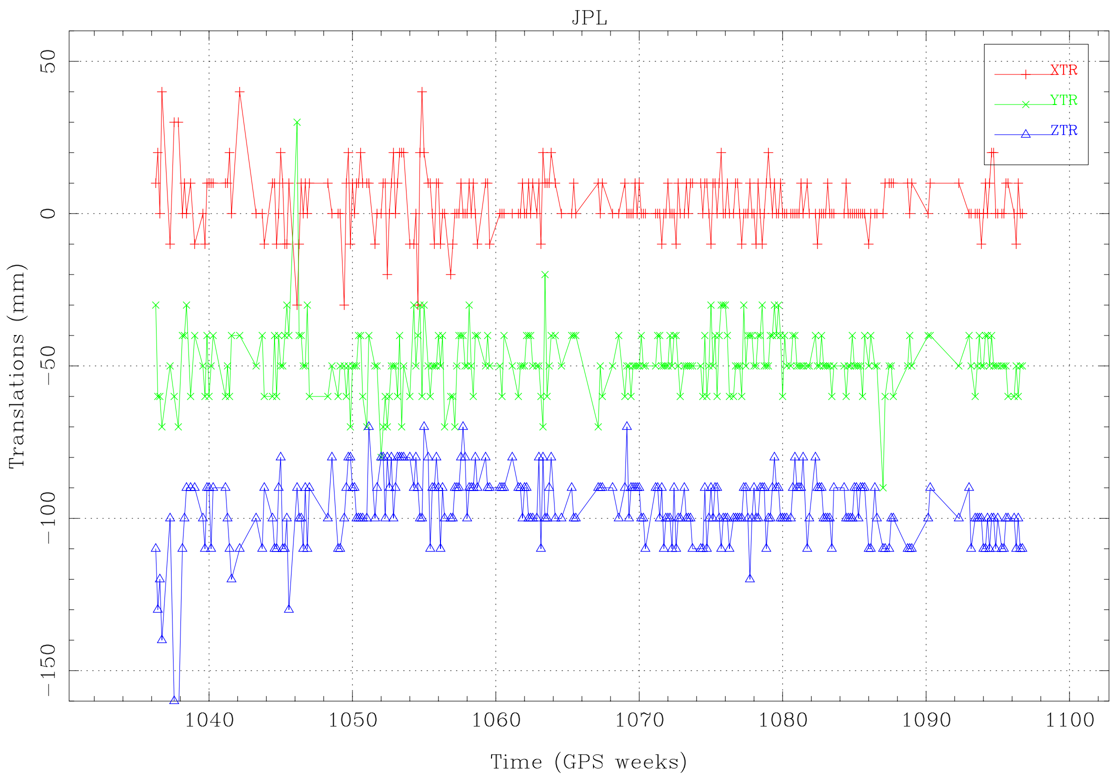


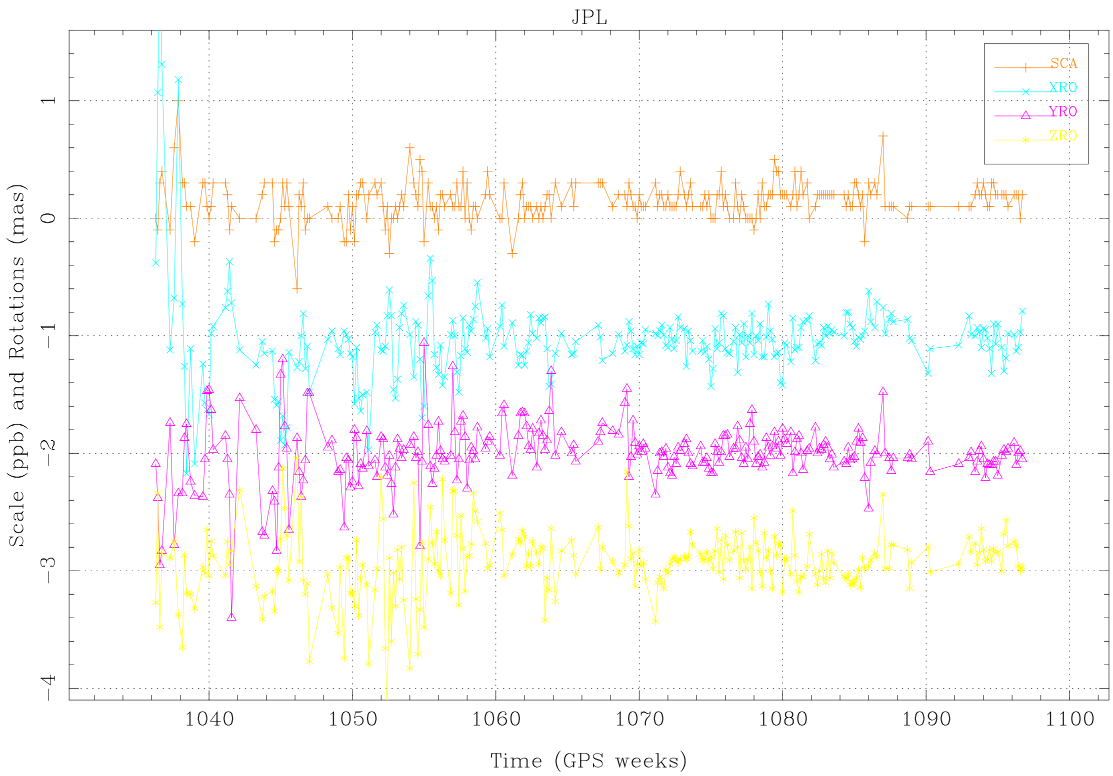
Figures 15a,b: Daily Transformation parameters of the ESA Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



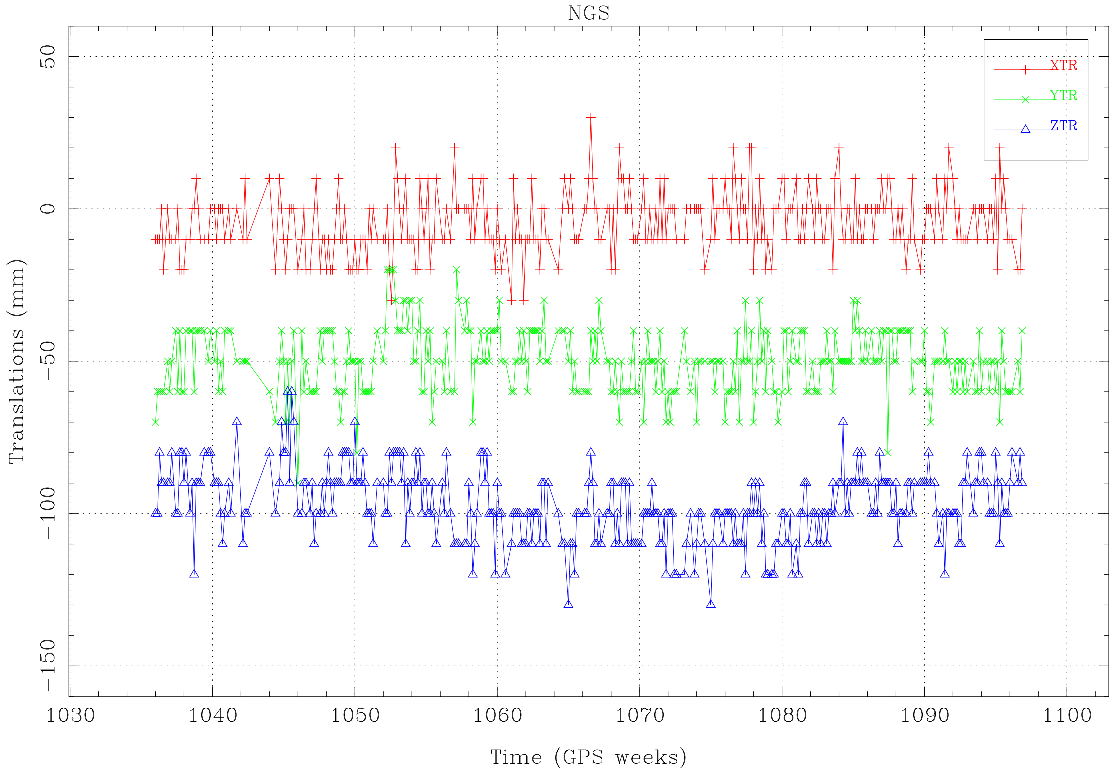


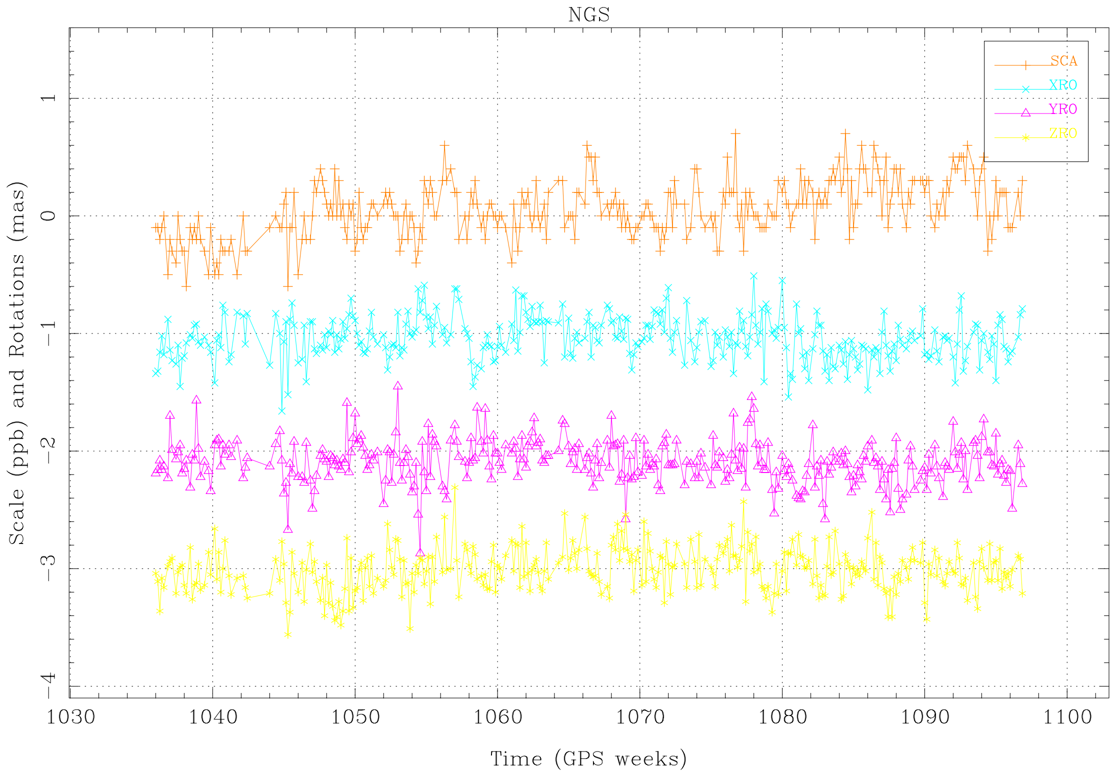
Figures 16a,b: Daily Transformation parameters of the GFZ Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



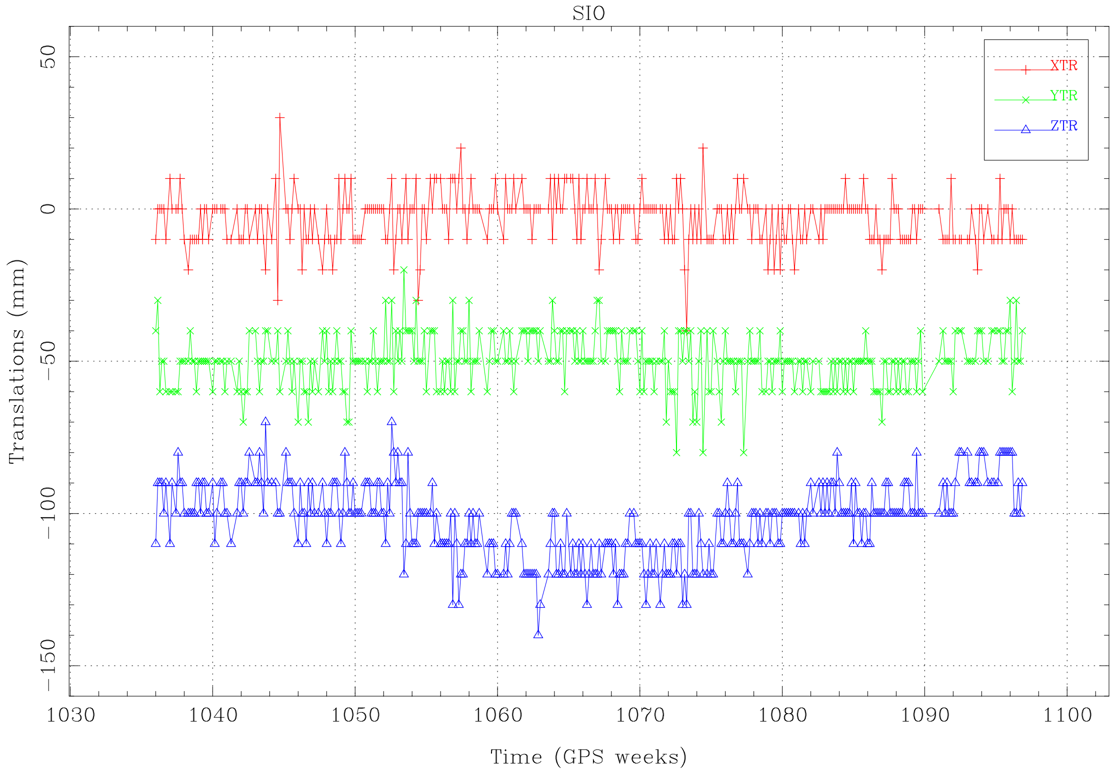


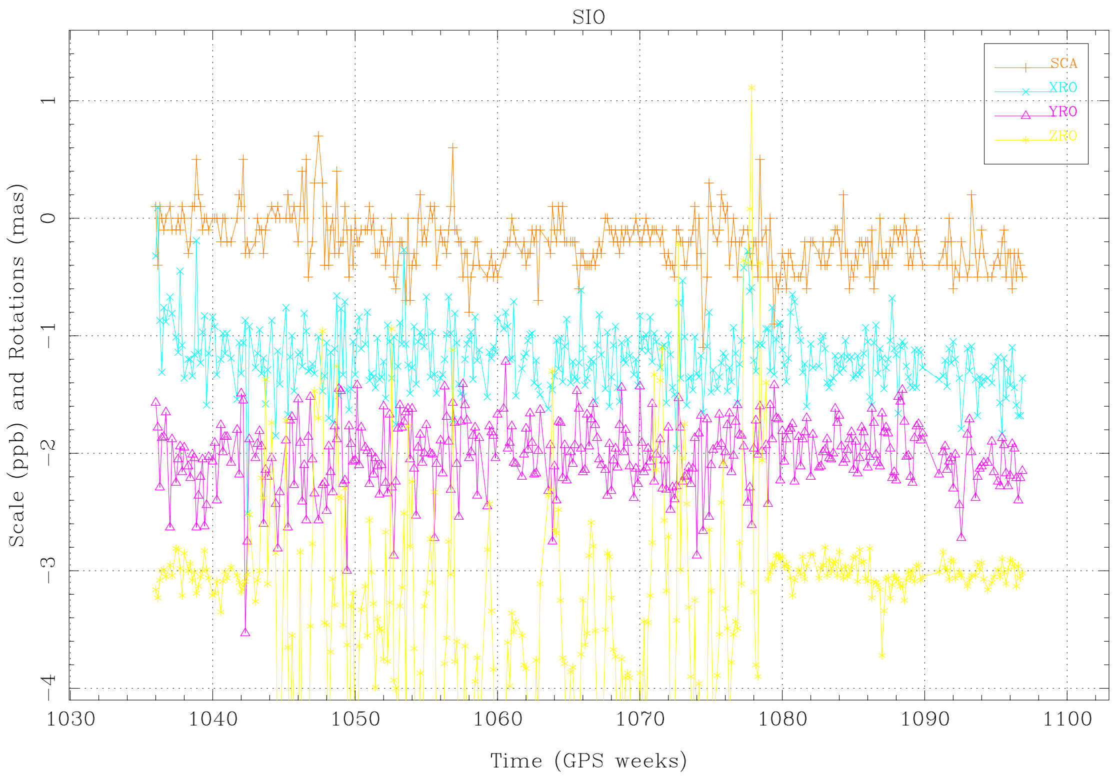
Figures 17a,b: Daily Transformation parameters of the JPL Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



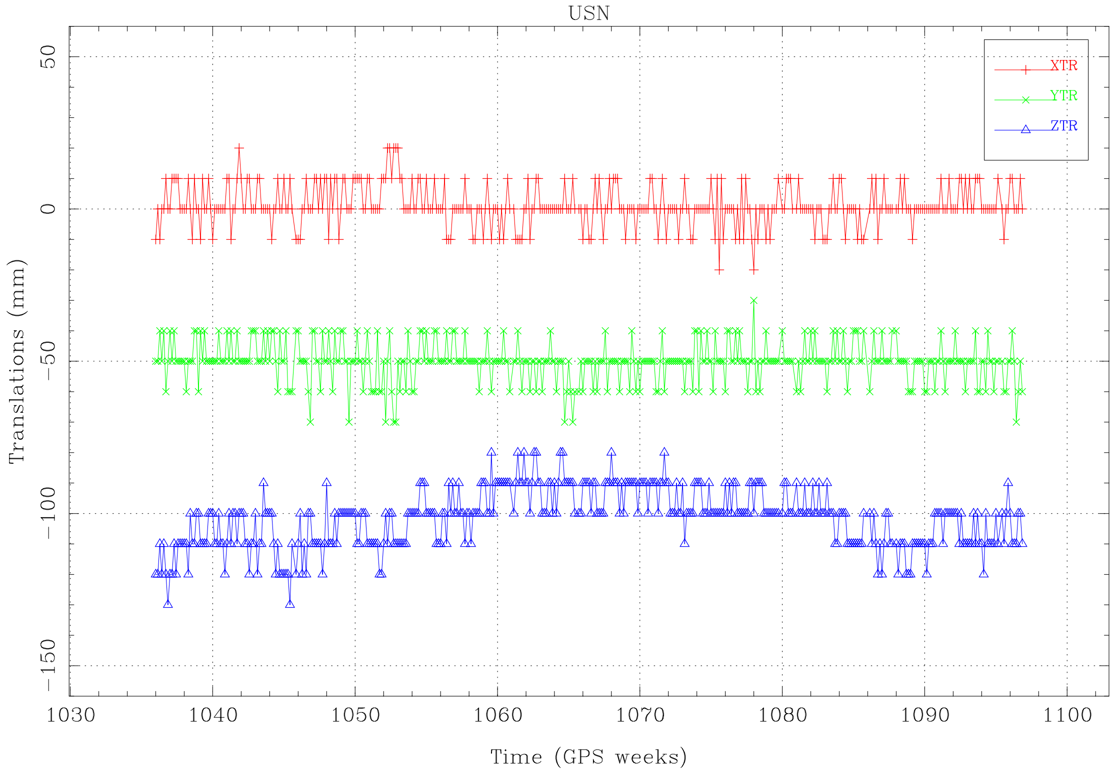


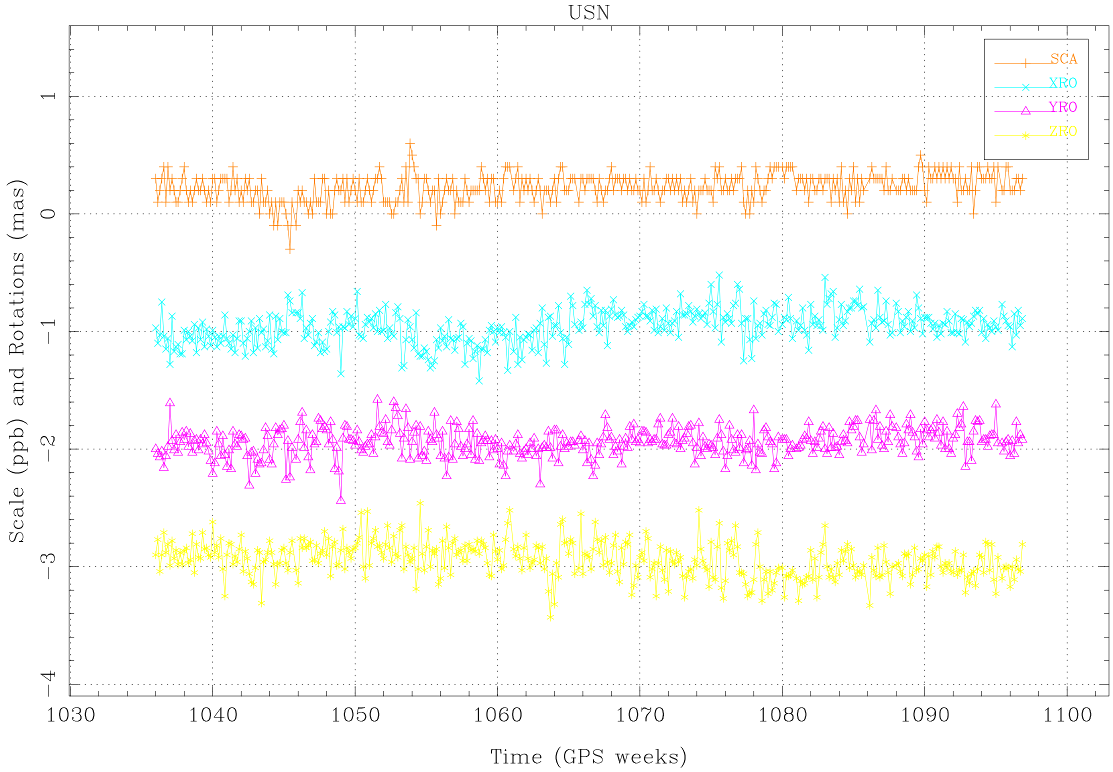
Figures 18a,b: Daily Transformation parameters of the NGS Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



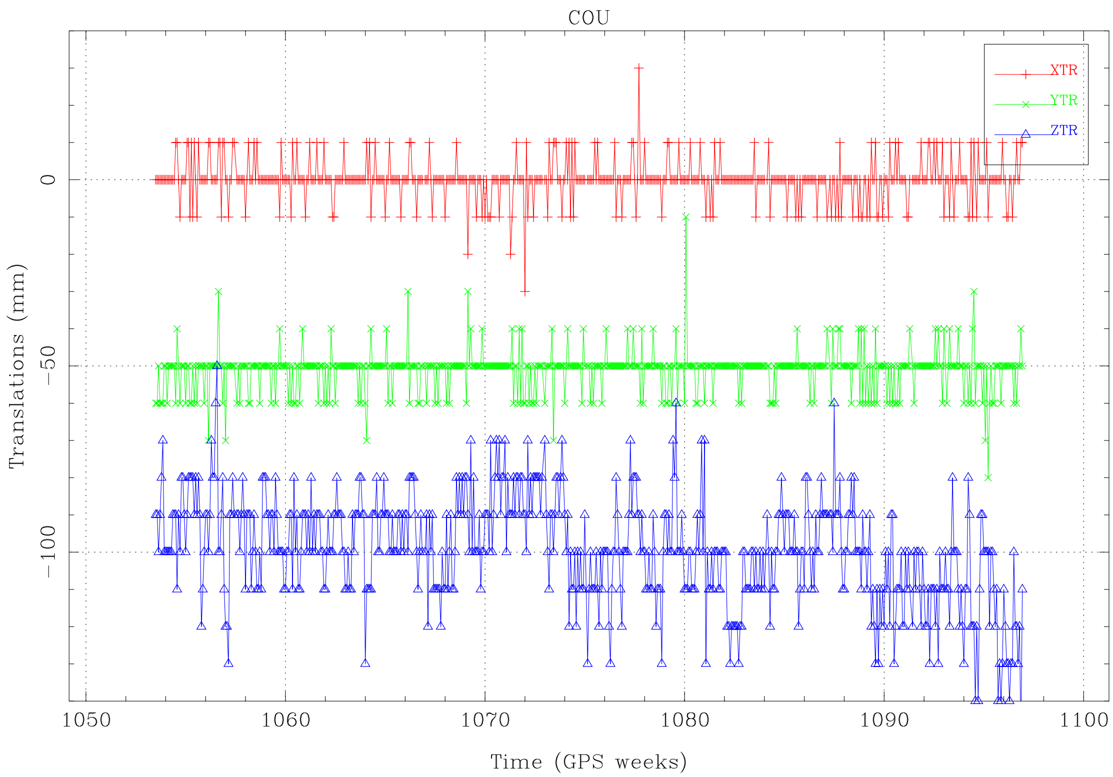


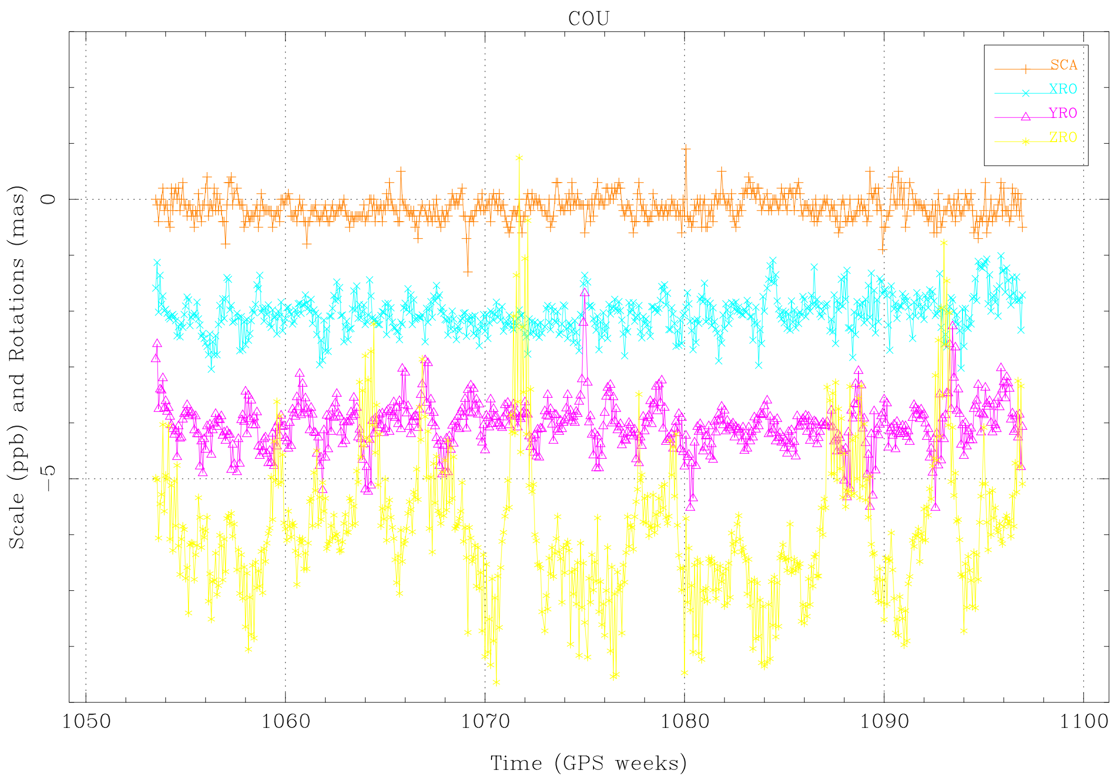
Figures 19a,b: Daily Transformation parameters of the SIO Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



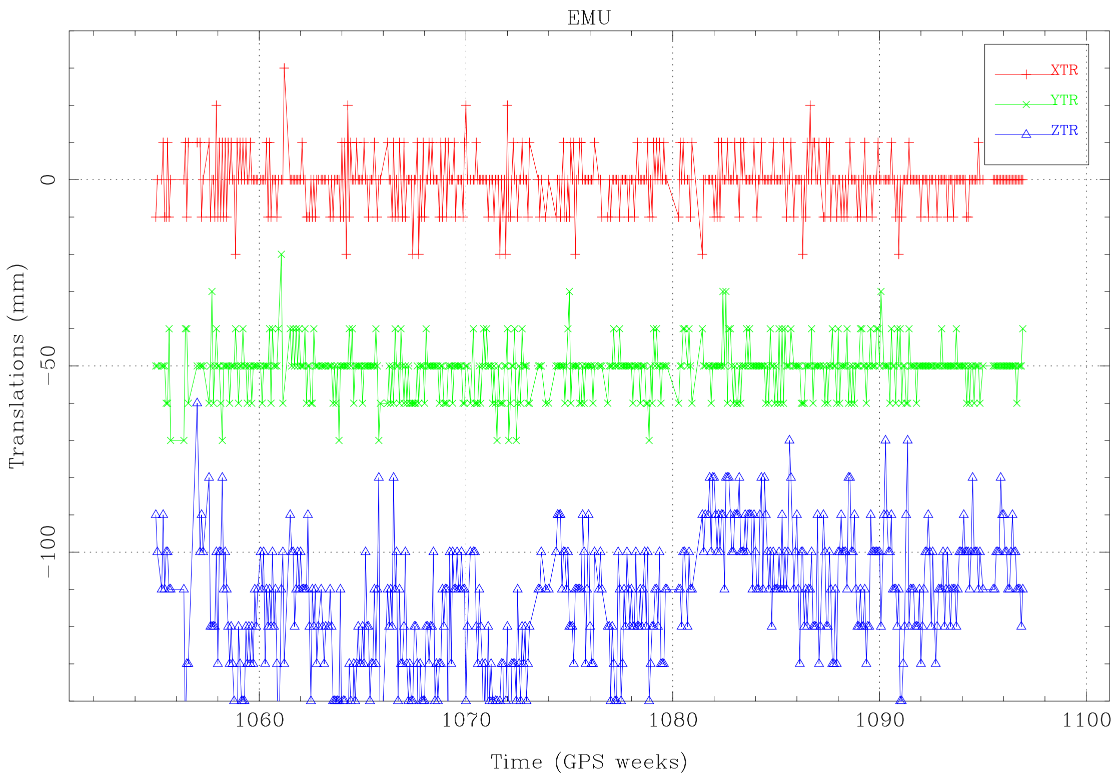


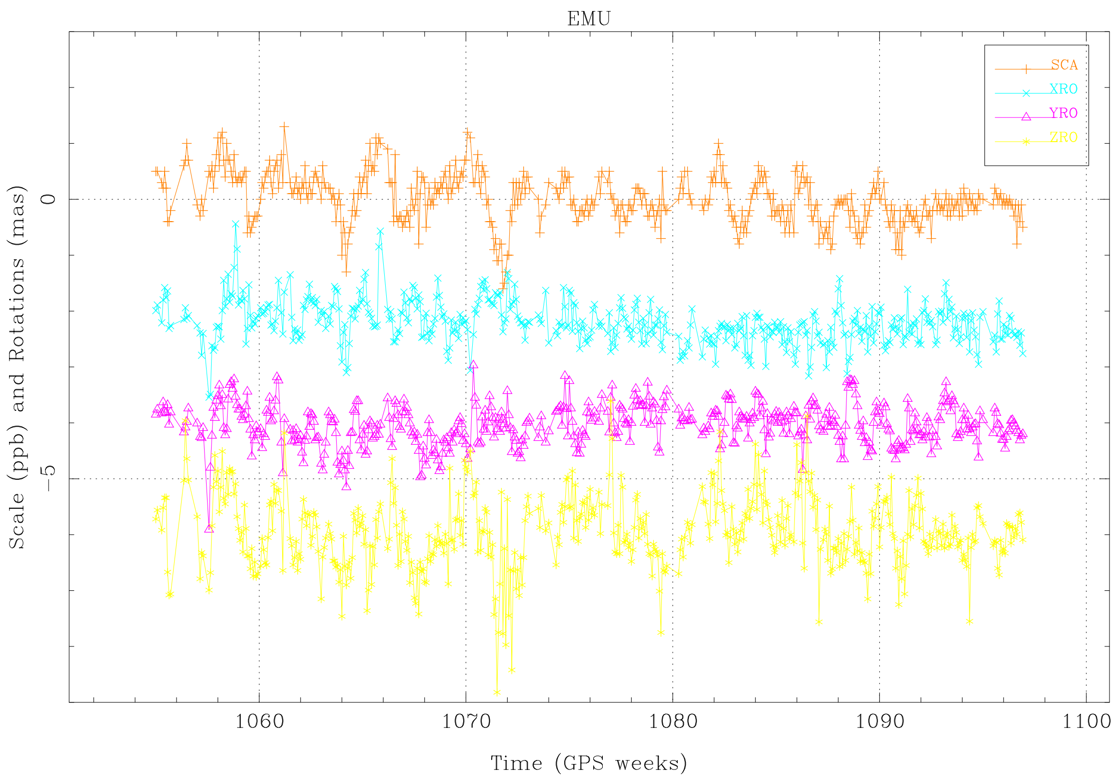
Figures 20a,b: Daily Transformation parameters of the USN Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 1 mas.



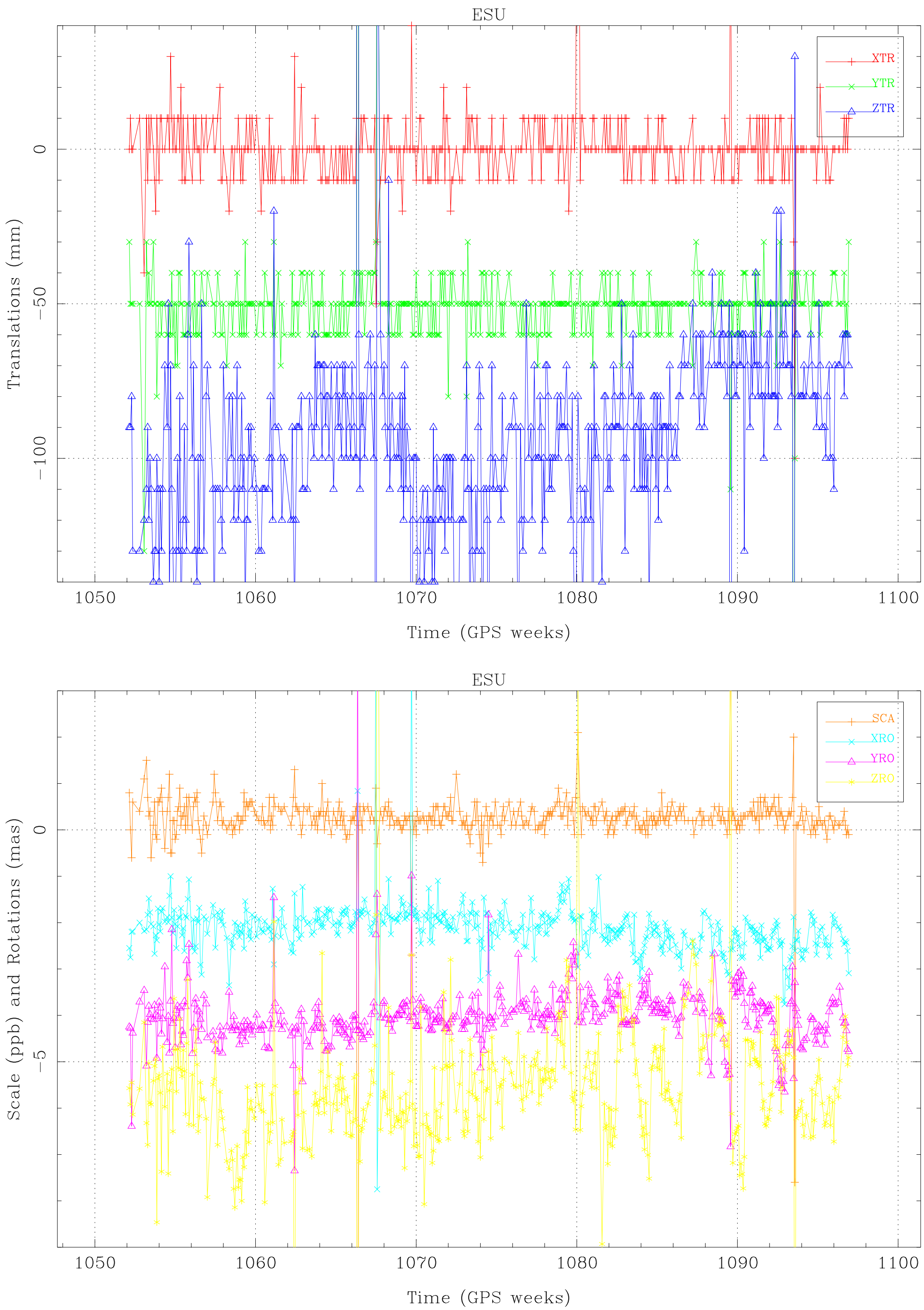


Figures 21a,b: Daily Transformation parameters of the COD Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.

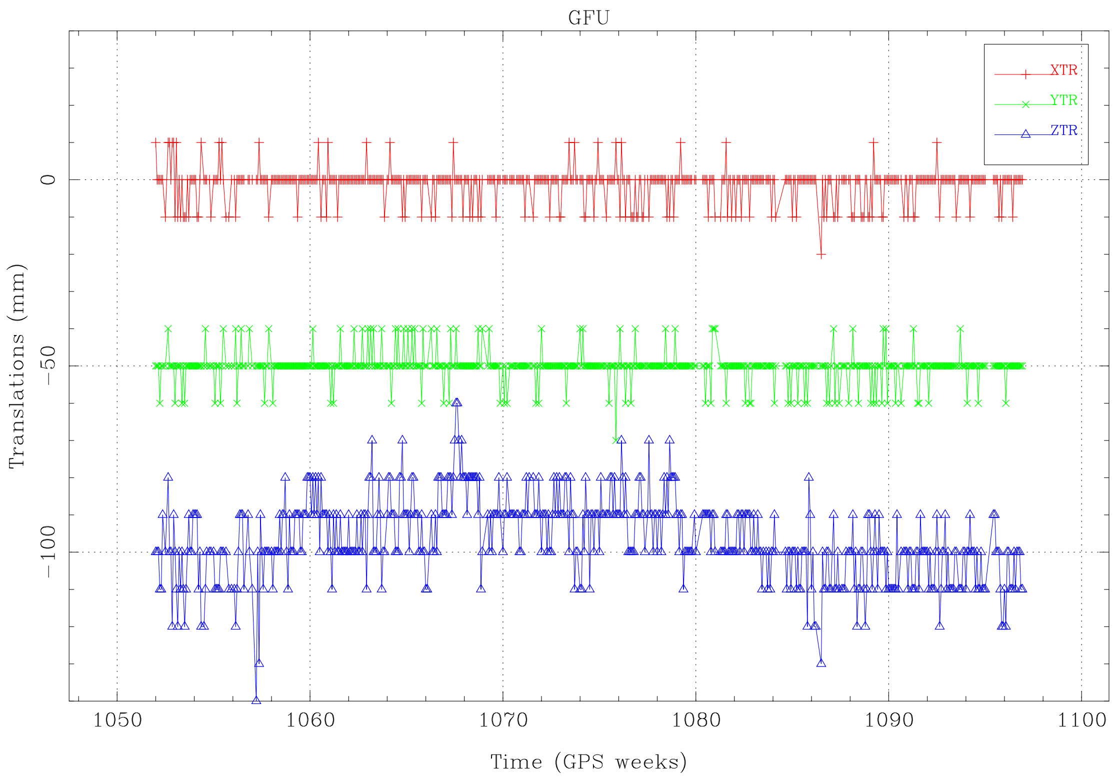


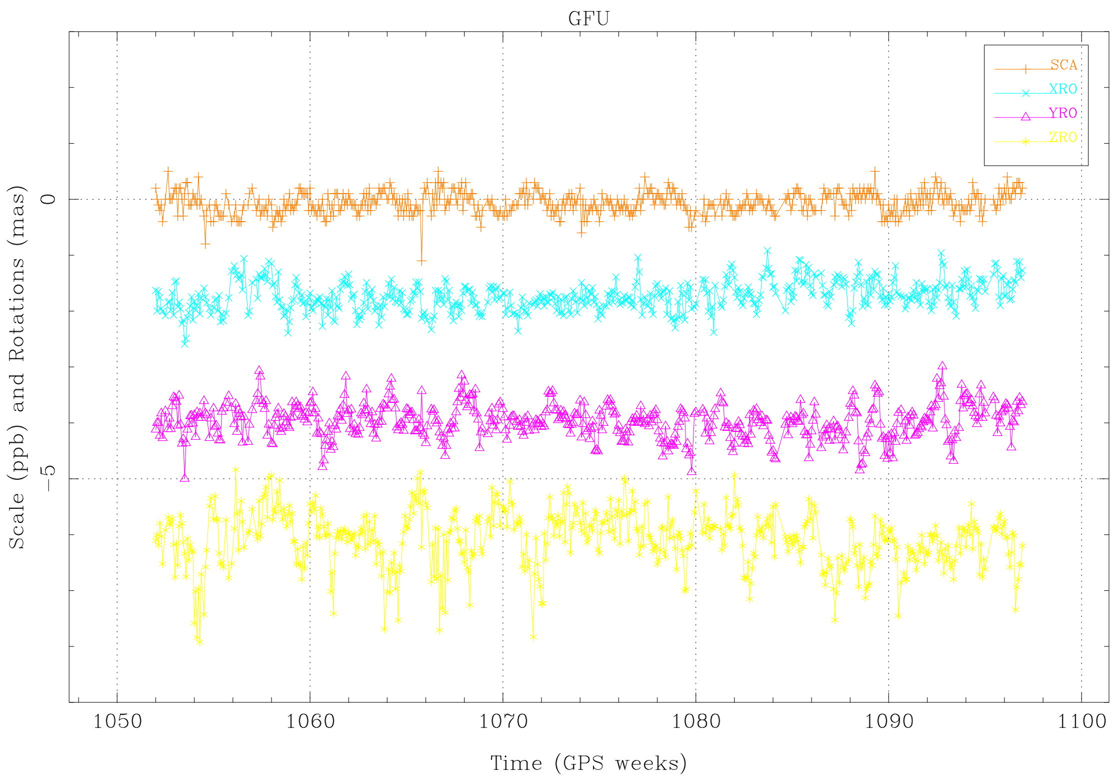


Figures 22a,b: Daily Transformation parameters of the EMR Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.

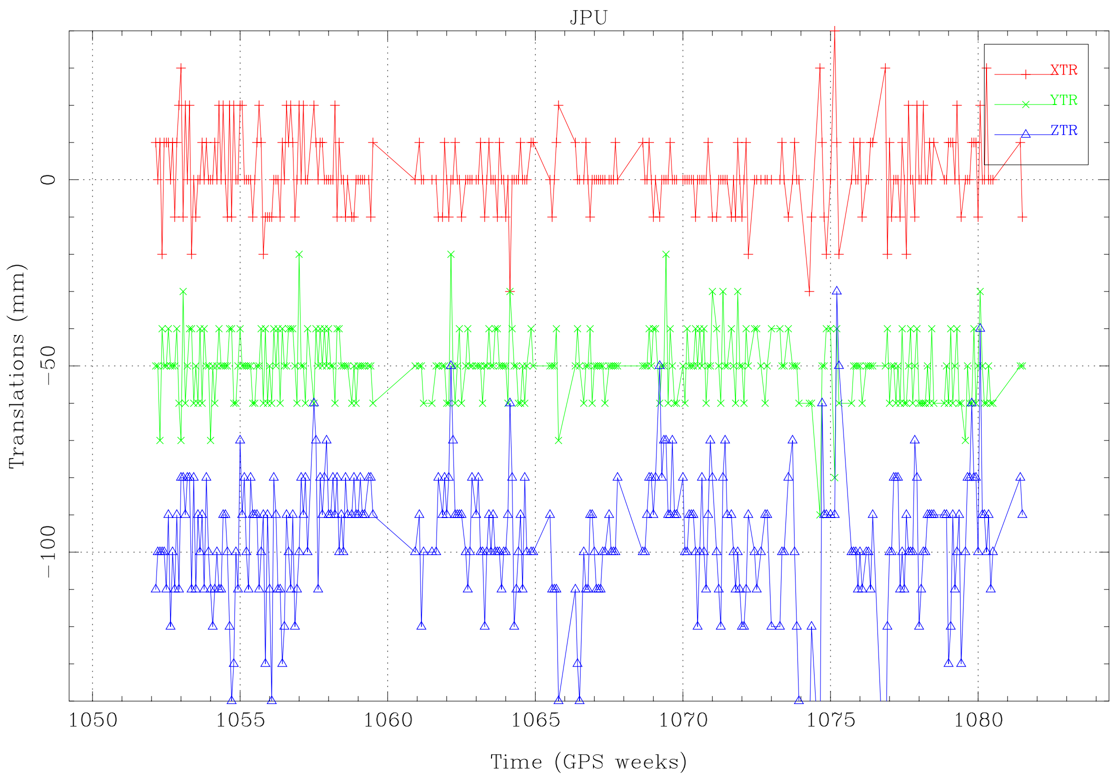


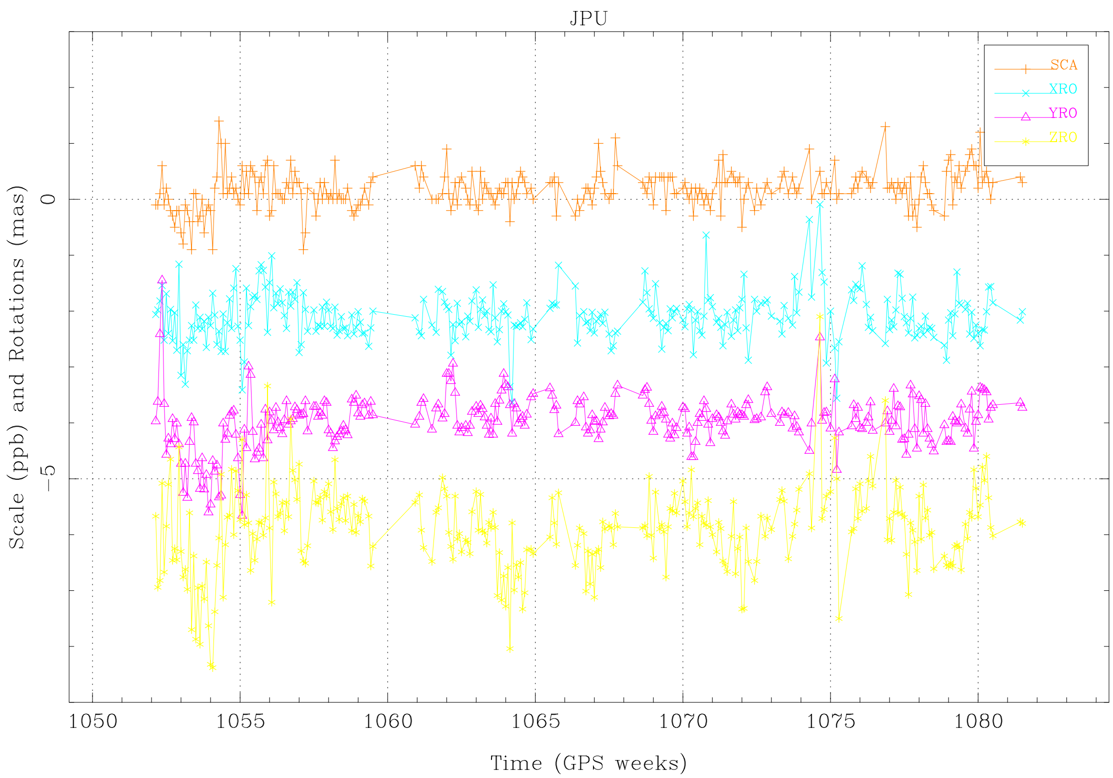
Figures 23a,b: Daily Transformation parameters of the ESA Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.



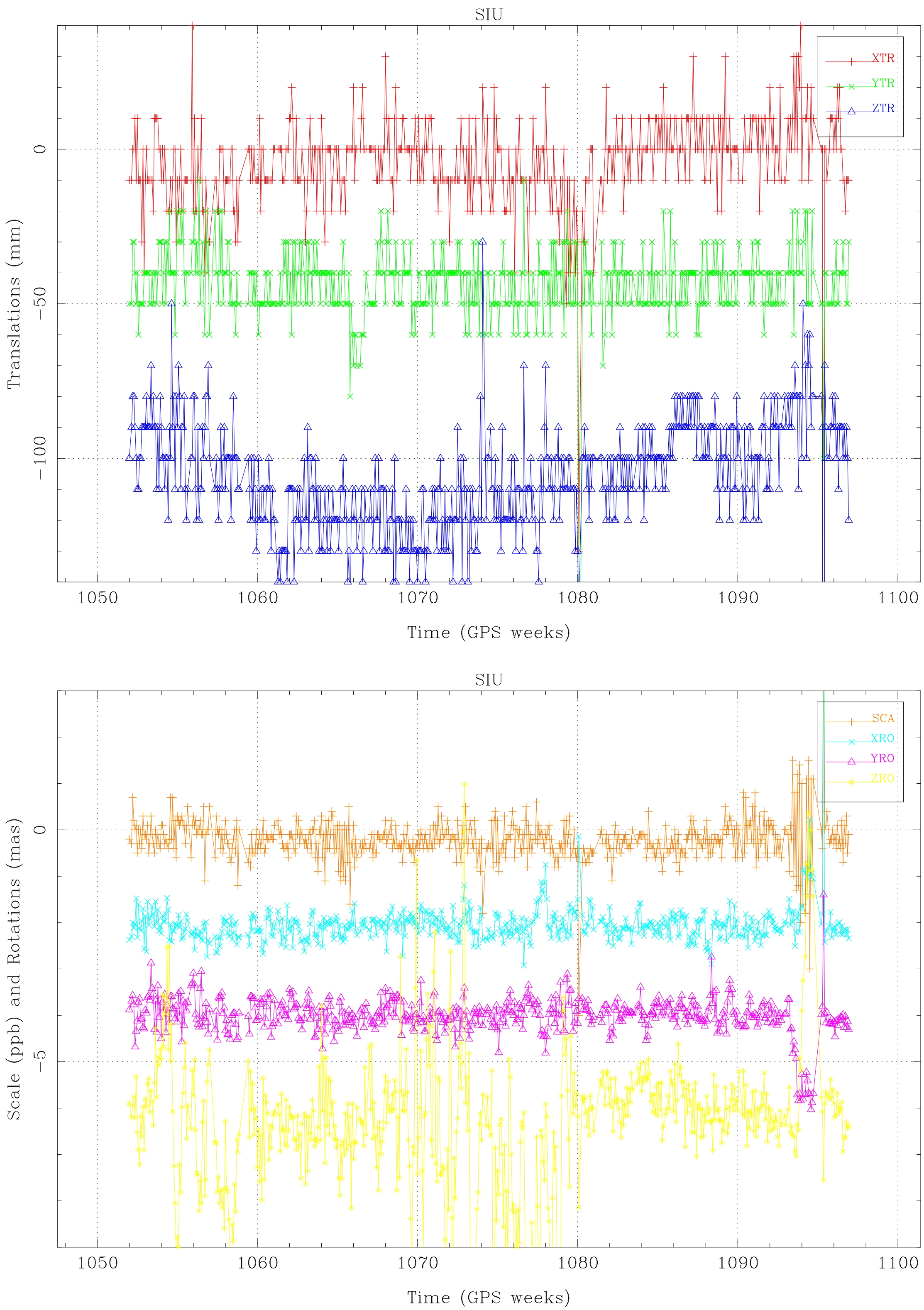


Figures 24a,b: Daily Transformation parameters of the GFZ Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.

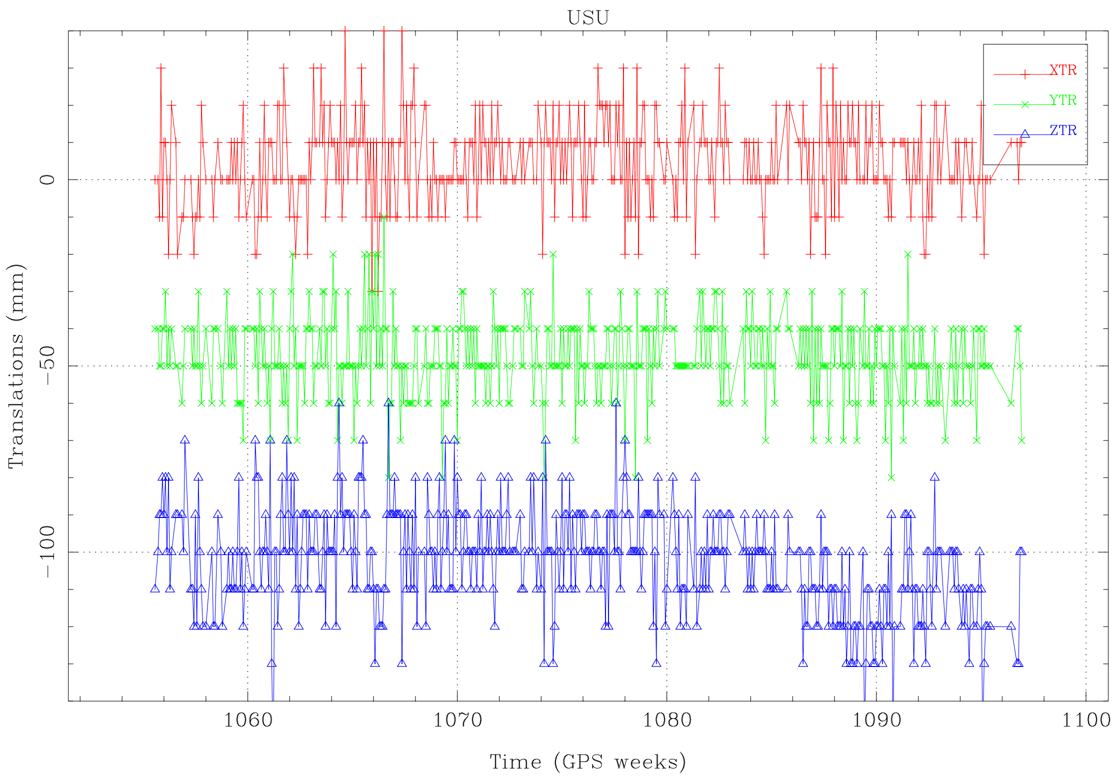


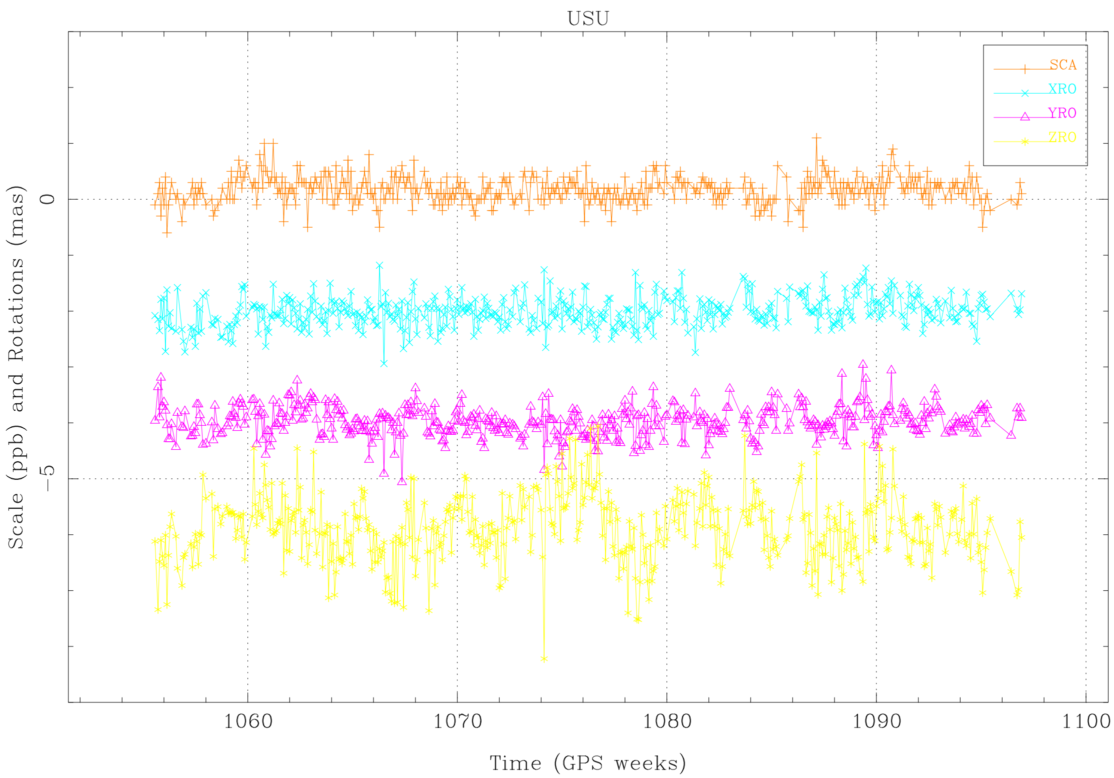


Figures 25a,b: Daily Transformation parameters of the JPL Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.

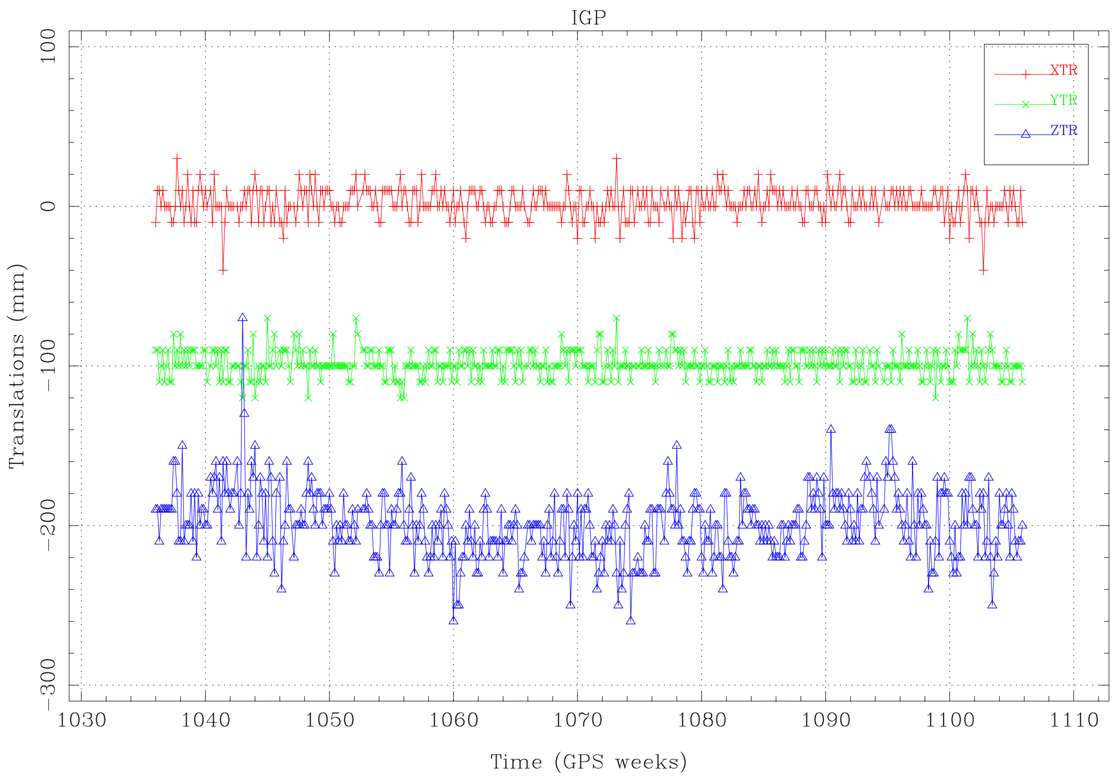


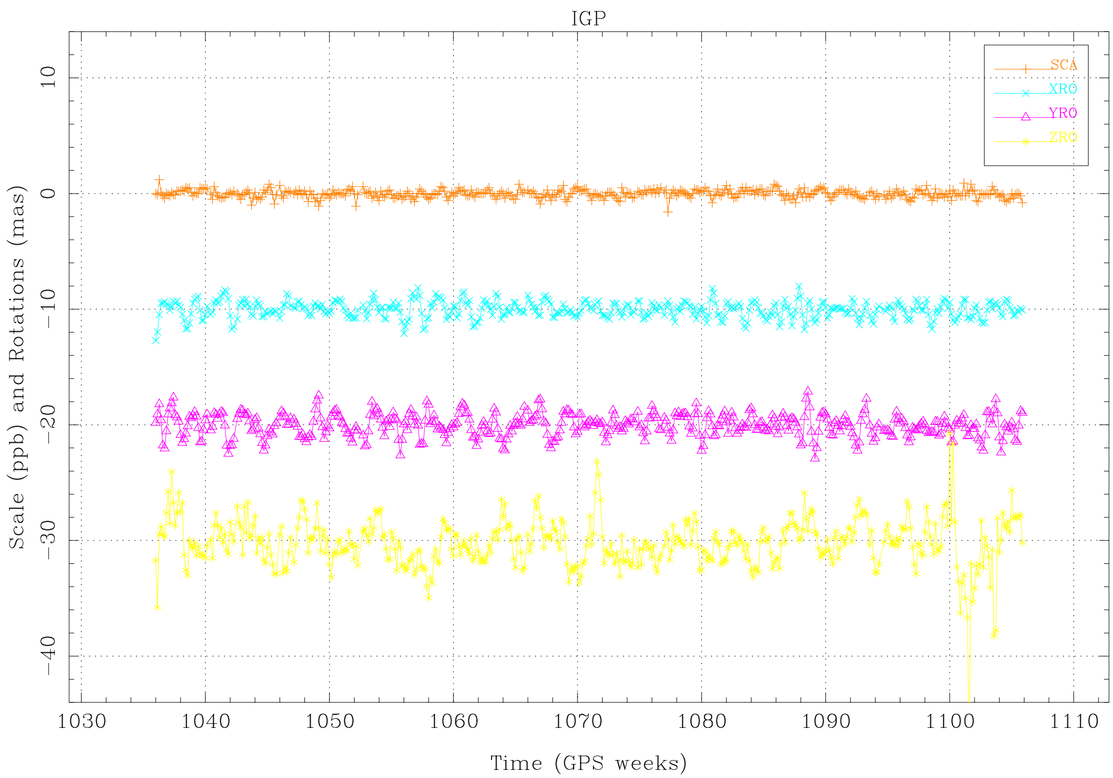
Figures 26a,b: Daily Transformation parameters of the SIO Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.





Figures 27a,b: Daily Transformation parameters of the USN Ultra Rapid orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 50 mm, Rotations are shifted by 2 mas.





Figures 28a,b: Daily Transformation parameters of the IGS Predicted orbits w.r.t. the IGS Rapid orbits. Translations are shifted by 100 mm, Rotations are shifted by 10 mas.

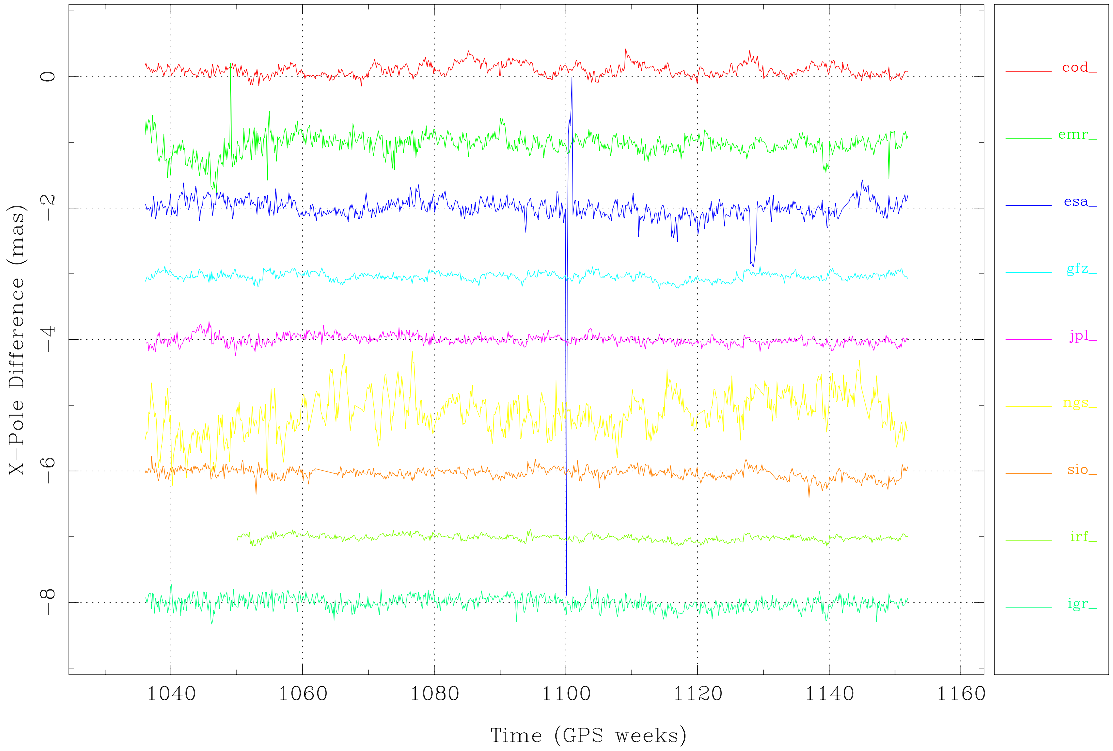


Figure 29: Daily AC Final x-Pole Differences w.r.t. the IGS Final x-Pole. ACs are shifted by 1 mas.

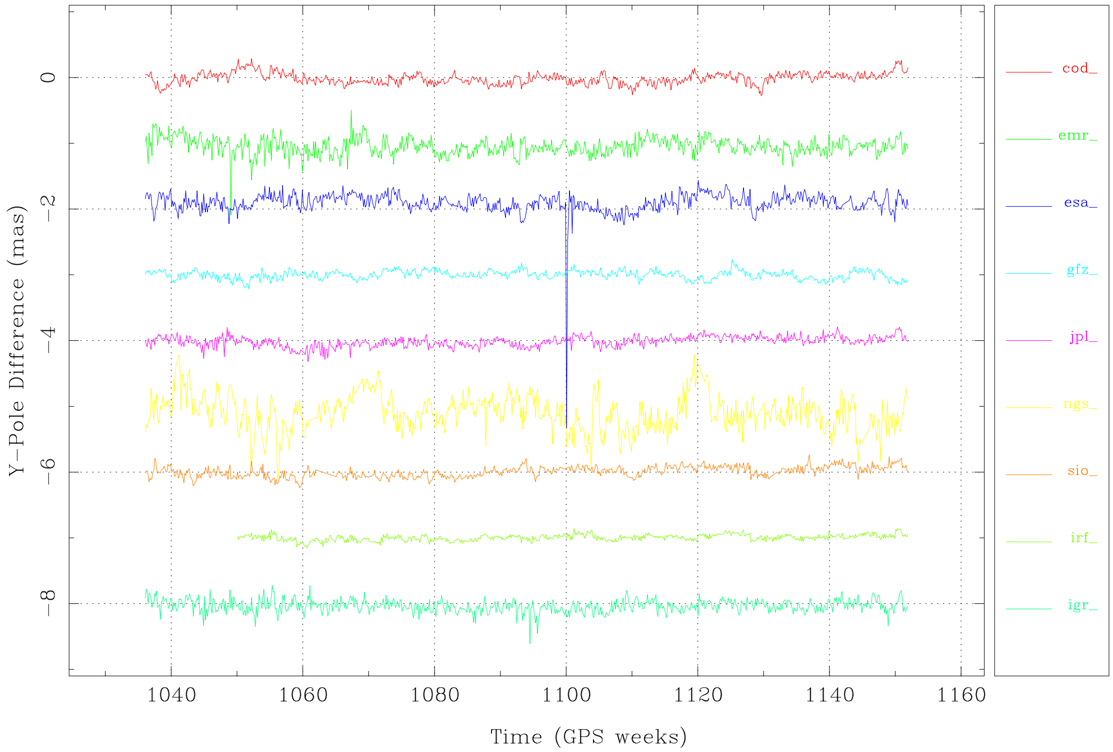


Figure 30: Daily AC Final y-Pole Differences w.r.t. the IGS Final y-Pole. ACs are shifted by 1 mas.

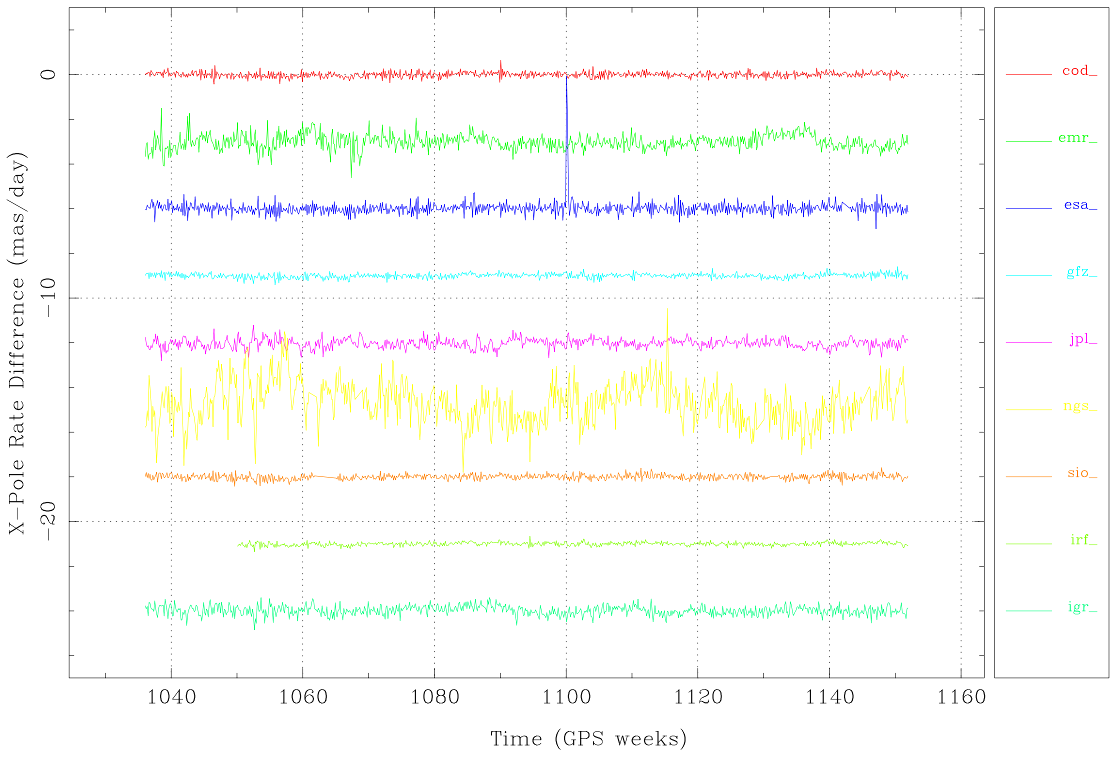


Figure 31: Daily AC Final x-Pole-rate Differences w.r.t. the IGS Final x-Pole-rates. ACs are shifted by 3 mas/day.

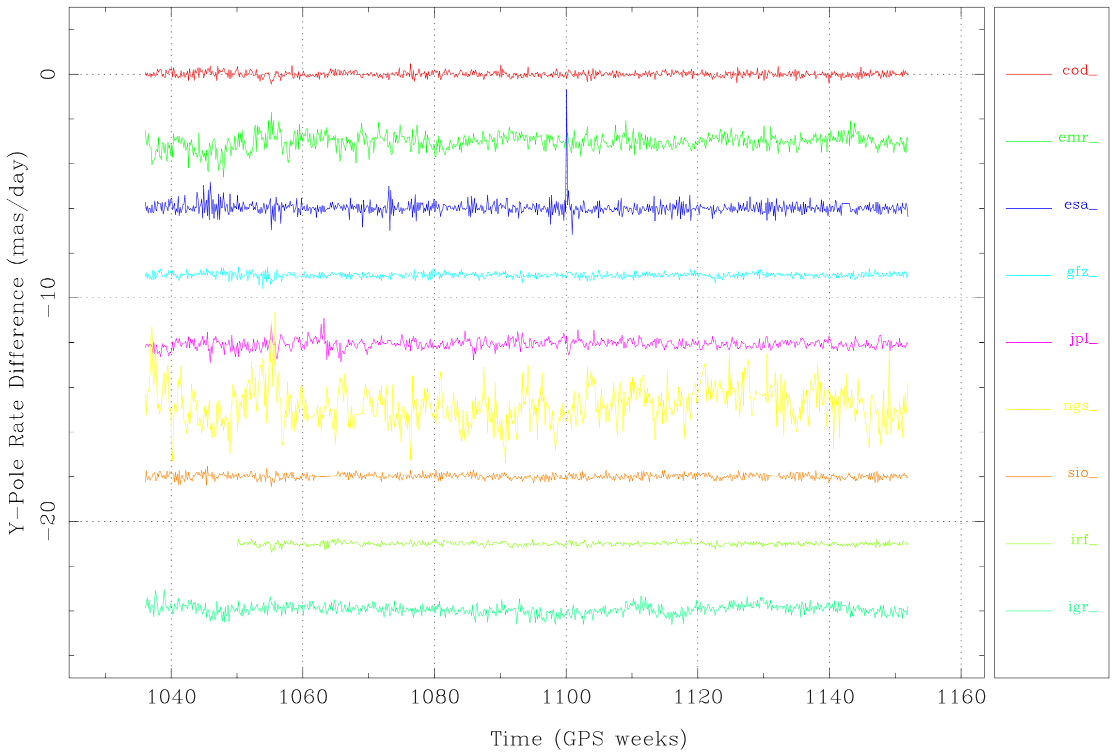


Figure 32: Daily AC Final y-Pole-rate Differences w.r.t. the IGS Final y-Pole-rates. ACs are shifted by 3 mas/day.

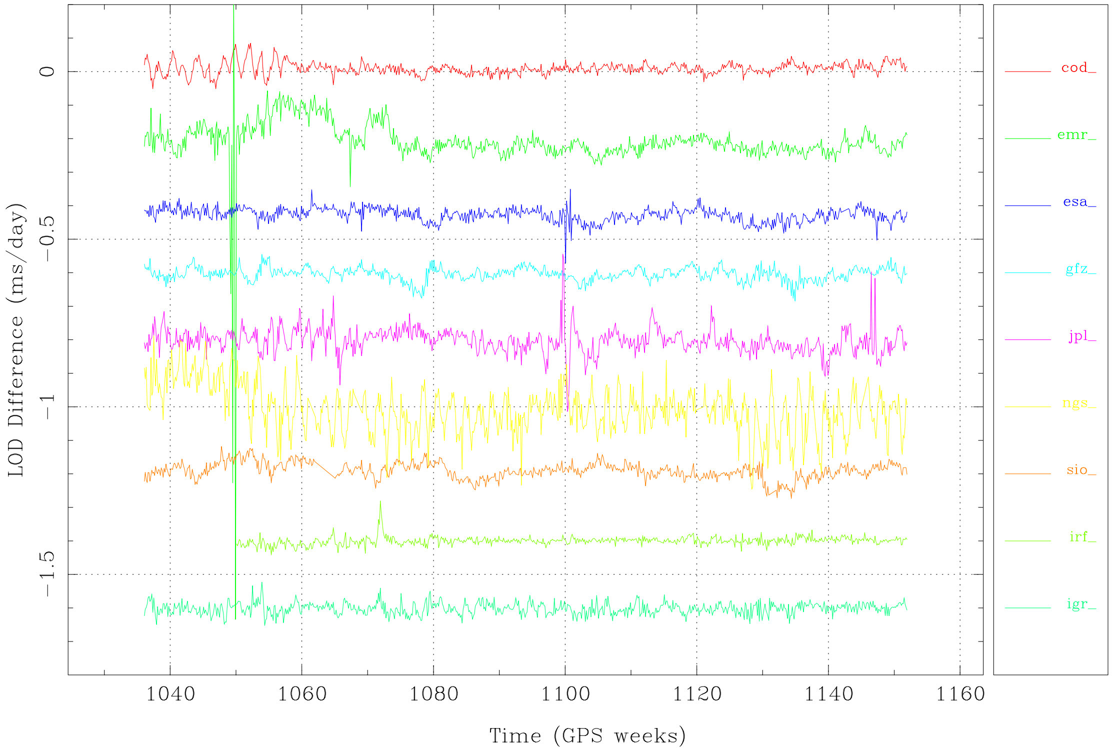


Figure 33: Daily AC Final LOD Differences w.r.t. the IGS Final Pole.
ACs are shifted by 0.2 ms/day.

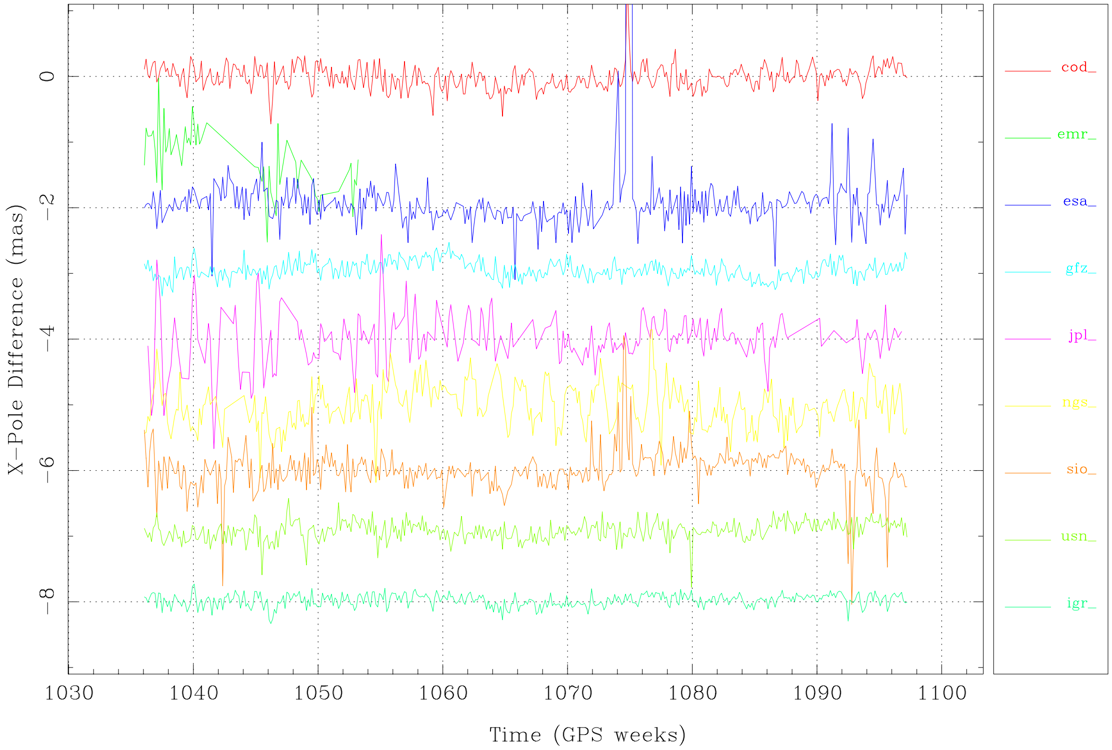


Figure 34: Daily AC Rapid x-Pole Differences w.r.t. the IGS Final x-Pole.
ACs are shifted by 1 mas.

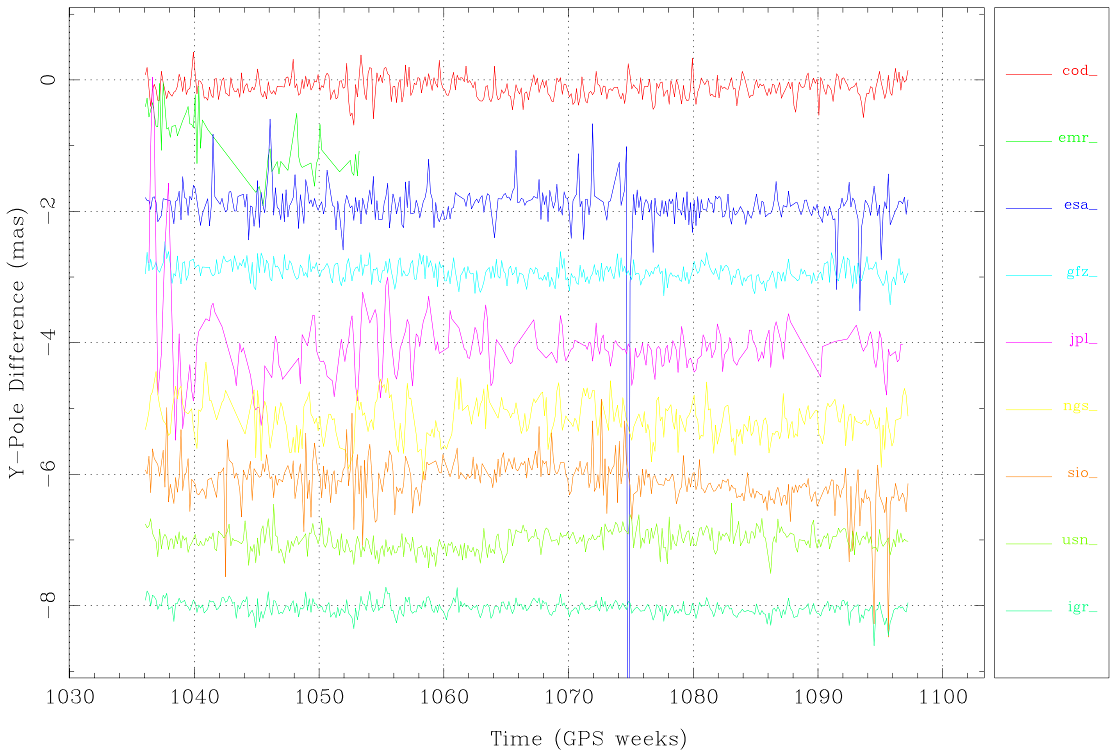


Figure 35: Daily AC Rapid y-Pole Differences w.r.t. the IGS Final y-Pole. ACs are shifted by 1 mas.

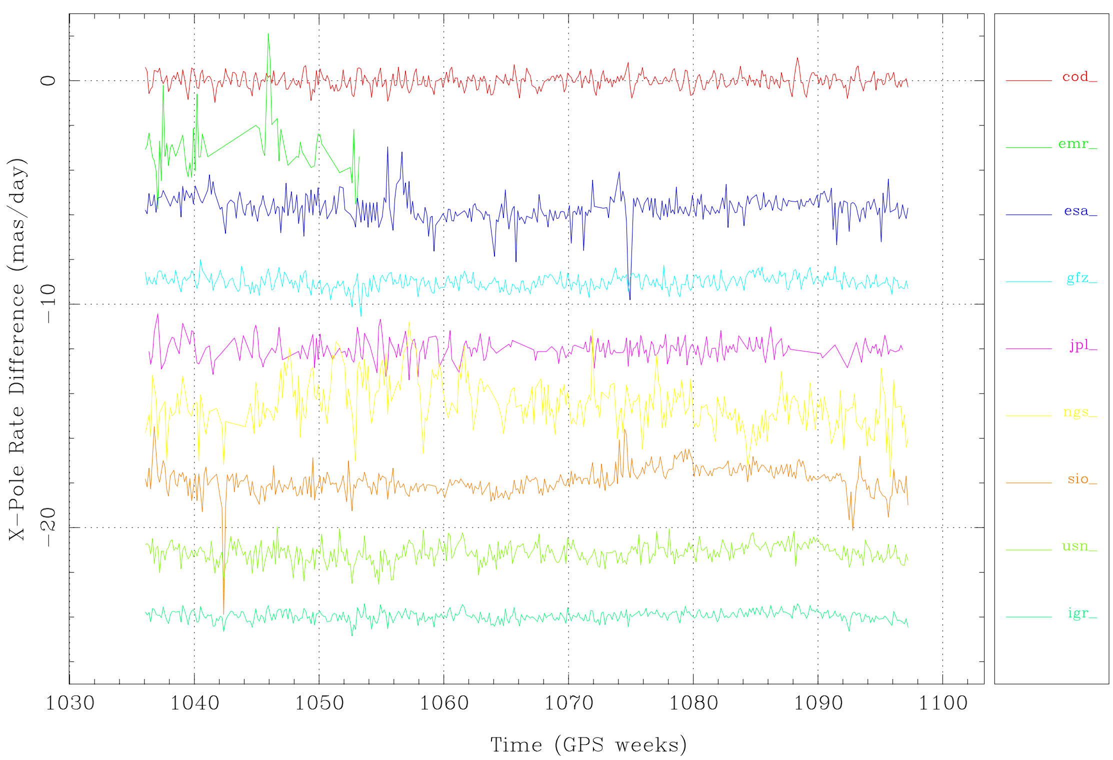


Figure 36: Daily AC Rapid x-Pole-rate Differences w.r.t. the IGS Final x-Pole-rates. ACs are shifted by 3 mas/day.

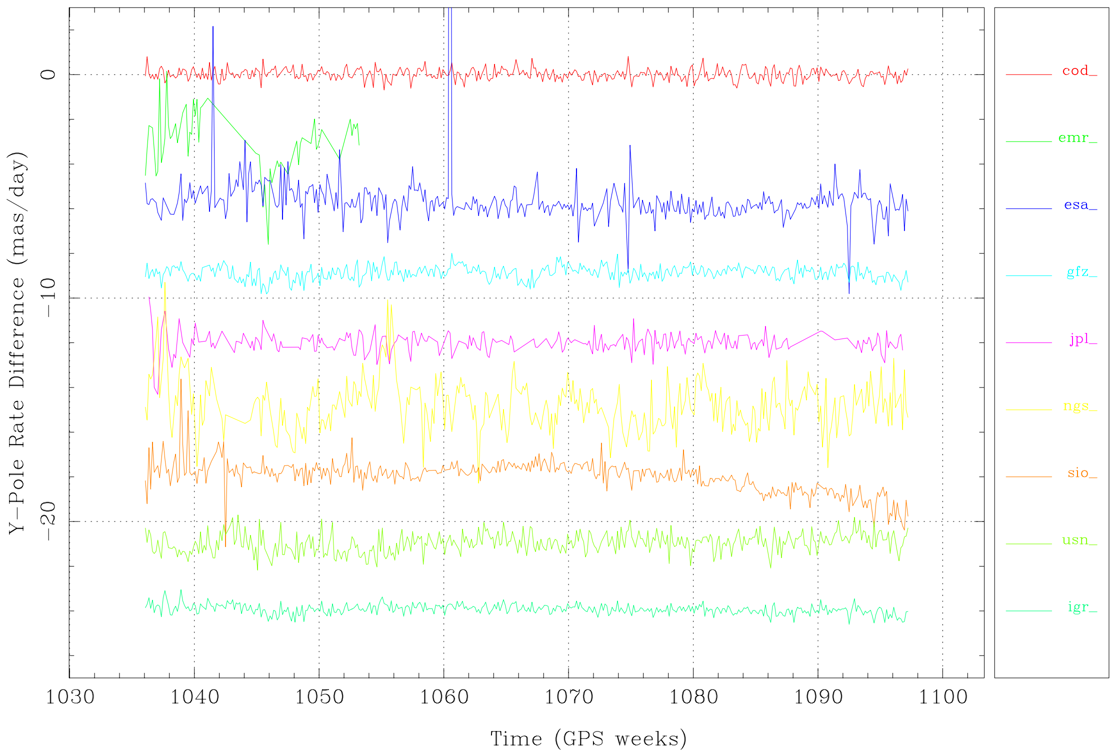


Figure 37: Daily AC Rapid y-Pole-rate Differences w.r.t. the IGS Final y-Pole-rates. ACs are shifted by 3 mas/day.

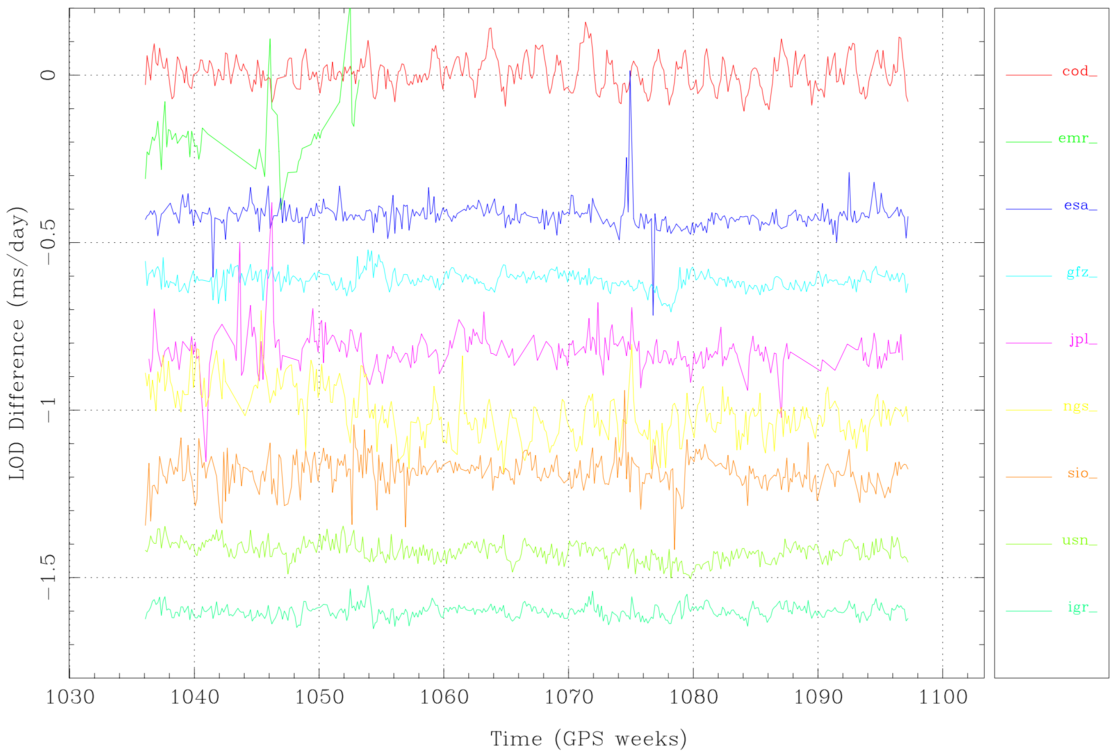


Figure 38: Daily AC Rapid LOD Differences w.r.t. the IGS Final Pole. ACs are shifted by 0.2 ms/day.

Current State of IGS Analysis: Quality Assessment

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Abstract

In this paper we examine the current state of the IGS analysis of GPS data and the needs of users. Since the initial sessions of the meeting examine near real-time analysis issues, we will examine the conventional IGS products. We will examine the needs of users for knowing the quality of both IGS products, and more fundamentally the quality of individual satellites and stations in the IGS network. There already exists a number of methods that can be used to assess IGS quality and we will review the contents of these existing mail, ftp, and web sites. We will consider how best to report marginal satellites and sites to users particularly in the form of interactive web based tools that could be developed, and how to integrate the existing information into a coherent assessment tool for users.

Introduction

The International GPS Service generates products from the analysis of GPS data that are made available through international data centers. The primary IGS data center is located at the Goddard Space Flight Center in Greenbelt, Maryland (cddisa.gsfc.nasa.gov). The products are stored in directories, accessible with anonymous ftp, with names of the form gps/products/[WWWW] where [WWWW] is the GPS week number. The current IGS products are (a) orbits for the GPS satellites that are available in three forms: final orbits; rapid orbits; and predicted orbits, (b) Earth orientation parameters, (c) tropospheric delay estimates, and (d) combined terrestrial reference frame SINEX files, one for the week and the other an accumulation to the week. In addition to the products themselves there are many summary and log files that contain a wealth of information about the products if the correct files are examined. In addition to these official products, there are other products in development that are available but are not deposited in the standard IGS product areas. These include satellite and ground receiver clock estimates, ionospheric delay maps, and combined GPS/GLONASS analyses. In this paper, we will discuss mainly the quality of the official products.

Within the area of quality we will consider timeliness and accuracy. For accuracy, we need to consider not only the accuracy of the products but also the quality of the data input to the analyses. In the latter area, we consider not only the GPS stations and receivers but also the satellites. In addressing these issues we also consider the needs of the users. We start the discussion, with user needs and then consider timeliness and accuracy.

User Needs

There has not been a recent widespread survey of the users of the IGS products but based the activities of the research community the main uses of the IGS products are reasonably clear. Probably the most used IGS products are the orbit files, although for volume of data transferred, the RINEX files from the IGS stations are the largest. The Earth orientation parameter (EOP) files are also widely used by the International Earth Rotation Service (IERS) but because the IGS orbits are distributed in an Earth fixed frame, the EOP parameters are not necessarily needed for processing GPS data. As users become more aware of the availability of the new IGS combined SINEX files, their use should increase for tectonic studies. The ways the tropospheric delay files are used is not clear at the moment although most likely these are used to evaluate the utility of these types of data in meteorological forecasts. Since these files are currently only available about 4-weeks behind real-time, their latency is too large to be of use in forecasting. The clock estimates are being studied by the international timing community as a means of transferring time globally with sub-nanosecond accuracy. We will concentrate here on the needs of users for precise positioning using IGS products and data. We will also emphasize that the IGS supports the research community and because all of the major GPS analysis programs are used by the IGS analysis centers, the IGS provides a natural framework for making significant improvements to accuracy of GPS results. Such improvements are very evident when the evolution of quality of GPS results is examined over the last decade.

Timeliness

For many users, the timeliness of products is important. For groups working near real-time this is particular important. But also many geophysical researchers who operate continuous GPS networks want results to be available at known times so that they can be sure that their processing can be done in autonomous fashion. To evaluate the timeliness of the IGS orbit products we examined the difference between the product date and the time-stamp on the file at the cddisa.gsfc.nasa.gov data center. We did this for files from late 1998 to the current date. (We can’t use this technique to go back too far in time because the file time stamps may have been reset when files are moved between storage areas). The results are shown in Figure 1 for the IGS final, rapid and predicted orbits. The two large excursions in the results starting in late July 1999 and the beginning of 2000 corresponds to a large disk failure and a particularly difficult Y2K transition, respectively. Excluding these intervals, the delivery of the IGS final orbit has been very reliable and generally within 3-weeks of real-time. The rapid and predicted results are more erratic and some of the excursions here may be due to re-posting of results rather than date of original transmission. However, if results are re-posted then users working with these products, in near real-time, would not have the best product at the time.

Probably the most worrisome feature of Figure 1, is the "single-point" failure mode of the results. The loss of the cddisa data center caused large delays until the use of alternative data centers was implemented by the IGS analysis center. The IGS should develop more formal contingency plans for the loss of a data center, and encourage the organizations that fund the data centers to allocate greater resources to ensure redundancy within the data centers themselves.

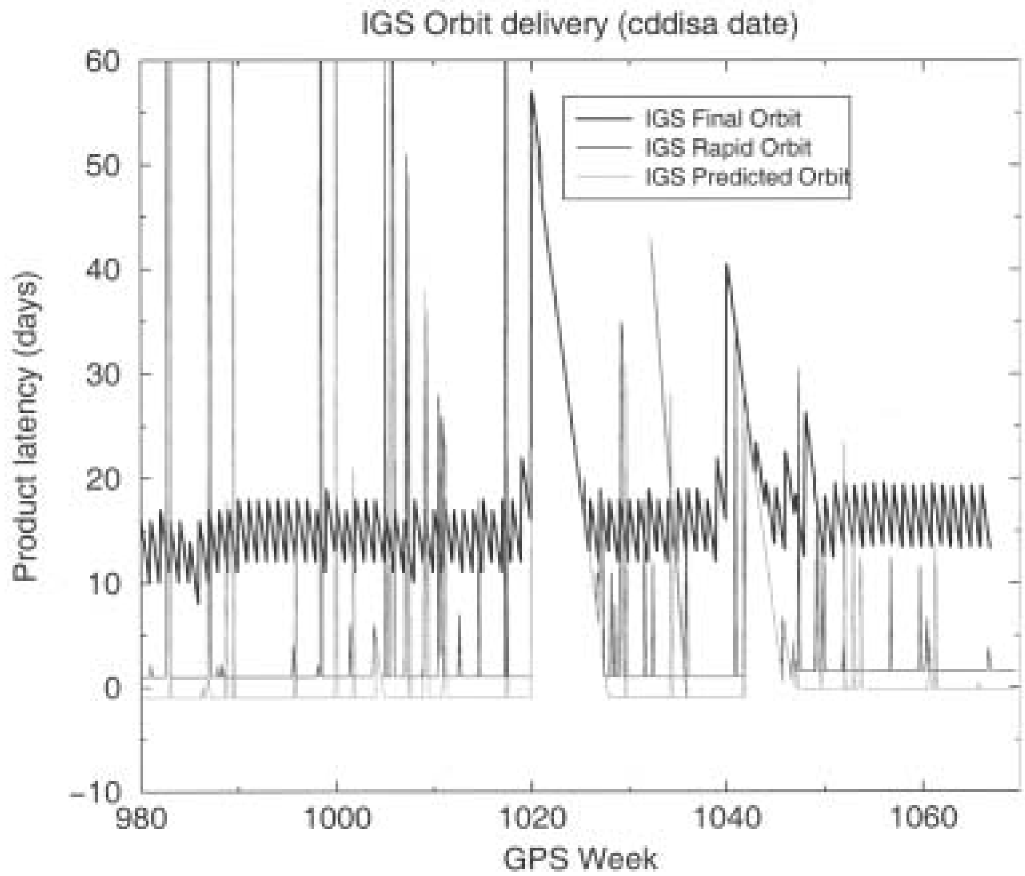

Figure 1: Difference between product date and file stamp for the interval between Oct 18, 1998 and July 2, 2000 shown as a function of GPS week number. The IGS final orbit (black line) is posted once per week, which explains the saw-toothed structure of the results. The rapid (red curve) and predicted (green curve) are posted daily. For results prior to Week 1042, the time difference has 1-day resolution of due to the nature of the time stamps.

Product Quality

There are a number of methods available for assessing the quality of the IGS products and the contributions of the individual analysis centers. The longest running product of the IGS is the final orbit of each satellite given in the SP3 format and these files have accuracy assessments each satellite. In addition, there are summary files that report the quality of each analysis center. Users can assess the accuracy of the products, if they know to look in the correct places in the files. However, what is not clear from these summaries is why a particular satellite is bad on a given day, and which parts of the orbits may be good to use for satellites that have thruster firings during the day. It is also not clear from these summaries, how individual analysis centers can improve their results for poorly behaved satellites. In particular, there are a group of satellites whose momentum wheels have either partially or fully failed, and while the list of these satellites is given in some IGS reports, conveniently finding this information is not easy. Efforts to improve the overall quality of the IGS analysis centers should concentrate on sharing this type of information and making available likely causes of problems rather than simply reporting (through RMS scatters of results) that a problem exists. These types of studies are carried out and disseminated in IGS reports by individual centers but what seems to be needed in more directed access to these results.

The other major effect on the quality of the IGS products is the operation of the GPS receivers in the network. Problems with receivers and/or the configuration of the stations are probably one of the greatest issues facing the IGS. In this category there are many facets that effect both the IGS analysis centers and the users of IGS data. The overall quality of the IGS data set and position results is impressive. Shown in Figure 2 are histograms of the RMS scatters of the position estimates from the 67 weeks of the combined IGS SINEX files after linear trends are removed from the results. The median RMS scatter for the horizontal components is about 2 mm and for the vertical 6 mm.

The average statistics of the IGS position determinations does not reveal the important fact that there are failures of some stations that can dramatically effect users if they are using these stations as the primary link to the IGS reference frame. Also not revealed in the statistics are the temporal and spatial correlations with the results. Within the IGS community there are some well-known receiver failures such as the MADR/MAD2 where for almost 3-years the station returned data regularly but the position estimates showed multi-centimeter scatters. Similarly, near the end of 1996 the WETT site started to show anomalous position estimates although the RINEX data from the site was not obviously corrupt. As far as we know, the data from these sites can still be obtained during these intervals by anyone doing “historical data” processing, nor do the IGS log files make any mention of the problems with these data during these times.

There are web sites that can be accessed to see the time series either from the IGS analyses or individual analysis centers. The Jet Propulsion Laboratory site http://sideshow.jpl.nasa.gov/mbh/series.html shows results from the JPL analysis. The Scripps Institution of Oceanography (SIO) site http://lox.ucsd.edu shows results from the SIO analysis. Both of these analyses show daily position estimates. MIT maintains a site http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC.html that shows results from different IGS analysis centers and recently from the IGS combined SINEX file. The IGS combined results are now updated weekly. This latter site allows results from the combination and from thee different analysis centers to be overlaid pair-wise. In all these sites, a possible problem with assessing the quality of data from site is that times when results from are poor, the data is likely not be included in the time series plots. This is particularly the case when sites are trying to present geophysical results (such as velocity fields) in addition to the time series. For a user of IGS data, the problem arises that it is not always clear when results from a site are missing whether this is due to poor quality data or if, due to communication problems, the data were simply not available in a sufficiently timely fashion to be included in the IGS analyses. Currently, there is no easy way for a user to access this information.

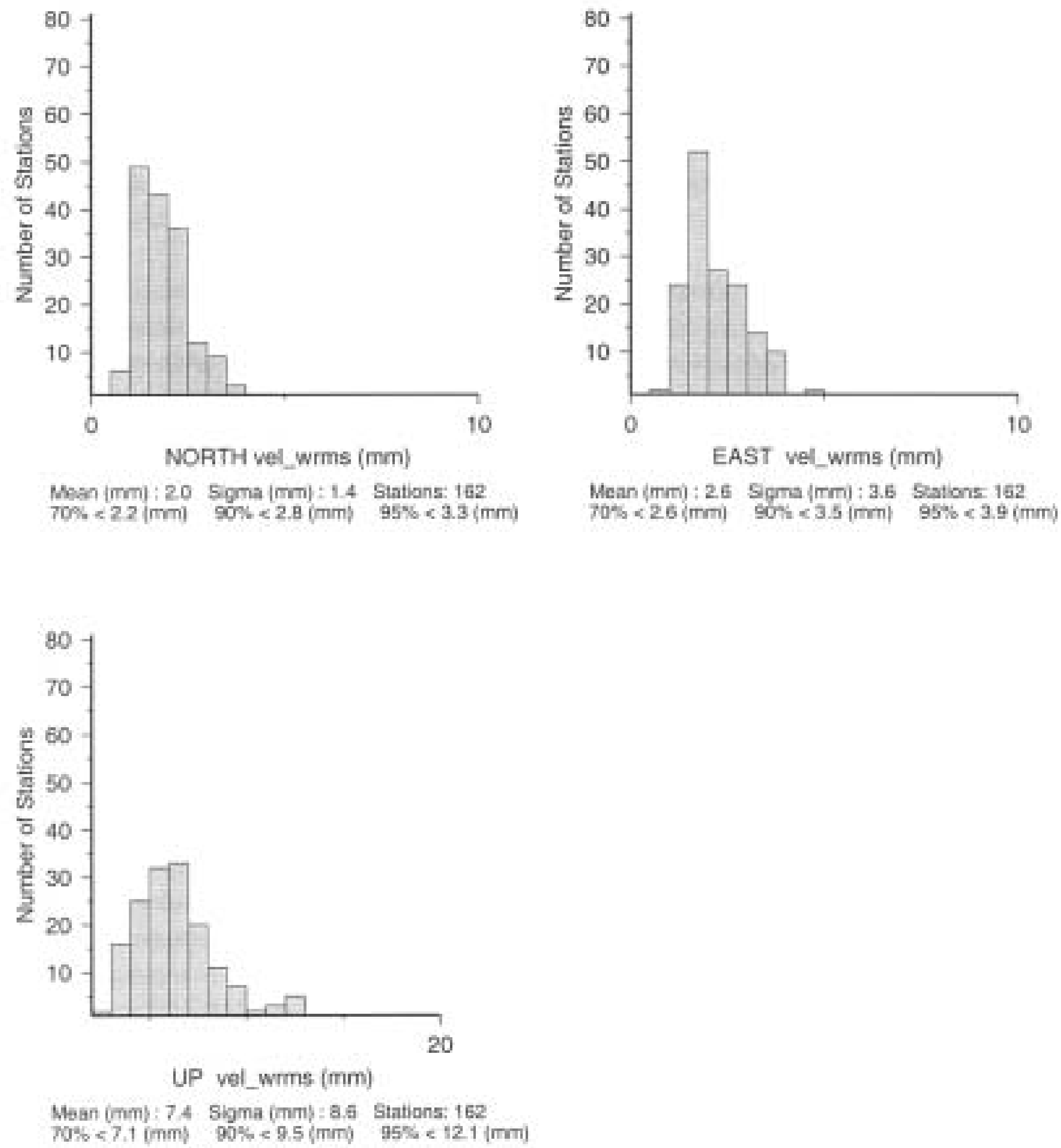

Figure 2. Histograms of the RMS scatter of the site position estimates (about a linear regression) from the weekly IGS combined SINEX files. In North, East and Up the median RMS scatters are 1.8, 2.0, and 6.2 mm, respectively.

In Figure 3, we show a recent example of the subtle failure of an IGS station and the way that this can effect IGS analysis (these results can be viewed and obtained from the MIT IGS web site). (On both the JPL and SIO web sites, the time series end near the beginning of 2000 although SIO continues to include the site their IGS submissions.) What has precisely happened at this site is not clear although all three components of the site position are affected. It is also that the data from the site is not obviously corrupt especially in early 2000 with the first northward motion where the error bars do not appreciably change size. (The most recent results have larger error bars suggesting that large portions of the data from the site are either not in the RINEX files or are being deleted during data analysis.) It is also clear that the COD analysis center stopped processing data from this site although the reason is not clear. Currently there is no formal forum for analysis centers to exchange information about the problematic sites. A user of data from this site would also find it difficult to know that data from this site was problematic.

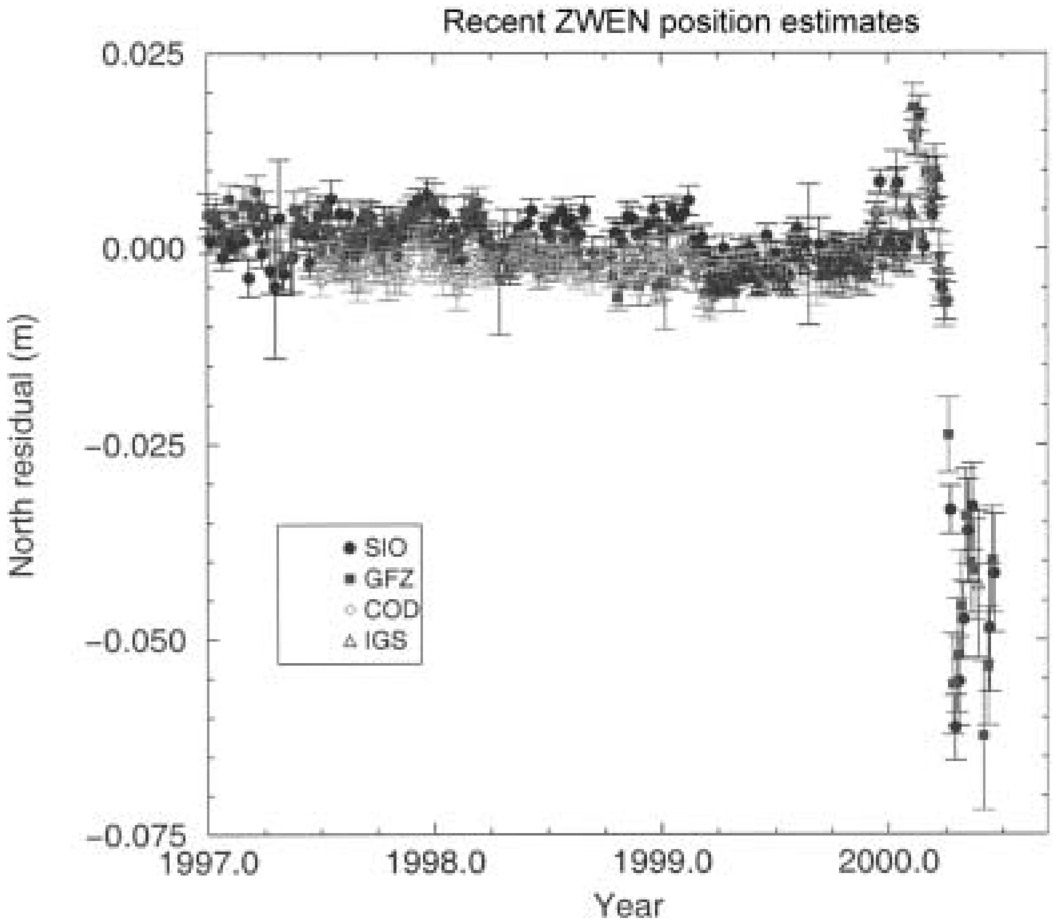

Figure 3: Recent time series for the North component of the IGS site ZWEN. There clearly is some failure of the site although it continues to generate results that are sufficiently high quality to be included in some IGS analysis center submissions.

Examination of all the results from the IGS analyses and other regional analyses such as the SCIGN array in California show a variety of failure modes of GPS receivers whose precise origins are rarely clear. In some cases, the reason is known. A specific case is the IGS SELE in Central Asia. In early 1999, the horizontal coordinates of the site show erratic daily deviations with amplitudes of 10-20 mm although the quality of the phase data seemed largely unaffected. The reason for the problem was traced to a loose antenna mounting (the antenna was literally being blown around by the wind). Although many IGS analysis centers include this station, there was never any report to the station operator that there was a problem. For many IGS stations, it is not clear that the operators of the stations process their own data because one of the advantages of being an IGS station is that your data is processed by the IGS. Currently, there is no formal feedback mechanism to station operators from the IGS analysis centers. Various sites in the Southern California Integrated Geodetic Network (SCIGN) have shown failure modes which appear to be related to water entering antennas and cables. Again, these failure modes do not necessarily produce obviously corrupt phase data; just the position estimates can be erratic.

One other class of failure mode is weather related. A number of IGS stations are located in regions where snow can accumulate during the winter. Depending in the raydome configuration, the present of snow near, in and on the antenna can have a dramatic effect on the position estimates. One of the extreme cases in the Antarctic site CAS1 where the height changed nearly 100 mm over a six-month interval. A visit to the site showed that the raydome on the antenna had been damaged and it was replaced. However, careful examination of date the raydome was replaced shows that the height of the site had returned to its nominal value about 1-month before the replacement. The implication is that the anomalous height changes were not due to damage to the raydome but rather due to snow entering the area through the hole in the raydome. This is a very remote site and so there were no direct observations of the sites at the time the height was anomalous. The effects of the presence of snow and other corrupting signals can be quantified using the signal-to-noise ratio (SNR) from the GPS receivers. Standalone software is available (http://www-gpsg.mit.edu/~tah/snrprog) that will read RINEX files with SNR included (e.g., by using the S1 and S2 observable types in the teqc program) and generates estimates of phase residuals to be expected from interfering signals. This analysis technique has been very successful at detecting the corrupting effects of the presence of snow. It can also show whether an anomalous change in station position is due to the receiver or to motion of the monument.

Some IGS sites show non-secular position variations whose origin is not clear. One very clear example is the permafrost site at Yakutsk. This site shows annual deviations in it north position with peak-to-peak variations of nearly 20 mm. The height shows even larger variations. Local measurements to a nearby site on a building have shown that these motions are due to the movement (most likely tilting) of the monument in the permafrost. Again, there is no easy way for a general user of IGS data to know that this site is problematic. Nearly all IGS sites show annual height variations whose cause is not directly known. In some cases, a portion of the movement could be due to atmospheric pressure loading and in other cases they could be due to ground water effects, either through loading and/or soil expansion and contraction. In many of the IGS log files, the precise configuration of geologic setting of a site is not given (in other cases, the descriptions can be quite expansive). As interest in interpreting non-secular motions of sites increases, there will need to be greater emphasis placed on the configurations of stations.

Enhancement of IGS Quality

Fundamentally, the quality of IGS products is controlled by the quality of station and satellite data used in the analyses. Currently a number of IGS stations yield problematic data and the characteristics of a number of satellites is less than desirable. Correction of these problems or increased dissemination of information about the causes of problems would increase the quality if IGS analysis and aid users of both the products and data.

A subtler problem is the overall accuracy of the GPS results being currently obtained. This is a more difficult problem because of the uniqueness of GPS in its temporal resolution and the overall number of stations. The IGS is at the forefront of developing standards that allow combination of initially results from different IGS analysis centers but now also includes results from different techniques. These rigorous combination procedures are now being investigated by the IERS and possibly in the future the IERS will the lead operational entity that makes the combinations. Such studies are now in their infancy but in long run will hopefully provide improvements to all techniques in the same way that IGS analysis centers have all improved over the last few years. Some recent combination results of merging VLBI and GPS with internally consistent earth orientation parameters have suggested that the VLBI results may be degraded by the combination. In examining time series from both systems the indication is that some part of the annual signals seen in GPS results may be artifacts (possibly induced by orbit modeling errors that have an annual modulation due to the orbital period of the GPS satellites). However, the assessment is difficult due to the sparse temporal and spatial coverage of VLBI measurements. Satellite Laser Ranging (SLR) results are starting to become available and these data may help clarify the situation.

Conclusions and Recommendations

While the overall quality and timeliness of IGS products is very high, we have some recommendations that should enhance these characteristics even more.

Timeliness

The IGS is very dependent on its data centers and we recommend that

- Formal contingency plans be developed and tested that allow transition between data centers in the event of a failure of one the centers; and
- The funding agencies for the data centers be made aware of their importance and be encouraged to provide sufficient funds to make the data centers more robust.

Quality

Since the IGS depends so much on the quality of the data from the IGS stations and the users of the products depend on these same data, we recommend that

- The IGS develop plans to have a more positive feedback between the site operators, the IGS analysis centers, and the IGS product and data users. Such plans, we imagine would include autonomous system to monitor station quality through both phase and position quality. When a station appears to be failing the IGS should be proactive in contacting the site operator to ascertain the problem and in informing users of the problems. A web site, maintained by the central bureau, could have a ranked list of sites that would be updated at frequent intervals. A historical ranked list should also be maintained for users that are processing older data.
- The IGS data centers should be encouraged to move data files for stations that were known to be corrupt from the main data areas to other areas where users will be aware that they use the data at their own risk.
- Station operators should be encouraged to make measurements to local reference sites at sites that are suspected of being unstable and that these local data be made available to the IGS data centers for anyone to process.
- The IGS encourage regional data centers to include the SNR in RINEX files. The impact on the size of the files is about a 10% increase in compressed files. These RINEX files can then be used as part of the monitoring system and provide a means of assessing quickly whether the degradation of site positions is receiver or monument related.

Reference Frame Working Group Technical Report

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Abstract

Natural Resources Canada's (NRCan) Geodetic Survey Division (GSD), on behalf of the International GPS Service (IGS) and its Reference Frame Working Group, combines a consistent set of station coordinates, velocities, Earth Rotation Parameters (ERP) and apparent geocenter to produce the IGS official station position/ERP solutions in the Software Independent Exchange (SINEX) format. The weekly combination includes solutions from the Analysis Centers (AC), while the Global Networks Associates Analysis Centers (GNAAC) provides quality control.

The weekly AC solutions include estimates of weekly station coordinates, apparent geocenter positions and daily ERPs. The ACs also provide separately, satellite orbit and clock estimates as part of their daily products, which are independently but consistently combined by the IGS AC Coordinator to produce the IGS orbit/clock products. All the AC products are required to be in a consistent reference frame. The combination of station coordinates originating from different ACs involves removing all available constraints and re-scaling the covariance information. The weekly combined station coordinates are accumulated in a cumulative solution containing estimated station coordinates and velocities at a reference epoch.

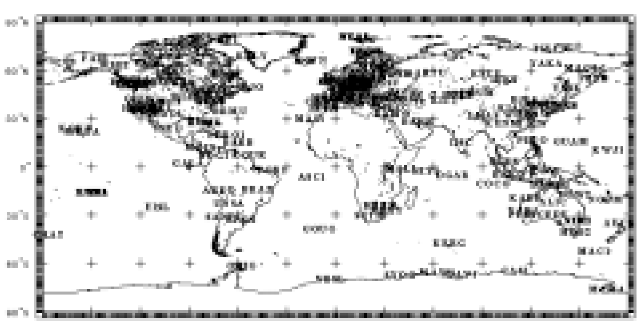


Figure 1. Stations in the Cumulative Solution

The weekly combination generally includes estimates of coordinates for 120 to 140 globally distributed stations. While the cumulative solution currently includes approximately 250 stations, about 180 (Figure 1) of them have complete information and reliable velocity estimates. The IGS combined products are required to be consistent with the most recent realization of ITRF (currently ITRF97 (Boucher et al., 1997)). This is done by transforming the weekly and cumulative solutions, respectively using 7 and 14 Helmert transformation parameters (3 translations, 3 rotations, 1 scale and their respective rates). The transformation parameters are determined from a subset of 51 high quality, globally distributed and collocated (with other space techniques) stations, also known as Reference Frame (RF) stations.

Since the beginning of 1996, weekly comparisons with ITRF97 show an accuracy of 3-4 mm horizontally and 10-12 mm vertically. Gradual improvements are apparent. Various non-random effects are present in the station coordinates time series residuals, such as periodicities and discontinuities. Equipment, local environment and processing changes are the causes for a number of discontinuities.

Introduction

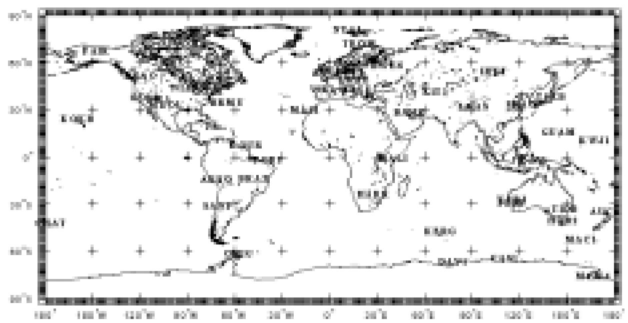


Figure 2. IGS stations used to realize ITRF97

The IGS contribution to ITRF can be subdivided into two main initiatives. First, the participation of ACs and IGS in the ITRF solutions and second, the realization and dissemination of ITRF. The IGS contribution to ITRF2000 consisted essentially in a cumulative solution that included data between GPS weeks 0837 and 1088 (96/01/21 – 00/11/18). The solution involved 167 stations distributed as shown above in Figure 1. The ITRF realization is accomplished with a station subset of the IGS network. For the realization of ITRF97, 51 high quality stations were selected (Figure 2) (Kouba et al., 1998). The accessibility to the reference frame is facilitated through the combined "IGS core products" of station coordinates, the Earth Rotation Parameters and/or the precise orbits, and the satellites/stations clock solutions. The IGS Reference frame realization of ITRF can be accessed, by GPS users, with the precise code and phase observations. The IGS participation (IGS stations) and the IGS realization aspects are very closely related. Data used to realize an IGS ITRF will also be subsequently contributed to the IERS combination process to generate ITRF at future epochs.

IGS Participation to ITRF2000

The ITRF2000 combines solutions from a number of space techniques including Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR), Doppler Orbitography by Radio-positioning Integrated on Satellite (DORIS) and GPS. The IGS solution was part of a group of about 20 global solutions used for the realization of ITRF2000. Five other GPS (AC) global solutions were also submitted as well as six densification solutions.

Between GPS weeks 0837 (96/01/21) and 0977 (98/10/03), the weekly combined solutions from JPL, MIT and NCL Global Associates Analysis Centers (GNAAC) were used in the cumulative solution. Since GPS week 0978 (98/10/04), the seven Analysis Centers (AC) (CODE, ESA, GFZ, JPL, NGS NRCan and SIO) are used in the combination, while the GNAAC are used to quality control the weekly combination (Table 1).

The AC solutions are combined using the least-squares technique. All the available covariance information between the station coordinates within each AC solution is used. Since GPS week 1013 (99/06/06) the weekly combination also includes daily ERP (pole position and rate, calibrated length of day (Mireault et al. 1999)) and since GPS week 0978 (98/10/04) weekly apparent geocenter estimates. The cumulative combination is updated every week with the latest weekly combination. This cumulative solution includes station coordinates and velocities for about 250 sites. Of those, about 180 have reliable velocity estimate. The cumulative solution is currently aligned to ITRF97 by applying a 14-parameter transformation estimated using the set of 51 RF stations. Inner constraints in origin, orientation and scale (and their rates) are applied to the solution. Due to the large number of input solutions used and the variety of sources, there are some concerns for potential numerical instabilities; but, at this time, they appear to be that under control.

Table 1

IGS Analysis Centers (AC)	
CODE	Center for Orbit Determination in Europe, AIUB, Switzerland
ESOC	European Space Operations Center, ESA, Germany
GFZ	GeoForschungsZentrum, Germany
JPL	Jet Propulsion Laboratory, USA
NOAA	National Oceanic and Atmospheric Administration / NGS, USA
NRCan	Natural Resources Canada, Canada
SIO	Scripps Institution of Oceanography, USA
IGS Global Network Associate Analysis Centers (GNAAC)	
NCL	University of Newcastle-upon-Tyne
MIT	Massachusetts Institute of Technology
JPL	FLINN Analysis Center Jet Propulsion Laboratory

IGS Analysis and Associate Analysis Centers

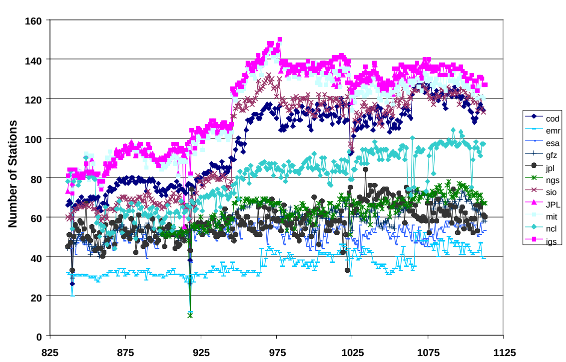


Figure 3. Number of AC/GNAAC/IGS stations in the weekly solutions

The number of stations contributing to weekly SINEX solutions has increased steadily since the beginning of IGS. The number of stations has gone from 25 to 60 stations in 1996 to between 40 and 130 stations currently (Figure 3). There is a significant overlap between the stations used by each AC. Out of the 130 stations actively used in the IGS network, about 95 are used weekly by 3 or more ACs. Human and computer resource limitations are the main factors constraining the number of stations used by each AC. The ACs have continuously upgraded their software and approaches, which has resulted in gradual improvements of their solution results. Ideally, all the processed data should be done in a consistent manner. But, due to the large quantity of data and processing load involved, none of the ACs has yet to complete the reprocessing. On the hardware side, receiver/antenna, communication and computer technologies have also progressed, resulting in higher quality data, faster access and processing.

The standard deviations of residuals between the ITRF2000 and the IGS solution are summarized in Table 2. They show a horizontal position precision approaching the 1mm level and the vertical component approaching 3mm. The velocity precision is approaching 2mm/y horizontal while the vertical component is about 5mm/y. These are probably somewhat optimistic, since the GPS solutions in the ITRF2000 combination used, to a large extent a common set of IGS stations. As mentioned above, the common station coordinates are to a large extent derived from a common set of code and phase measurements.

Table 2.

	Position (mm)	Velocity (mm/y)
Latitude	1.1	1.8
Longitude	0.9	2.3
Height	3.1	5.1

IGS standard deviations (STD) with respect to ITRF2000

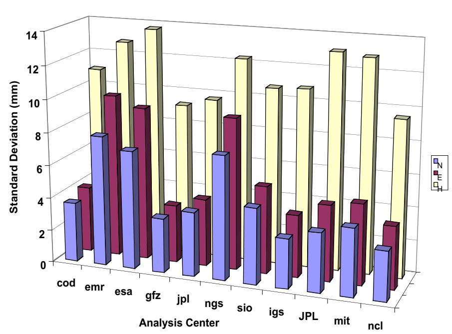


Figure 5. AC/GNAAC Station Coordinates Residuals STD with respect to the Cumulative Solution

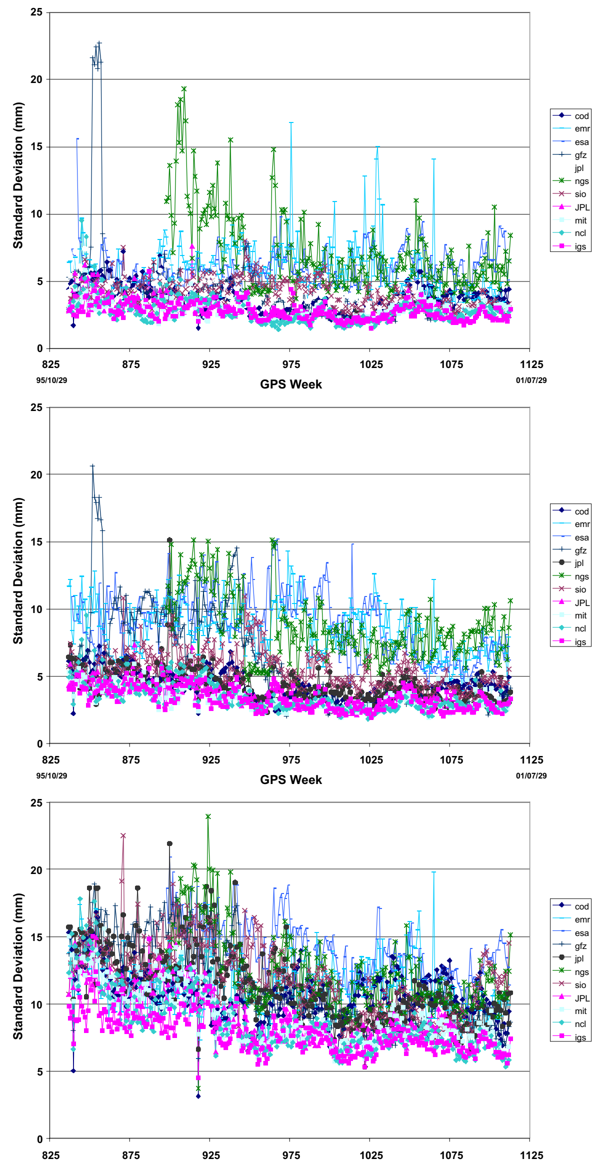
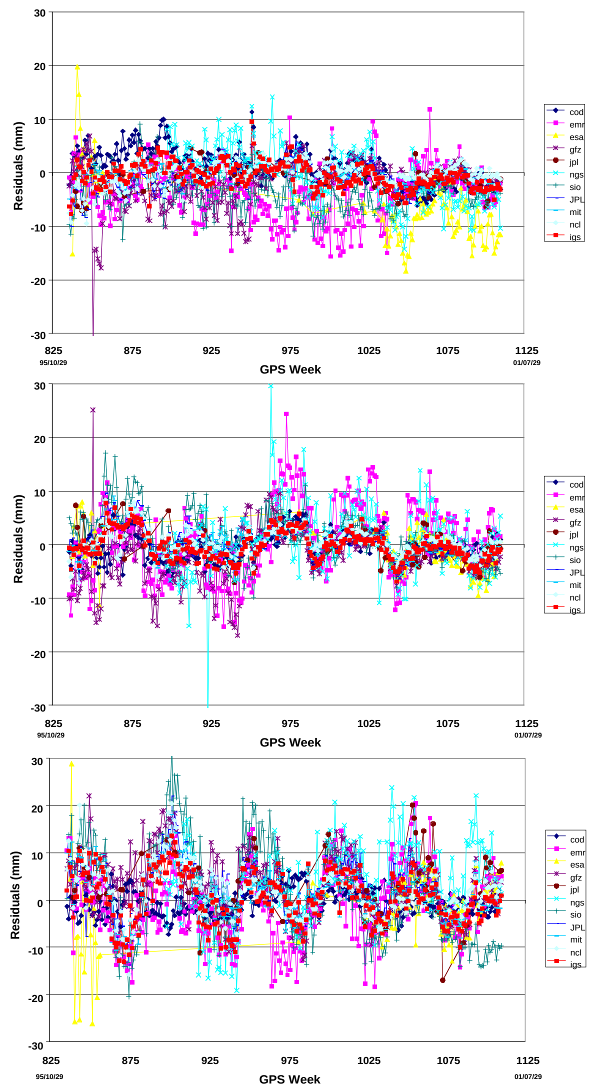


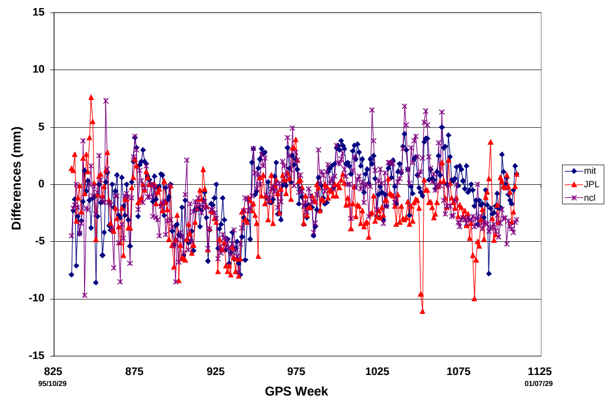
Figure 4 a-b-c
Latitude, Longitude and Height weekly STD with respect to Cumulative Combination

The standard deviations of the residuals between the weekly and the cumulative solutions for all stations have been estimated for each center (AC/GNAAC/IGS). Figure 4 a-b-c shows the time series of the standard deviations for the latitude, longitude and height components. The IGS and GNAAC standard deviations are 3-4mm horizontal and 7-10mm vertical (Figure 5). The ACs are also generally close to that level. Also noticeable is the gradual improvement of the statistics, especially in the height component (Figure 4c). The bandwidth of the standard deviations is also decreasing, indicating a better level of agreement between the various solutions. Similar improvements have been reported for the precise orbit/clock combinations also done weekly by the IGS AC Coordinator (http://www.aiub.unibe.ch.acc.html).

At the station level, a detailed look at the residual position time series shows the longer-term systematic effects present at some stations. For example, Figure 6 a-b-c shows residuals of the weekly AC/GNAAC/IGS solutions with respect to the cumulative solution for the latitude, longitude and height components at station Penticton (DRAO). An annual period with amplitude of about 7mm is noticeable in the height component. Some periodic effects can also be seen in the longitude residuals. The level of agreement among the AC's also improves with time. The RMS of the residuals for the AC/GNAAC/IGS are respectively (Lat:5.4/2.4/2.4, Lon: 5.3/2.7/2.7, Hgt: 8.2/5.7/5.4). This station shows a rather large periodic signal (although not the largest). Most stations have little or no significant periodic signal. This periodic effect is possibly caused by variations in seasonal atmospheric pressure loading, which are not currently modeled in AC solutions. A detailed analysis of the periodic effects will be possible once the reprocessing is completed. Occasionally, biases do exist between the solutions, usually in the height component. Those biases are sometimes caused by incorrect antenna height used in the processing. The redundant time series are very useful to separate isolated outliers from ongoing biases. As part of the reprocessing of the AC solutions, a number of stations



Figures 6 a-b-c. Latitude, Longitude and Height residuals between the weekly and cumulative solutions at station Penticton (DRAO) coordinate residuals time series discontinuities problems have been explained and corrected. Comparisons done in the past between the weekly and the cumulative solutions statistics have indicated that 60-70% of the noise is caused by short-term effects, while the rest has a longer-term signature. Those long-term signatures often take the form of discontinuities, which tend to affect mainly the height. They are generally caused by either blunders, equipment or processing changes.



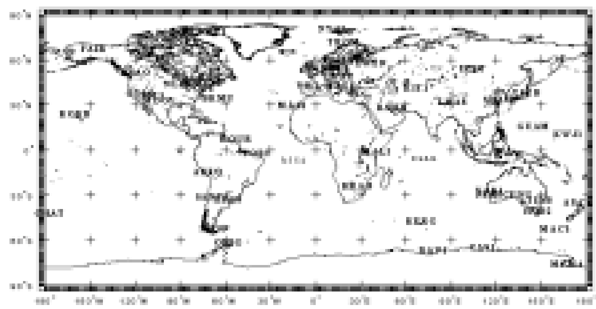
Penticton (DRAO) Height differences (IGS-GNAAC)
Figure 7

Figure 7 shows height differences between the IGS and the GNAAC solutions at station Penticton. The standard deviation is 3 mm over a period of about 5 years. Differences of this magnitude are expected, due to differences in the processing strategies of the GNAACs. A small bias is apparent in the early weeks, a more refined analysis is expected to explain and potentially correct this artifact.

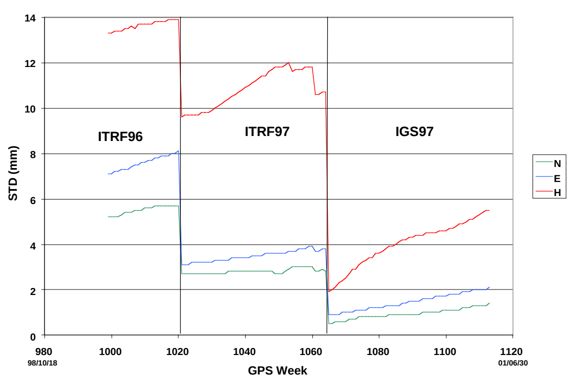
The reprocessing of the AC SINEX solutions between GPS weeks 0837 (96/01/21) and 0977 (98/10/03) is currently underway. Two iterations have at this time been completed. During the first iteration, the most obvious inconsistencies were removed. Nearly 9000 outliers were flagged. Explanations for many outliers could be found, thus allowing for corrective measures to be applied. A second iteration was run. This allowed to test the validity of the corrective measures applied to a number of weekly solutions, and to uncover new outliers. The exact number of iterations required is yet unknown. Once complete, the reprocessing will improve the quality of the weekly and cumulative solutions as well as its consistency and traceability by using a consistent strategy (Ferland et al. 2000). This reprocessing is using all the available information provided by the ACs and GNAACs. Each solution (AC/GNAAC) is unconstrained, its covariance information is rescaled with an estimated variance factor (chi squared per degree of freedom). AC/GNAAC station coordinates estimates are compared and rejected if they exceed the thresholds of 5 sigmas or 50mm (8 sigmas and 80mm for the first iteration). The residuals in the in the variance factor estimation are determined by taking the difference between each AC and the cumulative solution. The AC and GNAAC solutions are considered independent during the processing. In reality there is a significant level of correlation between the AC solutions mainly because they use the same code and phase observations for all the common stations. The differences between the AC solutions are mainly caused by variations in the processing strategies and the network distribution. A variance factor is also estimated and applied to the weekly IGS combination, again by using the cumulative solution as a reference. This should partially compensate for the neglected correlation between the AC solutions during the weekly solution combination. Similar correlations also exist between the IGS and the GNAAC weekly solutions. This is somewhat less of a concern, because the GNAAC are used mainly for quality control. The cumulative solution also needs to be rescaled, because the parameters covariance information gradually becomes unrealistically small as weekly solutions are added. More investigation is required to properly rescale the cumulative solution.

IGS Realization and Dissemination Of ITRF2000

The current IGS realization of ITRF97 has been shown in Figure 2. It includes 51 globally distributed RF stations. The proposed set of stations to realize the ITRF2000 is shown in Figure 8. It currently includes 55 stations. All the proposed additions/changes are in the Southern Hemisphere with the objective to improve the station distribution. Two new stations are proposed in South America while one would be removed. Three other stations are proposed, one on Ascension Island in the Atlantic Ocean and one on Diego Garcia Island in the Indian Ocean as well as one in Australia.



Proposed IGS Stations for the Realization of ITRF2000
Figure 8



Weekly Reference Frame Station Coordinates Residuals STD between each Reference Frame Realization and the IGS Cumulative solutions
Figure 9

Figure 9, shows the quality of the fit between the successive IGS/ITRF realizations and the weekly updated cumulative solutions in ITRF96, starting with GPS week 0999 (99/02/28). There were already some improvements between the realization of ITRF96 and the original realization of ITRF97, and further improvements were made with the implementation of the IGS97. For ITRF96, ITRF97 and IGS97, the horizontal standard deviations went down from 5-8mm, to 3-4mm and to 1-2mm. In the vertical component they decreased from 13-14mm, to 10-12mm and to 2-6mm, respectively. The gradual degradation is caused mainly by propagated errors in the station coordinates and velocity of the reference frame realizations, as the extrapolation time increases. Preliminary tests done with the proposed IGS realization of ITRF2000 would result in sub-mm standard deviations for GPS week 1110-1114 (May 2001). The use of ITRF2000 directly would

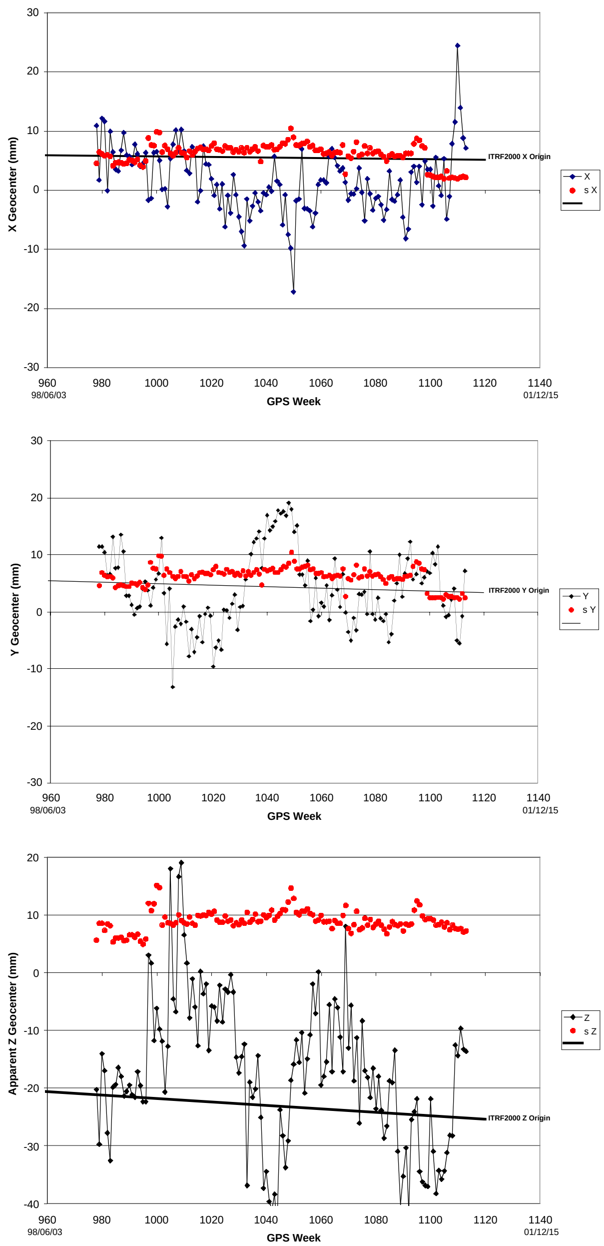


Figure 10 a-b-c . Apparent Geocenter Weekly estimates and formal sigmas as well as proposed IGS realization of ITRF2000 origin with respect to current IGS realization of ITRF97.

results in standard deviations of about 3mm horizontally and 6mm vertically for the same epoch.

The weekly estimated IGS geocenter is also affected by the proposed realization. Figure 10 a-b-c shows the X, Y and Z estimated geocenter with respect to the realization of ITRF97. The estimated weekly geocenter positions currently rely on COD, ESA and JPL SINEX solutions. The Figure 10 a-b-c also shows the position of the origin of the proposed IGS realization of ITRF2000 with respect to ITRF97. The time series show an average offset 1.6mm, 4.0mm and –17.4mm for the X, Y, and Z components in ITRF97.

The average offsets of the ITRF2000 geocenter for the same period are 5.5mm, 4.0mm and –22.7mm. This leaves a difference of 3.9mm, 0.0mm and 5.3mm for each component. This shows an improvement for each axis, specially the Z component.
The ERPs are combined in the weekly SINEX solution along with the station coordinates by making use of all covariance information. The best AC pole (and rates) are consistent at the 0.05-0.10mas (0.10–0.20mas/d), while the calibrated LOD are consistent at 20-30us. Figure 11 show the daily time series residuals for the X and Y pole (Top) and their rates (Middle) between the combined solution “igs00p02” and the AC/GNAAC. The bottom portion shows the daily difference between the combined solution and Bulletin A. The IGS combined solution and the Bulletin A are not independent, since the AC solutions

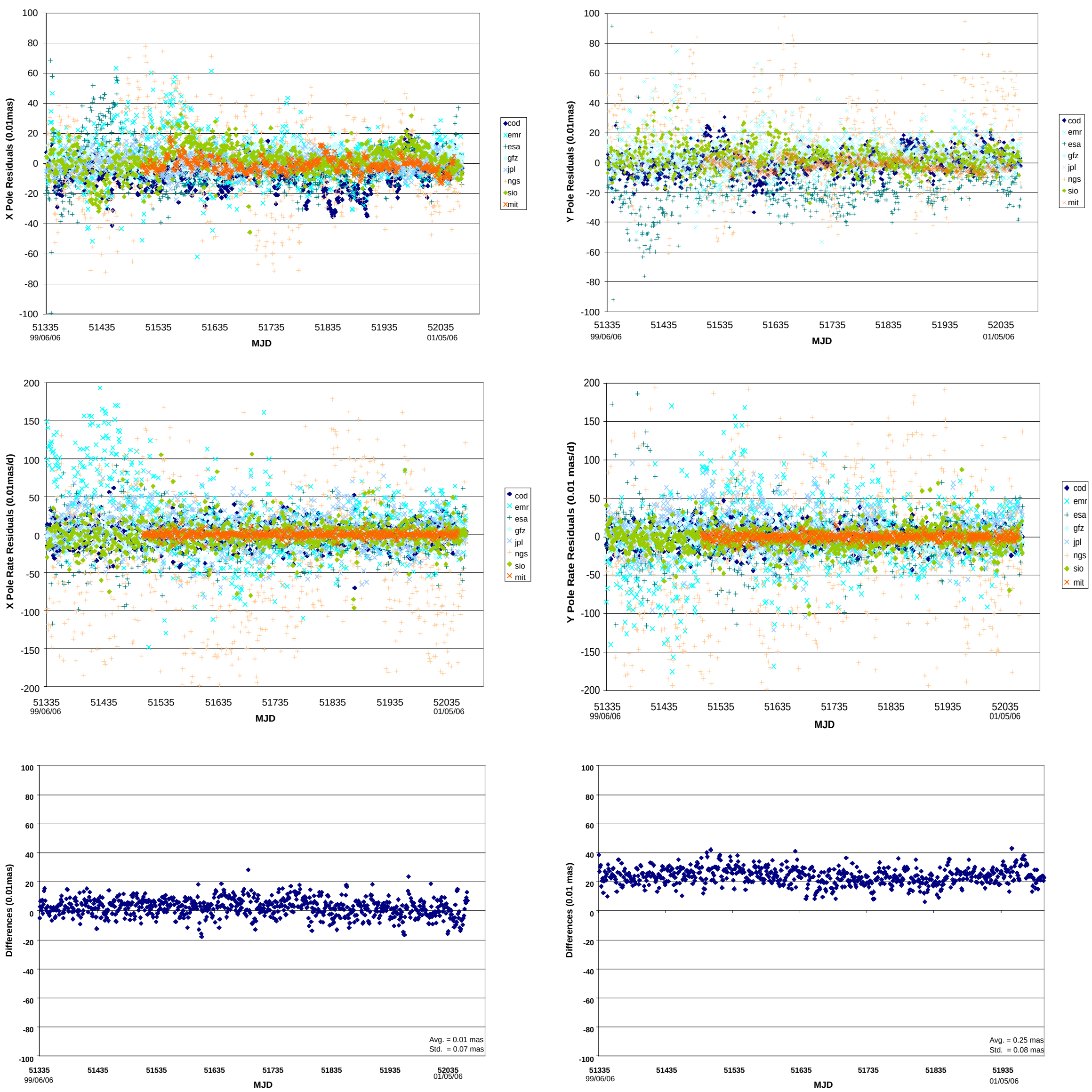


Figure 11 a-b (top) c-d (middle) e-f (bottom).
Daily X Pole, Y Pole, (top) X Pole Rate, Y Pole Rate (middle) differences between the combined solution “igs00P02” and the AC/GNAAC estimates.
Daily X Pole, Y Pole, (bottom) differences between the combined solution “igs00P02” and the Bulletin A.

contribute significantly to Bulletin A. The Bulletin A daily estimates were linearly interpolated to match the IGS combined values epochs. Small differences between the AC combined pole and pole rates are due to differences in processing strategy (e.g.: different weighting and rejection criterion). Similar daily ERPs are also estimated as part of the final GPS orbit combination process “igs95p02”. Comparison between the igs00p02 and igs95p02 show no significant average difference between them, and a noise level of about 0.07mas which is similar to the differences with respect to Bulletin A (bias removed). The combined ERPs are consistent with those combinations at about 0.05mas (0.10-0.20mas/d).

Summary

The IGS cumulative solution now contains about 270 stations among which 167 were submitted to ITRF for inclusion in ITRF2000. Analysis of the residuals of the ITRF2000 combination show horizontal/vertical position RMS of about 1mm / 3mm and horizontal/vertical velocity RMS of 2mm/y / 5mm/y. The IGS realizations of ITRF uses a subset of the IGS cumulative solution. This improves the internal stability and consistency of the weekly product alignment. The use of the 7 ACs and the 3 GNAACs provide significant redundancy and robustness to the analysis. The analysis has also shown that station statistics have a gradually improved over the years. The weekly apparent geocenter estimates show improved agreement with the proposed IGS realization of ITRF2000 origin compared to the IGS realization of ITRF97.

Acknowledgements

A large number of agencies contribute to IGS. Among them are the agencies responsible for the installation and maintenance of the tracking stations, the regional and global data centers in addition to the ACs and GNAACs already mentioned. A complete list of contributors can be found at the IGS web site (http://igscb.jpl.nasa.gov/).

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ANALYSIS CENTERS

CODE IGS Analysis Center Technical Report 2000

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Introduction

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

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

CODE is located at the AIUB. All solutions and results are produced with the latest version of the Bernese GPS Software [Beutler et al., 2001].

This report covers the time period from January through December 2000. It focuses on major changes taken place in the routine processing during this period and shows new developments and products generated at CODE. The processing strategies used until December 1999 are described in the CODE annual reports of previous years [Rothacher et al., 1995, 1996, 1997, 1998, 1999, Hugentobler et al., 2000].

CODE did commit to take over the responsibility for the IGS ACC activities from 1999 through 2002 and Dr. Tim Springer was assigned to manage this task. His unexpected announcement to leave our institute by the end of 2000 for a job in telecommunication industry was a real surprise for us and raised a number of vital questions. We had to accept his decision and the fact to loose a supporting member of AIUB's GPS research group. We were encountered with the problem to find a valuable successor and were glad that Dr. Robert Weber from the Technical University of Vienna, Austria, accepted to take over Tim Springer's position as IGS ACC.

An essential, but rather time-consuming step in 2000 was the transfer of our routine processing from a VAX/VMS cluster to a Sun E6500 server. While the IGS combination procedures were already running on the Sun system since beginning of 1999, the CODE products could be generated on the new platform starting with June 4, 2000. The related

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conversion was taken as an opportunity to review and partly restructure processing sequences. The change-over was performed without noteworthy problems in terms of product quality and availability.

A severe crash of the Unix server on January 29, 2000, caused a temporary interruption of the IGS rapid combination for two days. An unrelated malfunction of the VMS system during the same weekend did prevent the use of that system as a backup system. For the same reason, we were not able to generate the CODE rapid products for the mentioned two days.

A wide variety of GPS solutions are computed at CODE. Tables 1 and 2 give an overview of the products which are made available through anonymous ftp. In addition, a regional analysis considering about 40 stations of a sub-network of a European permanent network are processed on a daily basis. The main product of this analysis, weekly coordinate solutions in SINEX format, are regularly delivered to EUREF (European Reference Frame, Subcommission of IAG Commission X). Details concerning the delivered solution as well as a description of the different test solutions may be found in [Hugentobler et al., 2000].

Table 1: CODE products made available through anonymous ftp.

CODE rapid and predicted products available at ftp://ftp.unibe.ch/aiub/CODE	
CODwwwwd.EPH_R	Rapid orbits
CODwwwwd.EPH_P	24-hour orbit predictions
CODwwwwd.EPH_P2	48-hour orbit predictions
CODwwwwd.EPH_5D	5-day orbit predictions
CODwwwwd.ERP_R	Rapid ERPs belonging to the rapid orbits
CODwwwwd.ERP_P	Predicted ERPs belonging to the predicted orbits
CODwwwwd.ERP_P2	Predicted ERPs belonging to the 2-day predicted orbits
CODwwwwd.ERP_5D	Predicted ERPs belonging to the 5-day predicted orbits
CODwwwwd.CLK_R	Rapid clock product, 5-minute values, clock-RINEX format
CODwwwwd.TRO_R	Rapid troposphere product, SINEX format
CODGddd0.yyI	Rapid ionosphere product, IONEX format
COPGddd0.yyI	1-day or 2-day ionosphere predictions, IONEX format
CODwwwwd.ION_R	Rapid ionosphere product, Bernese format
CODwwwwd.ION_P	1-day ionosphere predictions, Bernese format
CODwwwwd.ION_P2	2-day ionosphere predictions, Bernese format
GLOwwwwd.EPH_5D	5-day GLONASS orbit predictions (based on broadcast)
CGIMddd0.yyN_R	Improved Klobuchar-style coefficients, RINEX format
CGIMddd0.yyN_P	1-day predictions of improved Klobuchar-style coefficients
CGIMddd0.yyN_P2	2-day predictions of improved Klobuchar-style coefficients
P1C1.DCB	Moving 30-day P1-C1 DCB solution, Bernese format
P1P2.DCB	Moving 30-day P1-P2 DCB solution, Bernese format

Table 2: CODE products made available through anonymous ftp.

CODE final products available at ftp://ftp.unibe.ch/aiub/CODE/yyyy	
CODwwwwd.EPH.Z	Final orbits, our official IGS product
CODwwww7.ERP.Z	Final ERPs belonging to the final orbits, values for full week
CODwwwwd.TRO.Z	Final troposphere product, SINEX format
CODGddd0.ION.Z	Final ionosphere product, Bernese format
CGIMddd0.yyN.Z	Navigation messages containing improved Klobuchar-style ionosphere coefficients
CODwwww7.SNX.Z	Weekly SINEX product
CODwwww7.SUM.Z	Weekly summary files
COXwwwwd.EPH.Y	Precise GLONASS orbits (for GPS weeks 0990-1066)
COXwwww7.SUM.Z	Weekly summary files of GLONASS analysis
P1C1yymm.DCB.Z	Monthly P1-C1 DCB solutions, Bernese format
P1P2yymm.DCB.Z	Monthly P1-P2 DCB solutions, Bernese format

Currently, no real ultra rapid orbits are computed at CODE. The solution delivered to the IGS since March 2000 for comparison purposes is actually a pure prediction on the basis of our daily rapid orbit solutions. It is excluded from the IGS ultra rapid orbit combination, but might be considered as an adequate backup solution. The comparatively good quality of this solution, at least for the satellites not experiencing modeling problems, is due to the fact that the orbit extrapolation relies on long-arc data, specifically on 3-day arcs. Tests towards a true ultra rapid solution are foreseen for 2001.

The computation of precise GLONASS orbits in the framework of IGEX was stopped on June 18, 2000. CODE proposed a full participation for the IGLOS Pilot Project as soon as new GLONASS satellites are launched to provide a reasonable constellation. The combined computation of GPS and GLONASS orbits has not been started until the end of 2000. The reasons for the reserved engagement are the termination of the possibility for a continuation 'as is' (associated with the shut-down of the VMS cluster), the manpower effort considered substantial for the complete implementation of a routinely combined processing, and the steadily declining GLONASS satellite.

Changes in the Routine Processing

The major changes implemented in the CODE routine analysis for the year 2000 are listed in Table 3. During the time period covered by this report, the used models remained essentially unchanged. For details we refer to the analysis questionnaire of CODE available at the IGS CB.

Several changes are related to the modeling of the tropospheric delay. Until the end of August 2000, the total tropospheric zenith path delay was mapped with the dry-Niell mapping function. Afterwards an a priori dry delay based on the Saastamoinen model is introduced and mapped with the dry-Niell mapping function. The wet-Niell mapping function is used to map the corrections due to the wet component. Starting in October 2000, the minimum elevation angle in the rapid analysis was lowered from 10 to 5 degrees, and the estimation of troposphere gradient parameters (two per station and day) was enabled. The number of troposphere zenith parameters was increased from 4 to 6 per station-day.

Table 3: Modifications to the CODE processing strategy accomplished between January 2000 to December 2000.

Date	Doy/Year	Description of Change and Impact
30-Dec-99	364/99	Download additional station data for the GIM generation.
27-Feb-00	058/00	Create, distribute, and archive satellite and station clock files in RINEX clock format.
09-Apr-00	100/00	Differential (P1-C1) code bias values are determined as part of the global clock solution. An improvement of the clock estimates is clearly detectable.
16-Apr-00	107/00	Switch to another routine to create weekly IGS ERP file as from GPS week 1058 (solving a problem with the delivered LOD values).
06-May-00	127/00	Use of P1-C1 DCB values based on a moving 30-day combination (instead of JPL values) as a priori information.
04-Jun-00	156/00	Official CODE products are generated on the new platform.
04-Jun-00	156/00	Rapid and final clock solution based on code and phase (instead of smoothed code).
27-Aug-00	240/00	Instead of mapping the total tropospheric delay with the dry-Niell mapping function, an a priori, Saastamoinen-based dry delay is mapped with the dry-Niell mapping function, now solving for the wet component mapped with the wet-Niell mapping function.
24-Sep-00	268/00	Minimal elevation decreased from 10 to 5 degrees for the rapid solution. Solving for L1-L2 satellite antenna offset parameters as part of the ionospheric solution. Two sets of such parameters (w.r.t. Block-II/IIA and Block-IIR) are set up and heavily constrained.
03-Oct-00	277/00	Solve for troposphere gradient parameters. Number of troposphere zenith parameters increased from 4 to 6 per station and day for the rapid analysis.
29-Oct-00	303/00	Clock estimation in rapid analysis using global clusters combined via satellite clocks (instead of regional station clusters).

Contribution to ITRF2000

In March 2000, CODE submitted its contribution to the ITRF2000 reference frame realization. The solution was produced using GPS observations spanning a time interval from GPS week 0782 (Jan. 1, 1995) to GPS week 1050 (Feb. 26, 2000) and includes coordinates and velocities for 164 stations. The coordinates of all stations are constrained to the reference frame ITRF97 using a minimum constraint condition (three rotations) at the reference epoch (April 1, 1993). Figure 1 shows a comparison of the estimated velocity vectors (arrows) with the ITRF97-derived vectors (lines) for a solution which is constrained to the ITRF97 reference frame.

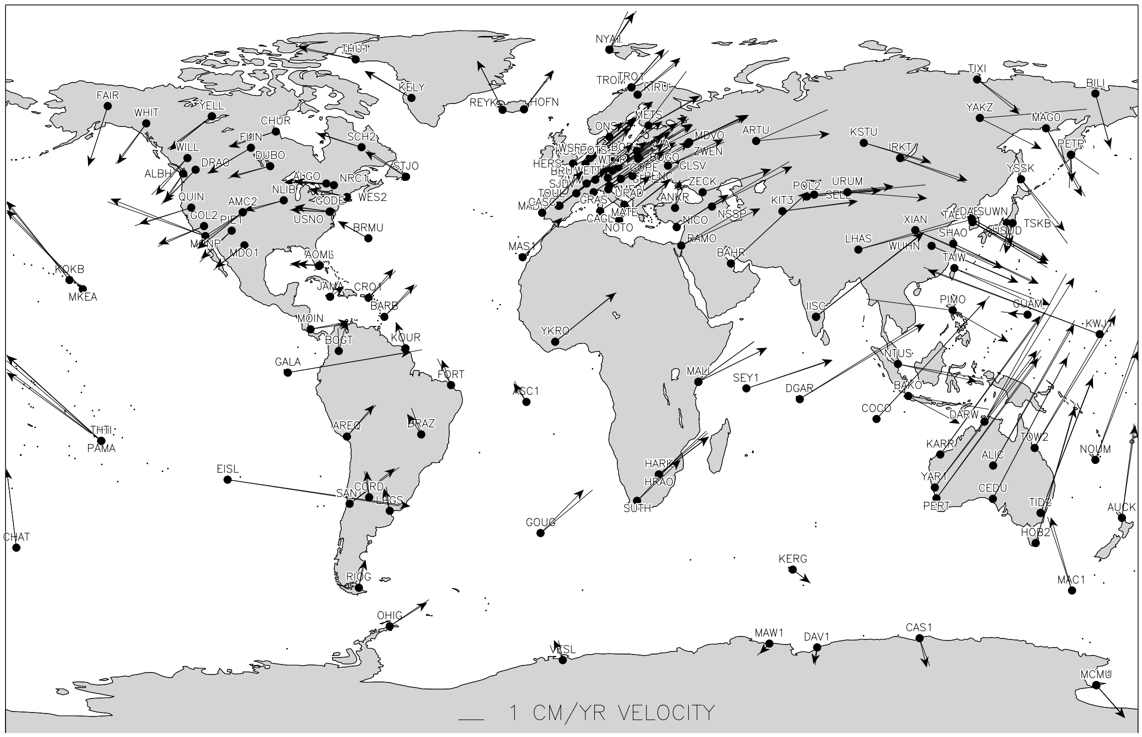

Figure 1: Velocity vectors estimates from a constrained solution (arrows) and from ITRF97 (lines).

Estimation of Satellite and Receiver Clock Parameters

A main effort in 2000 was put into the improvement of our station and receiver clock products. Relevant changes were activated in the course of the switch of the routine computations from the VMS cluster to the Unix Sun/Solaris server on June 4 (doy 156/2000). Prior to this date, the clocks delivered with the final solution were based on smoothed code, and the rapid solution did contain broadcast clock information. With the switch to the new platform, CODE started to deliver clocks based on code and phase observations in both the final and the rapid solution taking advantage of the experience gained in a transatlantic time transfer campaign using GPS carrier phase data [Dach et al., 1999]. The final clock solution is based on about 100 stations while the rapid solution contains typically 80 stations. Starting on February 27 (doy 058/2000), satellite and station clock results are archived and distributed with a sampling rate of five minutes following the RINEX clock format.

The clock zero-difference processing is based on the results from the double-difference processing. The satellite orbits as well as the station coordinates and troposphere parameters are introduced as fixed into the clock solution. The coordinates and troposphere zenith delay parameters are estimated for additional stations. Three solutions with about 33 stations each are computed independently and combined in a final step. The computing time of a complete solution is of the order of three hours. A significant fraction is due to the data cleaning procedures.

The stations are selected according to the quality of their delivered observations. The three clusters are constructed such that an optimum geometry results for each of them. As a matter of fact stations need not necessarily appear in one cluster only. Modifications in the data cleaning procedures and in particular the use of global instead of regional clusters resulted in a further improvement of the clock results as of October 29 (doy 303/2000).

Determination of Differential Code Bias Values

As part of the process of the estimation of ionosphere parameters, P1-P2 DCB values are determined for all active GPS satellites and for about 160 IGS/EUREF stations. The daily repeatability of these parameters is of the order of 0.1 ns. Combined values are computed taking into account the last 30 daily sets of values. Monthly P1-P2 DCB solutions are available as of October 1997.

Starting with GPS week 1056, the IGS analysis centers have to take P1-C1 code biases into account in order to ensure that their precise clock information is fully consistent to P1/P2 code measurements. CODE is accounting for this type of code bias as of GPS week 1057 (April 9, 2000) by solving for satellite-specific code bias parameters as part of the clock estimation procedure. The bias values are estimated directly from the data sets for which they will be applied. No use is made of C1 code measurements from non-cross-correlation style receivers (providing C1/P1/P2). Instead of these measurements, C1/P2' code measurements from cross-correlation receivers are considered. In other words, our P1-C1 DCB estimates directly reflect the code bias differences between non-CC and CC receivers as seen by an analysis center in its clock estimation procedure. Our approach works as long as a mixture of data from CC receivers and modern receivers is processed. At present, about 30-40 of about 80 stations used for the clock estimation may be related to a CC style receiver providing C1 and P2' code measurements. Our analysis includes a large number of receivers, usually a superset of those used by other analysis centers and does not explicitly rely on any particular receiver models.

The daily repeatability of the (satellite-specific) P1-C1 values is of the order of 0.1 ns rms. The improvement of our clock estimates due to the consideration of the P1-C1 DCB parameters is clearly detectable. Since doy 127/2000, P1-C1 DCB a priori information is taken from a 4-week combination, available as of May 2000.

We continue in monitoring P1-C1 and P1-P2 differential code biases since they are not as constant as one might like. Another motivation to continue with this service is the circumstance that CODE P1-C1 bias values are recommended to be adopted for use with the IGS official products from GPS week 1097 onwards (see IGS Mail 3160).

More details on CODE's DCBs and ionosphere products may be found on our ionosphere-dedicated web site http://www.aiub.unibe.ch/ionosphere.html.

Klobuchar-Style Ionosphere Parameters

Since mid of July 2000, Klobuchar-style ionospheric coefficients (alphas and betas) best fitting CODE IONEX global ionosphere maps are computed on a regular basis. A validation study based on two months of data confirmed that our predicted coefficients perform significantly better than the coefficients broadcast by the GPS system for the single-frequency user. Coefficients derived from CODE final and rapid IONEX data (for days where the final product is not yet available), as well as coefficients based on 1-day and 2-day IONEX predictions are generated. They are made available via anonymous ftp in form of content-reduced RINEX navigation data files (see Tables 1 and 2). Moreover, the CODE analysis center is able to supply post-processing users of the GPS broadcast ionosphere model with a unique, continuous time series of RINEX files containing improved Klobuchar-style ionospheric coefficients starting with January 1, 1995 [Schaer, 2001].

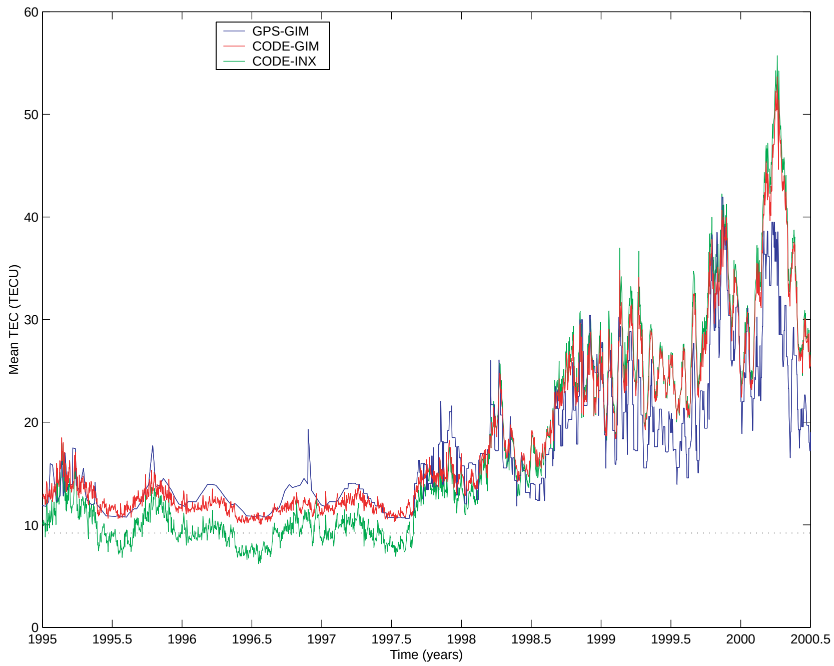

Figure 2: Mean TEC of the ionosphere derived from GPS broadcast model coefficients, CODE generated model coefficients, and CODE IONEX reference, compared from 1995.0 to 2000.5, gathered from [Schaer, 2001].

Sensitivity of GPS and GLONASS Orbits to Geopotential Resonance Terms

Studies are carried out to evaluate the sensitivity of GPS and GLONASS orbits on resonant geopotential terms. The most important terms for satellites near the 2:1-commensurability with the Earth's rotation are the C_{32} and S_{32} terms in the harmonic expansion of the geopotential, followed by the terms C_{44}, S_{44} and C_{22}, S_{22} [Hugentobler, 1998]. The GPS satellites are in exact resonance (revolution period of half a sidereal day) and are, thus, significantly affected by the resonance terms. As a consequence, quite frequent along-track orbital manœuvers are necessary to keep the satellites at their requested position. GLONASS satellites, on the other hand, perform $2^1/_8$ revolutions within one sidereal day and are, therefore, not in deep resonance with the Earth's gravity field. Infrequent orbital manœuvers are a positive aspect of this configuration.

Our studies indicate, however, that the GLONASS satellites show a higher sensitivity to the resonant geopotential terms than the GPS satellites. The reason is a strong coupling of the resonance terms with the radiation pressure coefficients, in particular the y-bias: The very similar signal of some of the radiation pressure parameters and the resonant geopotential terms along the satellite's orbit impedes the decoupling of the effects for GPS satellites due to their equal periods. For GLONASS satellites the periods of the effects are non-commensurable which makes a decoupling possible. GLONASS satellites may, therefore, be more adequate to extract the gravity signal caused by the resonant terms.

Kinematic and Dynamic Orbit Determination for Low Earth Satellites

The AIUB is participating in the IGS LEO Pilot Project. In this context a new program (SORBDT) for orbit integration was developed as well as techniques for generating high rate GPS clock corrections and kinematic LEO orbits based on code and phase differences from one epoch to the next [Bock et al., 2000].

Program SORBDT allows a highly flexible selection of the physical model in terms of the force field and of the parameters to be set up. It includes new capabilities necessary for LEOs such as air drag modeling. The setting up of an arbitrary number of stochastic parameters is possible. Furthermore, the program allows to introduce accelerometer measurements to remove the effect of the non-conservative forces. Input to the program are cartesian satellite positions, i.e., a kinematic orbit, as pseudo-observations.

The current approach to generate kinematic orbits for LEOs is based on a precise point positioning generating positions from code observations as well as position differences from phase differences from one epoch to the next. Positions and position differences are combined to high precision positions in a second step. GPS orbits are introduced as fixed while high rate clocks are generated by combining clock corrections derived from code with clock correction differences from one epoch to the next derived from phase, both based on observations of the IGS tracking network.

The procedure for generating kinematic orbits is very efficient, but depends heavily on the quality of the code observations as well as on the number of receiver resets.

Significant effort has to be put into the development of sophisticated data cleaning algorithms. First tests of the procedures were performed using data from TOPEX/POSEIDON as well as from the released day 220/2000 of CHAMP data.

Summary and Outlook

The year 2000 has seen a number of changes at CODE, the most important being the leave of Tim Springer at the end of the year, which was a significant loss for CODE and our institute. With Robert Weber, a well-established scientist and 'veteran' of the AIUB could be won to continue the tasks of the IGS ACC as of January 2001.

With the release of a new version of our software, the Bernese GPS Software Version 4.2, and a number of improvements in routines and procedures, the high standard of our products delivered to the IGS could be assured and increased. The transfer of the complete routine processing to the new platform was certainly a milestone and a chance to review our processing strategies – although it was a harsh task.

In the near future, developments are foreseen in different fields and the existing involvement will be extended by new challenges. The modeling of atmospheric delays will be reviewed and the estimation of troposphere gradient parameters will be activated for the final analysis. Significant effort will be put into the zero-difference processing and the clock correction generation. In this context it is worth mentioning that the implementation of clock extrapolation and of high-rate clock generation are planned. Studies into the direction of an ultra-rapid orbit product are in preparation. They shall indicate the procedure to make optimum use of the rapid orbit information for strengthening the ultra-rapid solution. Studies of GLONASS orbits are underway as well, and, provided that the satellite constellation remains stable enough, an engagement in the IGLOS Pilot Project may be envisaged. Finally, the development and adaptation of algorithms and procedures for the computation of kinematic and dynamic LEO orbits in the framework of the IGS LEO Pilot Project will continue and increase.

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The ESA/ESOC IGS Analysis Centre Annual Report 2000

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Introduction

This Report gives an overview of the ESOC Analysis Centre activities and a presentation of the activities during the year 2000, plus the direction for the future.

During this year the main development has been the launch of the ESOC Ultra-Rapid submission to the IGS, as part of the routine GPS data processing for POD. All the other routine activities, including GLONASS data processing, have continued and some minor internal modifications have been introduced to further automate the processing.

Currently ESOC's GPS-TDAF (Tracking and data Analysis Facility) handles automatically the ESA ground receiver network, the IGS network data retrieval and storage and all of the routine daily and weekly data processing of the different IGS products. The system is capable of performing autonomous operations for up to about five days.

Changes and activities in 2000

These have been the changes and activities that ESOC has been involved in from January to December, 2000:

Jan 2000	Tested Niell mapping function for the dry and wet tropospheric component, to substitute the inverse cosine mapping function currently used. Results encouraging but not implemented into IGS processing yet.
Feb 2000	Switched the GLONASS POD to a 5 day processing arc, also eliminated all combined receivers which do not track both constellations in dual frequency mode.
Mar 2000	Started twice-daily GPS POD Ultra-Rapid submissions to the AC Coordinator for combination and comparisons to other AC results.
Apr 2000	Ceased making any changes to pseudorange data from modern receivers and began modifying data from cross-correlation style receivers, as explained in IGS mail #2744.
Jun 2000	Switched from ITRF97 to IGS 97, the IGS realisation of the reference frame.
Sep 2000	Introduced undifferenced data processing for LEO on-board GPS receivers, tested with Topex data. As preparation for the analysis of CHAMP data.

Routine Activities

ESOC participates in the IGS as an Analysis Centre providing the following routine products either to the Analysis Centre coordinator or to the IGS Global Data Centre CDDIS:

- Final GPS Orbits plus clocks
- Final GLONASS Orbits plus clocks
- Rapid GPS Orbits plus clocks
- Twice Daily Ultra-Rapid GPS Orbits plus clocks
- Daily Rapid EOP file
- Daily Ultra-Rapid EOP file
- Weekly final EOP file
- Weekly final processing summaries
- Weekly free network solution in SINEX format
- Daily final tropospheric files
- Daily rapid RINEX clock files with 5 minutes sampling
- Daily final RINEX clock files with 5 minutes sampling

Processing Method

The ESOC GNSS precise orbit determination processes for all the cases are based on a batch least squares estimation solution of RINEX IGS station data using various numbers and distributions of stations based on availability, past performance and processing time available. The average numbers of stations used for each of the processes at ESOC are as follows:

- Final GPS POD: 52 stations
- Final GLONASS POD: 27 to 30 stations
- Rapid GPS POD: 40 to 45 stations
- Ultra-Rapid GPS POD: 25 to 30 stations

The distribution of the stations selected for GPS POD processing aims at providing worldwide coverage with stations of the latest ITRF whenever possible. Figure 1 shows the station distribution for a typical GPS Final processing day. The stations selected for the Rapid and the Ultra-Rapid processes are subsets of this group, selection being made on data availability and processing time before submission.

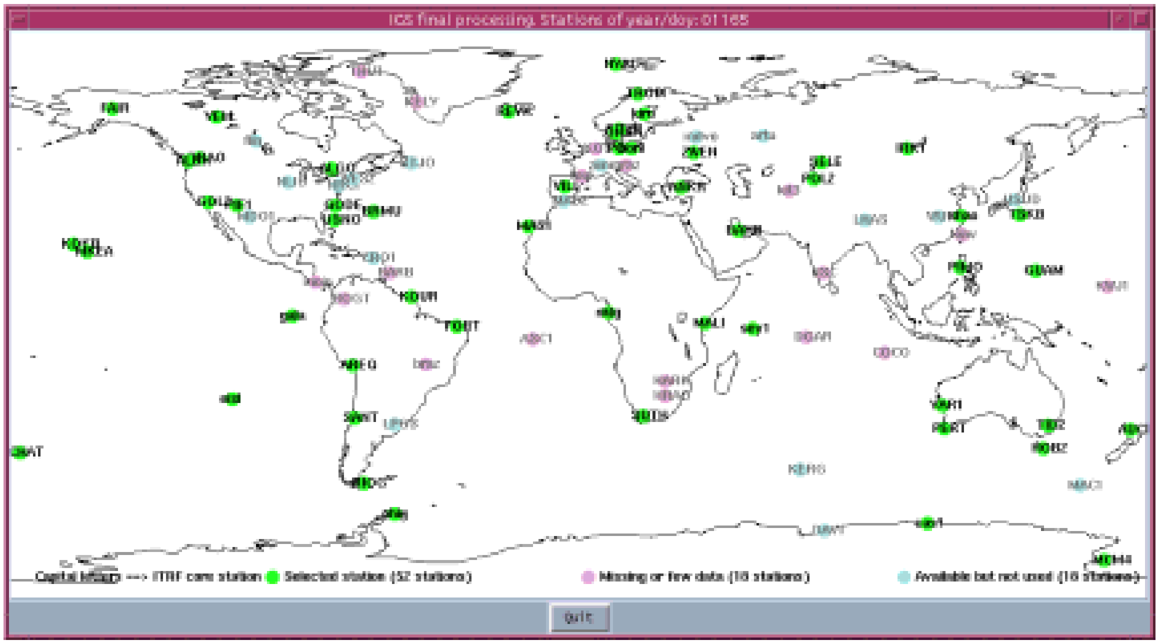

Figure 1: GPS stations typically selected for Final processing.

On the other hand the IGEX station network is still of limited number and distribution. The stations selected for a typical GLONASS processing day are shown in Figure 2. These can be seen to be poorly distributed around the globe, with a heavy concentration of stations in Europe (only dual-frequency data for both GNSS systems are processed at ESOC, so they are the only ones shown). The stations in capital letters are ITRF core stations, which are very highly constrained in the processing to fix the solution to the latest ITRF.

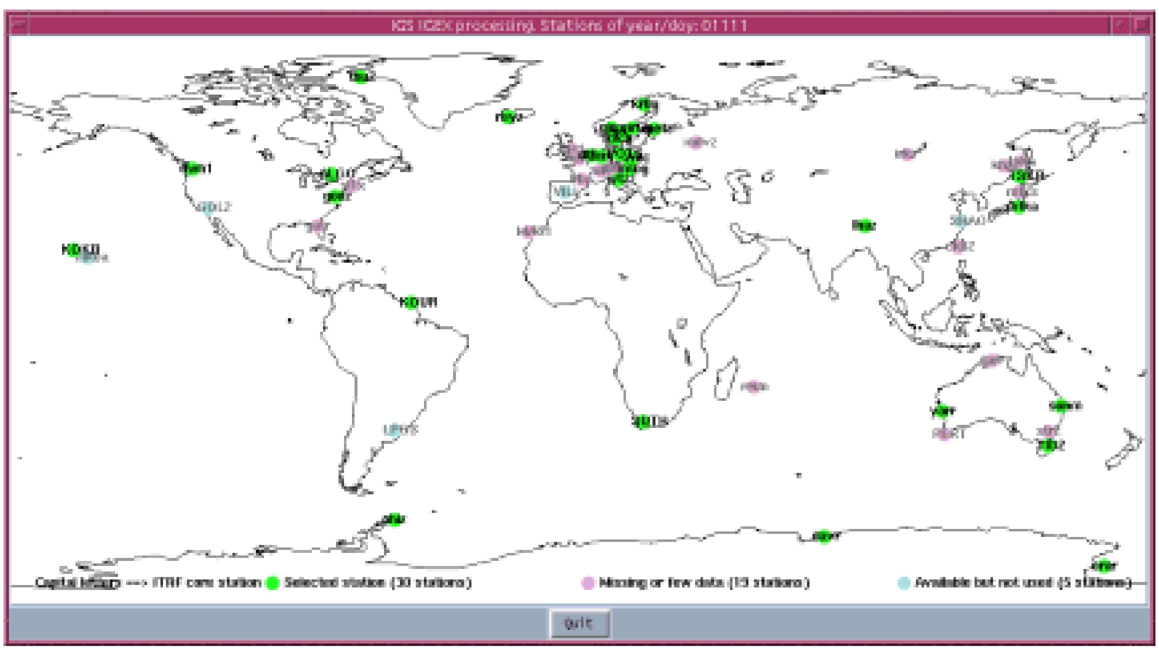

Figure 2: GPS/GLONASS stations typically selected for IGEX processing.

The estimation method for all the POD activities uses an in-house estimation program, BAHN, currently in version 7 and which can handle most types of data for satellite POD activities (ranges, range rates, SLR, Doris, Prare, altimetry, GNSS observables in un-, single- and double- differenced modes). The quantities estimated by the program are variable depending on the focus of the run. For the IGS submissions the quantities estimated are:

- The station coordinates
- The satellite state vectors
- The solar radiation pressure extended force model parameters
- Cycle-per-revolution empirical accelerations
- The undifferenced carrier phase ambiguities for the ionospheric linear combination
- The GPS-GLONASS receiver biases (for the GLONASS processing only)
- The Earth rotation parameters: *x* and *y* pole position and rates and Length of Day,
- The tropospheric zenith delay for every station every 2 hours
- Station and satellite clock biases, estimated as time-dependent parameters (one value for every observation epoch).

More information on our routine GPS and GLONASS processing, processing description, model usage, result plots, etc can be found at:

http://nng.esoc.esa.de/
http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn

Ultra-Rapid implementation

As proposed in the 1999 IGS Workshop in La Jolla, CA, a new IGS product should be produced by the Analysis Centres (ACs) called the Ultra Rapid orbits (Gendt, et al. 1999). As their name indicate these are GPS satellite orbits produced very soon after the data gathering has occurred, and they cover an existing gap in the IGS products between the official rapid and predicted orbits. Initially, the product was to contain only orbit information, no clock bias estimations, but now that SA has been turned off it has been feasible to develop the satellite clock predictions and include clocks for the entire Ultra-Rapid period. This is currently done by up to 4 IGS Analysis Centres. The orbit files are in the standard sp3 format but contain 48 hours of orbit positions and clock biases instead of the usual 24 hours as for the other IGS products. The first 24 hours are from fitting the data available over the period and the last 24 hours from predicting the solution into the next day.

The implementation of the new product at ESOC borrows heavily from both the Rapid and the Predicted processing strategies. The Ultra-Rapid processing steps can be summarised as follows:

1. RINEX data is downloaded and checked for a period covering the 24 hour arc of the orbit to be determined, plus the previous 24 hours (Figure 3). This 48 hour arc of RINEX data is normally used. Data from up to 30 stations are used, depending on data availability from the IGS receiver network.

2. A number of days of Earth fixed positions are also used as observations either from the IGS rapid orbits or from the ESOC rapid orbits for the 3 or 4 days before the RINEX data start. These Earth fixed positions of the GPS constellation are used as observations together with the RINEX observations (Figure 1, where the arrow indicates the start time of processing).

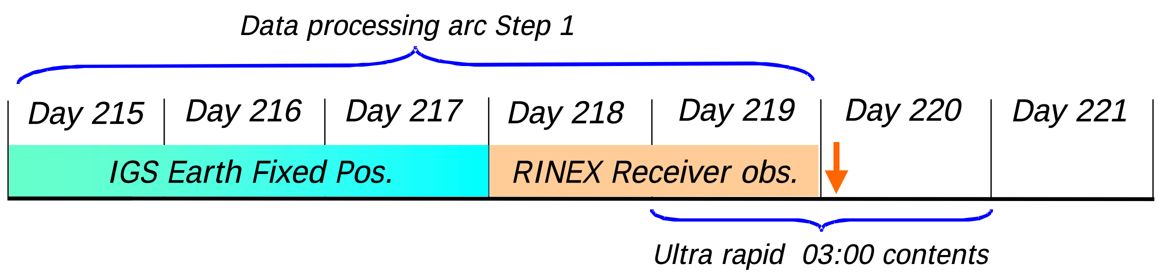

Figure 3. ESA Ultra rapid solution first step, data types and processing arc.

3. The two frequency RINEX data is combined in a zero difference ionospheric-free combination and antenna phase corrections are applied. The pseudo-range and carrier phase observations are written to an observation file together with the satellite Earth fixed positions, from the previous 3 days as described above.

4. ESOC's least squares dynamic parameter estimation program, BAHN, is run and the satellite orbits, satellite dynamic models, station positions, satellite and station clock biases and Earth Rotation Parameters (ERP) are estimated.

5. The satellite orbit results from the estimation are formatted into satellite Earth fixed positions and used in a second estimation step which fits all of the Earth fixed positions (Figure 4). This second step tends to produce higher quality orbit predictions for the Ultra rapid submission.

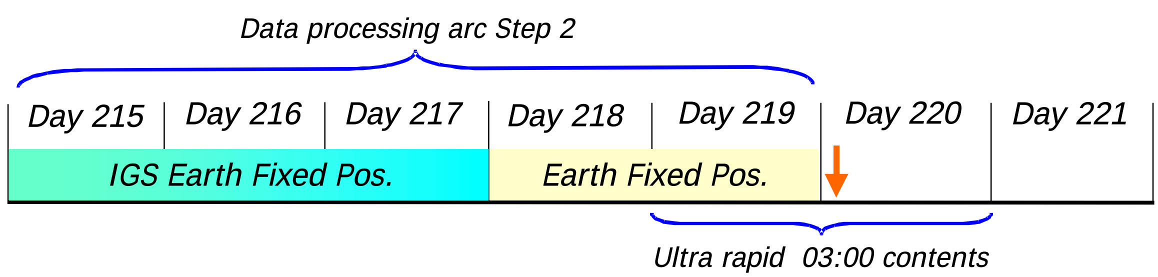

Figure 4: ESA Ultra rapid solution second step, data types and processing arc.

This strategy is still being refined in-house as more experience and more results accumulate. Tests have been run without the use of the Step 2 with good results, as long as enough station data exists, therefore the processing strategy will continue to evolve.

6. Currently the clocks are predicted at ESOC by post processing the results of the least squares estimator and fitting a simple curve for each of the satellites:

$$clk_i(t) = B_i + D_i t + E_i \sin\left(F_i t + G_i\right)$$

where i is the PRN number of each satellite, and B_i, D_i, E_i, F_i, and G_i are the estimated coefficients. If the curve fitting satisfies a convergence criterion of 10 nanoseconds over the 48 hours of fitted data, in a least squares sense, then the clock for the entire 48 hour arc is sent out. If for some reason the function is not fitted correctly then no clock is provided for the satellite.

7. Finally the results are formatted into the appropriate sp3 orbit files, and ERP file spanning the necessary periods, and the satellite exponential correction values are applied, based on the overlap comparisons to the previous day solution.

ESOC's Ultra-Rapid orbit-only submissions began on March 3rd, 2000. Whereas orbits + clocks started being submitted by ESOC on March 9th, 2001.

In week 1052 the first combination and comparison results started to appear which combined each centre's solution into an IGS Ultra-Rapid product and then compared each centre's solution to the combination. Excluding short periods of problems with the processing, or with specific satellites, the ESOC overall rms value for the Ultra-Rapid orbits in the combinations has stabilised at a 15 to 25 cm level for each of the two daily submissions. A real-time plot of the comparison results for all the AC's submissions can be seen at: `http://nng.esoc.esa.de/gps/igs_ana.html` for both ultra-rapid submissions.

It is nonetheless unsatisfactory most of the time to analyse the performance of the Ultra-Rapid submission based on one RMS error value for the entire 48 hour file, considering the mixed character of the product (fit + prediction). Therefore at ESOC we also produce, for quality analysis, epoch-by-epoch comparison plots versus the combined product (*igu*). The plots are made in order to detect the character of the agreement or disagreement of our submission with the other ACs and with the combined solution. Two examples of these plots are shown in Figure 5.

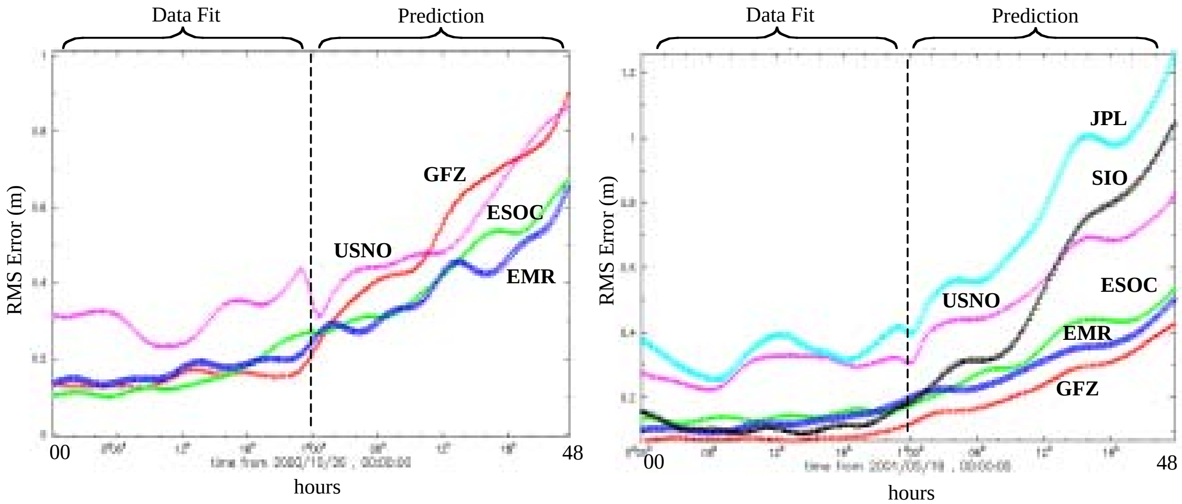

Figure 5: Epoch by epoch unweighted RMS error versus IGU for October 26th,2000 (00300) on the left and May 19th, 2001 (01139) on the right.

The weighted RMS values for these two days are as shown in Table 1. Analysing these plots together with the values in Table 1 clearly show that the majority of the error in the combination of the AC submissions occurs for the predicted part of the Ultra-Rapid orbit.

Table 1: Weighted RMS values for Ultra-Rapid Orbits for two specific days (ACC summaries).

AC	00300	01139
EMR	22 cm	12 cm
ESA	14 cm	14 cm
GFZ	16 cm	11 cm
JPL	--	27 cm
SIO	52 cm	15 cm
USNO	26 cm	24 cm

The plots in Figure 6 also show the well-known effect of linear prediction degradation (Fang, et al., 2001), and support the call to eventually increase the frequency of the Ultra-Rapid product, so that the prediction available to users is always less than 6 hours old.

At the same time, whenever possible, a different series of plots comparing the predicted part of the Ultra-Rapid with the IGS Rapid, once it is available, are produced to monitor the degradation over time of the orbit predictions. The plots in Figure 6 show these epoch-by-epoch comparisons

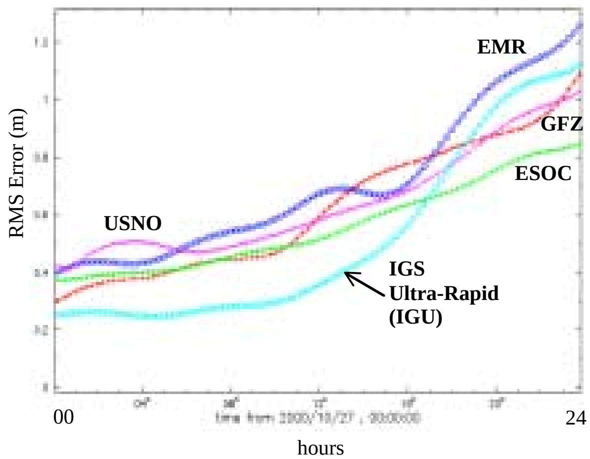

Figure 6: Epoch by epoch unweighted RMS error of predicted part of Ultra-Rapid AC submissions and the IGU versus the IGR for October 26th,2000 (00300) on the left and May 19th, 2001 (01139) on the right.

The four plots presented above are sample plots for specific days. They are not intended to be representative of the state of the Ultra-Rapid, since day to day variations in the satellite constellation as well as in the timely availability of station data can affect the results greatly.

Clock predictions show agreement to the observed values down to the 3 to 5 nanoseconds level over the entire GPS constellation. Figure 7 shows the satellite clock bias epoch-by-epoch for GPS satellite PRN05 (sv-35, Cesium internal clock), and for GPS satellite PRN07 (sv-37, Rubidium internal clock) for the entire 48 hour period. Currently at ESOC the clock predictions are based on fitting with a function the 5 minute clock values, solved for in the least squares process, after the relativistic effect of non-zero orbital eccentricity is corrected, and applying a continuity condition at the switch over.

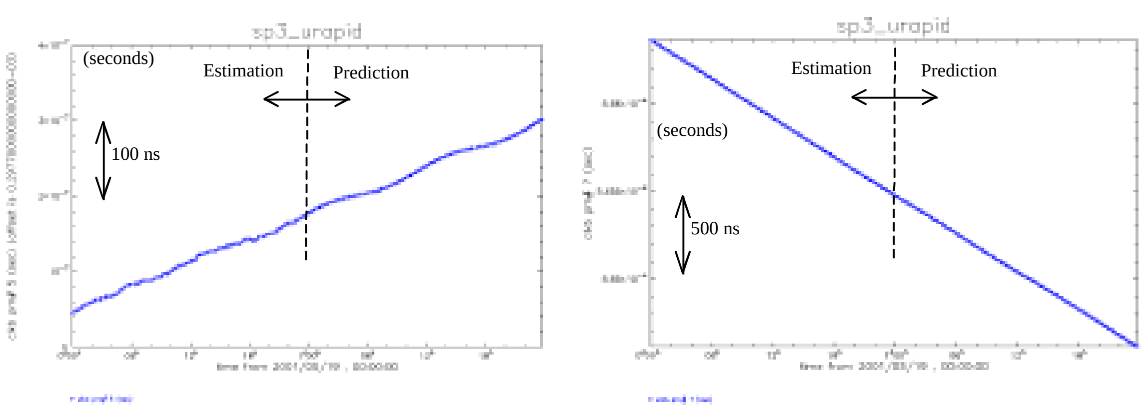

Figure 7: PRN 05 (left) and PRN07 (right) Satellite clock bias estimated and predicted for May 19th,2001 (01139).

It can be seen from Figure 7 that Cesium clocks have worse short term stability, whereas Rubidium clocks have better stability but much larger drifts. Examples of two other

Cesium clocks, are given in Figure 8. The satellites shown in both Figures highlight the difficulties of improving the clock bias predictions beyond the current level (3 to 5 nanoseconds) across the entire GPS constellation.

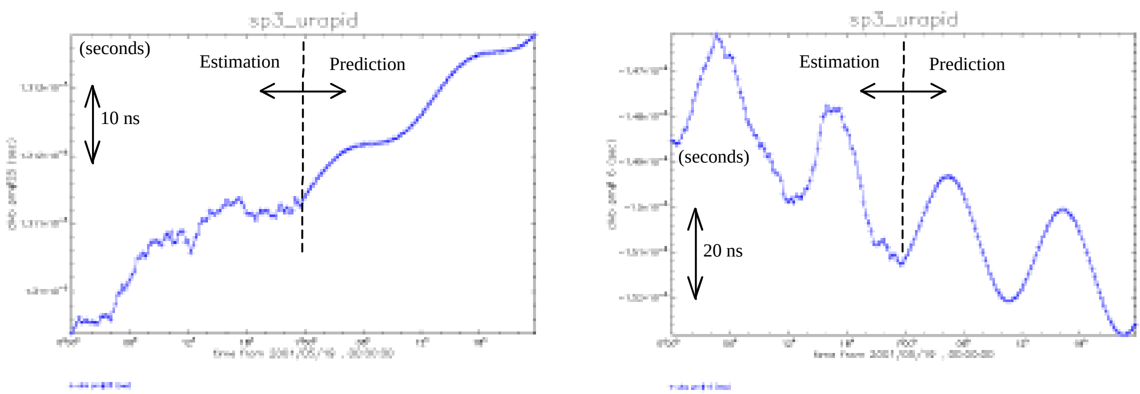

Figure 8: PRN 25 (left) and PRN06 (right) Satellite clock bias estimated and predicted for May 19th,2001 (01139).

Even accounting for the difficulty of modelling the satellite on-board clock behaviour the most important thing to produce good clock predictions is to select a known stable reference station for the clock bias estimations. At ESOC the IGS station Algonquin is used if it is available for all of the processing epochs, otherwise another one of the IGS stations with an H-maser is selected. This ensures good orbit stability and smooth clock bias calculations and predictions.

GLONASS Processing

GLONASS processing at ESOC has continued following the activities of the processing campaign IGEX-98 (Willis et al., 1999). Since most of the IGEX stations have continued to gather and transfer their GPS + GLONASS data to the IGEX Data Centres at ESOC it was deemed appropriate to continue calculating GLONASS precise ephemerides.

The GLONASS constellation of satellites has continued to decrease in numbers. Even with the launch of three new satellites in November 2000 (which were introduced into active service after some delay), the number of satellites being decommisioned meant that the total number of active dual-frequency satellites by the time of this writing was only eight. At the same time the IGEX station network has continued to increase, which has made for more stable day to day solutions for each of the remaining satellites, as more data is available.

Figure 9 shows the orbit comparisons between the solutions from CODE, BKG, MCC (Moscow Control Centre) and ESOC versus the GLONASS combination up to the time of writing. CODE orbit contributions ceased during 2000, and the ESOC comparison to the combination stabilised at an error level of around 20 cm. The degradation observed in the plot for the beginning of 2001 could be due to the new satellites introduced, new stations, or a difference in the combination processing (in particular with respect to the treatment of the MCC orbits).

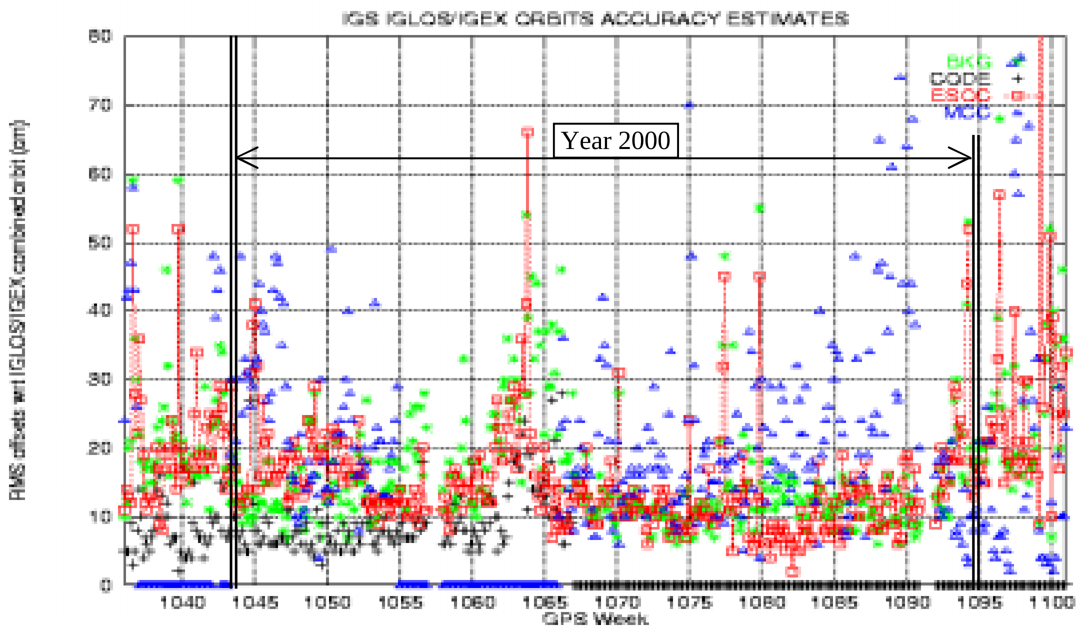

Figure 9: IGLOS/IGEX AC orbit comparisons versus the combination.

In anticipation of the IGLOS Pilot Project kick off ESOC has also purchased and installed a Topcon (formerly Javad) GPS+GLONASS receiver at our permanent station in Kourou (French Guyana), which will start supplying dual system data during 2001, both for IGS and IGLOS activities.

Ionosphere Processing

Routine processing of ionospheric Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 2000.

The processing in final mode continued with the rapid orbits. The number of ground stations used could be increased to about 150. The 24 hours time resolution with which the TEC maps are produced, could not be increased yet. The daily routine ionosphere processing is now as follows:

1) A nighttime TEC data fit is made to obtain a set of reference DCB values for that day. The nighttime TEC itself is absorbed in this fit with a low degree and order spherical harmonic. In the other fits 2) - 4) these DCBs are then introduced as constraints.

2) A Chapman profile model is fitted to the TEC data of that day, where the layer of maximum electron density N0 and its height h0 are estimated as surface functions of geomagnetic latitude and local time. h0 is restricted to have values within a

predefined range only, currently 350 km =< h0 =< 450 km or 400 km =< h0 =< 450 km.

3) A Chapman profile model is fitted to the TEC data, where h0 is estimated as a global constant.

4) A Chapman profile model is fitted to the TEC data, where h0 is kept fixed as global constant at a height of 450 km, and the influence of the solar zenith angle is not accounted for. This run is made for test reasons and theoretical studies.

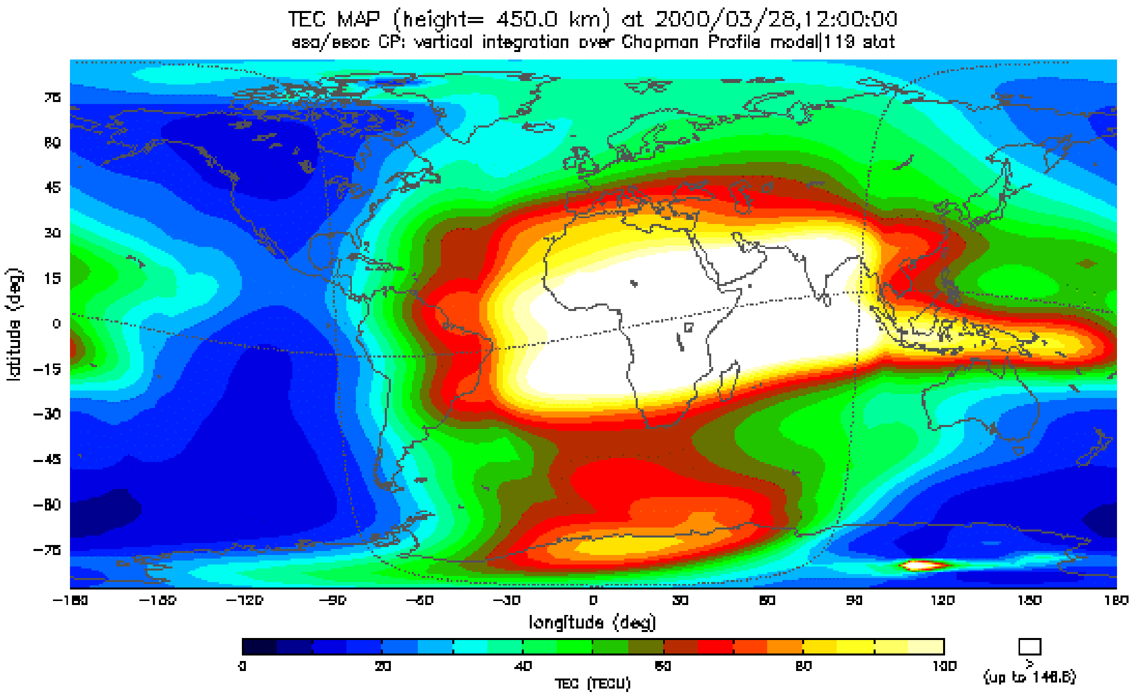

Figure 10: Global TEC map obtained from a fit of type 2) for 28 March 2000, a day during a period in the current solar maximum, when the TEC level was very high.

Beyond the routine processing of our own TEC maps, ESOC is also chairing the IGS Ionosphere Working Group (Iono_WG) and is thus responsible for the weekly comparisons of Iono_WG products and for the coordination of the activities of this working group.

Future Activities

ESOC Analysis Centre will remain active during the next year, continue the regular contributions to the IGS orbit and clock products, troposphere, ionosphere and station network solutions. The Ultra-Rapid processing development at ESOC will continue as more experience is accumulated over time, including improvements to the clock prediction.

A new activity will also start during 2001 as the IGS LEO Pilot Project gets underway with the release of Champ on-board GPS data. The ESOC Analysis Centre will act as Associate Analysis Centre for the Pilot Project, and also as AAC Coordinator for the further Centres. The initial task as AAC will be to move towards routine LEO data processing, leading to stable data products that include at least precise CHAMP orbit and clock solutions but perhaps also some associated products (e.g. improved gravity field models). Once that a nominal set-up has been reached, applications of LEO data for improving other IGS products will be considered. The responsibilities as AAC Coordinator will initially be aimed at exchange of information between the various AACs, and at quality monitoring of independent solutions. In the longer term the LEO output should include an IGS combination solution for the CHAMP orbit and clock, similar to what is presently done for GPS. The moment at which routine combination solutions can become available depends of course on the availability of routine output from all IGS LEO AACs.

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GFZ Analysis Center of IGS - Annual Report for 2000

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Summary

In 2000 no significant changes for the classical IGS/IGR products were introduced. Improvements were performed for the Ultra-Rapid analysis especially for the clock predictions.

Classical IGS/IGR products

During 2000 the P1-C1 corrections on the RINEX files were introduced. While GFZ not followed the older unification of RINEX files on this topic, where the new non-cross-correlation (non-cc) observation were transformed to be compatible to the observations from the older cross-correlation (cc) receivers , the new standard correction from cc-type to non-cc-type was followed accordingly. This way the ongoing replacements of the older receivers will have no significant influence on the consistency of the clock products anymore.

Ongoing effort was concentrated improving the robustness of the GFZ software to guaranty the high quality of the results also under the increasing burden which raised from additional projects.

Table 1. Changes in the analysis strategy

Week	Date	Description
1063	2000-05-21	Generation of station clock solutions for the Rapid product
1065	2000-06-04	P1-C1 bias corrections from cc to non-cc receivers
1097	2001-01-14	Generation of clock predictions with the Ultra-Rapid Product

The quality of the main IGS Final/Rapid products are summarized in the Figures 1 and 2. The Final satellite orbits have reached an accuracy of 2-3 cm and the satellite clocks are approaching the 0.05 ns level. The Rapid products, available each day at 9:00 UTC for the day before, have with 4-6 cm (median) for the satellite orbits and 0.08-0.12 ns for the clocks already a high level which is sufficient for many applications.

The weekly computed SINEX files contain solutions for the station coordinates and Earth rotation parameters (ERP) and enter into the official IGS combination. The quality of the GFZ station coordinates can be extracted from the corresponding combination reports (Fig. 2). Compared to the weekly combined solution the quality of the horizontal and vertical components is about 1.5 to 2.5 mm and 5 to 8 mm, respectively. The corresponding values from the comparisons to the cumulative solution show slightly higher values (~ 30 %) which indicate that small periodic fluctuations in the station positions exists which are similarly in all weekly analysis center submissions.

Ultra-Rapid Products

As already reported last year (Gendt et al. 2000) GFZ had started the generation of Ultra-Rapid products in October 1999. In 2000 other Analysis Centers had joined this activity so that a combined product was feasible. At the beginning of 2001 daily reports are generated by the AC coordinator which compare the individual AC predictions (first 12 hours of the prediction only) with the latest Rapid product. The quality of the GFZ Ultra-Rapid products retrieved from these reports are shown in Figure 1. The daily median for the orbits is about 10 to 15 cm. This accuracy is sufficient for near real-time estimations of tropospheric water vapor for numerical weather prediction, which is the most striving applications for this product within IGS.

The GFZ technique for generation of Ultra-Rapid products can be described in the following way:

a. The hourly RINEX data are continuously retrieved using ftp and accumulated into daily RINEX files. The P1-C1-biases is corrected for during this process.

b. In the general case, data are extracted for the analysis the from two daily RINEX files using a sliding window of 24 hours. In the preprocessing step only the data of the last hour (with a small overlap) are cleaned in a two step procedure:
   - Larger cycle slips are identified by using wide-lane and geometry-free linear combination on a site-by-site basis.
   - Double-difference cleaning procedure in a network follows to identify further zero-difference cycle slips.

c. Based on the pre-cleaned data the orbit analysis is performed in the usual way the rapid products are generated, i.e. iterative orbit improvement and post-fit residual editing. In the final iteration stochastic impulses are introduced for all satellites in the middle of the arc.

The procedure is organized in such a way that our Ultra-Rapid product would be identical with the Rapid one, if the same number of stations could be used. That means, if the global hourly network would improve in such a way that its site distribution is identical with the daily sites used in the Rapid analysis, the orbits would have an accuracy quite below the 10 cm level (see Zumberge, Gendt 2000; Fang, Gendt, et al., 2001).

Results from this step are the fitted SP3 orbits for the 24-hour data part and the ERPs, as well as the clock solutions for the satellites and stations (frequently updated stations clocks are not provided yet, but are available if there is interest in).

d. In the final step the predictions are performed on the basis of the above SP3 product and the Rapid SP3 orbit from the day before (either IGR or GFZ). A long orbital arc is fitted through all SP3 positions using the Bernese 9-parameter radiation model (Beutler, et al. 1994). This model is applied instead of the impulses because its sinusoidal terms are better suited for prediction purposes. The GFU product (48-hour SP3) is generated from the long arc solution.

The described technique yields a continuous orbit, and it should be noticed that it is not the best one for the part covered with data. However, tests showed that the differences to the orbits derived in step (c.) are in the range of 2-5 cm, which is not relevant for the near real-time applications.

The whole Ultra-Rapid analysis takes about 25 minutes (10 minutes for preparation part and 15 minutes for the analysis).

Clock predictions. The high quality Ultra-Rapid clocks can be used to compute clock predictions. Based on the experiences at USNO we used the most recent two days to fit a linear trend plus sinusoidal terms to the clock values, for the rubidium clocks even a quadratic term is added. The adjusted functions used for the computation of the clocks for the predicted part in the SP3 product. The fit for the clocks is usually of the level of 1-3 ns. If the fit is worse than 5 ns no prediction is generated, presently this happens rather often for satellites PRN 17, 19, 21, 23.

The quality of the predicted clocks for the 12-hour prediction interval are already at the level of the broadcast clocks (5-7 ns, see Fig. 1) and can easily be improved at least by a factor of two if the Ultra-Rapid products will be updated more frequently.

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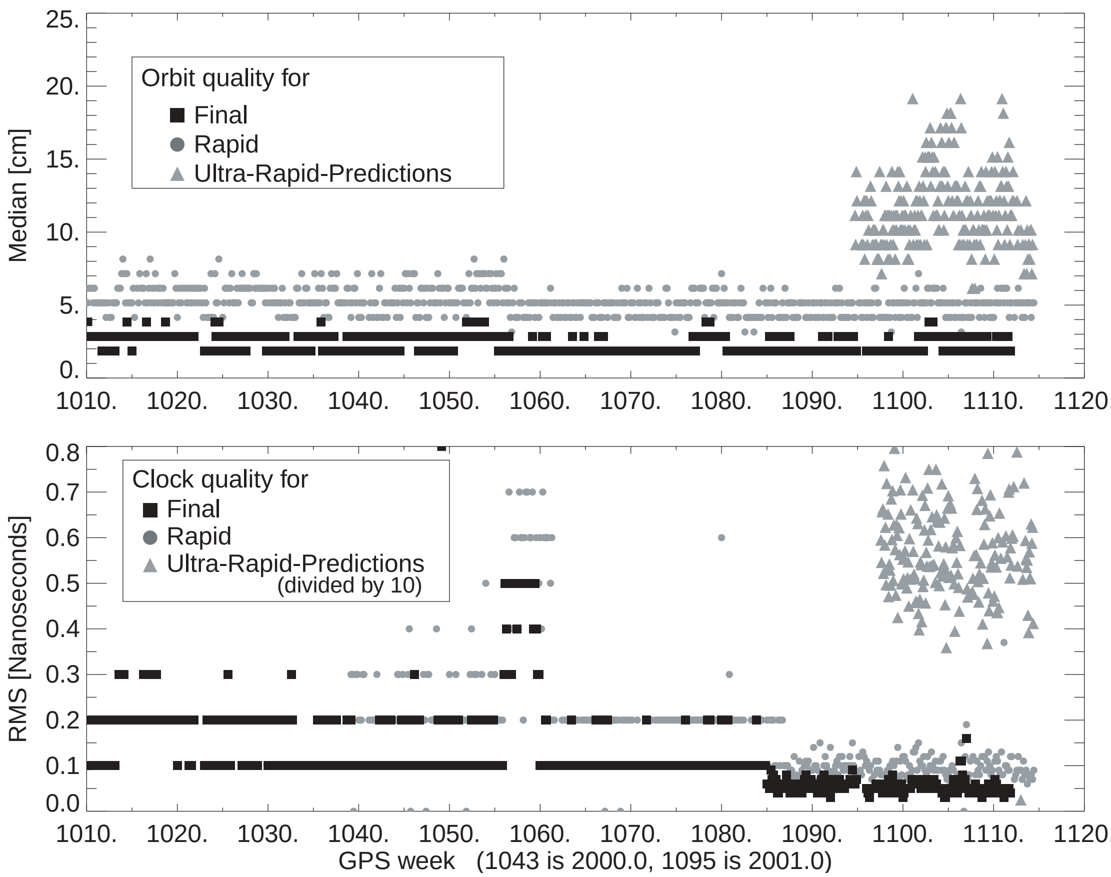

Figure 1. Quality of the various GFZ satellite orbit and clock products taken from the official combinations reports (Rem.: Clock resolution until GPS week 1085 was only 0.1 ns)

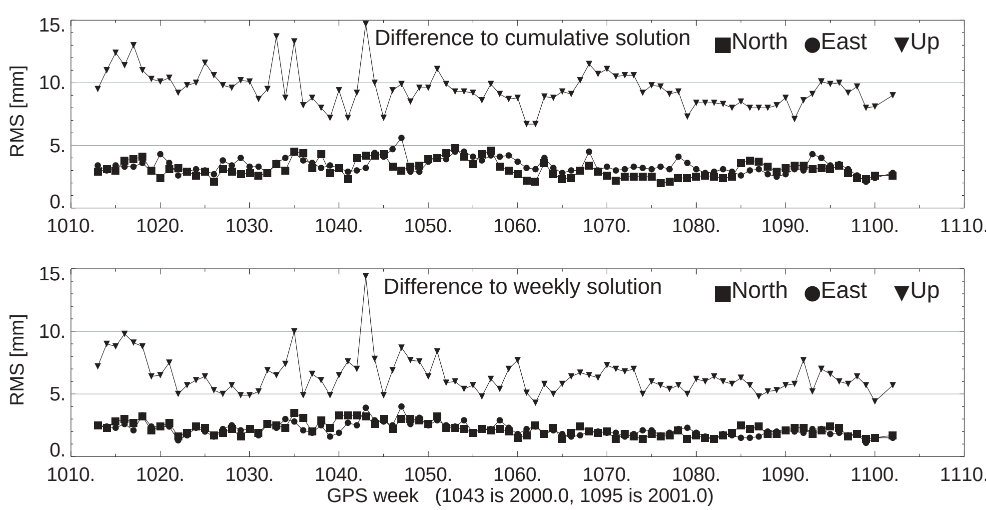

Figure 2. Quality of GFZ station coordinate solutions extracted from the IGS SINEX combination reports

JPL IGS Analysis Center Report, 2000

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Summary

JPL activities as an IGS Analysis Center continued throughout 2000 with regular deliveries of rapid, precise, and high-rate GPS orbits and clocks, Earth orientation parameters, and free-network ground station coordinates. Submissions of ultra-rapid products were began in February, and 15-minute solutions based on real-time 1-second data began in November. Our rapid products realized an improvement in latency due to more efficient allocation of system resources, as well as in improvement of product quality due to the use of more global stations and higher-quality reference clock sites. Multi-platform versions of our analysis software have allowed us to expand our processing capability, leading to lower latency for our final precise solutions. Rapid clock products in RINEX clock format are now being produced. New strategies include accounting for pseudorange biases between the P1 and C1 data types and the use of nominal core station coordinates in the IGS97 terrestrial reference frame. Overall performance continued to improve; the accuracy of our final orbit product is at the 3-cm level compared with the IGS Final orbit solution.

Evolution in 2000

Material relating to JPL participation as an IGS analysis center, beginning in 1992, can be found in [1] and references therein. Table 1 indicates the evolution of our activities during 2000.

Table 1: 2000 Analysis Evolution

Action	Date
Begin production of ultra-rapid products	Feb 20
Apply P1-C1 pseudorange bias corrections in cross-correlating receivers	Apr 2
Begin submission of rapid clock solutions in RINEX clock format	May 28
Adopt IGS97 coordinates and velocities for 20+ subset of 51 IGS core sites	Jun 4
Apply recomputed Benchmark-based P1-C1 bias corrections	Oct 15
Adopt R. Ray sub-daily extended Earth orientation model (IERS, 1996)	Nov 12
Begin 15-minute deliveries of orbits and clock products from 1-sec data	Nov 29

Product Summary

Tables 2 and 3 summarize the regular products that result from JPL IGS AC activities. Newly added products are the ultra-rapid (twice daily) and real-time (15-minute) GPS satellite orbit and clock products. Table 4 contains addresses of World Wide Web pages with related information.

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

Example File	Contents
`1095/jpl1050.sum.Z`	narrative summary for GPS week 1050
`1050/jpl1050[0-6].sp3.Z`	free-network precise orbits for days 0-6 (Sun through Sat) of GPS week 1050
`1050/jpl1050[0-6].yaw.Z`	free-network yaw-rate data for eclipsing satellites, days 0-6, GPS week 1050
`1050/jpl10507.erp.Z`	free-network Earth orientation parameters for GPS week 1050 (fixed-network prior to week 0947)
`1050/jpl10507.snx.Z`	free-network station coordinates for GPS week 1050 (7-parameter transformation to ITRF beginning wk 0947) (3-parameter rotation to ITRF beginning wk 0964)
`1050/jpl1050[0-6].tro.Z`	free-network troposphere solutions, days 0-6, GPS week 1050 (fixed-network prior to week 0949)

Table 2: Regular products from the JPL IGS Analysis Center, at ftp://sideshow.jpl.nasa.gov/pub/jpligsac (cont'd)

Example File	Contents
`1050/jpl1050[0-6].clk.Z`	free-network 30-sec GPS and 5-min station clocks, days 0-6, GPS week 1050, in RINEX clock format
`hirate/JPL1050[0-6].sp3.Z`	fixed-network 30-s GPS orbits and clocks, days 0-6, GPS week 1050
`2000.eng.Z`	engineering data for 2000, sites in global solution
`2000_p.eng.Z`	engineering data for 2000, point-positioned sites
`ytd.eng`	year-to-date engineering data, sites in global solution
`ytd_p.eng`	year-to-date engineering data, point-positioned sites

Table 3: Other products at ftp://sideshow.jpl.nasa.gov/pub/gipsy_products;
(†15-minute products are in ftp://sideshow.jpl.nasa.gov/pub)

Example File	Contents
`RapidService/orbits/jpl1050[0-6].sp3.Z`	quick-look fixed-network precise orbits for days 0-6 (Sun through Sat), GPS week 1050
`RapidService/orbits/jpl1050[0-6]_pred.sp3.Z`	quick-look fixed-network 3-day predicted orbits for days 0-6, GPS week 1050
`RapidService/orbits/jpl1050[0-6].clk.Z`	quick-look fixed-network 5-min clocks, days 0-6, GPS week 1050, in RINEX clock format
`RapidService/orbits/2000-01-01.*`	daily quick-look and predicted fixed-network files for use in GIPSY

`UltraRapid/00h/jpu1050[0-6].sp3.Z`
`.../jpu1050[0-6].erp`
`.../jpu1050[0-6].sum`
	ultra-rapid fixed-network precise orbits, earth orientation, and text summary for days 0-6, GPS week 1050, 1st delivery

Table 3: Other products at ftp://sideshow.jpl.nasa.gov/pub/gipsy_products;
(†15-minute products are in ftp://sideshow.jpl.nasa.gov/pub) (cont'd)

Example File	Contents

`UltraRapid/12h/jpu1050[0-6].sp3.Z`
`.../jpu1050[0-6].erp`
`.../jpu1050[0-6].sum`
	ultra-rapid fixed-network precise orbits, earth orientation, and text summary for days 0-6, GPS week 1050, 2nd delivery

`2000/clocks/2000-01-01.*`	precise daily free- and fixed-network clocks and yaw-rates for use in GIPSY
`2000/orbits/2000-01-01.*`	precise daily free- and fixed-network precise orbits, polar motion, shadow-events data for use in GIPSY
`hrclocks/2000-01-01.*`	high-rate free- and fixed-network clocks (in TDP format) for use in GIPSY
`15min/2000-12-01*`	15-minute† orbits (eci and sp3 format), clocks, earth orientation, yaw rates, and tropospheres for use in GIPSY
`IERSB/*`	IERS Bulletin-B information

Table 4: Addresses of Relevant Web Pages

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

Strategy Update: P1-C1 Bias Corrections

As described in IGS Mail Message Nos. 2320, processing data from a network of mixed receiver types reveals a bias in pseudorange observables between different receivers. Cross-correlating receivers (typically TurboRogues and Trimbles) report C/A (C1) code that is unexpectedly offset from the P1 code of non-cross correlating receivers (typically Ashtechs, Benchmarks, and ACT upgraded TurboRogues). Beginning with GPS week 1056 (April 2, 2000), we account for these biases, which are satellite-dependent, by applying long-term estimated bias values (http://gipsy.jpl.nasa.gov/igdg/demo/camp) to the C1 code of any cross-correlating receivers in our chosen daily station network.

When these biases are applied, they have a direct effect on the ability to resolve carrier-phase ambiguities and estimated clock solutions. In testing, we observed an average increase of about 16% more phase biases being fixed, a 0.07-0.067 ns RMS change in GPS clocks, and an improvement of 1-2 cm in daily GPS orbit repeatability. These results and a further description of the P1-C1 bias estimation methodology can be found in [2].

Strategy Update: Use Of IGS97

At the outset of the year, station coordinates and GPS orbits were aligned with ITRF97. Beginning with GPS week 1065 (June 4, 2000), monument coordinates and velocities are taken from ftp://igscb.jpl.nasa.gov/igscb/station/coord/IGS00P04_RS51.SNX, and antenna heights from ftp://igscb/igscb/station/general/igs.snx. (Antenna reference points to L1 and L2 phase centers are from ftp://igscb/igscb/station/general/igs_01.pcv.) Please see IGS Mail Message Nos. 2899 and 2904 for ITRF97/IGS97 comparisons and further details.

Clock Solution Update

Beginning with GPS week 1064 (May 28, 2000), JPL began to submit a contribution to the IGS rapid combined clock product. These files contain our daily quick-look estimates of the GPS and ground station at 5-min intervals for each satellite and station used in our rapid solution; station position estimates are also included in the file headers. The file format is the RINEX clock format as described at http://maia.usno.navy.mil/gpst/clock-format.

New Products

Ultra-Rapid:

Delivery of ultra-rapid products to the IGS AC began on GPS week 1050 (February 20, 2000). Both orbits and clocks are provided. The solutions for year 2000 are based on processing 20 ground stations, acquiring hourly data and then processing batches of 3-hour arcs. At 3-hour intervals, a 3-hour arc is processed and then at every 12 hours, 8 batches are smoothed for a product using 24 hours of data. The challenge is to produce orbits not later than two and one-half hours after the last data taken. GPS NANU messages are automatically processed to exclude data from maneuvering or unhealthy satellites. End products are delivered to the IGS in the NGS SP3 orbit file format twice daily. At each 12-hour interval the orbits cover 48 hours with 24 hours fitted and 24 hours predicted.

Ultra-rapid products were delivered from GPS week 1050 through week 1081 for the year 2000. Accuracies of the products are 8-25 cm for the fitted orbit and 25-110 cm for the prediction, measured as a WRMS with respect to the IGS rapid orbits (IGR).

Real-Time 15-minute

JPL has established a global network of roughly 20 real-time sites that send data every second via Internet for estimation of GPS orbits and clocks. The GPS clock estimates are updated every second while the GPS orbits are updated every minute. The real-time products are converted to standard GIPSY format every 15 minutes and made public via Internet at ftp://sideshow.jpl.nasa.gov/pub/15min.

The new 15-minute products include orbits, clocks, tropospheric delay estimates for the tracking sites, yaw rates, and earth orientation parameters. Availability was announced to the IGS on November 21, 2000 in IGS Mail Message No. 3108. Typical quality for the 15-minute orbits is 30-40 cm.

Results And Performance

Table 5 below displays the relative delivery schedule and accuracy of solutions produced by the JPL IGS analysis center:

Table 5: Latency and Accuracy of JPL IGS AC Products

15-minute and Ultra-Rapid, and Rapid product accuracies are mean RMS relative to the IGS combined rapid orbit solution. The Final products are relative the IGS combined final orbit.

Orbit Product	Latency	Accuracy (cm)
15-Minute	Every 15 minutes	35
Ultra-Rapid	Twice per day	20
Rapid	Once per day	12
Final/FLINN	Once per week	3

Figure 1 chronicles the progression of the final orbit solution 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 to improvement are the continuing expansion of the global network and quality of receivers used, the use of global phase ambiguity resolution (implemented in April 1996), the estimation of tropospheric gradients (implemented in August 1997, and the application of P1-C1 bias corrections (implemented in April 2000).

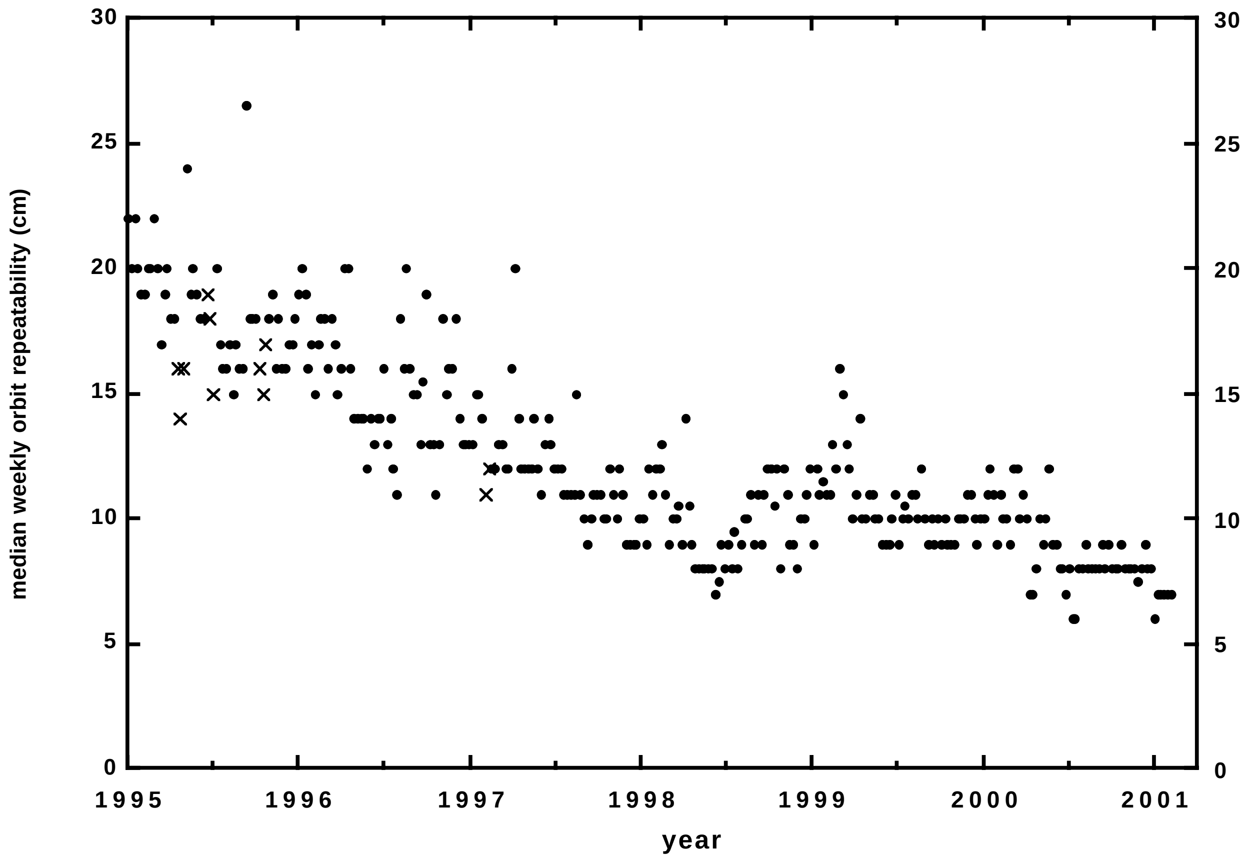

Figure 1: JPL orbit repeatability (3drms) since 1995. Each data point represents the median over all satellites and days for a particular GPS week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Weeks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

Another measure of performance is how well the JPL GPS solutions for station coordinates and velocities compare with those from other geodetic techniques. The first two columns in Table 6 below show the level of agreement between JPL derived station velocities and those independently realized from Very Long Baseline Interferometry (VLBI) and Satellite Laser Ranging (SLR). The last column shows dependent agreement with ITRF. Coordinates and velocities for this table are now in ITRF2000 and can be obtained from http://sideshow.jpl.nasa.gov/mbh/all/table.txt.

Table 6: Geodetic Velocity Comparisons

	JPLGPS-VLBI	JPLGPS-SLR	JPLGPS-ITRF00
N (mm/yr)	0.8	1.6	0.8
E (mm/yr)	0.8	1.7	0.7
V (mm/yr)	2.0	3.2	1.5
No. common sites	34	18	123

Acknowledgment

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

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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 *IGS 1994 Annual Report*, edited by J. Zumberge, R. Liu and R. E. Neilan, IGS Central Bureau, Jet Propulsion Laboratory, Pasadena CA, 1995, JPL Publication 95-18

[2] D. C. Jefferson, M. B. Heflin, R. J. Muellerschoen, “Examining the C1-P1 Pseudorange Bias, GPS Solutions, Volume 4, Number 4 (IGS Special Issue), J. Wiley & Sons, Inc., Spring 2001.

GPS Orbit and Earth Orientation Parameter Production at NOAA for the International GPS Service for 2000

National Geodetic Survey
National Ocean Service
National Oceanic and Atmospheric Administration
Silver Spring, MD USA

Spatial References System Division
William G. Kass, Robert L. Dulaney III, Robert B. Leonard Jr.

Geosciences Research Division
Gerald L. Mader, Mark S. Schenewerk, William H. Dillinger

Introduction

The GPS orbit and Earth Orientation Parameter (EOP) solutions submitted to the IGS by the National Geodetic Survey (NGS) are a joint effort between the Spacial Reference System Division (SRSD) and the Geosciences Research Division (GRD). The GRD is responsible for the development of the processing software and techniques while the SRSD is responsible for the operational production. SRSD and GRD are both activities within NGS which is part of the National Ocean Service (NOS) of NOAA (National Oceanic and Atmospheric Administration). A detailed description of the techniques and models can be found in the Analysis Strategy Summary located at http://www.ngs.noaa.gov/GPS/noaa_acn.html .

Station Network

Figure 1 shows a typical set of baselines used for forming double differences and for connecting the stations in the tracking network. NGS used an average of 65-70 tracking stations which are submitted to the IGS for the GPS orbit and EOP production. This list is not static but changes occasionally to include new stations that offer a more favorable geometry or new geographical coverage. If new stations are added in a region where the tracking network density is greater or redundant, other stations are dropped thereby keeping the total number at less than or equal to 70. This number appears adequate to provide overall tracking network stability that is relatively insensitive to daily tracking site drop outs within the global network. Included tracking sites are listed in the weekly summary available at the Crustal Dynamics Data Information System (CDDIS) at ftp://cddisa.gsfc.nasa.gov .

Software Changes

No major software enhancements were made during 2000. PAGES/GPSCOM, both developed at NGS, remain the software tools used for orbit production. Since the beginning of 2000, NGS has modelled deformations driven by ocean tidal loading using the Schwiderski model (Schwiderski 1983).

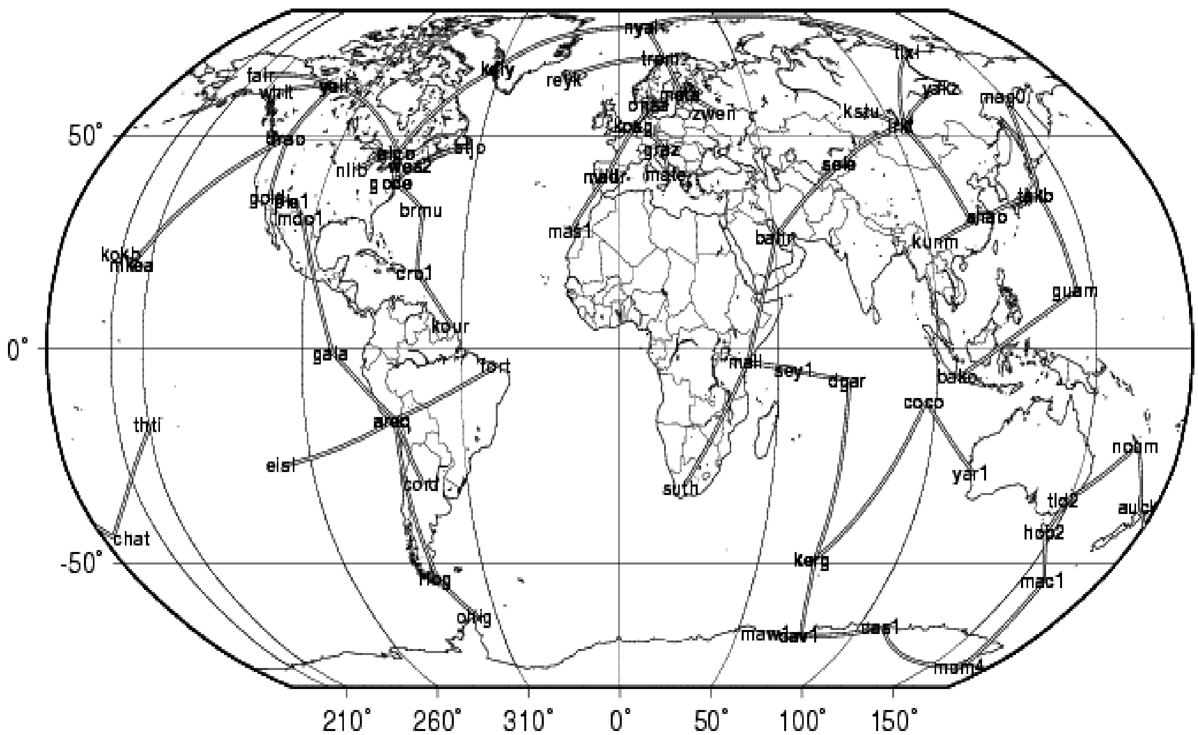

Figure 1.

On June 4, 2000 NGS, along with the other Analysis Centers, switched from the ITRF97 reference frame to the IGS realization of the ITRF97 referenceframe (IGS97).

Product Evaluation

Figure 2 shows the daily RMS differences between the NGS and IGS final ephemerides for the year 2000 after a "best fit" seven parameter transformation has been applied to the NGS ephemerides. It also shows the values of the associated seven parameter transformations. The subplots are: (left column, top to bottom) RMS of fit in meters, X translation in meters, Y translation in meters, Z translation in meters; (right column, top to bottom) scale in parts per billion, X rotation in milliarcseconds, Y rotation in milliarcseconds, and Z rotation in milliarcseconds. All available GPS satellites were included and universally the outlying points seen in the RMS subplot are caused by a single poorly estimated satellite within a day. On average over all 2000, NGS EOP match the National Earth Orientation Service Bulletin A values at: X pole -0.119 +/- 0.332 milliarcseconds and Y pole 0.164 +/- 0.253 milliarcseconds. The NGS software only uses double difference carrier phase as an observable and does not attempt to recover a UT1 time series.

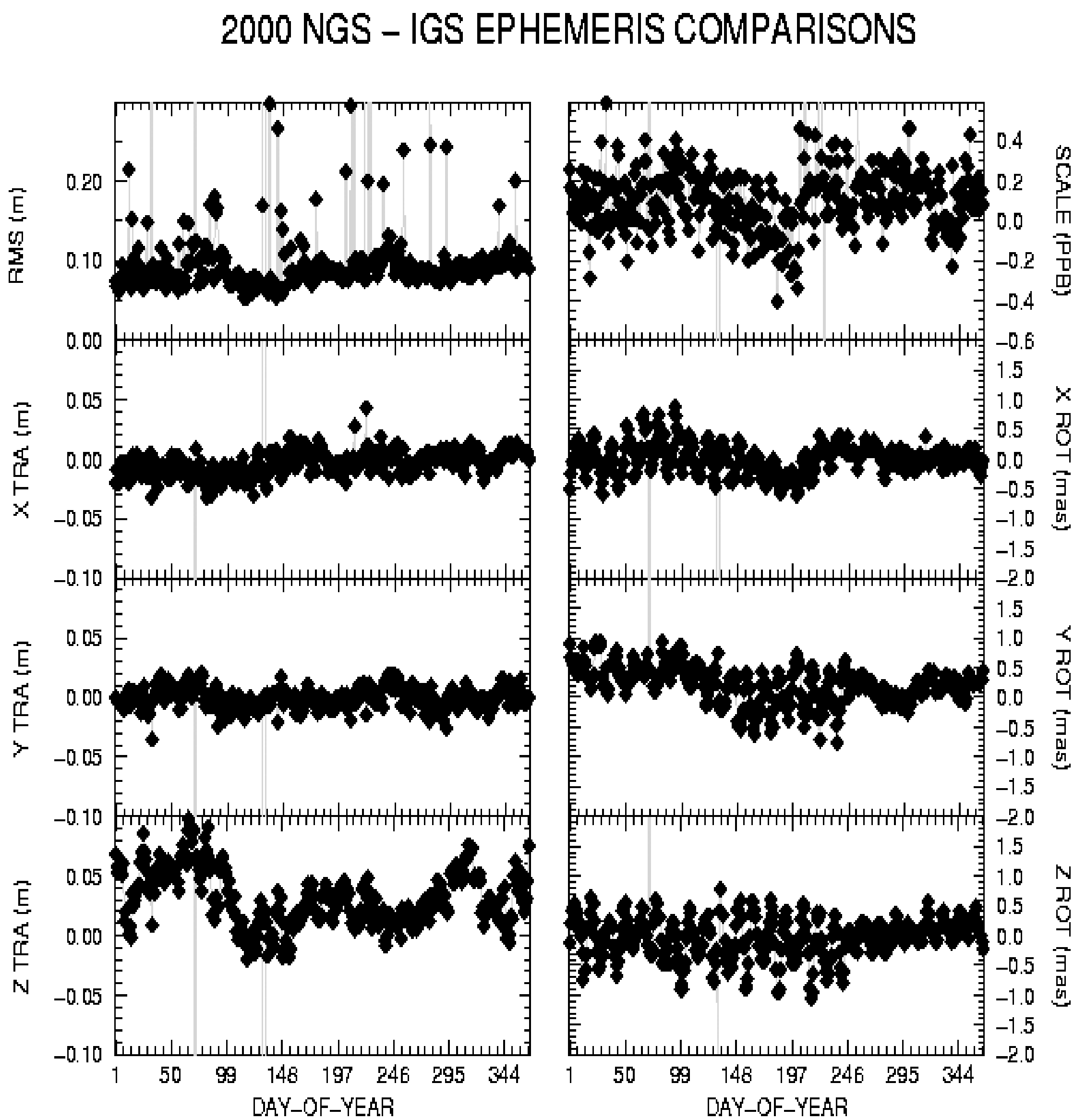

Figure 2

Orbit Products

I. Constrained Precise GPS Orbit: Up to 51 constrained IGS fiducial tracking sites in the IGS97, epoch 1997.0 reference frame available - 3 to 6 days from date of observation contact - http://www.navcen.uscg.mil/gps/precise/default.htm accuracy - approximately 5-10 centimeters

II. Minimally Constrained Precise GPS Orbit: A consistent minimally constrained weekly solution in the IGS97, epoch 1997.0 reference frame available - 4 to 10 days from date of observation contact - ftp://gracie.grdl.noaa.gov/dist/cignet/Ngsorbits accuracy - approximately 5-10 centimeters

III. Rapid GPS Orbit: Up to 50 constrained IGS fiducial tracking sites in the IGS97, epoch 1997.0 reference frame available - 16 hours from last observation contact - ftp://www.ngs.noaa.gov/cors/orbits/rapid accuracy - approximately 8-12 centimeters

IV. Ultra-Rapid GPS Orbit: A constrained estimated/predicted solution in the IGS97, epoch 1997.0 reference frame will be available - within 2 to 3 hours from last observation contact - under development accuracy - approximately 20-60 centimeters

V. Earth Rotational Parameters: Rapid and precise polar motion values available - 16 hours from date of last observation recipient - Bureau International de L'Heure (BIH) United States Naval Observatory(USNO) International GPS Service (IGS) accuracy - approximately 0.25 milli-arcseconds

VI. Troposheric estimates for the zenith path delay available - 4 to 10 days from date of observation recipient - GeoForschungsZentrum, Potsdam, Germany International GPS Service (IGS)

References

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NRCan IGS Analysis Center Report for 2000

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In addition to contributing to the classical IGS products, the Geodetic Survey Division (GSD) of Natural Resources Canada (NRCan) also initiated in 2000 contribution to the IGS Ultra Rapid Product. Unfortunately NRCan contribution to the IGS Rapid products had to be interrupted for most of 2000 until problems with NRCan estimation of Earth Orientation Parameters could be resolved. The following report documents the activities of the NRCan IGS Analysis Center during 2000.

The Classical IGS Products

In 2000, NRCan continued contributing to IGS all the classical products with the exception of the rapid products, which were interrupted between GPS Weeks 1054 to 1094. The NRCan estimation strategies and contributed products are described in ftp://igscb.jpl.nasa.gov/igscb/center/analysis/emr.acn. All NRCan products with the exception of the ionospheric grid and the recent Ultra Rapid, described further, are computed using the Jet Propulsion Laboratory (JPL) GIPSY-OASIS software. The NRCan ionospheric grid is computed using an in-house software suite. Its estimation strategy remained unchanged in 2000.

Besides implementing the IGS recommendations for the computation of Rapid and Final products, see Table 1, efforts were also devoted to the optimization of the NRCan estimation strategy using GIPSY Version 2.5 which had been implemented in late 1999 in preparation for the infamous Y2K expected problems. Improved apriori validation of the GPS RINEX observations files was also implemented. Single station procedures to automatically reject bad or weak data were implemented using a point positioning approach. Table 2 lists the modifications that affected the GPS satellite constellation in 2000.

Table 1. Final/Rapid Processing Strategies Modifications and Improvements

GPS Week	Modification
1056	Adoption of IGS convention to transform cross-correlated pseudo-range observations into synthesized non cross-correlated
1065	Adoption of IGS realization of ITRF97 (IGS97) station coordinates and velocities
1066	Adoption of new set of bias values to transform cross-correlated pseudo-range observations into synthesized non cross-correlated

Table 1. Final/Rapid Processing Strategies Modifications and Improvements (cont'd)

GPS Week	Modification
1070	Implementation of a station selection algorithm based on network geometry and station spacing
1070	Implementation of validation of data files based on precise point positioning using IGS rapid orbits and clocks products

Table 2. GPS Constellation Changes in 2000

Date	PRN	Change
April 14	14	removed
May 11	20	added
June 28	18	removed
July 21	28	added
July 27	16	removed
November 28	14	added

EMR Regional Processing

Since the beginning of 2000, NRCan has been computing a regional GPS solution for Canada. This initiative is in support of the Canadian Spatial Reference System (CSRS) realization and positioning activities and for a future contribution to the International GPS Service (IGS) ITRF densification. Starting at the beginning of 2001, these solutions will be submitted to the North American Reference Frame (NAREF) Technical Working Group of the International Association of Geodesy (IAG) Commission X (http://www.naref.org) to be included in a North American solution. The regional solution is estimated using JPL's GIPSY/OASIS II software. The strategy follows the guidelines proposed by the IGS and those adopted by the NAREF Technical Working Group. The current strategy used for producing weekly coordinate solutions is to fix the IGS final orbits, IGS final weekly Earth Rotation Parameters (ERP), and one reference station clock, and to estimate station coordinates, station and satellite clocks, and station tropospheric delays. Daily SINEX coordinate files are combined into a weekly SINEX combination for distribution to NAREF.

We estimate 29 stations including all stations of the Canadian Active Control system (CACS) as well as 6 IGS stations located close to Canada. All stations have 100m apriori station coordinate weight except algo, drao, nlib, wes2, yell, and thu1 which are tightly constrained to their estimated IGS00P04_RS51.SNX coordinates and standard deviations. These six stations are the so-called anchor stations used to tie the local network to the global IGS network. The constraints placed on the anchor stations are removed using SINEX software during the computation of the weekly combination. Figure 1 depicts the stations currently included in the NRCan regional solution.

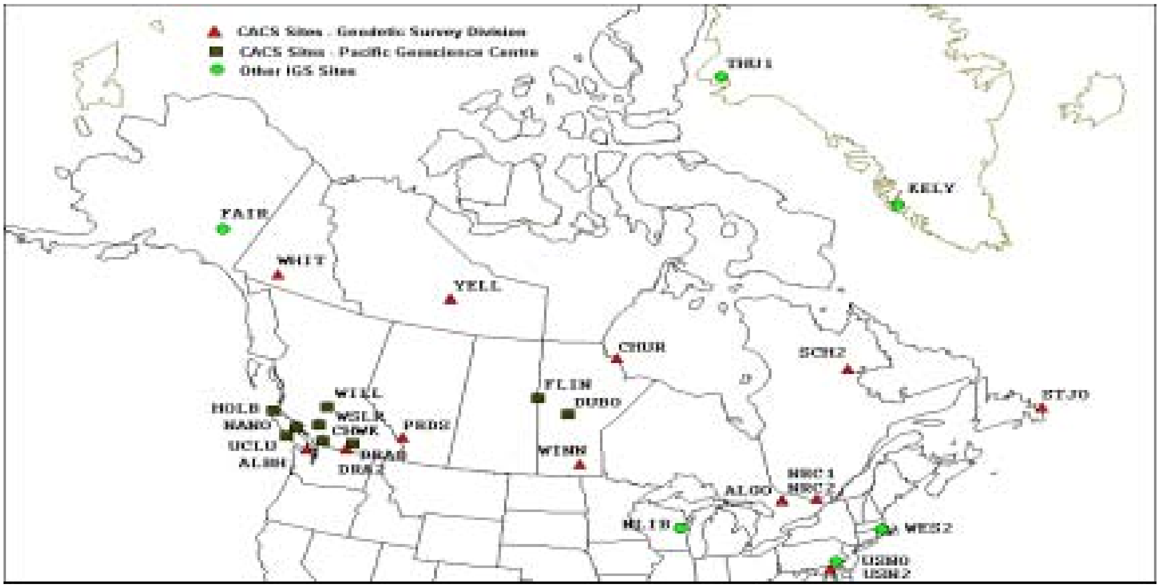


Figure 1. Stations included in NRCan Regional Processing

NRCan Ultra Rapid Products

The development of a strategy to compute Ultra Rapid orbits was initiated towards the end of 1999 and early 2000. It uses the Bernese v4.2 software (Hugentobler et al.) along with numerous in-house scripts. NRCan officially started submitting its Ultra Rapid products (emu) to the IGS Analysis Centre Coordinator (ACC) on March 20, 2000 (GPS Week 1054/ Day 1). User intervention is minimized and only required in "difficult times" such as several hours without enough IGS hourly station data files from the IGS Data Centres.

Processing Strategy

The processing strategy was adapted to our limited CPU capabilities at the time of development. In order to meet the IGS AC submission deadlines of 2h45m and 14h45m UT (i.e. 2h45m after the last observation), it was decided to process 3-hour batches, forming Normal Equations (NEQ) and stacking them to generate our Ultra Rapid products. The time required to process a 3-hr session, including the stacking of NEQ and the production of our Ultra Rapid orbit was about 1h20 min for a 35-station network. This strategy has some disadvantages like the shortage of timely hourly RINEX files and ftp connection problems to name a few. The main advantage however is that NRCan has a new Ultra Rapid solution every 3 hours reducing the average time of latency from 9 hours (IGU) to about 4.5 hours. Also, if the IGS decided to increase the number of IGU submissions per day from 2 to 4 (and possibly 8!), NRCan would not have to change its strategy!

About 60 IGS hourly stations are downloaded via ftp regularly and up to 45 stations can be used in our processing. The main ftp download is done from the Crustal Dynamics Data Information System (CDDIS) site every 15 minutes. Only missing stations from a pre-determined station list are downloaded. Frequent downloads are required to minimize ftp related problems and to obtain timely hourly data for our 3-hr session processing. We also retrieve data from a secondary ftp site located at the Federal Agency for Cartography and Geodesy in Germany (IFAG) to complement the ftp downloads from CDDIS in difficult times. To maximize the number of hourly stations used, the processing is delayed by at least 1h after the last observation but never more than 2h45m. NRCan relies heavily on the fact that hourly data files must be sent and be available at CDDIS as soon as possible **at all times** and not only prior to the two IGS Ultra Rapid combinations. This is very critical for us since we do not process a complete day (24 hours) of GPS data every time we generate our Ultra Rapid products, nor do we reprocess older 3-hr sessions.

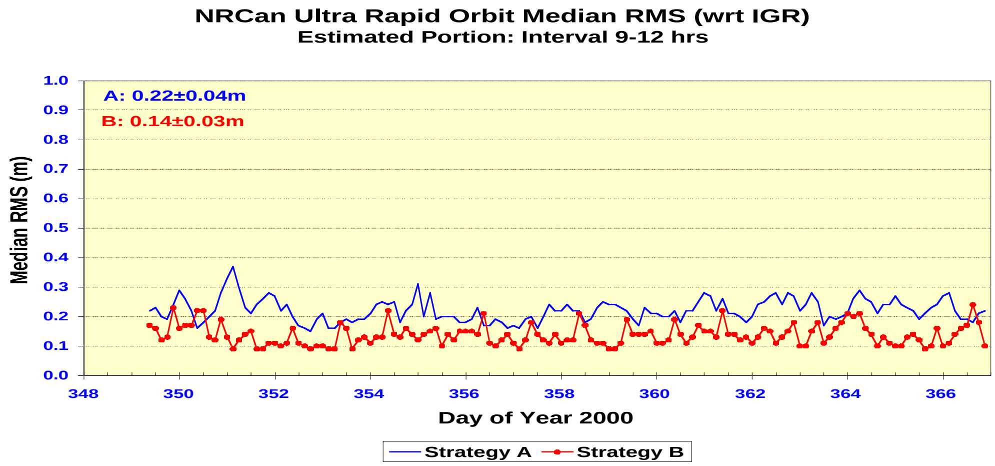
A number of different sources of apriori orbits can be used ranging from our own Ultra Rapid products to the less precise Broadcast ephemeris. As far as the apriori Earth Rotation Parameters (ERP) are concerned, we use the IERS Bulletin A at all times. IERS Bulletin A has been very reliable and is one of the most precise ERP series available for real time applications.

Products Generated and Results

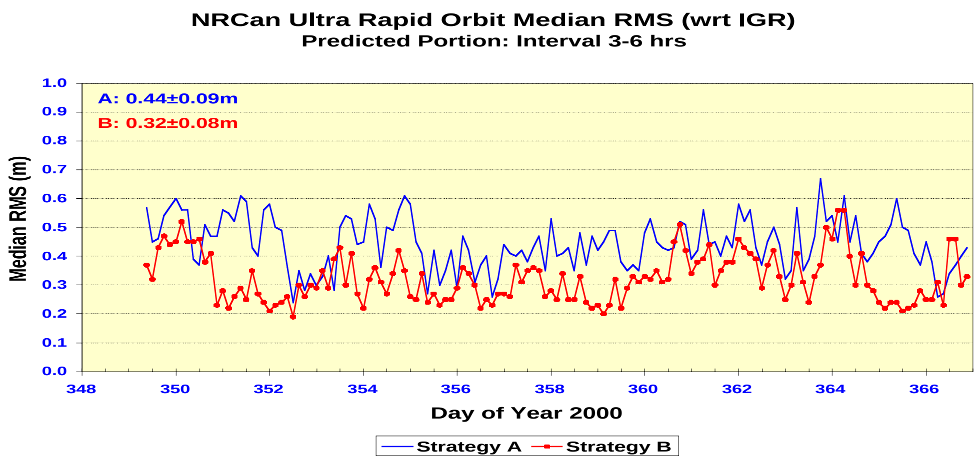
NRCan Ultra Rapid products consist of a 48-hr orbit file (24h estimated and 24h predicted) along with a 2-day ERP file (the first day is estimated and the second day is predicted). Although NRCan produces such product every 3 hours, only the sessions ending at 0h0m UT and 12h0m UT are sent to the ACC for the IGS Ultra Rapid combination (IGU). At this time, NRCan does not provide any satellite clocks in its Ultra Rapid.

Since we started the production in March 2000 and until the middle of December 2000, our Ultra Rapid orbit was strictly based on stacking at most sixteen 3-hr NEQ files corresponding to (at most) 48h worth of Ultra Rapid GPS processing (Strategy A). Starting in the middle of December 2000, we implemented an extra step (Strategy B), which consisted in fitting IGS Rapid and/or Ultra Rapid orbits (already available) along with our own Ultra Rapid orbit coming from Strategy A. Altogether, a minimum of two days and a maximum of three days worth of Rapid/Ultra Rapid orbit fitting are performed on a regular basis. As mentioned in Fang et al, 2001, the poor network geometry and lack of global GPS hourly data can harm the Ultra Rapid orbit precision quite heavily when compared to the IGS Rapid products and network coverage. The fitting process somewhat compensates for the poor coverage resulting in an overall better orbit prediction for real time applications.

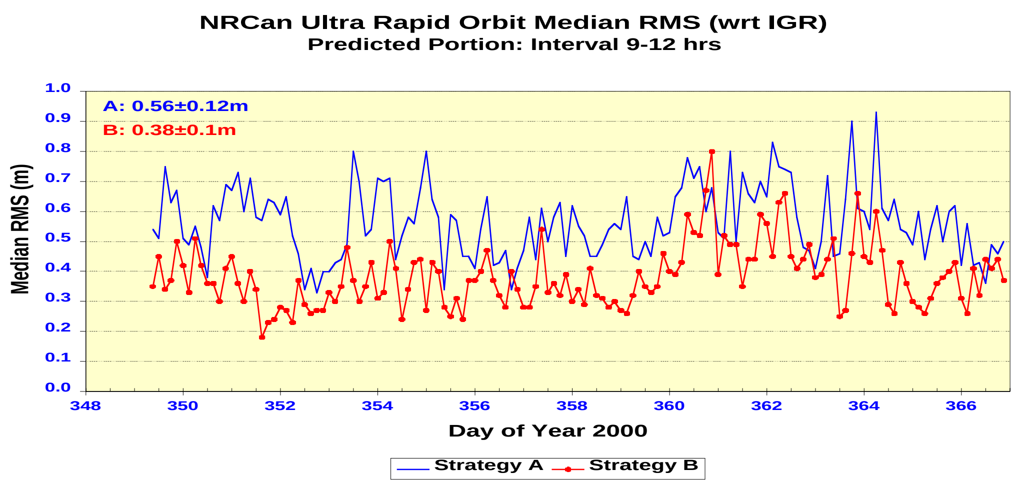
Strategy B proved to be very beneficial for the NRCan Ultra Rapid orbit precision. Depicted in Figure 2 is the NRCan daily Ultra Rapid orbit Median RMS (with respect to IGR) for both strategies A and B and for 3 different time intervals. Interval 9-12 hours of the estimated portion is shown on Figure 2a while intervals 3-6 and 9-12 of the predicted portion are shown on Figures 2b and 2c respectively. The plots cover the end of 2000 starting from December 14 at which time we implemented Strategy B. The mean and standard deviation of each series are also printed on top of each graphic. There is no doubt that Strategy B has a definite advantage over Strategy A!



(a)



(b)



(c)

Figure 2: NRCan Ultra Rapid Orbit Median RMS (wrt IGR) for Strategies A and B during December 14-31, 2000.

Finally, for completeness we show in Figure 3 the NRCan daily Ultra Rapid orbit median RMS (with respect to IGR) for the whole NRCan Ultra Rapid orbit, i.e. 48 hours, divided into 3-hour intervals for the same period as Figure 2. Strategy A and B are both included on the same graphic. The comparison is quite interesting and reveals again a clear improvement for Strategy B.

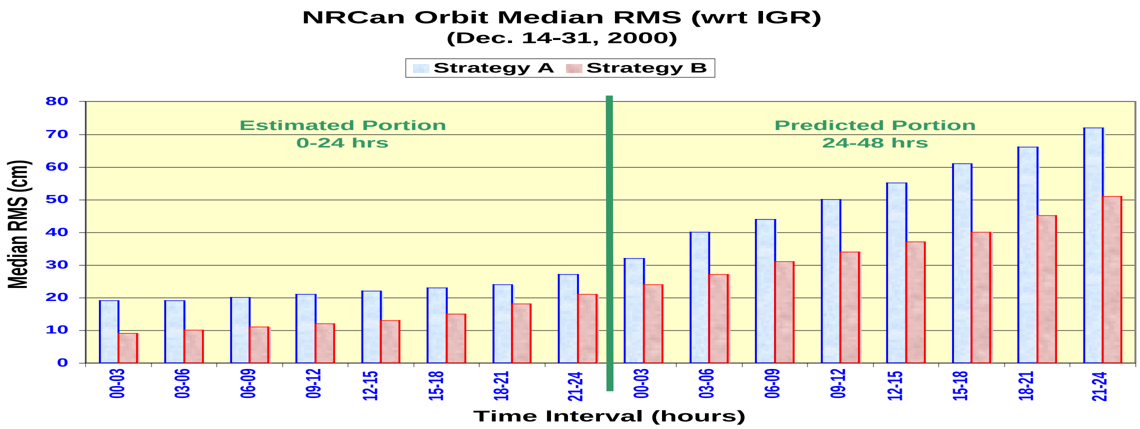


Figure 3: NRCan Ultra Rapid Orbit Median RMS (wrt IGR) for all 3-hour Intervals of Strategies A and B. Period covered: December 14-31, 2000.

Future Work

In the near future, we will investigate the quality of our Ultra Rapid Tropospheric Zenith Delays (TZD). We would also like to improve our Ultra Rapid orbit along with the associated ERP. Looking at the longer term, the broadcast satellite clocks or perhaps estimated satellite clocks could be added to our Ultra Rapid products. The latter will be difficult to implement due to (again) CPU limitations. New computers may facilitate and speed up the implementation.

Acknowledgment

NRCan IGS activities are performed in support of the Geodetic Survey Division's Canadian Active Control System. We thank all of our colleagues of the Active Control System Operations team. We also thank Dr. Jan Kouba for is invaluable support and advice.

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ASSOCIATE ANALYSIS CENTERS

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GLOBAL NETWORK ASSOCIATE ANALYSIS CENTERS

The Newcastle GNAAC Annual Report for 2000

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The GNAAC at University of Newcastle continued activities with submissions of a weekly G-network and P-network SINEX files. The analysis procedure outlined previously (P. Davis, G. Blewitt, 2000; Nurutdinov et al., 2000) remained unchanged throughout the year 2000. Starting with GPS week 1021 the ITRF-97 (51 stations) has been used instead of ITRF-96 (47 stations) to constrain the solution. Starting with GPS week 1065 the ITRF-97 from IERS has been replaced with IGS-97 realization of ITRF-97.

G-network Results

A-network SINEX data from all seven global analysis centres (COD, EMR, ESA, GFZ, JPL, NGS, SIO) were processed in the year 2000, the appearance of a station in a minimum of 3 solutions defining a global station and inclusion in the combined NCL G-network (Figure 1). Any remaining stations and RNAAC (AUS, EUR, GSI, SIR) stations (Figure 2) are defined as regional stations and are included in P-network along with global stations. During 2000 an average of 100 global and 60 regional stations appeared in weekly P-network, this contrasts with 90 and 54 during 1999.

The loose G-network solution (GNET) is estimated from block of normal equations composed of each deconstrained A-network. The corresponding covariance matrix is augmented to remove Helmert rotation parameter constraints. This solution is constrained later to the CORE 51 stations of ITRF-97 for the year 2000 producing constrained G-network.

Figure 3 shows the weighted RMS of residuals for each weekly A-network solution after Helmert transformation to the weekly loose G-network solution for all weeks of the year. RMS values for weighted RMS are in the region 0.6-2.0 mm describing repeatability of the G-network estimates.

Figures 4 through 7 show the translation (for X, Y, Z coordinates) parameters for 7-parameter Helmert transformation from deconstrained AC and GNET solutions to ITRF-97. Mean values for scale parameter are in the range $(1 + (1.48 \div 2.74) * 10^{-9})$ with RMS values $(2.73 \div 8.46) * 10^{-10}$.

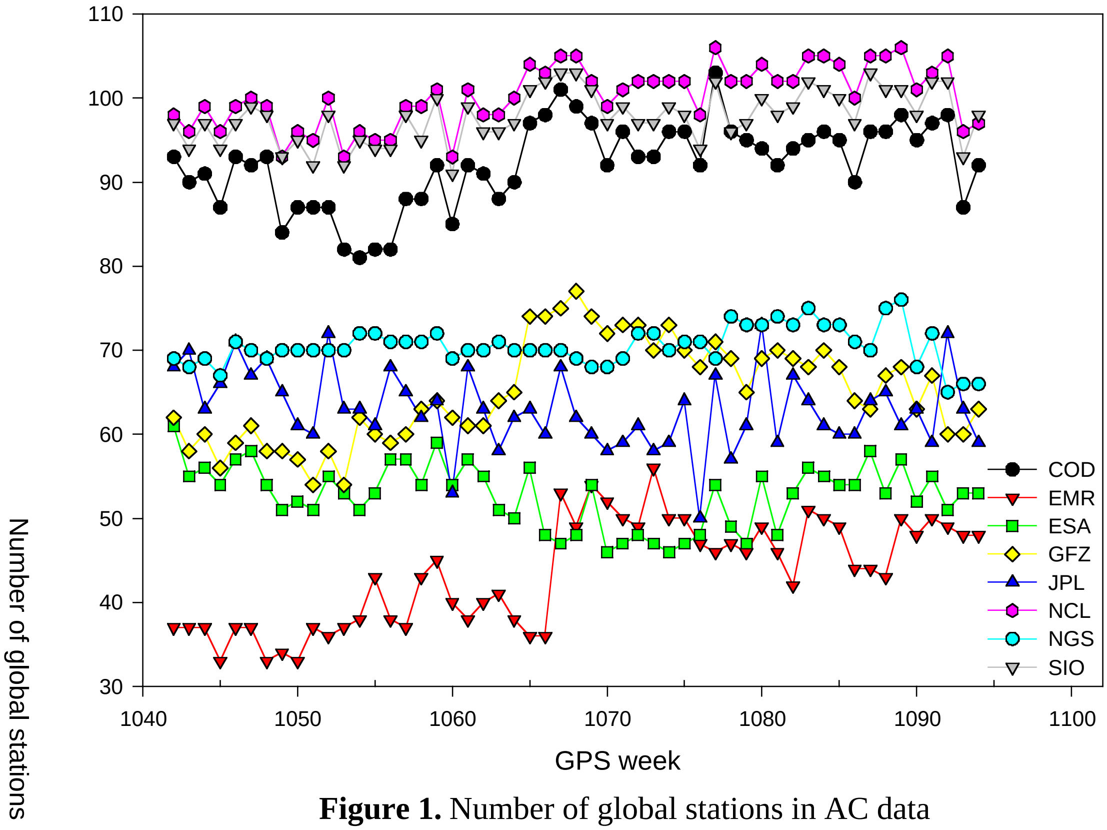

Figure 1. Number of global stations in AC data

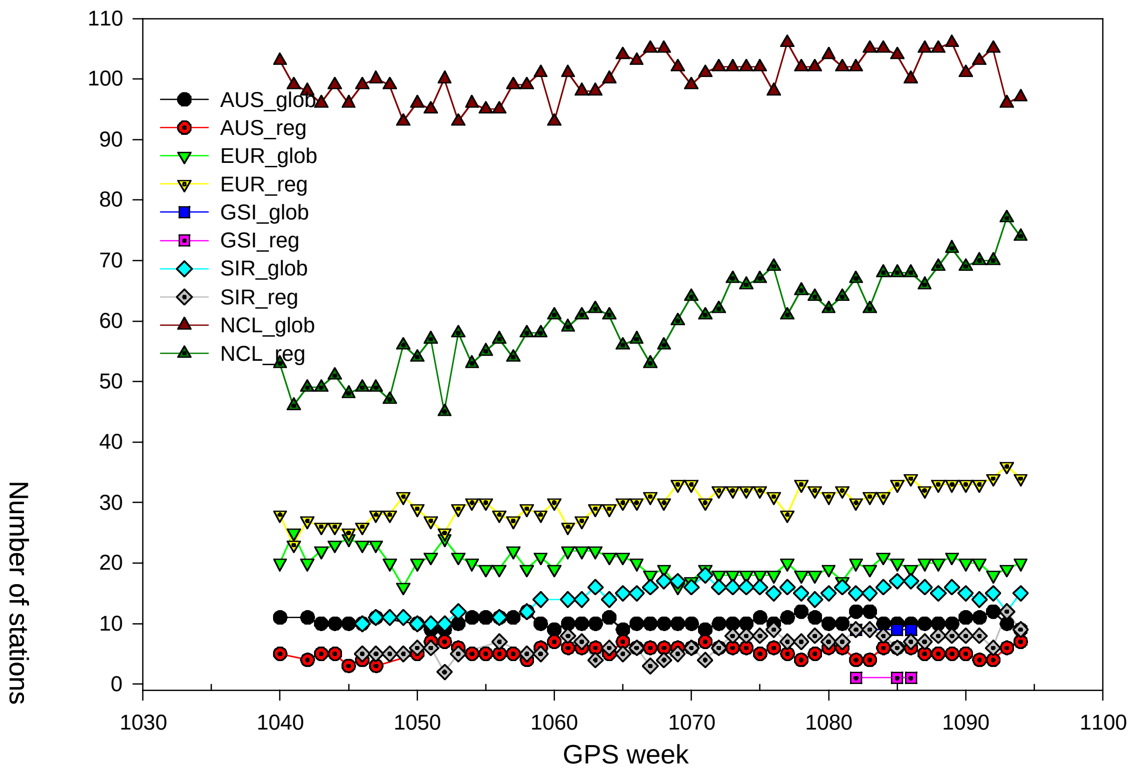

Figure 2. Number of global and regional stations in RNAAC and P-network solutions

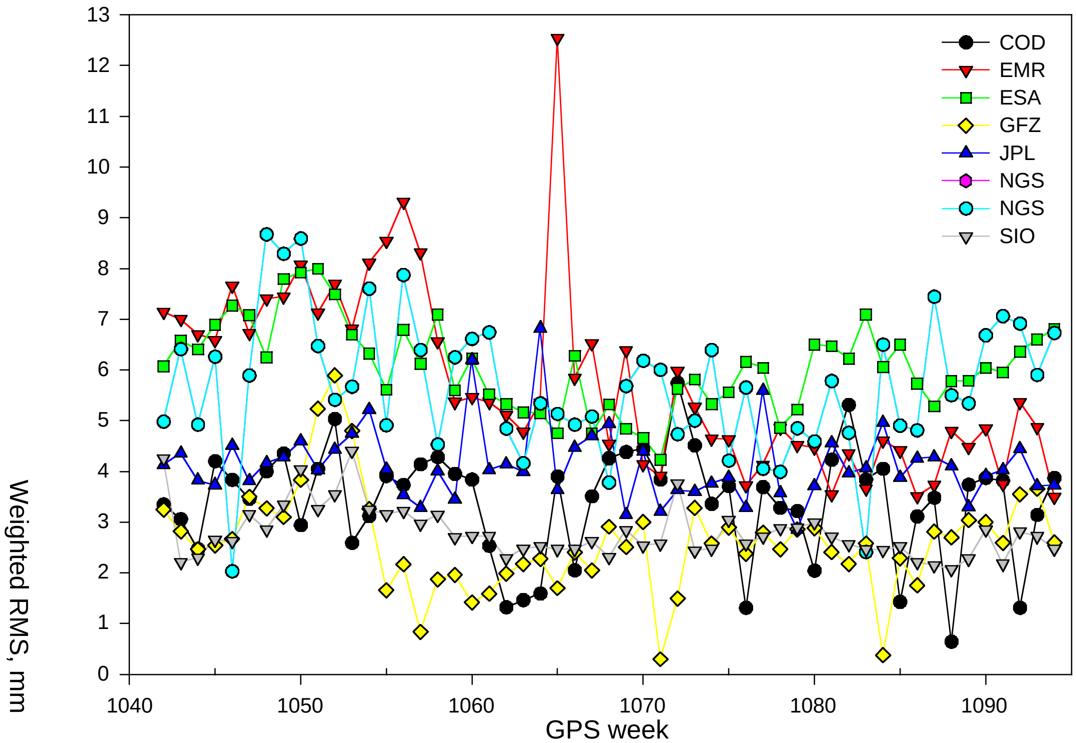

Figure 3. Weighted RMS of residuals for AC network transformation to loose NCL G-network

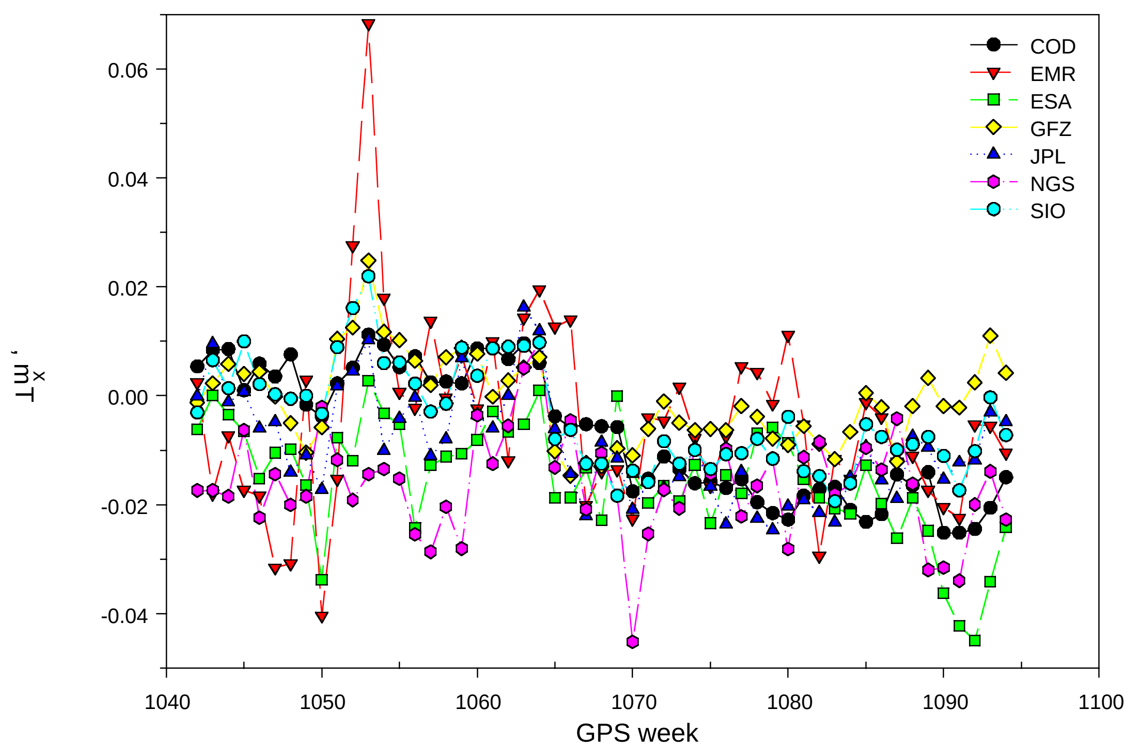

Figure 4. Time series of T_x transformation parameter for the ACs to ITRF

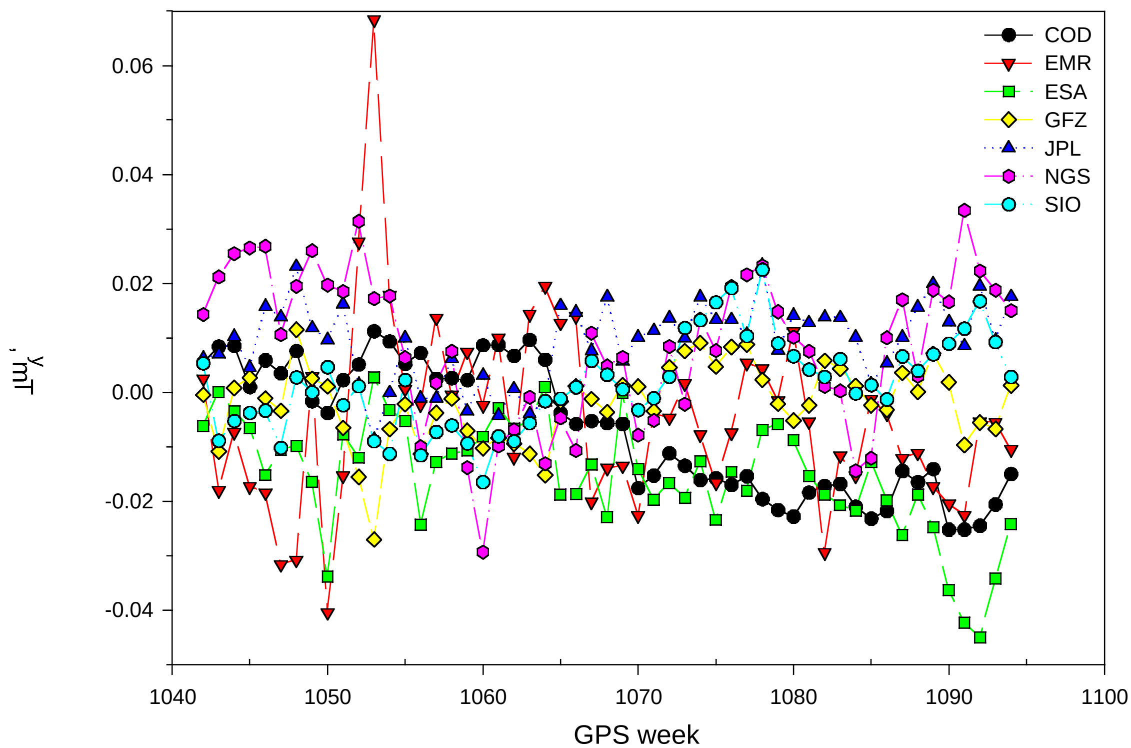

Figure 5. Time series of T_y transformation parameter for the ACs to ITRF

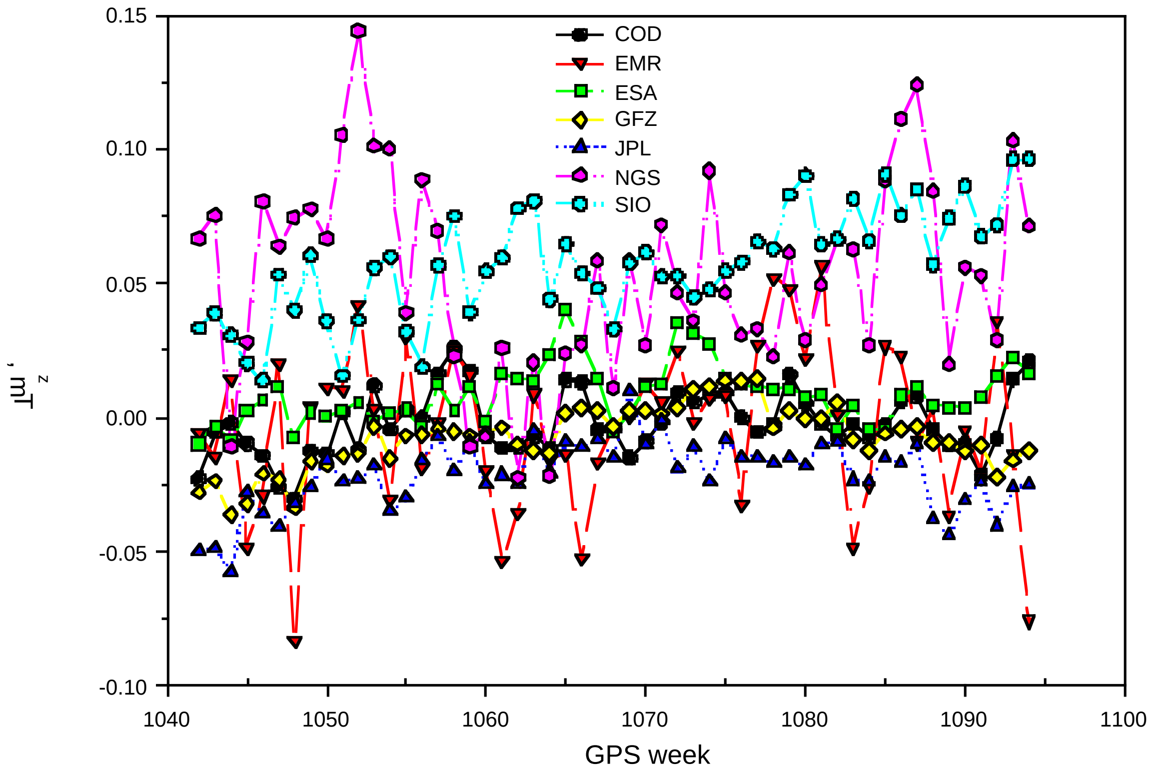

Figure 6. Time series of T_z transformation parameter for the ACs to ITRF

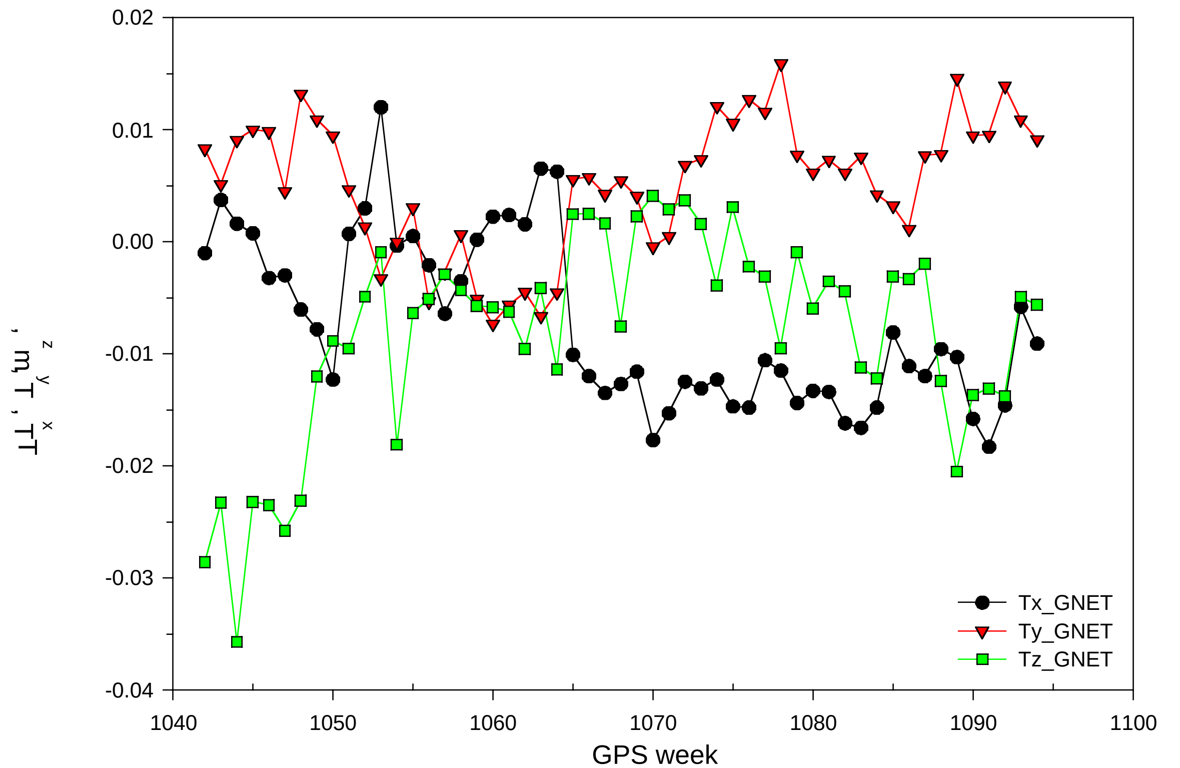

Figure 7. Time series of T_x , T_y , T_z transformation parameters for the NCL GNET to ITRF

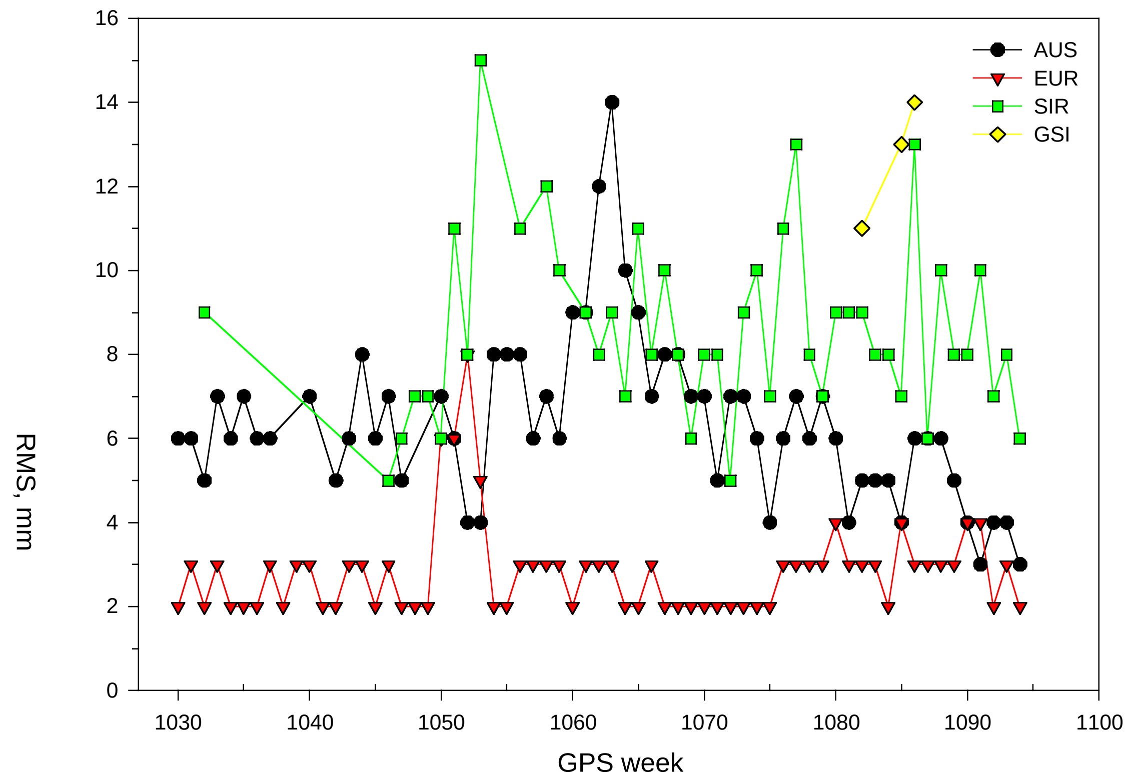

Figure 8. RMS of residuals for RNAAC R-network transformation to loose NCL G-network

P-network Results

Creation of P-network is based on G-network and the weekly input R-SINEXes from the RNAACs. A minimum of 3 global and 1 regional stations is required for inclusion of solution in the P-network. However this was not the case sometimes. More often, late submission (later than three weeks after the G-network process) of SINEX files by some RNAACs was the main reason of why their solutions have not been included in P-network.

From the RNAACs the solutions from AUS, EUR, SIR, GSI were included 51, 53, 45 and 3 times respectively during 2000, contrasting with 11, 52, 31 and 0 times during 1999.

In the used “attachment” method of network combination the G-network is not allowed to be perturbed by the R-networks. Figure 8 shows time series of the RMS residuals of station coordinates after 7-parameter Helmert transformation of deconstrained R-network to GNET.

Other activity

The NCL GNAAC’s solution **(NCL) 00 P 01** has been used by IERS to produce ITRF-2000 reference frame. The solution is a kinematic combination of weekly P-sinex solutions from the Newcastle GNAAC. The data span is four years (Aug 95 - Aug 99) and the minimum observation period for individual sites is 2 years.

The transformation parameters between **(NCL) 00 P 01** and ITRF-2000 can be found on the web-page http://lareg.ensg.ign.fr/ITRF/ITRF2000-PA/gcomb/stat.dat.

NCL GNAAC P-sinex solutions on five years interval have been used to detect seasonal variations of station coordinates and geocenter position (G. Blewitt et al, 2000; G. Blewitt et al, 2001).

Summary and Outlook

The GNAAC at University of Newcastle continued successfully to submit weekly G-network and P-network SINEX files to IGS. The most problems encountered were because of inversion problems with covariance matrix and late submission of solutions from ACs and RNAACs,

In 2001, the Newcastle GNAAC will continue to submit combined solution to IGS. TANYA software will be updated to combine Earth rotation parameters. TANYA will be the base for a new software to be developed within GPSVEL project (G. Blewitt et al. 2000).

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REGIONAL NETWORK ASSOCIATE ANALYSIS CENTERS

The EUREF Permanent Network Report 2000

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Introduction

Within the IAG Commission X, EUREF is the sub-commission, which is responsible for the maintenance of the European Reference System ETRS89. Members of the group are mainly federal survey authorities, universities and research institutes interested in the realization of a unified horizontal and vertical reference frame. Since 1995, the epoch-wise EUREF GPS campaigns were replaced to a great extent by the installation of the EPN, the EUREF Permanent GPS Network (EPN). This was done in close collaboration with the IGS seeking for regional densifications. In 1996 the EPN was accepted as a regional Network Associate Analysis Center (RNAAC) of the IGS for Europe.

EPN Management and new Structure

Since its start in 1995, the activities within the EPN are coordinated and guided by the EUREF Technical Working Group (EUREF TWG). A dedicated network coordinator took care of the day-to-day management of the permanent network. With the growth of the network and the tasks involved, EUREF started a re-organization at its 10th yearly Symposium in Tromsø, Norway, June 22nd-24th, 2000. Three units will, from now on, be involved in the management and development the EPN. These are the EPN Coordination Group (CG), the EPN Central Bureau (CB) and the EPN Special Projects (SP).

The EPN CG coordinates all activities related to the EPN. Members are the network coordinator, the data flow coordinator, the analysis coordinator, a representative of the TWG and the special projects liaison persons. The special projects are intended to study newly developing demands and activities based on EPN data and their potential use. Presently two special projects are ongoing, the "Generation of an EUREF-troposphere product" and "Monitoring of the EPN to produce coordinate time series suitable for geokinematics". Special projects, if successful, may, turn to EPN products after a 4-year project term.

Extensions of the EPN Tracking Network

Figure 1 shows the status of the EUREF permanent tracking network as in June 2001. The number of stations is 118. From these, 47 % of them belong also to the IGS network.

To encourage the installation of EPN stations in less dense regions, the EUREF TWG has adopted (November 24, 2000) a new guideline concerning the station location: a minimal distance of 300 km to already existing EPN stations is required, accepting the interest of each nation to have at least one EPN station. Exceptions to this rule are possible for stations submitting hourly data or contributing to EPN Special Projects. Thanks to this new guideline 45% of the EPN stations are now submitting hourly data.

Figure 1 – EPN tracking network, as of June 2001

EPN Data Flow

During the year 2000, the data flow within the EPN was considerably increasing since several EPN stations started transmitting hourly data together with daily data. Up to now, the delivery of daily transfers is still advisable for approximately 10% of the stations: they are still not delivering routinely the full 24 files/day.

The quality of the daily data flow has improved: at the EUREF Data Centre (BKG), the proportion of bad files (unreadable or wrong contents) fell from 1% to 0.05%. A part of this improvement was achieved by introduction of checking routines at the EPN Data Centers (DC). Unfortunately the checking procedures are not yet consistent at all DCs.

Recommended checks are:
- The unix/Hatanaka compression/decompression test
- Teqc, to get a basic overview of the data quality
- A test for the correspondence between file name and contents (e.g. wrong day).

If an error was found during transfer the file should be rejected.

The Regional Data Centre at BKG is the only EPN data center holding the majority of the EPN data. This single-center-dependency puts the EPN is a vulnerable position. A preparation for a mirror DC is under way. In case of outages users will have the possibility to switch from the Regional DC to the mirror, and this for both data input as data retrieving. This procedure is already working for the Local DCs.

Data Analysis

The observations of the EPN are currently analyzed by 13 Local Analysis Centers (LACs): ASI (Nuova Telespazio S.p.A., Space Geodesy Centre, Italy), BEK (International Commission for Global Geodesy of the Bavarian Academy of Sciences, Germany), BKG (Bundesamt für Kartographie und Geodäsie, Germany), COE (European solution created at CODE (Centre for Orbit Determination in Europe), DEO (Delft Institute for Earth-Orientated Space Research, Delft University of Technology, Netherlands), GOP (Geodetic Observatory Pecny, Czech Republic), IGN (Institut Géographique National, France), LPT (Bundesamt für Landestopographie (L+T), Switzerland), NKG (Nordic Geodetic Commission), OLG (Observatory Lustbühel Graz, Austria), ROB (Royal Observatory of Belgium), UPA (Universita di Padova, Italy) and WUT (Warsaw University of Technology, Poland).

The LACs submit weekly solutions of their subnet in the SINEX format (SINEX, 1996) to the EUREF Data Center at BKG .

The EPN Network Coordinator selects the subset of stations of each LAC in order to guarantee that each station is processed by at least 3 LACs. This resulting redundancy is used for quality control and outlier detection ; the individual LAC solutions are successively compared to the combined solution. Stations or even complete LAC solutions which show such a difference to the combined quantity that exceeds a predefined range (5 mm for the position or 10 mm for the height) are excluded in the final combined solution. Graphical visualization tools, e.g., the plot of correlation coefficients of the coordinates, are used for quality control.

Combination Scheme

The ADDNEQ program of the Bernese Software (Beutler et al., 1996) is used to combine the weekly SINEX files. At that time the a priori constraints of the station coordinates are removed. The normal equations are first combined into a free network solution, where 13 stations are selected to define the "minimum constrained conditions" in the ADDNEQ program. This solution is used for outlier detection.

After the exclusion of all outliers the official EUREF solution is generated where the coordinates of 13 stations are fixed to the ITRF-97.

In order to check the coordinate time series, a free network combination of the last seven EUREF combined solutions is routinely computed. This may lead to the exclusion of more stations and may require an additional iteration of all combination steps.

Introduction of a new Local Analysis Center

A new LAC located at the Delft University of Earth-Orientated Space Research, Netherlands (DEO) submitted its first solution on GPS week 1095. It is the first LAC within the EPN using GIPSY software (Web and Zumberge, 1995). The original solution from DEO could not be combined, as is, with the other 12 contributions, using the ADDNEQ program. However, using a different scheme, the combination could be performed. This different scheme was based on the estimation of a seven-parameter Helmert transformation between the station coordinates of the individual solutions and a "reference solution". In a second step those transformed coordinates were combined. Some investigations explained that the original combination could not be performed because of the very small (0 to 0.1) correlation coefficients between the station coordinates in the DEO SINEX solution. After some small changes in the processing scheme of DEO, significant correlations of 0.5 to 1.0 between the station coordinates showed up in the DEO SINEX files. As a result, since the beginning of GPS week 1100, the ADDNEQ program has successfully been used to add the DEO solution to the EUREF combined solution.

Weighting of Solutions

The various analysis softwares used by the LACs requires a scaling of the co-variances of each solution before the combination, and this in order to remove the software specific differences. For the LACs working with the Bernese Software, the SINEX files include the RMS of unit weight (d), which is used as the weighting factor : all elements of the covariance matrix are multiplied with the factor 1/d2 when the SINEX files are converted to normal equations. However, the RMS of unit weight is not available from the GIPSY and Microcosm solutions, which are the two other GPS data analysis packages contributing to the EPN. In addition to the weighting with 1/d2, an external weight file is introduced to scale each normal equation file in the combination. The factors given in this weight file are currently empirically determined to result in an equal contribution of all LAC solutions to the combined solution. It is clear that the weighting scheme is currently still one of the topics of investigation.

Time Series Special Project

The EPN may be considered as a kinematic network, where the stations have an increasing role in geokinematic interpretation as well. The quality of the EPN kinematic products (coordinate time series, velocities) is highly dependent on the station monumentation/data quality and the combination scheme used. In 2000, an EPN SP has been established in order to improve the EPN performance with a careful analysis and overview of each station encompassing the coordinate time series, the stability of the monumentation and the environmental effects. The SP is a joint effort of 6 different groups, where each group is responsible for a specific sub-region of the whole EPN. The groups are also encouraged to involve additional, non-official EPN sites into the analysis in order to derive a more detailed kinematic pattern of Europe.

To help the assessment of station quality and kinematic relevance, the SP contributed significantly to the preparation of the new IGS GNSS log format.

In the 1st work phase, the coordinates jumps and outliers are determined and collected into a uniform station problem file. This work is in progress, a retrospective analysis will be completed by the end of 2001. In the following work phases the spectral properties (periodical effects, noise spectra) of the time series will be analyzed.

Using all collected information an improved multi-year combination solution and time series are computed and also updated regularly. The improved time series including a table with station problems are displayed on the EPN CB Web pages (www.epncb.oma.be/series_sp.html). These pages also summarize all activities related to the SP.

Troposphere Special Project

Within the routine analysis of a network of ground-based GPS receivers, tropospheric parameters are part of the estimation. Longer series of the zenith path delays, for example, support climate research. Therefore EUREF decided to create a Special Project "Troposphere Parameter Estimation".

Similar to combining weekly SINEX files for the derivation of a combined coordinate product, BKG is going to produce a combined troposphere solution with input from the individual troposphere solutions of all ACs, which contribute to the coordinate solution. Their analysis is carried out in post processing mode on the basis of precise orbits. Initially supported by GFZ, the combination will be done following today’s IGS standards (Gendt, 1997): epoch-wise combination of the single solutions as weighted mean with rigorous outlier detection in consecutive steps; biases between the individual solutions have to be taken into account. As a result two weekly files will be produced. (1) A summary file with some statistics about e.g. the frequencies of the analyzed sites and about the accuracies of a single AC solution. This file provides feedback to the contributing ACs. (2) An output file (EURwwwwd.TRO) with the combined troposphere estimates from which the estimates for a single site can easily be extracted. The coordinates, as a necessary part of this file, will be taken from EUREF’s official combined SINEX file.

Beginning with GPS week 1108 the first ACs delivered their daily troposphere solution files to BKG. Thus, the testing of the combination software could be started. A common tropospheric sampling rate of 1 hour is desirable while at the beginning most of the solutions have a two-hour sampling rate.

Outlook

The analysis guidelines, adopted in April 1997 by the EUREF AC's to guarantee the homogeneity of the EUREF solution have aged. New analysis guidelines have been developed at the EUREF Analysis Centers Workshop held in Warsaw, Poland in May 2001. The EPN AC's have agreed to switch to the new analysis guidelines on GPS week 1130 (September 2, 2001). More details about the new guidelines will be available in next year's annual report.

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Acknowledgements

Without the labor and the commitment of the responsible agencies, their representatives at the observation sites, the data centers and the analysis centers, the EUREF network would not be the success that is it today. The authors would like to acknowledge especially the responsibles of the EUREF analysis centers.

AUSLIG RNAAC – 2000 Annual Report

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Introduction

AUSLIG continued processing all stations in the Australian Regional GPS Network (ARGN) during 2000. The weekly combined SINEX result files were submitted to the Crustal Dynamics Data Information System (CDDIS) as AUSLIG's role as an IGS type 2 Associate Analysis Centre.

Station Network

The station network processed by the AUSLIG RNAAC is shown in Figure 1. Thirteen of the seventeen stations in this network are operated by AUSLIG. DST1, PERT, TID2 and YAR1 are owned and operated by non-Australian agencies.

Data Analysis and Results

The Bernese GPS Software version 4.0 (Rothacher and Mervart 1996) is used for the GPS data processing. Daily solutions are computed using the following strategy:

- L3 double differenced phase observable.
- No resolution of integer ambiguities.
- Elevation cut-off angle of 20°.
- Estimation of tropospheric zenith delay parameters at 2 hourly intervals.
- IGS antenna phase centre variation model applied.
- IGS final orbits and EOPs held fixed.
- Station coordinates for a single station constrained (either TID2 or YAR1).

Seven daily solutions are combined at the normal equation level to obtain the weekly solution output in SINEX format submitted to the CDDIS. These solutions up to and including GPS week 1064 were tightly constrained to the ITRF97 coordinates at the following IGS reference stations; CAS1, DAV1, HOB2, MAC1, PERT, TID2 and YAR1. From GPS week 1065 onwards the IGS97 realisation of ITRF97 was used for coordinate constraint at these seven stations.

The AUSLIG RNAAC weekly SINEX solution files were included in the Type 2 GNAAC combination generated by the Massachusetts Institute of Technology (MIT) and the University of Newcastle upon Tyne GNAAC Polyhedron solutions.

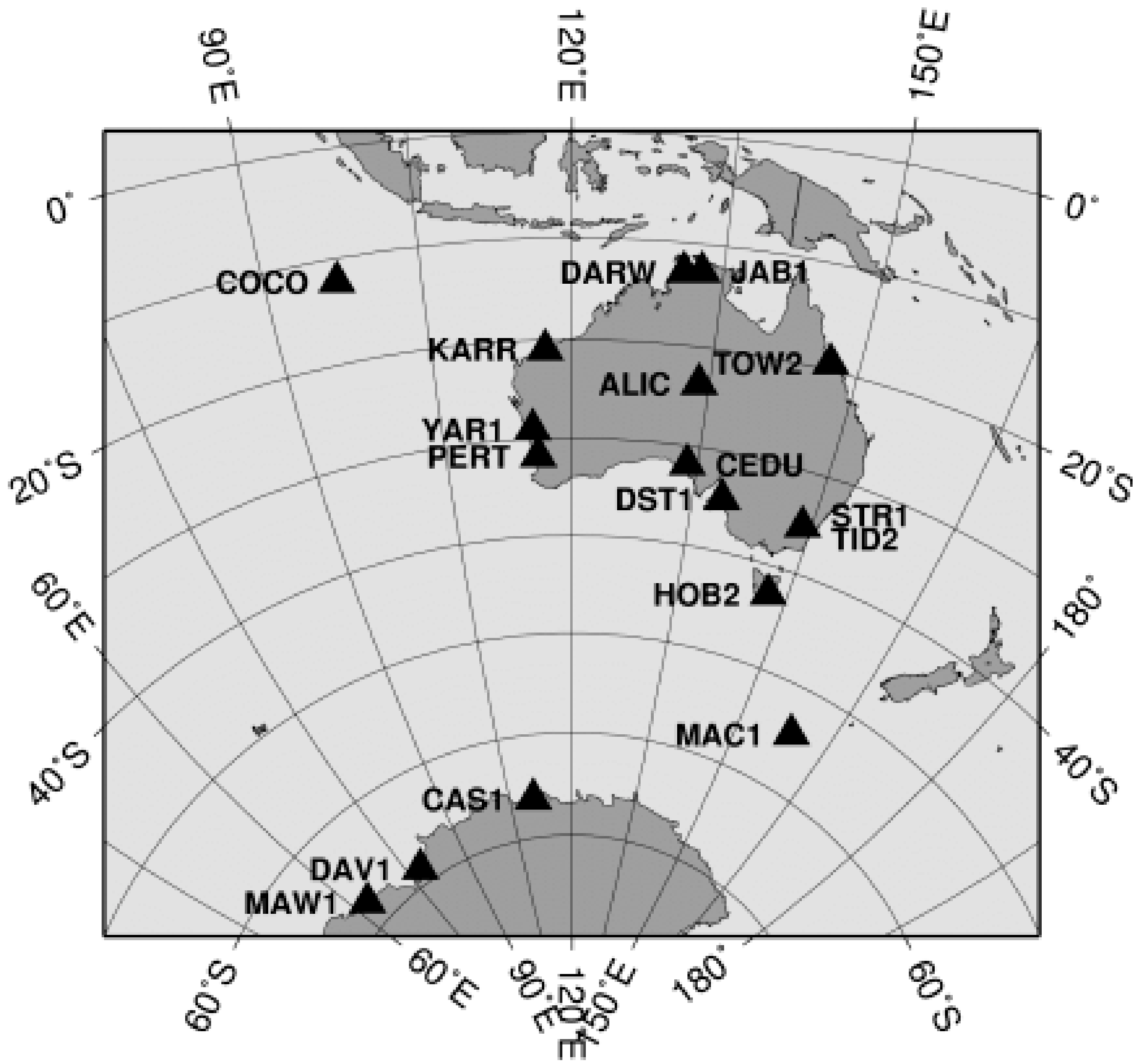

Figure 1. AUSLIG RNAAC station network as of 31 December 2000

Future Plans

AUSLIG plans to participate as an IGS Associate Analysis Centre (AAC) in support of Low Earth Orbiter (LEO) Missions.

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GSI RNAAC Technical Report 2000

A. Yamagiwa

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Geographical Survey Institute, Japan

Introduction and Overview

Since 1996, Geographical Survey Institute (GSI) has been contributing as a Regional Network Associate Analysis Center (RNAAC).

In 1999, our fiducial IGS site TSKB (located in Tsukuba, Japan) had suffered from GPS End of Week Rollover Problem and we had had to re-convert navigation files for RNAAC processing. This problem was fortunately solved in March 2000 and complemental analysis was finished in March 2001.

Outline of Processing

7 domestic GPS sites, as well as 10 IGS global sites, are selected for this regional analysis (Figure 1a, 1b). Daily coordinate solutions are generated using GAMIT version 9.95 and they are combined with GLOBK version 5.04 to generate weekly constraint solutions.

Characterizing features of the performed solutions are as follows;

- Finale IGS orbits and Earth orientation parameters are applied.
- Measurement elevation angle cut off 20 degrees, sampling interval 60 secs for single-day adjustments.
- Tropospheric zenith delays are estimated every 3 hours.
- Station coordinates estimated in the International Terrestrial Reference Frame (ITRF), applying a priori sigma of ~10m.

Estimated parameters are obtained as Software/Solutions Independent Exchangeable (SINEX) format and submitted to Crustal Dynamics Data Information System (CDDIS).

Current State

The standard deviation of GSI RNAAC analysis 2000, which represent the reliability about this analysis, is shown in Figure 2.

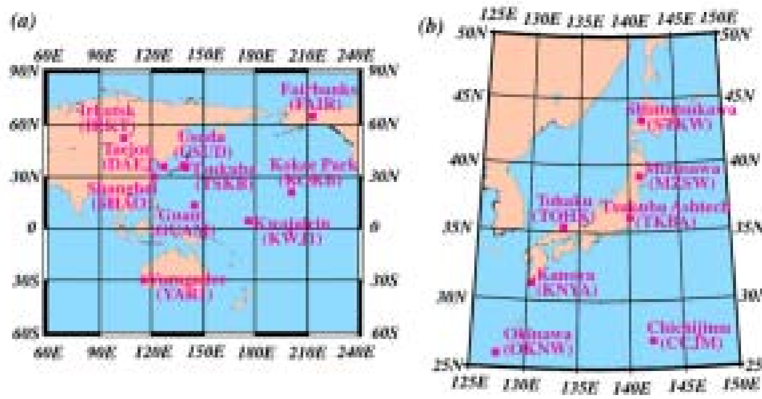

Figure 1. GPS observation sites for GSI RNAAC analysis
(a) IGS global sites (b) domestic sites

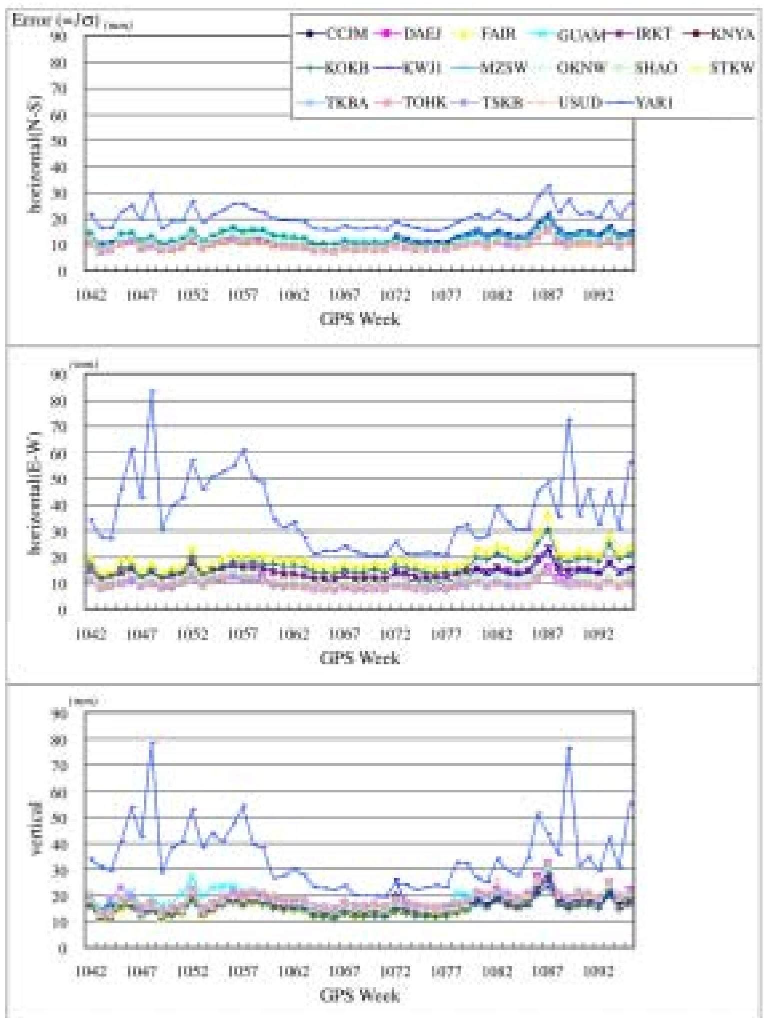

Figure 2. Standard Deviation of GSI RNAAC weekly solution

Annual Report 2000 of IGS RNAAC SIR

Wolfgang Seemüller and Hermann Drewes

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Introduction

Since July 1996, the Deutsches Geodätisches Forschungsinstitut (DGFI), Munich, acts as the IGS Regional Network Associate Analysis Center for the South American geocentric reference system SIRGAS, RNAAC SIR (Seemüller and Drewes, 1998, 1999, 2000). All available data in this region are routinely processed with the automated version of the Bernese software (Rothacher et al., 1996) on a weekly basis and submitted as SINEX files to the IGS Data Centers. The RNAAC SIR solutions are then included in the global combined polyhedron solutions of the IGS GNAACs.

Station Network

The RNAAC SIR strives permanently for densifying its regional network. This year, four new global GPS stations were added to the network. These stations are Guatemala (GUAT), San Lorenzo (SLOR), and San Salvador (SSIA) in Central America, and Puerto Rico (PUR3) in the Caribbean Sea. The network consists at present of 47 stations, 31 stations are global and 16 are regional (Figure 1).

Solutions

Since GPS week 1053 the processing strategy was slightly modified. The sampling rate was changed from 2 min. to 30 sec., and the troposphere is estimated once per two hours instead of four hours. These changes produce better results of the solutions.

In the last Annual Report (Seemüller and Drewes, 2000) we presented the first IGS RNAAC SIR solution for coordinates and velocities (DGFI00P01) generated by a complete reprocessing based on the latest realization of the IERS Terrestrial Reference Frame (ITRF1997). At the end of year 2000 a new solution was computed including all weekly RNAAC SIR solutions from 1996 to 2000. It provides position and linear velocity estimates of sites being in operation since at least one year. IGS combined orbits and Earth orientation parameters were held fixed. The datum was constrained with respect to the ITRF97 coordinates and velocities of stations CRO1, FORT, SANT, AREQ, BRAZ, LPGS, and OHIG. The reference epoch is 2000:000 (see figure 1).

The observations of the IGS RNAAC SIR stations were also included in the SIRGAS 2000 campaign. By this means the RNAAC stations contribute to this latest realization of the American Reference System (Figure 2) where emphasis is given to the establishment of a unified continental vertical reference system by including all the tide gauges that define the classical national height systems.

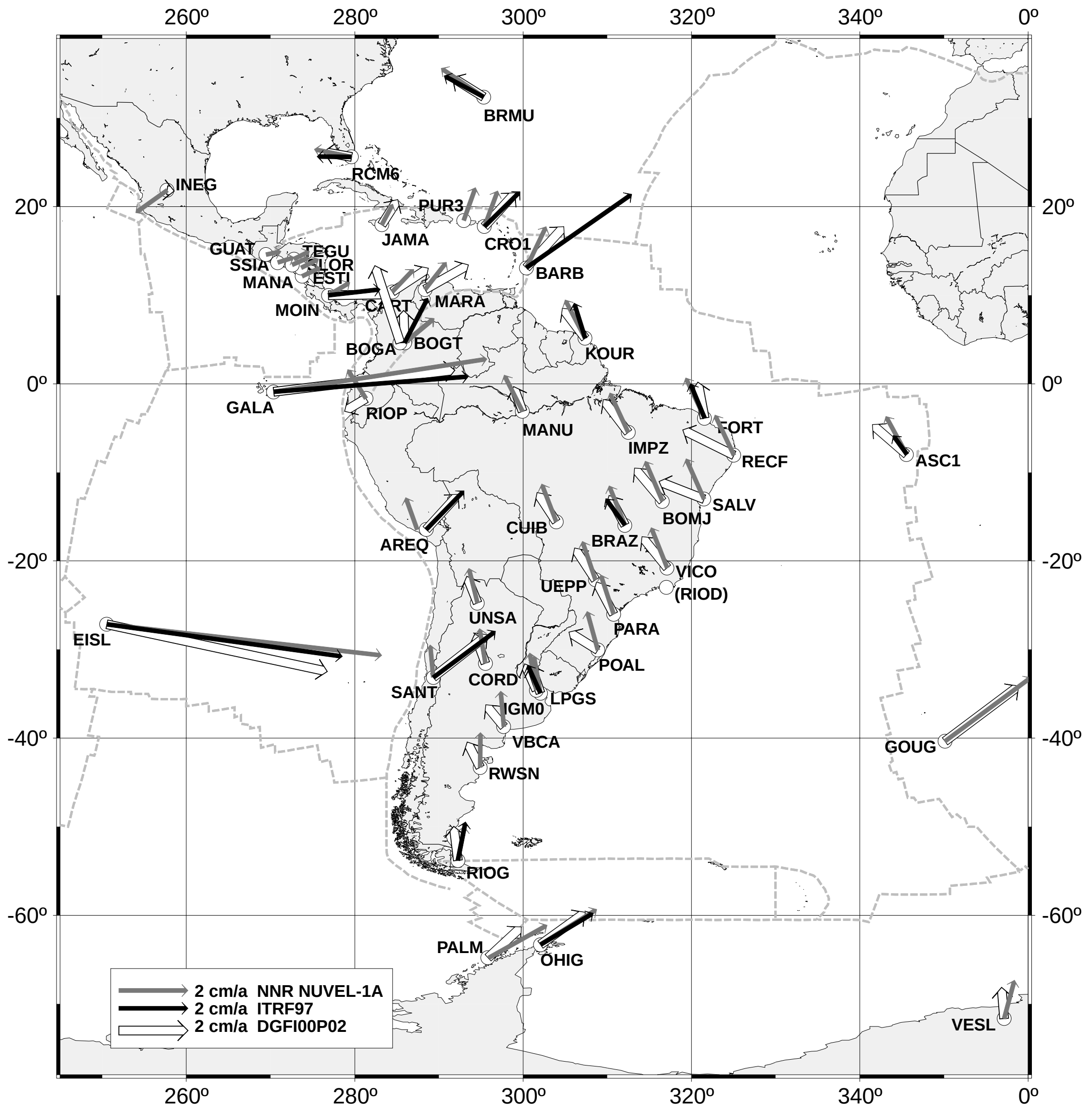

Figure 1: Horizontal velocities of IGS RNAAC SIR stations

Conclusion

Figure 1 shows the velocities of the new solution DGFI00P02 compared with the velocities of ITRF97 and the geophysical model NNR NUVEL-1A. The comparison with the ITRF97 yields a good agreement for most of the stations. Discrepancies exist with respect to the NUVEL-1A model in stations close to plate boundaries (e.g. AREQ and SANT). This is because NNR NUVEL-1A does not model deformations in plate boundary zones. Obvious are the discrepancies between both solutions in stations with short time series. The velocities tend much more to the east, like in the stations RWSN, VBCA, POAL, SALV, and RECF. The reason for these deviating velocities is still unknown, and has to be investigated. The same is valid for station INEG, where the velocities have opposite azimuths.

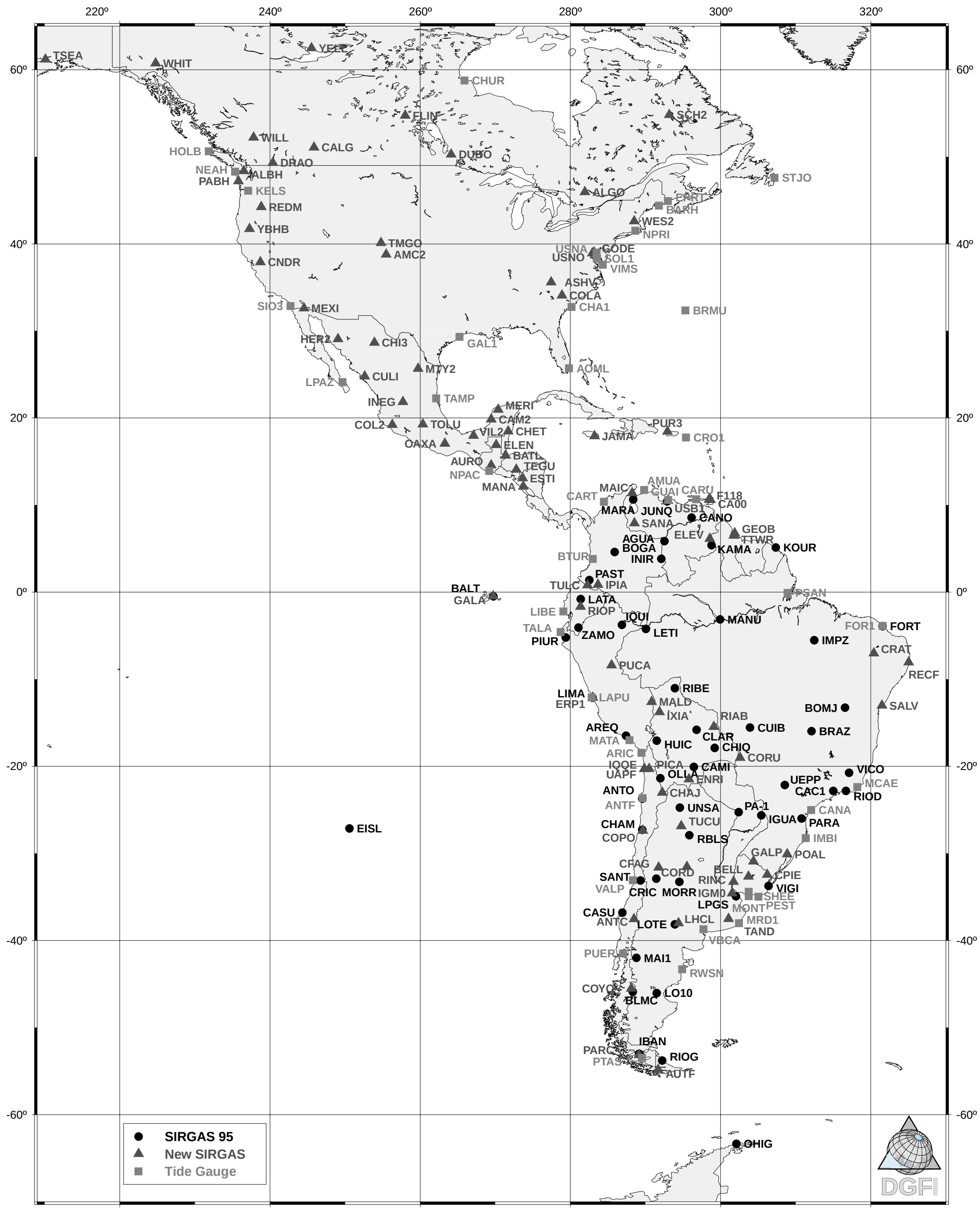

Figure 2: Network of the SIRGAS 2000 campaign

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SEEMÜLLER, W. and H. DREWES: Annual Report 1998 of RNAAC SIRGAS,1998 Technical Reports, R. NEILAN, A. MOORE, K. GOWEY, eds. Pasadena, CA: Jet Propulsion Laboratory, 1999.

SEEMÜLLER, W. and H. DREWES: Annual Report 1999 of RNAAC SIRGAS, 1999 Technical Reports, IGS Central Bureau, eds., Pasadena, CA: Jet Propulsion Laboratory, 2000.

IGS

IERS CONTRIBUTIONS

International Earth Rotation Service (IERS) / International Terrestrial Reference System (ITRS) Contributions

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Introduction

Following its terms of reference, IGS works in close cooperation with the International Earth Rotation Service (IERS). The Product Center of the International Terrestrial Reference System (ITRS) of the IERS, hosted by the Institut Géographique National, cooperates very closely with the different IGS components (Central Bureau, Analysis Centers, and tracking stations) for ITRF station coordinates and analysis of solutions provided by IGS analysis centers as well as site information and local ties of the collocation sites. For more information, see *http://lareg.ensg.ign.fr/ITRF*.

ITRF and IGS Relationship

Since the beginning of the IGS preliminary test activities in 1992, the IGS Analysis Centers have used ITRF coordinates for some subset of stations in their orbit computations. Moreover, the combined IGS ephemerides are expressed in ITRS because the coordinates used by the IGS are based on ITRF91 from the beginning until the end of 1993; ITRF92 during 1994; ITRF93 during 1995 until mid-1996; ITRF94 since mid-1996 until the end of April 1998; ITRF96 starting on March 1, 1998; ITRF97 starting on 1 August 1999, and ITRF2000 in late 2001.

IGS supports the continuous improvement of the ITRF by contributing to the extension of the ITRF network, providing new collocations or by improving position accuracy. The IGS Analysis Centers contribute greatly to ITRF by providing IGS/GPS solutions, which are included in the ITRF combinations.

IGS provides also a very efficient method to densify the ITRF network: one can now obtain millimetric positions directly expressed in ITRS by processing suitable GPS data together with IGS products.

ITRF2000

The ITRF2000 solution is the most dense and accurate frame ever developed, containing about 800 stations located at about 500 sites. It has been achieved by simultaneous combination of positions and velocities using full variance/covariance matrices of the individual solutions provided by the IERS analysis centers. It includes primary core stations observed by very long baseline interferometry (VLBI), lunar laser ranging (LLR), satellite laser ranging (SLR), GPS, and DORIS (usually used in previous ITRF versions), as well as regional GPS networks for its densification (Alaska, Antarctica, Asia, Europe, North and South Americas, and Pacific). Figure 1 shows the distribution of the primary sites of ITRF2000, highlighting the collocated techniques.

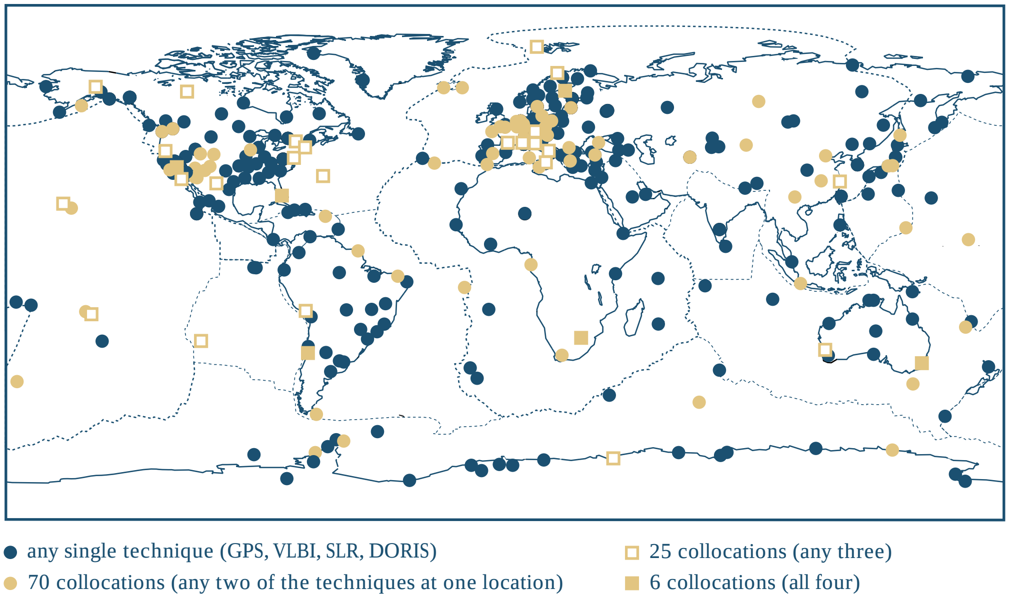

Figure 1. The ITRF2000 primary network. Symbols indicate collocations of space geodetic techniques (GPS, VLBI, SLR, DORIS).

The ITRF2000 is intended to have an accurate datum definition, achieved as follows:

- The origin and its rate by a weighted average of most consistent SLR solutions.
- The scale and its rate by a weighted average of VLBI and most consistent SLR solutions. Unlike the ITRF97 scale expressed in the Geocentric Coordinate Time Frame, that of the ITRF2000 is expressed in Terrestrial Time Frame.
- The orientation is aligned to that of ITRF97 at 1997.0 epoch and its rate to be such that there is no-net-rotation rate with respect to NNR-NUVEL-1A. Note that the orientation as well as its rate are defined upon a selection of ITRF sites with high geodetic quality.

The ITRF2000 long-term stability, evaluated over 10 years, is estimated to be better than 4 millimeters in origin and better than 0.5 parts per billion in scale, equivalent to a shift in station heights of approximately 3 millimeters over the Earth's surface.

All the ITRF2000 related files are available at: *http://lareg.ensg.ign.fr/ITRF/ITRF2000*.

IGS

DATA CENTER REPORTS

IGS

GLOBAL CENTERS

CDDIS 2000 Global Data Center Report

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Introduction

The Crustal Dynamics Data Information System (CDDIS) has supported the International GPS Service (IGS) as a global data center since 1992. The CDDIS activities within the IGS during 2000 are summarized below; this report also includes any changes or enhancements made to the CDDIS during the past year. General CDDIS background and system information can be found in the CDDIS data center summary included in the *IGS 1994 Annual Report* (Noll, 1995) as well as the subsequent updates (Noll, 1996, Noll, 1997, Noll, 1998, Noll, 1999, and Noll, 2001).

System Description

The CDDIS archive of IGS data and products are accessible worldwide through anonymous ftp. The CDDIS is located at NASA's Goddard Space Flight Center (GSFC) and is accessible to users 24 hours per day, seven days per week.

Computer Architecture

The CDDIS is operational on a dedicated Compaq AlphaServer 4000 running the UNIX operating system. All GPS data and product files are archived in a single filesystem, accessible through anonymous ftp, and are stored in UNIX compressed format. At present, nearly 100 Gbytes of on-line magnetic disk space is devoted to the storage of daily GPS tracking data and products.

The CDDIS staff continues to archive older GPS data, not currently on-line, to CD-ROM for eventual access through a 600-platter CD-ROM jukebox. Thus far, GPS data from 1992 through 1999 have been archived to CD, at least one week per CD. These data are migrated from magneto-optical disks (in VAX/VMS format) to the UNIX system where a CD-ROM image is created. After mounting the resulting CDs in the jukebox, users can access the data contained on these CDs in a transparent fashion, i.e., the jukebox software creates a filesystem similar to on-line magnetic disk filesystems.

Archive Content

As a global data center for the IGS, the CDDIS is responsible for archiving and providing access to both GPS data from the global IGS network as well as the products derived from the analyses of these data.

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. The following operational or regional data centers make data available to the CDDIS from selected receivers on a daily (and sometimes hourly) basis:

- Australian Survey and Land Information Group (AUSLIG) in Belconnen, Australia
- Alfred Wegener Institute (AWI) for Polar and Marine Research in Bremerhaven, Germany
- Bundesamt für Kartographie und Geodäsie (BKG) in Frankfurt, Germany
- Chinese Academy of Surveying and Mapping (CASM) in Beijing, China
- Centre National d'Etudes Spatiales (CNES), France
- Deutsches Geodätisches ForschungsInstitut (DGFI) in Munich, Germany
- European Space Operations Centre (ESOC) in Darmstadt, Germany
- GeoforschungsZentrum (GFZ) in Potsdam, Germany
- Geographical Survey Institute (GSI) in Tsukuba, Japan
- Jet Propulsion Laboratory (JPL) in Pasadena, California
- Korean Astronomy Observatory (KAO) in Taejeon, Korea
- National Geography Institute (NGI) in Suwon-shi, Korea
- National Imagery and Mapping Agency (NIMA) in St. Louis, Missouri
- NOAA's Geosciences Laboratory (NOAA/GL) Operational Data Center (GODC) in Rockville, Maryland
- Natural Resources of Canada (NRCan) in Ottawa, Canada
- Pacific Geoscience Centre (PGC), NRCan in Sidney, Canada
- Regional GPS Data Acquisition and Analysis Center on Northern Eurasia (RDAAC) in Moscow, Russia
- University NAVSTAR Consortium (UNAVCO) in Boulder, Colorado
- United States Geological Survey (USGS) in Reston, Virginia

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 an operational or regional data center. Table 1 lists the data sources and their respective sites that were transferred daily to the CDDIS in 2000. Over 62K station days from 199 distinct GPS receivers were archived at the CDDIS during the past year; a complete list of these sites can be found at URL *ftp://cddisa.gsfc.nasa.gov/pub/reports/gpsdata/cddis_summary.2000*.

Daily GPS Data Files

Once the daily RINEX data files 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.

The CDDIS daily 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 program TEQC (Estey 1999) and are used for data inventory and quality reporting purposes. During 2000, the CDDIS archived data on a daily basis from an average of 170 stations. Each site produces approximately 0.8 Mbytes of data per day (compressed RINEX, compressed compact RINEX, navigation, meteorological, and summary); thus, one day's worth of GPS tracking data totals nearly 130 Mbytes. Although the "compact RINEX" data format is the operational format for exchange of GPS data between the IGS and analysis centers, the CDDIS continues to archive and make data available in the compressed RINEX format for use by the general user community. In 2000, the CDDIS GPS data archive totaled over 50 Gbytes in volume; this figure represents data from nearly 62K observation days. Of the 170 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 ephemeris data files for a given day are decompressed and then merged into a single file that contains the orbit information for all GPS satellites for the day. This daily ephemeris data file, named *brdcddd0.yyn.Z* (where *ddd* is the day of year and *yy* is the year), is then copied to the ephemeris subdirectory as well as a general directory of all merged ephemeris files (*/gps/gpsdata/brdc*). Users can thus download this single daily file instead of all broadcast ephemeris files from the individual stations.

At this time, the CDDIS on-line archive of daily GPS data contains data from January 1998 through the present. Prior to early 2001, these data are available in compact RINEX only; later data are archived in both compact RINEX and uncompacted RINEX formats. As the disks supporting this archive fill up, older uncompact RINEX observation data are deleted. The CD-ROM jukebox contains GPS data from 1992 through 1997; it is hoped the software interface to this device will be operational in mid-2001.

The majority of the data delivered to and archived in the CDDIS during 2000 was available to the user community within six hours after the observation day. As shown in Figure 1, nearly fifty percent of the data from the global sites delivered to the CDDIS were available within three hours of the end of the observation day; over twenty percent were available within one hour. 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.

Hourly GPS Data Files

By the end of 2000, seven operational/regional data centers (BKG, ESOC, JPL, NOAA, GFZ, PGC, and NRCan) were transmitting hourly data files to the global data centers. Each file of observation (in compact RINEX format only), navigation, and meteorological data contains a single hour's worth of thirty-second data. These individual hourly files are labeled by incrementing the sequence number digit in the RINEX file naming convention; e.g., the file *mmmmddd*a.*yy*o.Z contains the observation data for the first hour of day *ddd* (or the first file transmitted for day *ddd*) in year *yy* for site *mmmm*. Within minutes of receipt, the files are archived to separate subdirectories (*/gps/nrtdata*) by day and hour on the CDDIS. These data are retained on-line for three days. After that time, the hourly data files are deleted; the daily file, transmitted through normal channels with a typical delay of one to two hours, will have been received and archived already and thus the hourly data are of little use. Furthermore, to ensure the most rapid delivery of these data to the user community, no validation or checks on data quality are performed. As shown in Figure 2, in 2000, fifty percent of these hourly data files were available to the user community within 15 minutes of the end of the hour; nearly eight-five percent were available within thirty minutes. GPS sites supplying hourly data to the CDDIS in 2000 are denoted by an * in Table 1; over seventy sites transmitted hourly data files to the global data centers in 2000.

Meteorological Data

The CDDIS currently receives meteorological data from over thirty sites, as noted in Table 1. The meteorological data provided are dry temperature, relative humidity, and barometric pressure at thirty minute sampling intervals. These data are stored on CDDIS with the daily GPS observation and navigation data files in parallel subdirectories.

IGS Products

The seven IGS data analysis centers (ACs) retrieve the GPS tracking data on a daily basis from the global data centers to produce daily orbit and clock products as well as weekly Earth rotation parameters (ERPs) and station position solutions; the seven 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 the central disk archive, and made available in compressed format on the CDDIS by automated routines that execute several times per day. The IGS Analysis Coordinator then accesses the CDDIS (or one of the other global analysis centers) on a regular basis to retrieve these products and derive the combined IGS orbits, clock corrections, and Earth rotation parameters as well as to generate reports on data quality and statistics on product comparisons. Users interested in obtaining precision orbits for use in general surveys and regional experiments can also download the IGS products. The CDDIS currently provides on-line access through anonymous ftp or the web to all IGS products generated since the start of the IGS Test Campaign in June 1992.

Regional Network Associate Analysis Centers (RNAACs) routinely generate station position solutions for regional networks in Software INdependent EXchange (SINEX) format. The three Global Network AACs (GNAACs) perform a comparison of these files and submit the resulting SINEX files to the CDDIS. The GNAACs also access the SINEX files from the IGS ACs and RNAACs and produced comparison and combined, polyhedron station position solutions. The CDDIS provides "short-SINEX" files, designated with an *.ssc* extension, for all AC and AAC SINEX files. These files contain the site information from the SINEX file but no matrices. All RNAAC solution files are also stored in the weekly IGS product subdirectories. The official IGS combined weekly SINEX solutions and cumulative combined SINEX solutions generated by the IGS Reference Frame Coordinator are also available in the weekly IGS product subdirectories.

Both the rapid (designated IGR) and the predicted orbit, clock and ERP (designated IGP) combined products generated by the IGS Analysis Coordinator continued to be available through 2000. Furthermore, a new product, the IGS ultra-rapid combination (designated IGU) were made available twice daily (at 03:00 and 15:00 UTC) starting in September 2000 (GPS week 1080). The IGS global data centers, including the CDDIS, download the rapid, predicted, and ultra-rapid products from the Analysis Coordinator and made them available in a timely fashion to ensure their usefulness to the user community.

Since January 1997, the IGS has conducted a pilot experiment on the combination of troposphere estimates. Using a sampling rate of two hours, the zenith path delay (ZPD) estimates generated by the IGS analysis centers were combined by GFZ to form weekly ZPD files for approximately 150 global GPS sites. As of early 1998, these troposphere products are available through the IGS global data centers; at the CDDIS the files are in a subdirectory of the weekly GPS products directories (i.e., */gps/products/wwww/trop*, where *wwww* is the GPS week number).

As of June 1, 1998, several IGS Analysis Centers began supplying daily, global ionosphere maps of total electron content (TEC) in the form of IONEX (an official format for the exchange of ionosphere maps) files. These products are also available from the IGS global data centers. At the CDDIS, the IONEX files are located in daily subdirectories of the main product area (e.g., */gps/products/ionex/yyyy* where *yyyy* is the four-digit year), rather than under the weekly subdirectory structure, since the files are produced daily.

Supporting Information

Daily status files of GPS data holdings, reflecting timeliness of the data delivered as well as statistics on number of data points, cycle slips, and multipath continue to be generated by the CDDIS. By accessing these files, the user community can receive a quick look at a day's data availability and quality by viewing a single file. The daily status files are available through the web at URL *ftp://cddisa.gsfc.nasa.gov/pub/reports/gpsstatus/*. The daily status files are also archived in the daily GPS data directories.

Ancillary information to aid in the use of GPS data and products are also accessible through the CDDIS. Weekly and yearly summaries of IGS tracking data archived at the CDDIS are generated on a routine basis and distributed to the IGS user community through IGS Report mailings. These summaries are accessible through the web at URL *ftp://cddisa.gsfc.nasa.gov/pub/reports/gpsdata*. The CDDIS also maintains an archive of and indices to IGS Mail, Report, and Network messages.

GLONASS Data and Products

In early 2000, the IGS Governing Board approved the International GLONASS Pilot Project (IGLOS-PP) as a formal working group within the service. The CDDIS proposed to continue its role as a global data center for GLONASS data and products to the IGLOS-PP Call for Participation issued in 2000. The CDDIS archived GLONASS data from over forty sites totaling nearly 10K station days of data; the data centers and sites active during 2000 are shown in Table 2. GLONASS products from four analysis centers (BKG, CODE, ESA, and MCC) as well as the Analysis Coordinator (at the Technical University of Vienna) were also made available to the public. GLONASS data and products are accessible via anonymous ftp to host *cddisa.gsfc.nasa.gov*, in the filesystem */igex*. At present, the CDDIS continues to archive both GLONASS data and products in a filesystem separate from IGS data and products.

System Usage

Figures 3 through 5 summarize the monthly usage of the CDDIS for the retrieval of GPS and GLONASS data and products for February through December 2000. Figure 3 illustrates the amount of GPS data retrieved by the user community during 2000. Over fourteen million files were transferred in 2000, with an average of 1.3 million files per month. The chart in Figure 4 shows the number of product files retrieved from the CDDIS in 2000; these files are categorized by type, the orbit, clock, ERP, and SINEX product files, ionosphere product files, and troposphere product files. Figure 5 shows the amount of GLONASS data and products retrieved from the CDDIS in 2000. Figures 6 and 7 illustrate the profile of users accessing the CDDIS IGS archive during 2000. Most accesses were through network gateways, which did not yield sufficient information about the user. Both education and government users constituted the next largest user category of CDDIS users of GPS data and products. Figure 7 displays the usage information by geographic region; the majority of CDDIS users are from hosts in North America.

The figures referenced above present statistics for routine access of the on-line CDDIS GPS data archives. The CDDIS staff continues to satisfy special requests from the user community for data from the off-line archive as well as field routine questions about the system and the IGS in general. Table 3 summarizes the type and amount of special requests directed to the CDDIS staff during 2000. 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. As CD-ROMs of older data become available through the on-line jukebox this process will become easier for both the user and the CDDIS staff.

Other Activities

The CDDIS staff assisted in the preparation and editing of the proceedings from the 1999 IGEX Workshop.

Publications

The CDDIS staff attended several conferences during 2000 and presented papers on or conducted demos of their activities within the IGS, including:

- "1999 IGS Data Center Reports" (Carey Noll) for 1999 IGS Annual Report (submitted in 2000, to be published in 2001)
- "CDDIS 1999 Global Data Center Report" (Carey Noll) for 1999 IGS Technical Report (submitted in 2000, to be published in 2001)
- "Current Status of and Backup Plans for Flow of IGS Data and Products" (Carey Noll) was presented at the IGS Network Workshop in July 2000
- "The IGS Global Data Center at the CDDIS – An Update" (Carey Noll and Maurice Dube) was presented at the IGS Network Workshop in July 2000
- "IGS Data Centers" (Carey Noll) was presented as part of the IGS Forum during the ION GPS 2000 Meeting in September 2000

Electronic versions of these and other publications can be accessed through the CDDIS on-line documentation page on the web at URL *http://cddisa.gsfc.nasa.gov/reports.html*.

Future Plans

Computer System Enhancements

The AlphaServer 4000 computer supporting the CDDIS has been operational for over three years. Additional RAID disk space will be procured in 2001, as well as a dedicated tape backup system.

Changes in the Data Archive

In early 2000, the IGS Governing Board approved the International GLONASS Pilot Project (IGLOS-PP) as a formal working group within the service. The IGLOS-PP committee issued a Call for Participation in early 2000. Later that year, the steering committee, in conjunction with representatives of various IGS components, developed recommendations for incorporating the flow of GLONASS data and the generation of official products into the existing IGS infrastructure. Plans are to complete this transition in mid-2001.

In 2000, the CDDIS proposed to serve as a data center supporting the IGS Pilot Project for Low Earth Orbiting (LEO) Missions. The GPS products required by these missions require one second GPS data on an hourly basis. The CDDIS will begin the archive and distribution of one-second data, stored in files containing fifteen minutes of data, from a network of thirty to forty sites during the mid-2001 timeframe. The CDDIS will also become involved in the archive of space-borne GPS receiver data. A pilot program for the use of this flight data will begin operation in 2001.

Contact Information

To obtain more information about the CDDIS IGS archive of data and products, contact:

Ms. Carey E. Noll	Phone:	(301) 614-6542
Manager, CDDIS	Fax:	(301) 614-5970
Code 920.1	E-mail:	*noll@cddis.gsfc.nasa.gov*
NASA GSFC	WWW:	
	http://cddisa.gsfc.nasa.gov/cddis_welcome.html	
Greenbelt, MD 20771		

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Table 1: Sources of GPS data transferred to the CDDIS in 2000

Source				Sites					No. Sites
AUSLIG	ALIC	CAS1	CEDU	COCO	DARW	DAV1	HOB2	JAB1	**15**
	KARR	MAC1	MAW1	STR1	_TID1_	TOW2	_YAR2_		
AWI	GOUG	VESL							**2**
BKG	EBRE	HOFN*	NVSK	_ORID_	TUBI	UZHL	WTZT	_YEBE_*	**8**
CASM	BJFS[m]								**1**
CNES	GRAS	HARB	KERG	_NKLG_	THTI				**5**
DGFI	BRAZ								**1**
ESA	KIRU*	KOUR*	MALI	MAS1*	PERT*	VILL*			**6**
GFZ	KIT3[m]	KSTU	LPGS	OBER*	POTS*[m]	RIOG*	_UNSA_*	URUM[m]	**9**
	ZWEN*[m]								
GSI	SYOG	TSKB							**2**
IGN	ANKR	BOR1*	BRUS*[m]	(EBRE)	GLSV	(GRAS)	GRAZ[m]	(HARK/B)	**27**
	HERS*[m]	(HOFN*)	IRKT	JOZE	(KERG)	(KIRU)	(KIT3)	KOSG	**(40)**
	(KSTU)	LHAS[m]	(LPGS)	(MAS1)	MATE*[m]	MDVO	METS[m]	NICO	
	NOUM	NTUS	NYA1	NYAL	OHIG	ONSA*	(POTS)	REYK*[m]	
	(THTI)	TRO1	TROM	WSRT	WTZR*[m]	ZECK	ZIMM*[m]	(ZWEN[m])	
JPL	AOA1*	AREQ*	ASC1	AUCK*[m]	CASA	CHAT[m]	CIC1*	CORD*	**44**
	CRO1*	DGAR	EISL*	FAIR*[m]	GALA*	GODE*	GOL2*	GOLD*	**(45)**
	GUAM*	HARV*	HRAO*	IISC	JPLM*	KOKB*[m]	KRAK	(KUNM)	
	KWJ1*	MAD2*	MADR*	MCM4*	MDO1*[m]	MKEA*	NLIB*	NSSP*	
	PIE1*	PIMO*	QUIN*	_RBAY_*	(RIOP)	SANT*	SEY1	SHAO	
	SUTH*	THU1	TID2*	TIDB*	USUD*	YAR1			
KAO	DAEJ								**1**
NGI	SUWN								**1**
NIMA	BAHR[m]								**1**
NOAA/GL	AMC2	AOML[m]	BARB	BARH*	BRMU	EPRT*	_ESTI_*	FORT	**21**
	_GUAT_*	HNPT	JAMA	KELY	_MANA_*	_SLOR_	SOL1[m]	_SSIA_*	
	_TEGU_*	USNA	USNO[m]	WES2[m]	WUHN				
NRCan	(ALBH[m])	ALGO*[m]	CHUR*[m]	(CHWK)	(DRAO*)	(DUBO)	(FLIN)	(HOLB)	**8**
	(NANO)	NRC1*[m]	NRC2*	PRDS*[m]	SCH2*[m]	STJO*[m]	(UCLU)	(WHIT)	**(19)**
	(WILL)	(WSLR)	YELL*[m]						
PGC	ALBH*[m]	CHWK	DRAO*[m]	DUBO	FLIN	HOLB	NANO	UCLU	**11**
	WHIT*	WILL	WSLR						
RDAAC	ARTU	BILI	MAG0	_NRIL_	PETP[m]	TIXI	YAKA	YAKZ	**9**
	YSSK								
SIO	AMMN	BAKO	_DRAG_	INEG[m]	_KODK_	MONP	PIN1	PVEP/3	**11**
	RAMO	SIO3[m]	VNDP[m]						
UNAVCO	CHUM	KAYT	KAZA	KUMT	KUNM	NSSP	_PODG_	POL2	**14**
	RIOP	SELE	SHAS	SUMK	TALA	TVST			
USGS	AMUN	PALM							**2**
Totals:						**199 sites from 21 data centers during 2000**			

Notes: Sites in () indicate backup delivery route
Sites in _italics_ indicate sites new to the CDDIS in 2000
* Indicates site also providing hourly data to the CDDIS in 2000
[m] Indicates site providing meteorological data to the CDDIS in 2000

Table 2: Sources of GLONASS data transferred to the CDDIS in 2000

Source	Sites								No. Sites
AUSLIG	*DARR*	DAVR	LINR	*STR2*	YARR				**5**
BKG	BORG	BRUG	DLFT	*GJOV*	GOPE	GRAB	HERP	KR0G	**22**
	LHAZ	METZ	MR6G	MTBG	OS0G	REYZ	THU2	*TIGZ*	
	VS0G	VSLD	*WROC*	WTZZ	ZIMJ	ZIMZ			
CSIR	CSIR								**1**
DLR	NTZ1								**1**
DNR	SUNM								**1**
ENRI	MTKA								**1**
GSFC	GODZ								**1**
GSI	TSKA								**1**
D. Hogarth	*DWH1* m								**1**
IGN	BIPD	GRAC	REUN						**3**
IMVP	IRKZ	KHAB							**2**
NPL	NPLC/*E*								**1**
UFl	GATR								**1**
USGS	CRAR								**1**
USNO	USNX								**1**
Totals:	**43 sites from 15 data centers during 2000**								

Notes: Sites in *italics* indicate sites new to the CDDIS in 2000
m Indicates site providing meteorological data to the CDDIS in 2000

Table 3: Summary of special requests for GPS data and information in 2000

Type of Request	Totals
General IGS/CDDIS information	~160 requests (phone, fax, e-mail)
Off-line GPS data	~25 requests (phone, fax, e-mail)
Amount of off-line data requested	~10,000 station days†
Volume of off-line data requested	~7.5 Gbytes

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

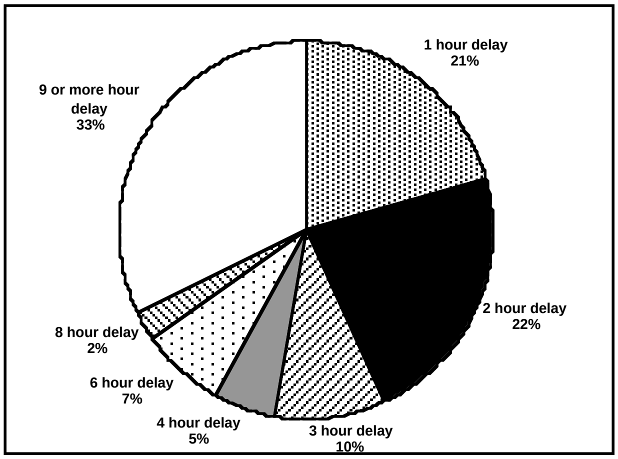

Figure 1: Average delay in delivery of GPS daily data files to the CDDIS in 2000

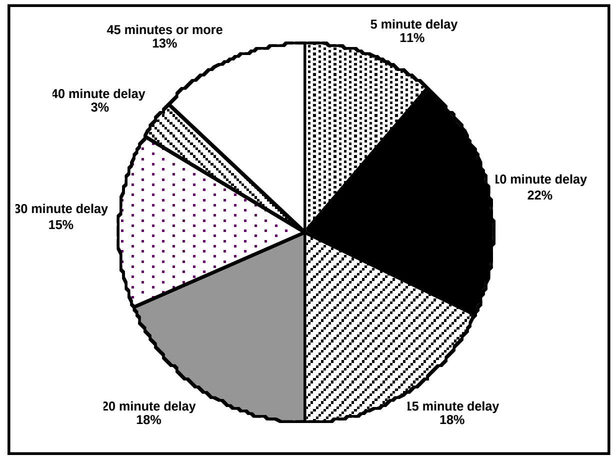

Figure 2: Average delay in delivery of GPS hourly data files to the CDDIS in 2000

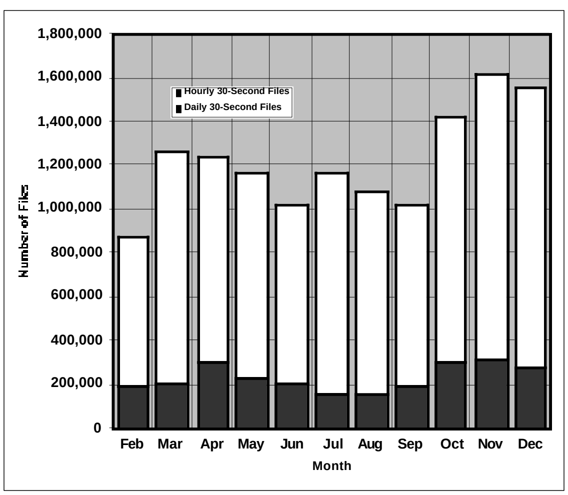

Figure 3: Number of GPS data files transferred from the CDDIS in 2000

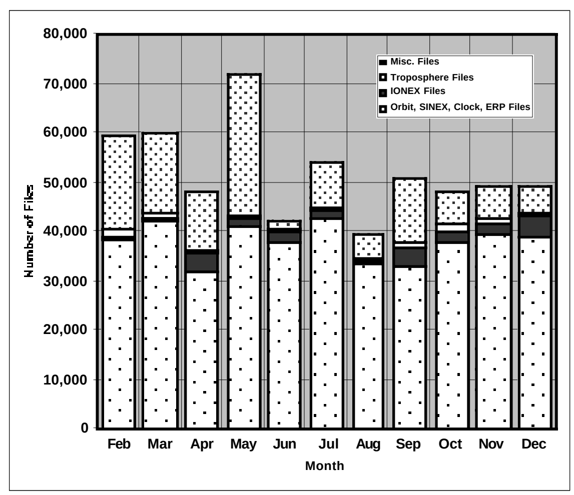

Figure 4: Number of GPS product files transferred from the CDDIS in 2000

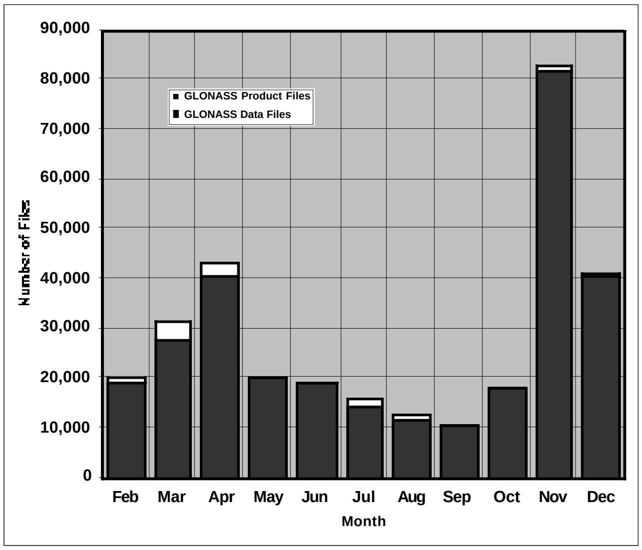

Figure 5: Number of GLONASS data and product files transferred from the CDDIS in 2000

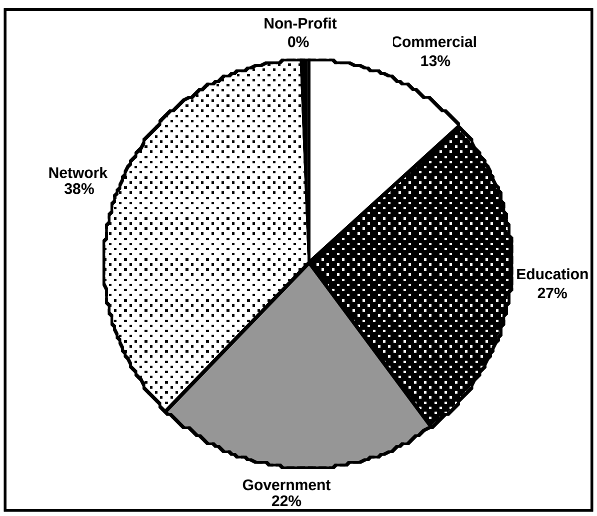

Figure 6: Distribution of IGS users of the CDDIS in 2000

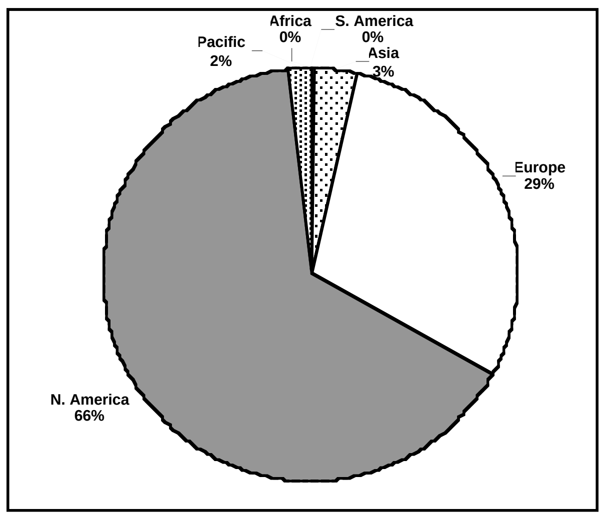

Figure 7: Geographic distribution of IGS users of the CDDIS in 2000

Scripps Orbit and Permanent Array Center (SOPAC) 2000 Report

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Brent Gilmore, Michael Scharber, Paul Jamason, David Malveaux (Archive)

Summary

The Scripps Institution of Oceanography's Orbit and Permanent Array Center (SOPAC) at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics (IGPP) has served as a Global Data Center and Global Analysis Center since the inception of the IGS in 1994. SOPAC is responsible for the collection, archiving, processing and publication of high-precision continuous GPS data to support the global GPS community. SOPAC's archive and analysis functions for the IGS overlap and complement other archiving and development activities at SIO for the Southern California Integrated GPS Network (SCIGN), NOAA/NOS' National Geodetic Survey, the California Spatial Reference Center (http://csrc.ucsd.edu), NOAA's Forecast Systems Laboratory (FSL), and UNAVCO, Inc.

Highlights of SOPAC activities through the end of 2001 of interest to the IGS, include:

- Complete redesign of the SOPAC Web Pages (http://sopac.ucsd.edu).
- Increase in the number of continuous GPS sites archived to just over 900.
- Maintenance of all historical (since 1990) and current data on-line, aided by converting from RINEX storage of UNIX-compressed files to Hatanaka compressed files.
- Complete redesign of the Site Information Manager (SIM).
- Increase in the number, scope, and utility of interactive user applications.
- Archive of one-hour global data files.
- Archive of all IGS orbital products including ultra-rapid orbits posted every 12 hours.
- Computation of real-time orbits based on hourly solutions of sliding 24-hour data window.

- Production of daily ITRF coordinates and SINEX solution files produced for over 600 sites, including all continuous GPS sites in Western North America (the "PBO" region).
- Production of decade-long consistent ITRF position time series, orbits, zenith delays, and EOP based on re-analysis of a large subset of global and regional data on SOPAC archive, starting in January, 1991.
- Development of GPS Seamless Archive (GSAC) for UNAVCO, Inc.
-

Data Archive

The SOPAC GPS archive currently has about 2.8 TB of on-line storage and includes current and historical data and data products since 1990. All operations are controlled by an Oracle 8.1 RDBMS (see Figure 1), supported by an equipment base significantly upgraded in 2000-2001 (Figure 2). See Appendix A for a complete list and locations of data and data products in the SIO archive. SOPAC continuously probes and collects RINEX data from more than 30 different global, regional and sub-regional GPS archives around the world. The automated processes which collect this data are continuously being upgraded and modified. The collection process compares the database description of the SIO archive to the remote archives, ftp's any needed files, quality checks the data, and makes them immediately available for on-line access. In addition, site log files are also compared and archived to provide current and historical listings of site equipment.

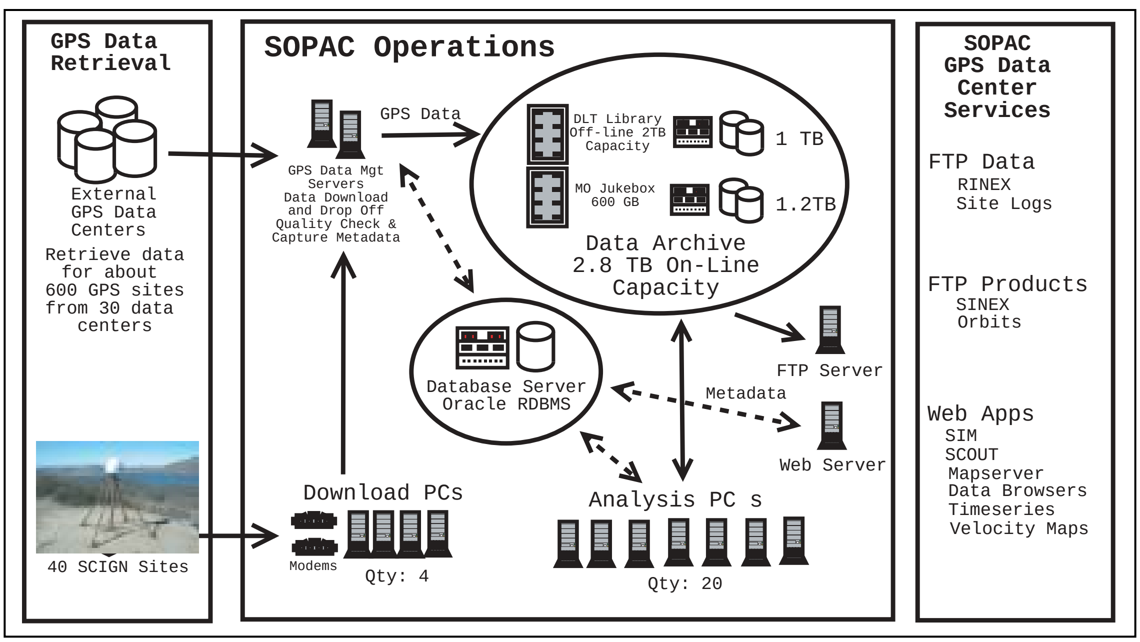

Figure 1. Schematic of SOPAC archive. See Figure 2 for a detailed hardware description.

SOPAC's publicly available data archive is accessible via anonymous ftp at the following URL: ftp://lox.ucsd.edu.

SOPAC makes every attempt to provide data that it collects or produces in a timely manner. All data on SOPAC's public archive may be obtained without restriction. An open data policy is intended to provide public users with the easiest means of collecting data from SOPAC on both a regular and irregular basis. Although private commercial use of such data is permitted, additional services and/or requests by private entities are given lowest priority. These policies are encouraged by SIO for other data centers wherever possible.

In addition to the regular nature of data collection and publication at SOPAC, older data and/or products are also added to the public archive, typically on an irregular basis. Various data formats are available from the SOPAC archive, such as ASCII and UNIX-compressed. In addition, formal requests for off-line data are handled by SOPAC and dealt with in a timely and appropriate manner.

In 2000 SOPAC saw its total archive size (first-copy data, excluding backups) actually decrease by nearly 400 hundred gigabytes thanks to the reclamation of over 500 gigabytes of space by the conversion of every RINEX file on SOPAC's archive from standard UNIX-compressed format to Hatanaka UNIX-compressed format. In addition to the obvious space savings are significantly reduced network usage and RINEX ftp transfer times for SOPAC's users. Accordingly, SOPAC's total archive usage decreased from around 1.4 terabytes in 1999 to roughly 1.0 terabyte by the end of 2000.

The steady increase in the number of permanent GPS sites archived at SOPAC since 1996 is shown in Figure 3, and by GPS network affiliation in Figure 4. By the end of 2000, SOPAC was collecting data from about 830 sites, by the end of 2001 that number had exceeded 900 sites.

The year 2000 was also a year where SOPAC saw continual growth in the number of file transfers by both public and private users, locally and from around the world (Figure 5). Nearing 5 million transfers for the year 2000 SOPAC continues to provide GPS data to an ever-growing constituency of GPS users the world over. By the end of 2001, the number of file transfers was almost 7 million. The most frequently downloaded GPS data at SOPAC were those affiliated with the IGS (Figure 6). By the end of 2001, we could identify more than 8000 unique ftp clients (Figure 7). The number of unique clients domains (e.g., ".gov", ".edu", ".com") leveled off in 2000-2001 to over 70 (Figure 8).

SCIGN, the Southern California Integrated GPS Network (http://www.scign.org), also grew substantially in 2000. SOPAC is the primary data archive for the SCIGN network. By the end of 2000 the SOPAC had at least one day of data from 229 different SCIGN sites. That number has climbed to over 250 by the end of year 2001 making SCIGN the largest RINEX data constituent at SOPAC, in terms of the number of total sites archived (Figure 4). Among file transfers from SOPAC, the SCIGN network was the second most popular network downloaded (Figure 6).

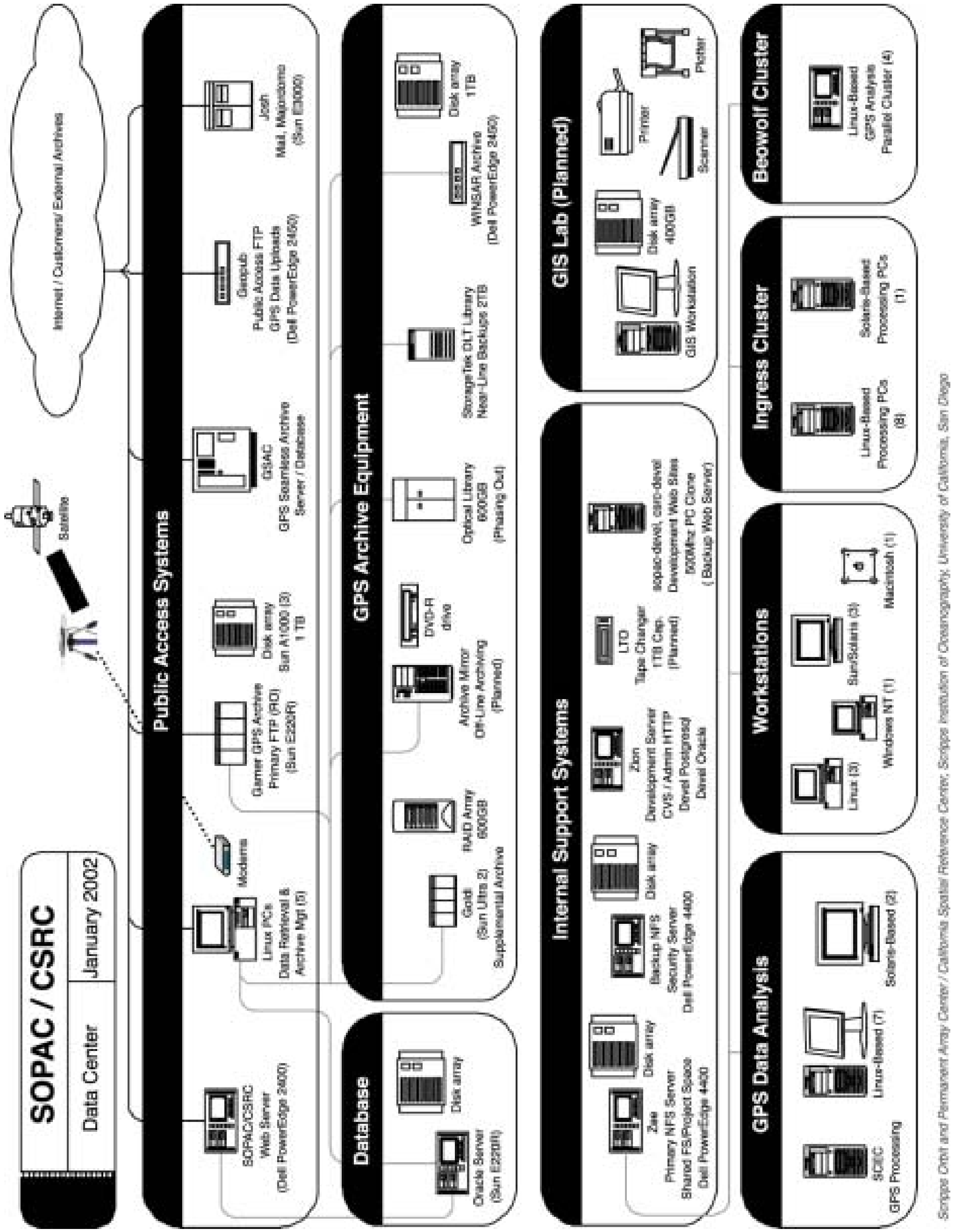

Figure 2. Schematic of SOPAC/CSRC hardware components.

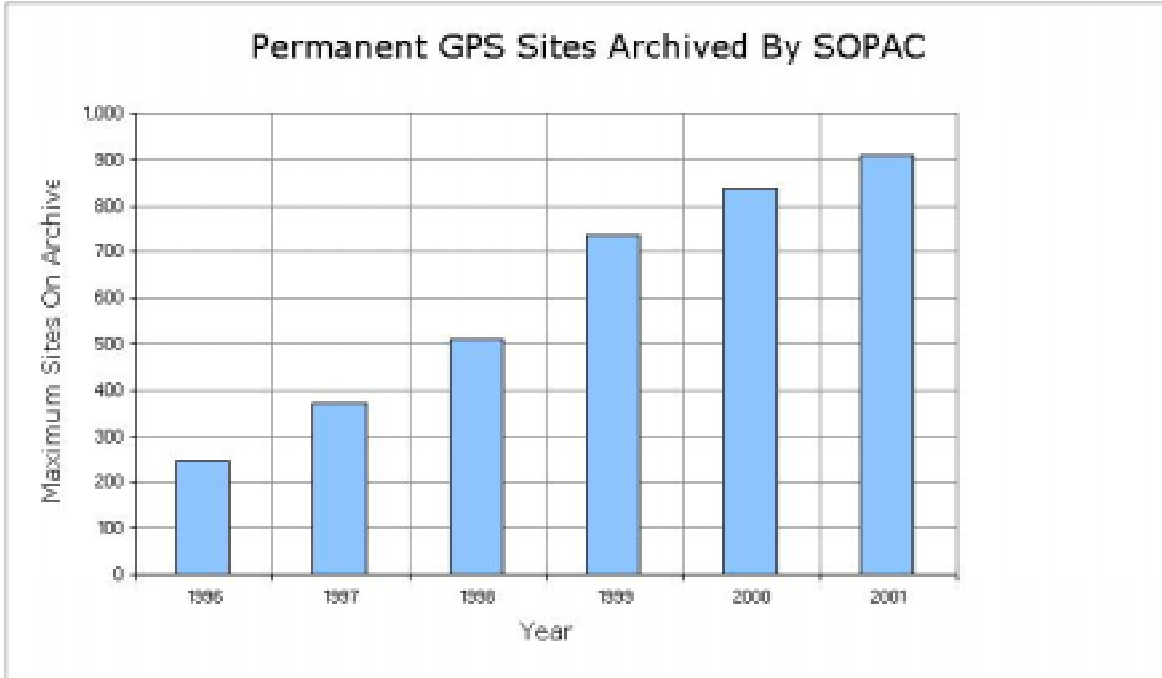

Figure 3. Number of continuous GPS sites archived at SOPAC between 1996-2001.

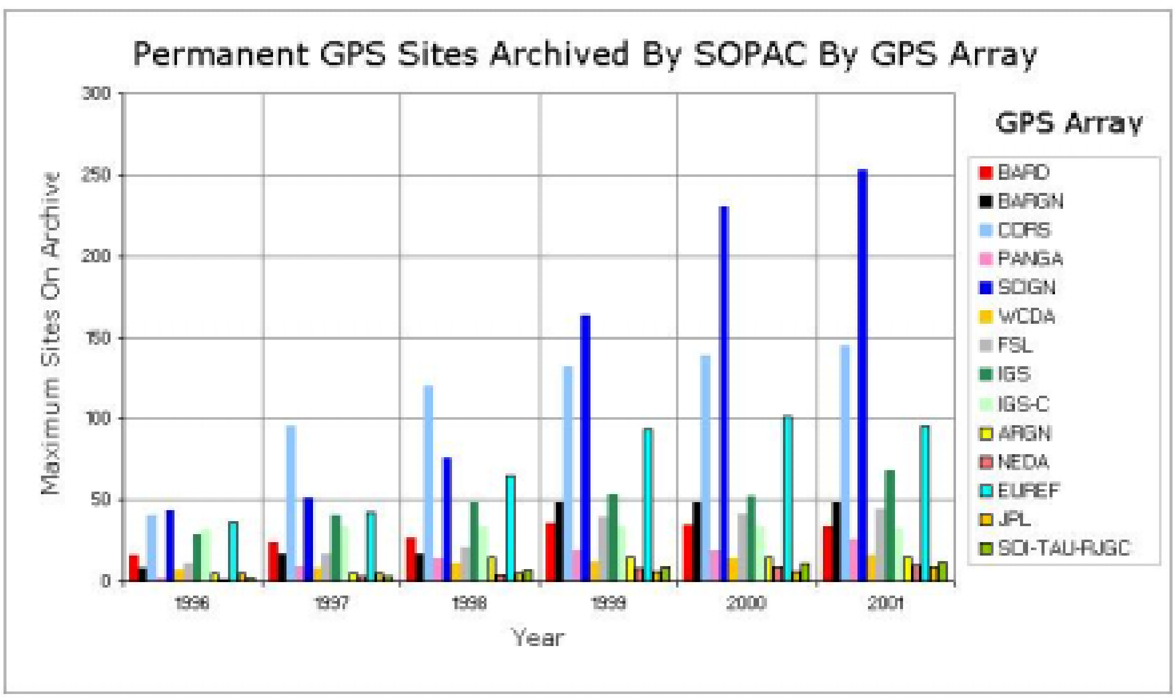

Figure 4. Number of continuous GPS sites archived at SOPAC between 1996-2001 by GPS array for 14 different arrays. "IGS-C" include core sites (that define the global reference frame) and "IGS" contain other IGS sites.

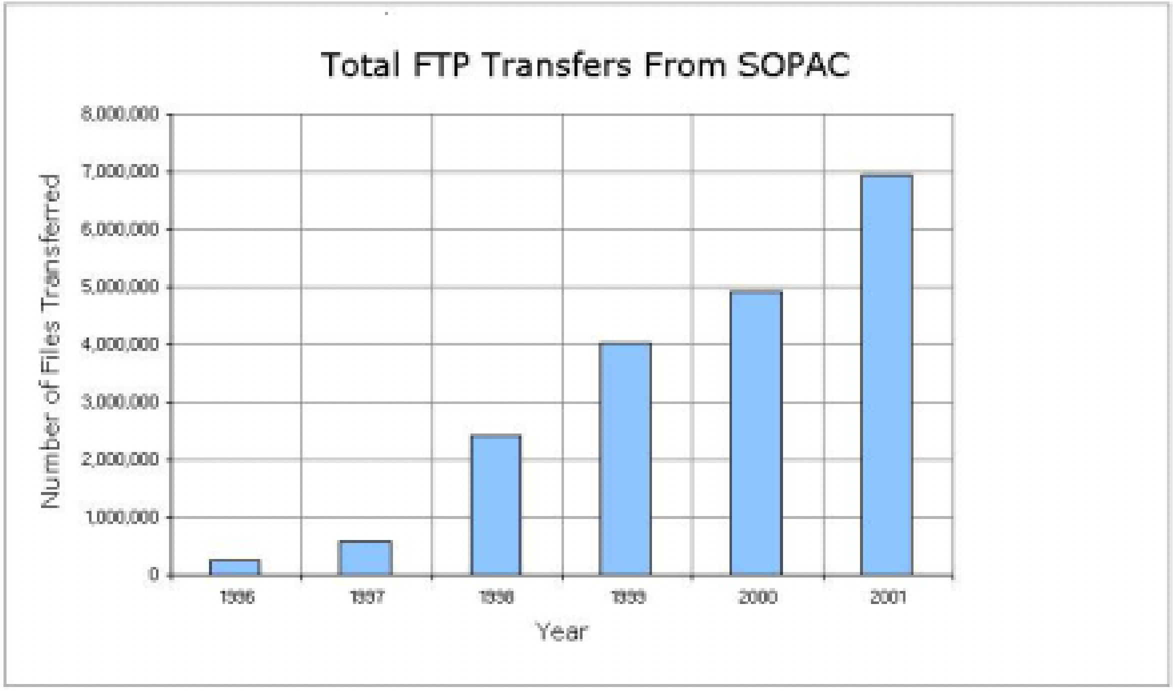

Figure 5. Number of files transferred from SOPAC via ftp://lox.ucsd.edu between 1996-2001.

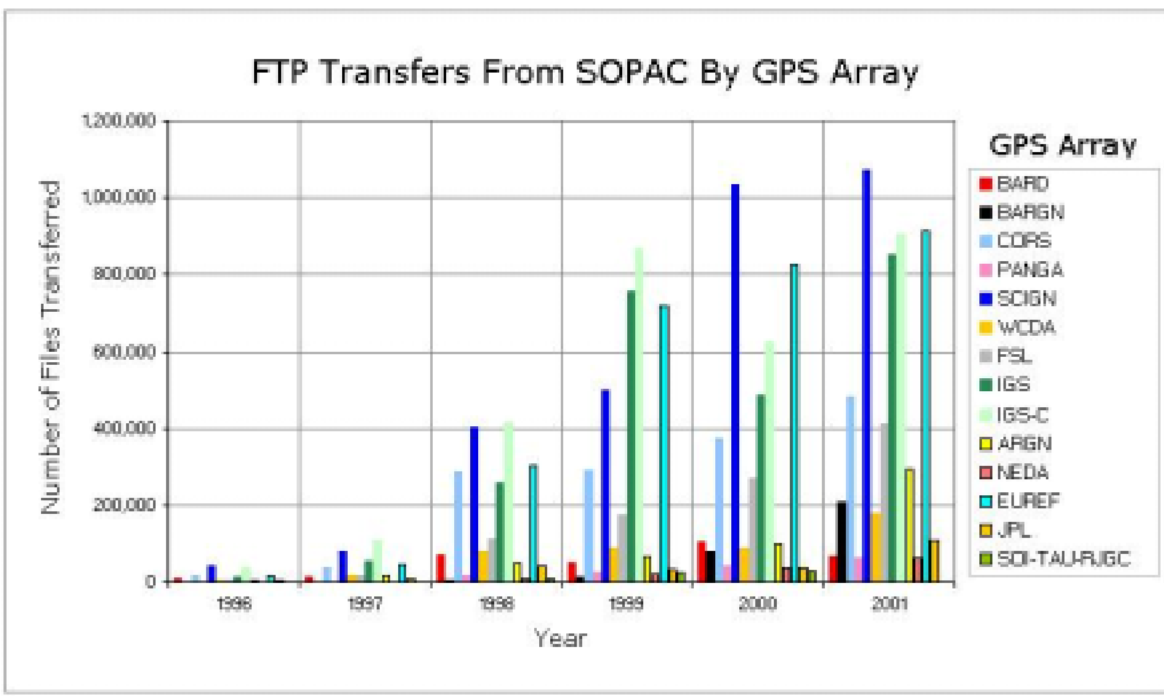

Figure 6. Number of files transferred from SOPAC via ftp://lox.ucsd.edu between 1996-2001 for 14 different GPS arrays.

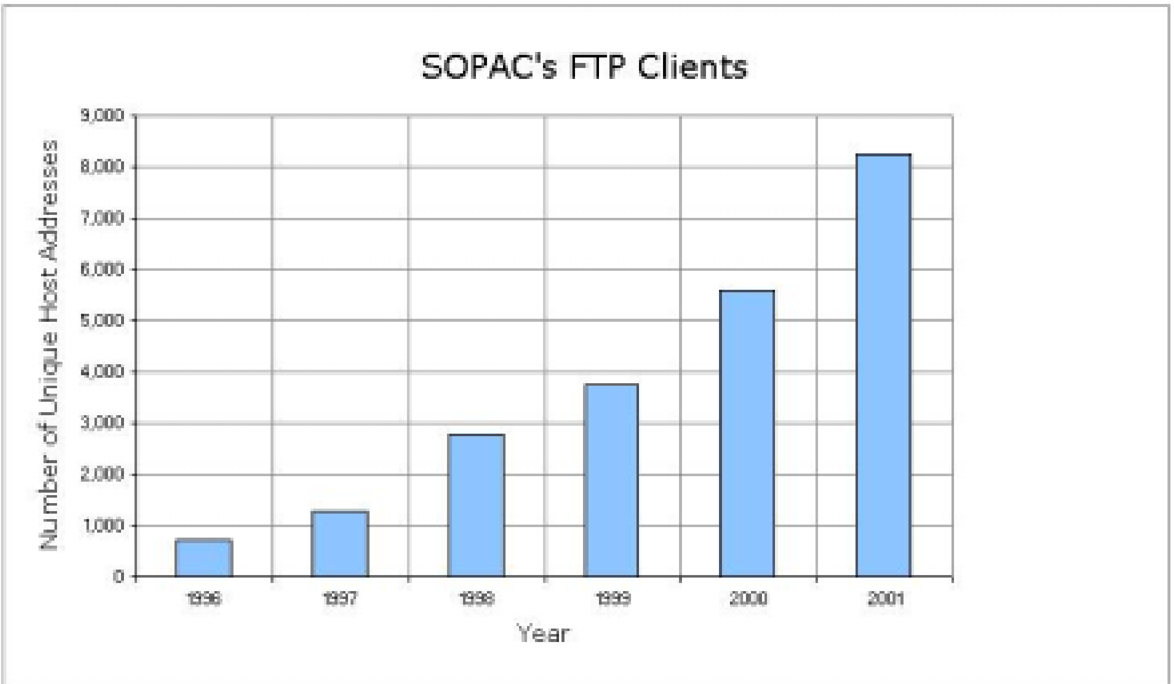

Figure 7. Number of unique ftp clients transferring data from SOPAC in the years 1996-2001. An ftp client is counted as a unique address for a user of the SOPAC archive. We have made an effort to ensure that ftp users provide a legitimate username.

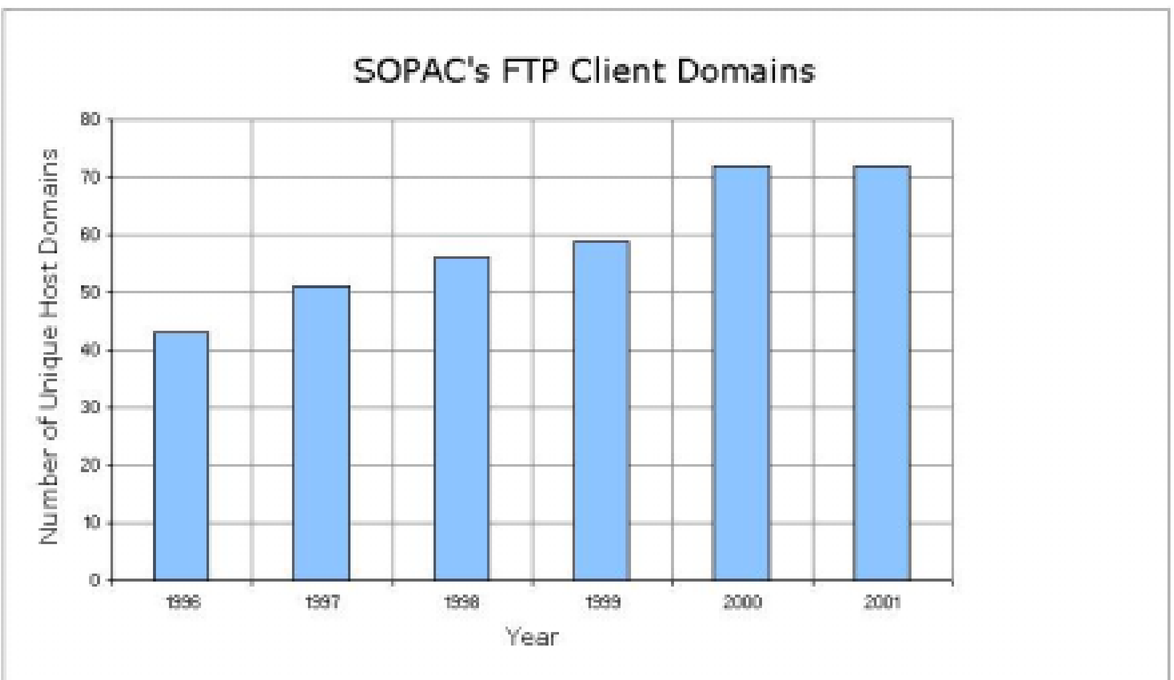

Figure 8. Number of unique ftp client domains (e.g., ".gov", ".edu", ".com") obtaining data from SOPAC in the years 1996-2001.

From the standpoint of a user constituency SOPAC, U.S. educational institutions accounting for the largest use of the archive with nearly 2 million file transfers alone. U.S. government and German domains were the second and third largest user groups of SOPAC's archive in 2000.

RINEX observation format GPS data files continue to be far and above the most frequently accessed data at SOPAC, accounting for over 90% of the total file transfers in 2000. As such, there is a high correlation between the number of permanent GPS sites archived on a daily basis at SOPAC and both the total size of the SOPAC archive and the number of file transfers from SOPAC. We expect this trend to continue to rise in the future and are taking appropriate steps to ensure SOPAC can maintain its high level of service to the global GPS community.

Information Management

SOPAC is dedicated to providing the GPS community with useful and timely information describing GPS data. In this effort SOPAC utilizes a relational database to track information about data, creates web-based software to assist with user entry and retrieval of site information (e.g., Figure 9), and maintains ftp statistics about the data's access by the GPS community.

Over the past few years, SOPAC has integrated an Oracle Relational Database Management System into its archiving operations. This has enabled us to increase the efficiency of both local and remote GPS data downloading, and improve the accuracy of GPS site metadata stored at SIO.

Front- and back-end database applications continue to be a top priority for SOPAC's archive management team each year. The "archive browsers" on SOPAC's web page feed directly off of our relational database server, providing a centralized and integral information source for numerous web-related utilities and services.

The SIO database catalogs and organizes SIO data holdings, and the tools used to obtain these data. Revised remote collection software then utilizes this information to determine which remote archive files are needed.

SOPAC continues to improve its management of GPS site-related information. The Site Information Manager (SIM) is a web-based application that allows users access to site information contained in the SOPAC database (http://sopac.ucsd.edu/scripts/SIMpl_launch.cgi). It provides secured users with a single mechanism of updating site information, which is then propagated to several applications. Alternatively, users may manually generate products such as site logs from the SIM. The SIM has relevant help sections with URL links to helpful resources, and limits equipment types to those recognized by the IGS.

Several of SOPAC's automated database applications make direct use of site information managed via the SIM. These include:

- Submission of SCIGN site logs to the IGS Central Bureau.
- GPS site log parsing into the database.
- SCIGN site log creation and updating.
- SCIGN mail generation.
- Updating of site equipment local download software to allow correct equipment types to be entered into RINEX headers.
- Automated station.info (GAMIT configuration file) creation.
- Automated SINEX creation.

FTP access statistics for the SIO archive are updated semi-hourly in the database. The number of transfers from the archive may be queried based on GPS site name, array, several temporal parameters, and by remote host types. This allows for a timely, detailed description of the data archive's usage, and creates a usage profile which enables SIO to better deliver its products to the GPS community (see http://sopac.ucsd.edu/cgi-bin/dbFtpStats.cgi).

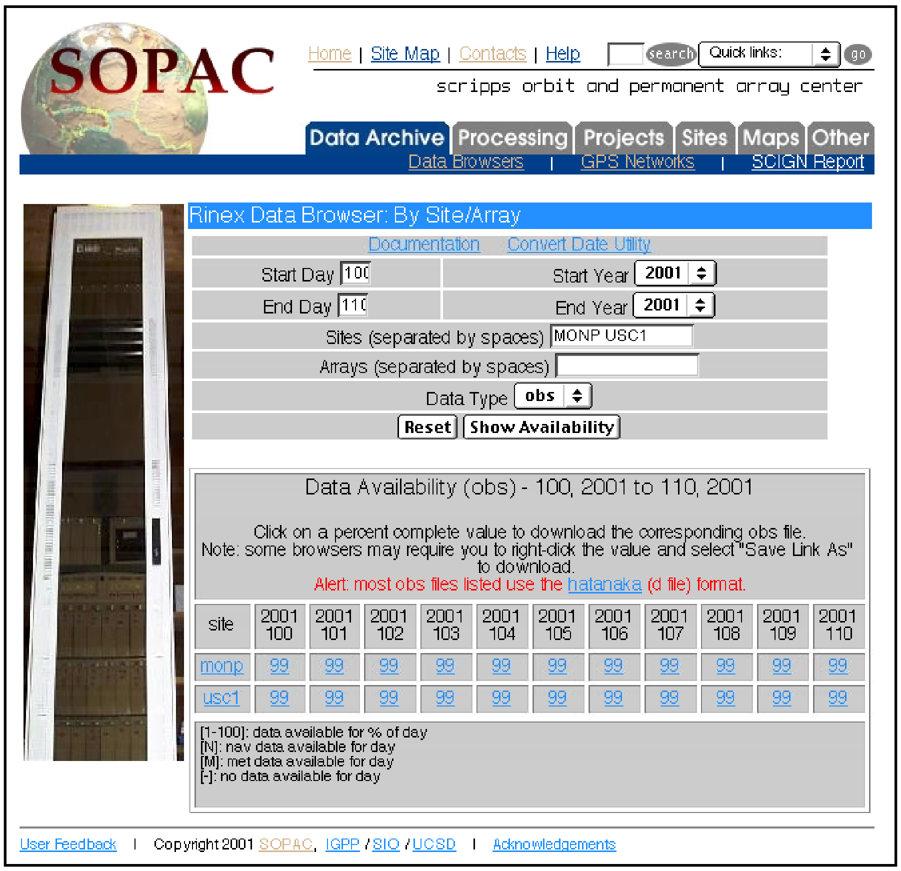

Figure 9. An example of a SOPAC user application. This application allows the user to browse the data archive for RINEX data availability. All interactive tools are interfaced to SOPAC's Oracle 8.1 RDBMS.

Analysis

In 2000-2001 SOPAC initiated computation of real-time orbits based on hourly solutions of a sliding 24-hour data window, primarily to support short-term weather forecasting for NOAA. Production of daily ITRF coordinates and SINEX solution files exceeded 600 sites, including all continuous GPS sites in Western North America (the "PBO" region). SOPAC completed production of an 11-year consistent ITRF position time series, orbits, zenith delays, and EOP based on re-analysis of a large subset of global and regional data on SOPAC archive, starting in January, 1991 (e.g., Figure 10). See Appendices A and B for a summary of analysis products and their locations in the SOPAC archive.

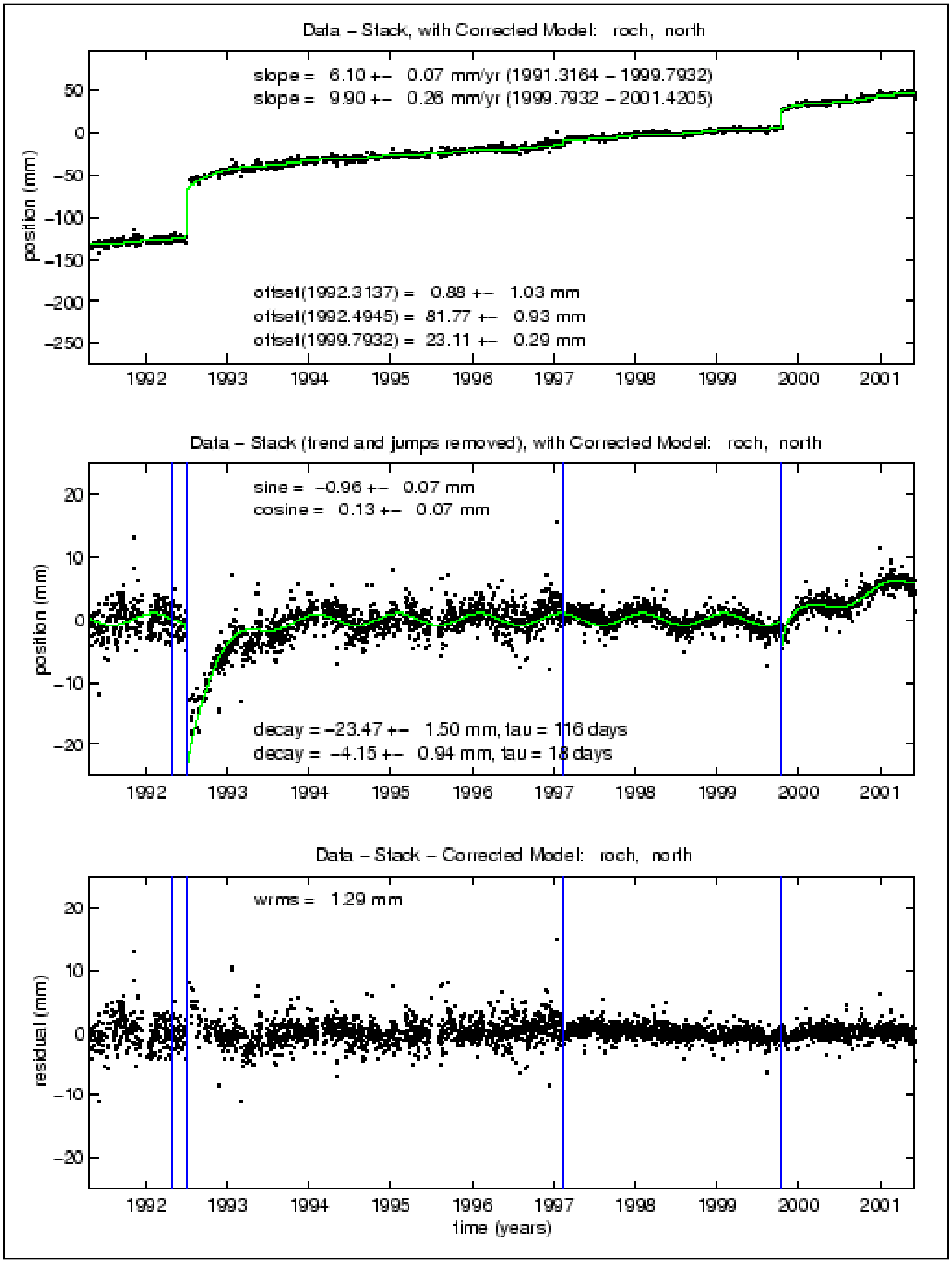

Figure 10. Typical coordinate time series of analyzed by SOPAC. The time series shows the north position component of the SCIGN site at Pinemeadows (ROCH). The time series is modeled by a linear trend, three coseismic offsets (Joshua Tree, Landers, Hector Mine), two postseismic decay (Landers and Hector Mine), an annual term, and one equipment-change offset (early 1997). The weighted rms is only 1.3 mm but exhibits some non-linear behavior.

Appendix A. Directory structure and directory information for SOPAC archive (ftp://lox.ucsd.edu)

DIRECTORY STRUCTURE

Directory	Filenames	Description
rinex/YYYY/DDD	ssssDDD0.YYd.Z	Hatanaka compressed RINEX obs files for stations 'ssss', day 'DDD', year 'YY'
	ssssDDD0.YYo.Z	UNIX-compressed RINEX obs (last 60 days only)
	autoDDD0.YYn.Z	RINEX navigation files concatenated from all stations day 'DDD', year 'YY'
nav/YYYY/DDD	ssssDDD0.YYn.Z	RINEX nav files for stations 'ssss', day 'DDD', year 'YY'
	autoDDD0.YYn.Z	RINEX navigation files concatenated from all stations, day 'DDD', year 'YY'
met/YYYY/DDD	ssssDDD0.YYm.Z	RINEX met files for station 'ssss', day 'DDD', year 'YY'
raw/YYYY/DDD	ssssDDDS.YYr.Z	ROGUE raw obs files for station 'ssss', day 'DDD', year 'YY', sess 'S'
	ssssDDDY.rSS	Trimble raw obs file for station 'ssss', day 'DDD', year 'Y', sess 'SS'
	rssssSYY.DDD	Ashtech raw obs files for station 'ssss', day 'DDD', year 'YY', sess 'S'
products/WWWW	igsWWWWD.sp3.Z	IGS Final Orbits for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6
	igrWWWWD.sp3.Z	IGS Rapid Orbits for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6
	iguWWWWD_HH.sp3.Z	IGS Ultra-Rapid Orbits for GPS week 'WWWW' day 'D' hour 'HH' in SP3 format, (H=00 or H=12)
	iguWWWW7_HH.erp.Z	IGS Ultra-Rapid Earth Rotation Parameter file for GPS week 'WWWW', hour 'HH' (H=00 or H=12)

iguWWWW7_HH.sum.Z	IGS Ultra rapid summary file produced by center 'ccc' for GPS week 'WWWW', hour 'HH' (H=00 or H=12)
cccWWWWD.sp3.Z	Orbits produced by center 'ccc' for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6
cccWWWW7.erp.Z	Earth Rotation Parameter file produced by center 'ccc' for GPS week 'WWWW'
cccWWWW7.sum.Z	Data Analysis Summary file produced by center 'ccc' for GPS week 'WWWW'
cccWWWW7.clk.Z	Combined Clock Estimates file for satellite and station clocks produced by center 'ccc' for GPS week 'WWWW'
cccWWWW7.cls.Z	Summary of Clock Combination file produced by center 'ccc' for GPS week 'WWWW'
jplWWWWD.yaw.Z	JPL Satellite Yaw File for GPS week 'WWWW', day 'D' D=0,..,6
sirWWWWD.sp3.Z	SIO (SOPAC) Rapid Orbits for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6
siuWWWWD_HH.sp3.Z	SIO (SOPAC) Ultra-Rapid Orbits for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6 Updated every 12 hrs (24 hours actual + 24 hour predicted)
sihWWWWD.sp3.Z	SIO (SOPAC) Hourly Orbits for GPS week 'WWWW' and day 'D' in SP3 format, D=0,..,6 Updated hourly (24 hours actual + 12 hour predicted)
sioigsWWWW7.snx.Z	Station Solution SINEX file for global sites produced by SIO for GPS week 'WWWW'
siopboWWWW7.snx.Z	Station Solution SINEX files for "PBO" sites in Western NA produced by SIO for GPS week 'WWWW' PBO: Plate Boundary Observatory

```
                      gpggaY.DDD.Z            Satellite initial conditions
                                              file (GAMIT/GLOBK users)
                                              generated from final analysis
                                              year 'Y', day 'DDD'

                      gpggaY.DDD.rap.Z        Satellite initial conditions
                                              file (GAMIT/GLOBK users)
                                                    generated from rapid analysis
                                              year 'Y', day 'DDD'

                      gpggaY.last.Z           Most recent satellite initial
                                              conditions file
                                              (GAMIT/GLOBK users)
                                                    Generated from SIO hourly
                                              solutions ('sih')
                                              year 'Y'
                                              Updated hourly

-------------------------------------------------------------------------------
               MISCELLANEOUS DIRECTORY INFORMATION
-------------------------------------------------------------------------------
Directory             Description
-------------------------------------------------------------------------------

GSAC                  SOPAC GPS Seamless Archive (UNAVCO GSAC) holdings

docs                  GPS sitelogs and SOPAC data reports (SCIGN, all sites)

misc                  Miscellaneous data and products

nrtdata               Hourly GPS RINEX data files

software              Publicly-available software

troposphere           IGS combinations of tropospheric estimates

For GAMIT/GLOBK users:

processing            GAMIT/GLOBK related tables

global                GAMIT solution files for daily SOPAC global analyses

regional              GAMIT solution files for daily SOPAC regional analyses

hfiles                Global and regional GAMIT/GLOBK h-file solutions

combinations          SOPAC's weekly GLOBK solutions

gfiles                Orbits in the GAMIT g-file format

-------------------------------------------------------------------------------
```

Appendix B. SIO orbital products

```
-----------------------------------------------------------------------------
Software Used     | GAMIT v. 10.05, GLOBK v. 5.05,   developed at MIT/SIO
-----------------------------------------------------------------------------
Final Products    | siowwwwn.sp3    GPS ephemeris files in 7 daily
generated for     |                 files at 15 min intervals in SP3 format,
GPS week 'wwww'   |                 including accuracy codes computed from
day of week 'n'   |                 overlapping analysis wrt previous day.
(n=0,1,...,6)     | siowwww7.erp    ERP (pole, UT1-UTC) weekly solution
                  | siowwww7.sum    Summary of weekly solution combining both
                  |                 IGS global and regional solutions.
                  | siowwww7.snx    Weekly coordinates in SINEX format
                  | siowwwwn.tro    Daily files of 1-h troposphere delay
                  |                 estimates in SINEX format (based
                  |                 on 1-day solutions).
Rapid Products    | sirwwwwn.sp3    Daily orbits for current-1 day. ~8 hour
                  |                 delay.
                  | sirwwwwn.erp    Daily EOP for current-1 day. ~8 hour
                  |                 delay.
Ultra Rapid       | siuwwwwn.sp3    Daily orbits for 24h(post)+24h(predicted).
Products          |                 3 hour delay (twice daily).
                  | siuwwwwn.erp    Daily EOP for 4day(post)+3day(predicted).
                  |                 3 hour delay. (twice daily)
Hourly            | sihwwwwn.sp3    Hourly orbits for 24h(post)+12h(predicted).
Products          |                 1 hour delay (24 times daily).
```

IGS

REGIONAL/OPERATIONAL CENTERS

BKG Regional IGS Data Center Report 2000

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D-60598 Frankfurt at Main, Germany

Introduction

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

GPS observation data from the permanent GPS network of the European Reference Frame (EUREF) and mixed GPS/GLONASS observation files from the International GLONASS Experiment 1998 (IGEX) are also available. The continuation of the IGEX campaign is now proposed to become an IGS pilot service for a period of four years (2000-2003) named International GLONASS Service – pilot project (IGLOS-PP). A subset of the IGS , EUREF, and IGEX stations deliver hourly observation files to BKG additionally to the daily files.

Computer Architecture

The data center runs on an HP-workstation under HP-UX. This workstation is connected to the Internet with a maximum transfer rate of 2 MB/s and a disk capacity of about 100 GB. The directory structure (see Figure 1) shows three project related directories (IGS, EUREF, and IGEX). The various projects show analogous directory structures. The data are accessible through both, ftp and http. The RINEX observation files of the stations are now online available for 3 years. During 2000 a new http-server (http://igs.ifag.de) had been installed, and the html pages had been newly created. They correspond now very well to the disk structure, to make the use of ftp and http as similarly as possible.

Hourly Observation Files

The hourly RINEX observation files may be used for near real time applications and could replace the daily files if all hourly files of one day are concatenated to one file successively. As soon as the daily observation files are available at the data center the hourly observation files are no longer of interest. Therefore, the hourly files are deleted after 7 days in the "nrt" subdirectory. For test purposes, BKG compares the

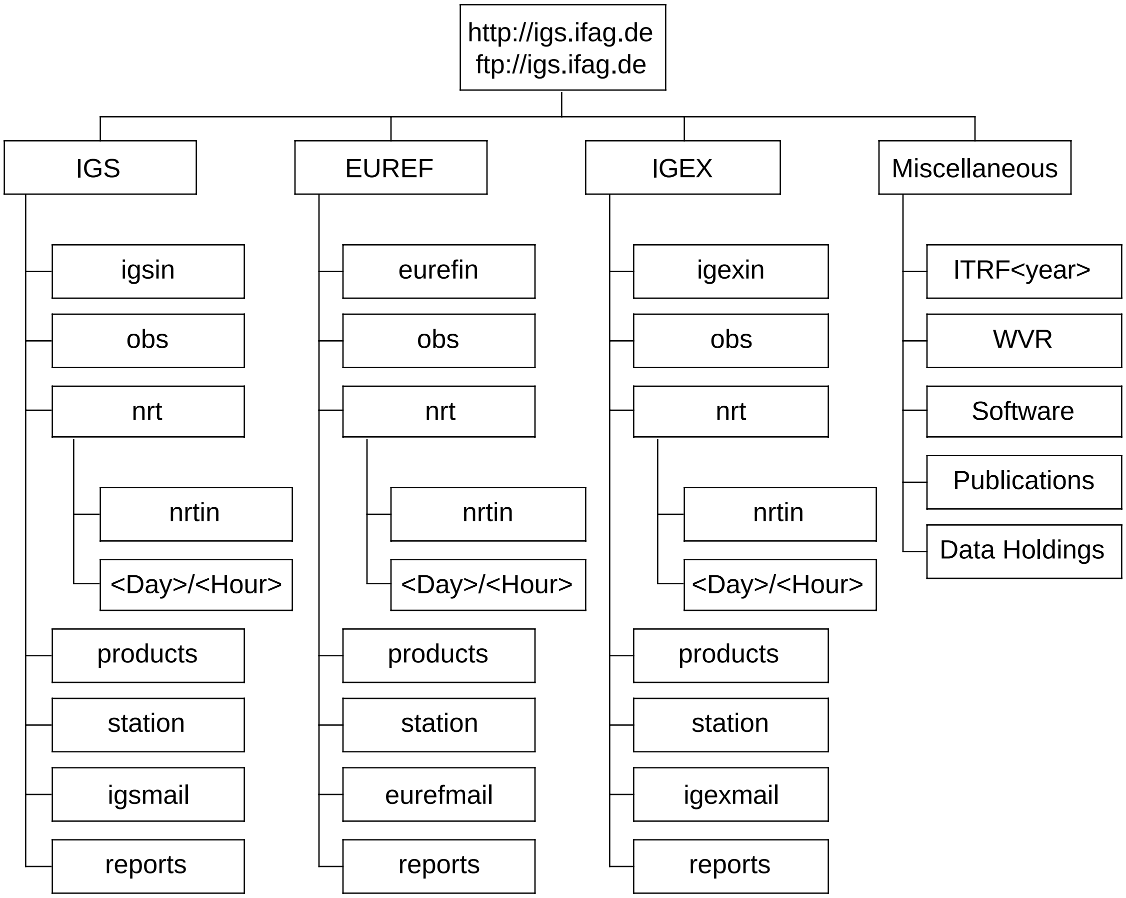

Figure 1: Access and Structure of the BKG Data Center

concatenated hourly files with the daily observation files, which are submitted by each station at the end of a day, using the program RNXDIF (Habrich H., 2001). Detected differences are saved into summary files for each station and publicly available. This long term study may be contribute to decide, that the daily observation files should no longer be submitted additionally.

Figure 2 shows the latency of hourly RINEX observation files for GPS week 1115. About 40 % of the hourly IGS observation files had been available at BKG at 8 minutes after the full hour, and only 1 % show a latency of more than 30 minutes. The files of the EUREF and IGEX projects show a latency of 8, i.e., 10 minutes for the majority of the sites.

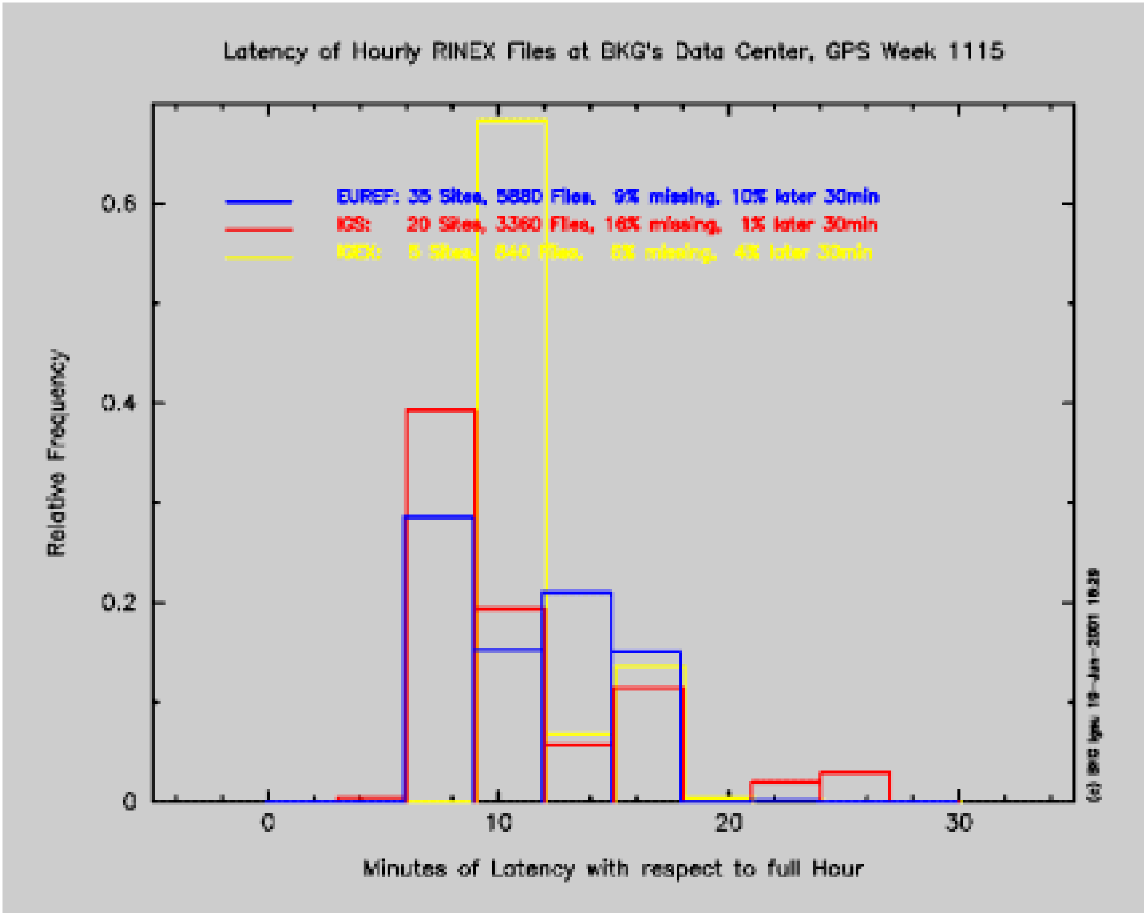

Figure 2: Latency of Hourly RINEX Files for GPS Week 1115

User Activity And Future Plans

The total number of stations (i.e. of receivers) of BKG's data center has increased to 160. Approximately 100 distinct users contact the data center and perform some 10,000 file transfers every day. In order the make the success to the data center more comfortable, it is planed to extend the html pages with dynamic links and the possibility of user queries.

References

Habrich H. (2001): *Concatenation of Hourly RINEX Files*, Physics and Chemistry of the Earth, Vol. 26, No. 6-8,pp, 561-567, 2001, Elsevier Science Limited, Oxford, England.

Hartebeesthoek Radio Astronomy Observatory (HartRAO)

Ludwig Combrinck

Abstract

This report gives an overview of our IGS activities during the year 2000. A brief description of our involvement with other space geodesy techniques is given.

Geodesy at HartRAO

HartRAO is located north of Johannesburg, South Africa, in a valley of the foothills of the Wit-waters mountain range (see Table 1). HartRAO uses a 26 metre equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961 (Figure 1). The telescope was part of the NASA deep space tracking network until 1975 when the facility was converted to an astronomical observatory. The radio telescope is collocated with an IGS GPS station HRAO and an SLR station MOBLAS6. HartRAO is the IGS regional data centre for Africa.

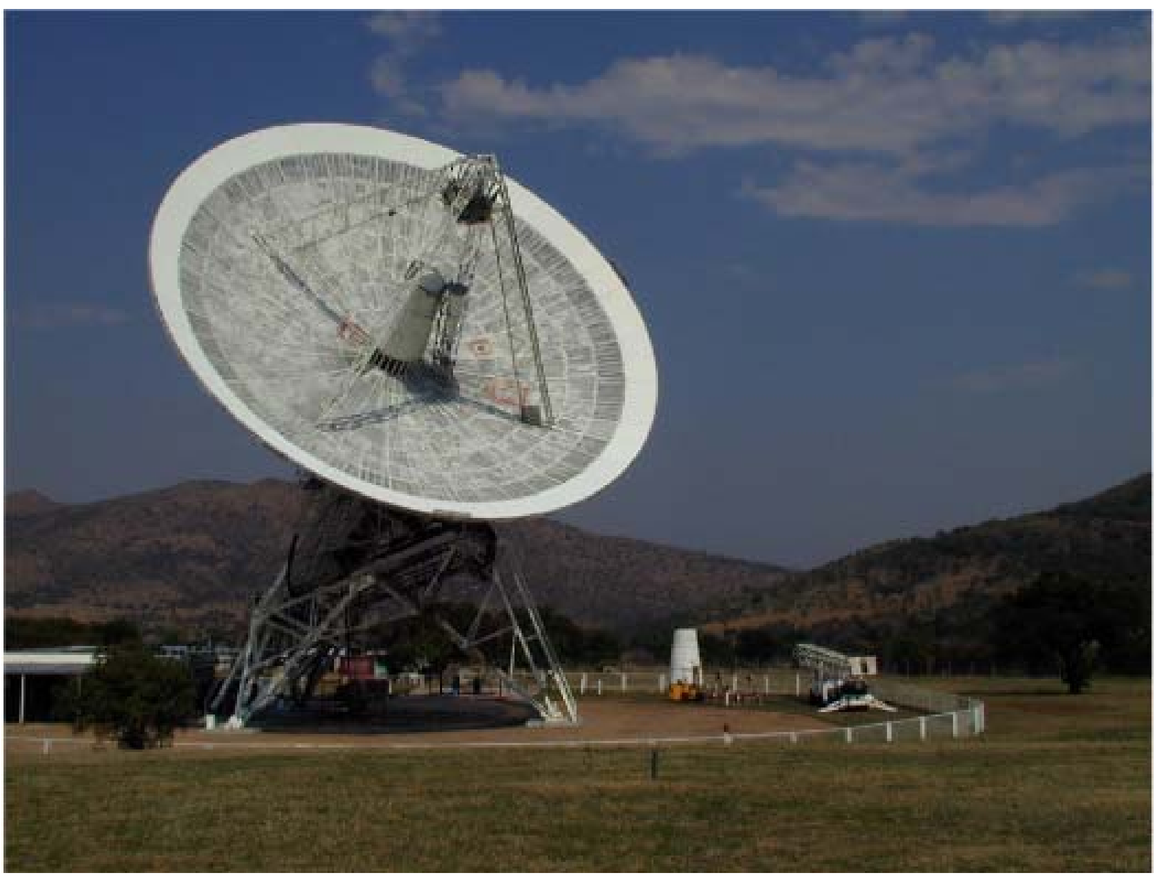

Figure 1. The 26 metre radio telescope. Solid panels have been fitted on the outer ring as part of a surface upgrade. All panels will eventually be replaced with non-perforated, higher tolerance panels. Typical rms accuracy of these panels is 170 microns.

Table 1. Location and addresses of HartRAO.

Latitude	25.889- S
Longitude	27.686- E
Hartebeesthoek Radio Astronomy Observatory	
Geodesy Programme	
PO BOX 443	
Krugersdorp, 1740, SOUTH AFRICA	
http://www.hartrao.ac.za/geodesy/geodesy index.html	

IGS Activities

HartRAO supported an IGS tutorial presented by Ruth Neilan (IGSCB), Angelyn Moore (IGSCB) and Jan Kouba (NRC) on the 3rd of April 2000. The tutorial was well attended by delegates from local universities, the Weather Bureau, local surveying companies and the Council for Geosciences. After the necessary equipment procurement, HartRAO will be able to operate as a mirror site for the IGSCB, which will facilitate the use of all its products by local users. The IGS tutorial was greatly appreciated and we wish to thank the IGSCB for visiting South Africa.

The author attended the Second Network workshop of the IGS in Oslo, Norway, during July 2000. A position paper was presented at the conference (Combrinck & Chin 2001). The author acted as one of the guest editors for the conference proceedings. The kindness of Hans-Peter Plag, Oddgeir Kristiansen and Gunnar Elgered led to very interesting and worthwhile visits to Statens kartverk (Norwegian Mapping Authority) and the Onsala Space Observatory. A special effort by Jan Johansson and his wife must be mentioned as this led to a day of sailing.

Regional Data Centre

Rinex data for 16 IGS stations and one regional station (NAMI, see Figure 2) were archived. The IGS station SUTH (Figure 3), located at Sutherland suffered data outage due to a nonfunctional receiver at the end of December 2000, but was restored to working order soon afterwards. An additional 20 GB hard disk was procured for GEOID, the data centre server, to cope with the increasing amount of data. Due to the exposure the IGS achieved during the year 2000, rinex data and IGS product retrievals have increased with regular access by local users and neighbouring countries.

Figure 2. The NAMI GPS antenna monumentation located in Windhoek, Namibia. The antenna needed to be elevated to alleviate the possible adverse effect of multi-pathing from a nearby corrugated iron roof. The pole is thick-walled and stayed for rigidity. NAMI is a regional station at the moment, but it is hoped that an equipment upgrade can bring it to IGS status. (Donors?)

Figure 3. The SUTH IGS GPS antenna monumentation. The antenna is situated on a hill overlooking the barren semi-desert of the Karoo.

Current Activities

We are continuing our footprint survey, which has as its main purpose the determination of eccentricities between the GPS, VLBI and SLR reference points as well as the maintenance of a control network to enable stability monitoring of the site on a local scale. The current eccentricities between VLBI and SLR (Table 2) were determined using GPS (Combrinck & Merry 1997) and the SLR to GPS eccentricities values are from 1998 footprint results. We are processing HRAO ina17 station regional (IGS) network and envisage processing the SLR (MOBLAS 6) data for eccentricity determinations. This will strengthen collocation and with accurate eccentricities should tie the independent ITRF coordinates to a high degree of accuracy.

Table 2. Table of eccentricities, VLBI telescope to SLR and GPS (HRAO) reference points.

Reference	Coordinate	Δ	σ (mm)
SLR	X	41.680	15.8
SLR	Y	-66.564	7.5
SLR	Z	-8.131	3.9
HRAO	X	90.236	15.8
HRAO	Y	-132.190	7.5
HRAO	Z	-34.704	3.9

Future Plans

In order to bring geodesy closer to home and the African continent, the Geodesy Programme is in the process of establishing a Geodetic Institute for Africa. The purpose of this Institute at HartRAO will be to establish strategic alliances and collaborative projects with other African countries. These projects will be tied in a unifying structure which will advance and support Africa's role in geodesy. It will support and promote the activities of the IVS, ISLRS and IGS. It will also support the objectives of the African Reference Frame (AFREF).

With the addition of the MOBLAS-6 SLR unit, several new staff members were recruited as part of the SLR project. Plans are in progress to expand GPS activities and to develop an active research component as an IGS Associate Analysis Centre. We are in the process to equip Zambia, Malawi, Mocambique, Madagascar, Botswana, Namibia and Zimbabwe with IGS stations. Members of the IGS who upgrade stations and have redundant equipment available should please contact the author.

References

[1] Combrinck W.L. and Merry, C.L. Very long baseline interferometry antenna axis offset and intersection determination using GPS. JGR, Vol.102, NO.B11, pp 24,741-24,743, 1997.

[2] Combrinck W.L and Chin, M. IGS Stations: Station and Regional Issues. Phys. Chem. Earth (A), Vol. 26, N0.6-8, pp. 539-544, 2001.

IGS

NETWORK AND STATION REPORTS

IGS

GLOBAL, REGIONAL, AND LOCAL NETWORKS

Growth of the IGS Station Network in 2000

Angelyn Moore

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Introduction

The IGS network of permanent dual-frequency GPS tracking stations formed by the cooperative efforts of the IGS site-operating agencies welcomed the addition of 25 sites in 2000:

- AMMN Amman, Jordan
- DRAG Metzogi Dragot, Israel
- DUBR Dubrovnik, Croatia
- DYR2 Diyarbakir, Turkey
- ESTI Esteli, Nicaragua
- GUAT Guatemala City, Guatemala
- HARB Pretoria, South Africa (Replacing HARK)
- KODK Kodiak, Alaska, USA
- MANA Managua, Nicaragua
- NKLG Libreville, Gabon
- NOT1 Noto, Italy (Replacing NOTO)
- NRIL Norilsk, Krasnoyarsk Region, Russian Federation
- NVSK Novosibirsk, Russia
- ORID Ohrid, Macedonia
- OSJE Osijek, Croatia
- RABT Rabat, Morocco (Replacing IAVH)
- RBAY Richardsbay, South Africa
- SFDM Piru, California, USA
- SLOR San Lorenzo, Honduras
- SPT0 Boras, Sweden
- SSIA San Salvador, El Salvador
- TEGU Tegucigalpa, Honduras
- UNSA Salta, Argentina
- YAR2 Dongara, Western Australia, Australia
- YEBE Yebes, Spain

This set includes sites which improve coverage in important areas such as Central America, Africa, northern Asia, and the Middle East, as well as desirable colocations with other geodetic techniques.

Figure 1 depicts stations added in 2000 emphasized by large circles, along with the complete network distribution at the end of 2000, which totalled 248 stations. Of these, 92 (shown in Figure 2) earned the "Global" classification for being regularly analyzed by at least three analysis centers (one on a continent other than that of the station). The Data Centers report in this volume notes that the number of sites participating in the hourly data subnetwork grew to more than 70.

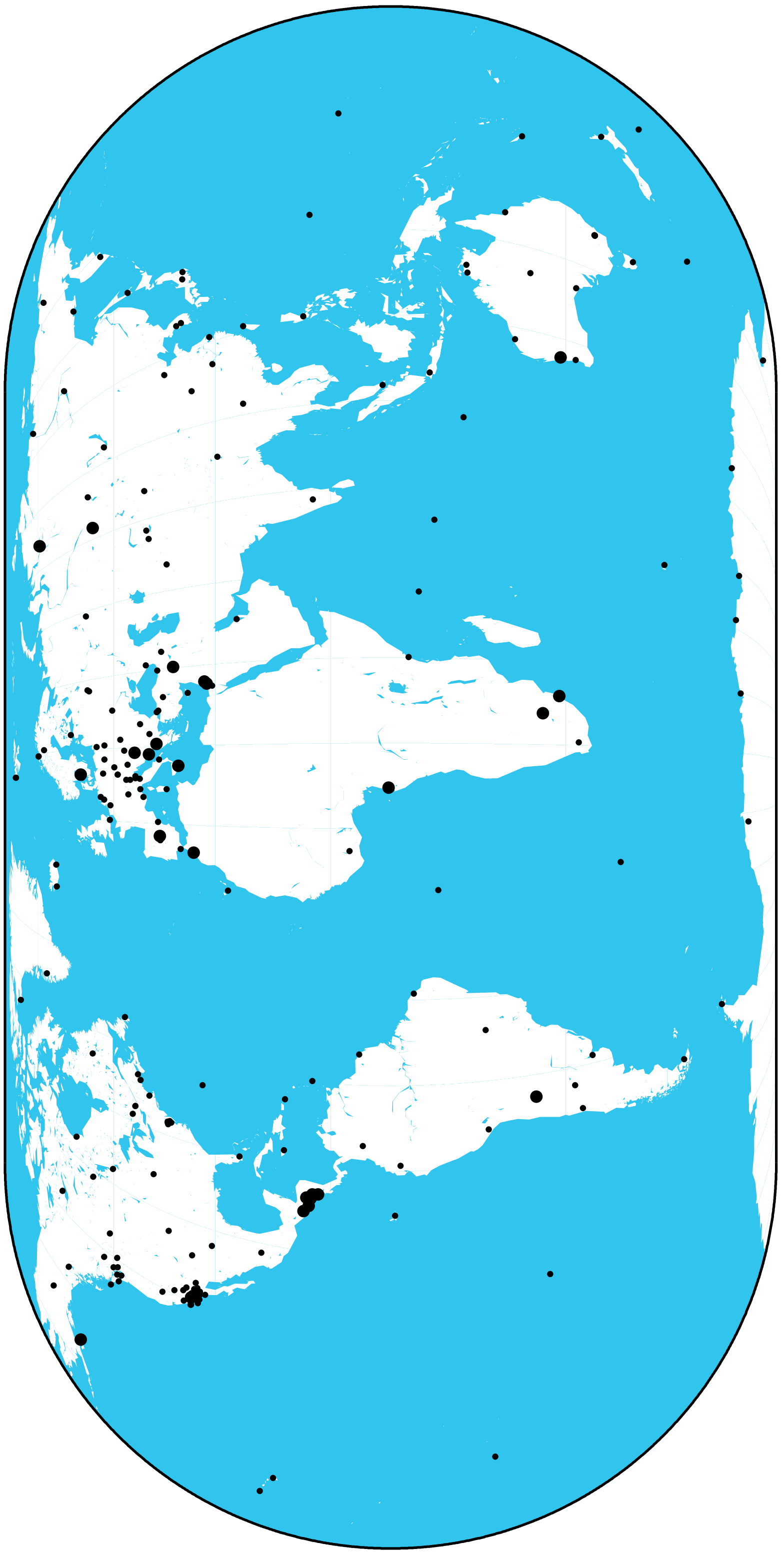

Figure 1. IGS Stations Added in 2000

Figure 2. IGS Stations Earning Global Classification

2000 Oslo Network Workshop and Proceedings

The workshop and its expert local organizers from the Norwegian Mapping Authority have already been lauded in the Central Bureau article in this Annual Report. Another highlight was the selection for "On Hourly Orbit Determination" by Jan Dousa and Leos Mervart of the Research Institute of Geodesy, Topography, and Cartography in the Czech Republic for the best poster of the joint meeting. A committee comprising representatives of the IGS and COST Action 716 considered all the posters and was pleased to see Dousa, as first author, presented with two Locus GPS receivers generously donated by Ashtech as a prize. The productivity of the entire event is apparent in the Proceedings, available as a special issue of Physics and Chemistry of the Earth, Part A, vol. 26, published by Elsevier Science. Coordinating editor Hans-Peter Plag, fellow IGS guest editors Mark Caissy and Ludwig Combrinck, the COST Action 716 team, and each author made the production of this document a pleasure and an education. This peer-reviewed, indexed journal probably represents the deepest penetration of a collection of IGS network articles into the world's libraries to date.

Network Coordination

As was suggested in the Network section of the 1999 Annual Report, the well-publicized Y2K rollover was readily handled by the IGS. Indeed, the new Central Bureau server installed to handle the rollover enabled enrichments such as self-service subscription management for the IGS email lists. Many users welcomed a noticeable improvement in response time.

Following the near-eradication of station metadata errors in calendar 1999, automatic quality audits of site logs and RINEX observation data file headers were increased to twice weekly. In this maintenance mode, station operators are notified by targeted email should a metadata error be inadvertently introduced by equipment or software changes. This system continues to maintain near-zero metadata error rates with minimal human effort and has enabled the long-envisioned SINEX combination and consistency of all products in the IGS realization of ITRF.

Looking Ahead

The expanding usage of the IGS network into new applications brings requirements for the collection and dissemination of such metadata. In late 2000, a revised site log template supporting GNSS equipment other than GPS was drafted, in anticipation of incorporating GLONASS stations into the IGS network. This provided an opportunity to also improve the collection of site eccentricity information, describing the spatial relation between a geodetic marker and a GPS antenna, and other geophysical information regarding each site. When reviewed and adopted, the new log format will allow the Central Bureau to provide increased and standardized station information to the user community.

The Australian Regional GPS Network - Report for 2000

Bob Twilley, Paul Digney
AUSLIG

Introduction

The Australian Regional GPS Network (ARGN) continued a period of consolidation during 2000, following the Y2K and GPS week rollover concerns of the previous year. All 15 sites across Australia, Antarctica, Macquarie Island in the Southern Ocean and Cocos Island in the Indian Ocean maintained a high level of output. All information is available at www.auslig.gov.au/geodesy/argn/argn.htm.

Performance

Figure 1 shows the quantity of data acquired on each day of the year, at each of the ARGN stations. The vertical bar in these diagrams indicates the relative size of the Rinex data file available and the line of joined dots shows the percentage of valid observations with respect to the total theoretically possible.

A number of significant events are apparent in Figure 1. The receivers at both Yarragadee & Tidbinbilla were relocated early in the year to maximize resources for the rollout of upgraded receivers at more remote sites, but JPL receivers continued to operate at these sites during this time. Improvement in performance is evident at sites where receivers were upgraded, as shown in Table 1. As expected, extreme weather conditions affected some sites, with lightning strikes taking Jabiru out of action for almost two months and causing communication problems at Darwin later in the year. A cyclone also caused severe disruptions at Karratha in early March and cyclone induced flooding in late November caused a loss of communications. Data loss at Davis late in the year was eventually traced to a faulty in-line amplifier, while also late in the year, decreased performance at Yarragadee was caused by problems with the external clock.

Improvements

In 1999 ARGN GPS receivers were upgraded at critical sites to cope with the GPS week rollover, the Y2K and increasing ionospheric disturbance. However, the remoteness of the Antarctic sites meant that some receivers were not upgraded until 2000. Some Australian mid-Latitude sites were also upgraded during the year as a lower priority. The effect of these receiver upgrades is apparent in Figure 1.

Table 1: GPS receiver upgrades during 2000

Site	Date Upgraded	Old Receiver	New receiver
Alice Springs	14 January 2000 24 January 2000	AOA ICS-4000Z AOA SNR-12 ACT	AOA SNR-12 ACT AOA ICS-4000Z ACT
Casey	6 February 2000	AOA ICS-4000Z	AOA ICS-4000Z ACT
Davis	8 February 2000	AOA ICS-4000Z	ASHTECH Z-XII3
Mawson	3 March 2000	AOA ICS-4000Z	AOA ICS-4000Z ACT
Yarragadee	8 March 2000	AOA SNR-12 RM	AOA ICS-4000Z ACT
Tidbinbilla	30 March 2000	AOA SNR-12 RM	AOA ICS-4000Z ACT
Ceduna	11 May 2000	AOA ICS-4000Z	AOA ICS-4000Z ACT
Karratha	13 June 2000	ASHTECH Z-II3	AOA ICS-4000Z ACT

A number of software amendments were made during 2000. These developments included refinement of receiver download programs and upgrading of data conversion and archiving processes. These changes were made to minimize data loss and increase the efficiency of the data transfer & conversion system

Local Monitoring Surveys

Although all ARGN sites were carefully selected for geological stability, they all include three stable reference marks, usually within about twenty metres of the main monument. Repeated accurate local surveys of these marks and the GPS monument allows any possible local movement to be detected. During 2000, local surveys were carried out at Ceduna and Mawson using a Leica TC2003 Total Station and Topcon DL-101C digital level to give sub-millimetre results. No significant local movement was found.

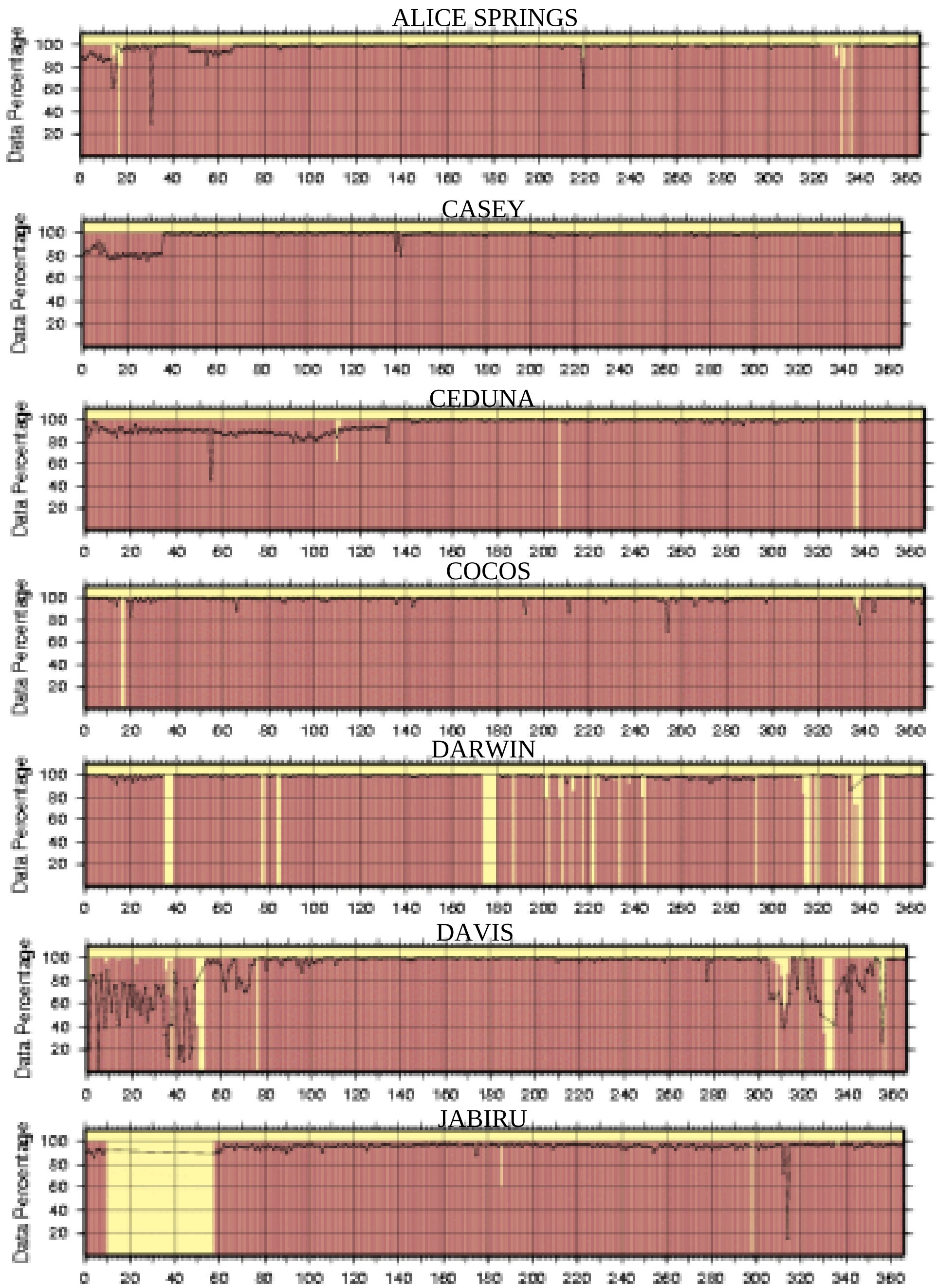

Figure 1 – Data availability at ARGN sites for 2000

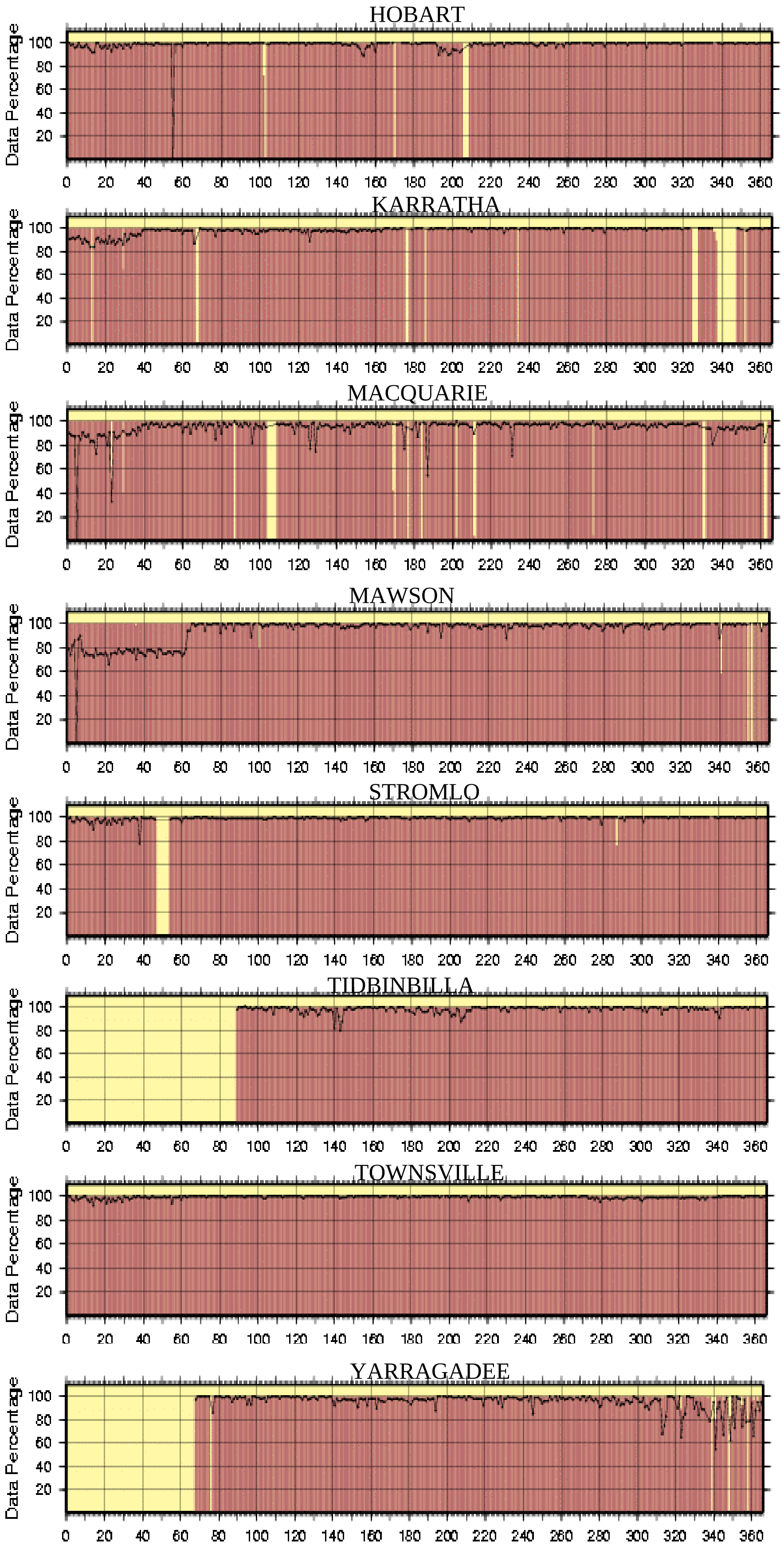

Figure 1 (cont.) – Data availability at ARGN sites for 2000

New Zealand Continuous GPS Network

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Introduction

It is timely to review the status of New Zealand's continuous GPS (CGPS) stations, because a major upgrade of CGPS monitoring is beginning in 2001/2002 and there will be a substantial increase in the data we will be providing to the IGS.

The CGPS array at December 2000 is shown in Figure 1, and the following paragraphs provide some notes on the stations.

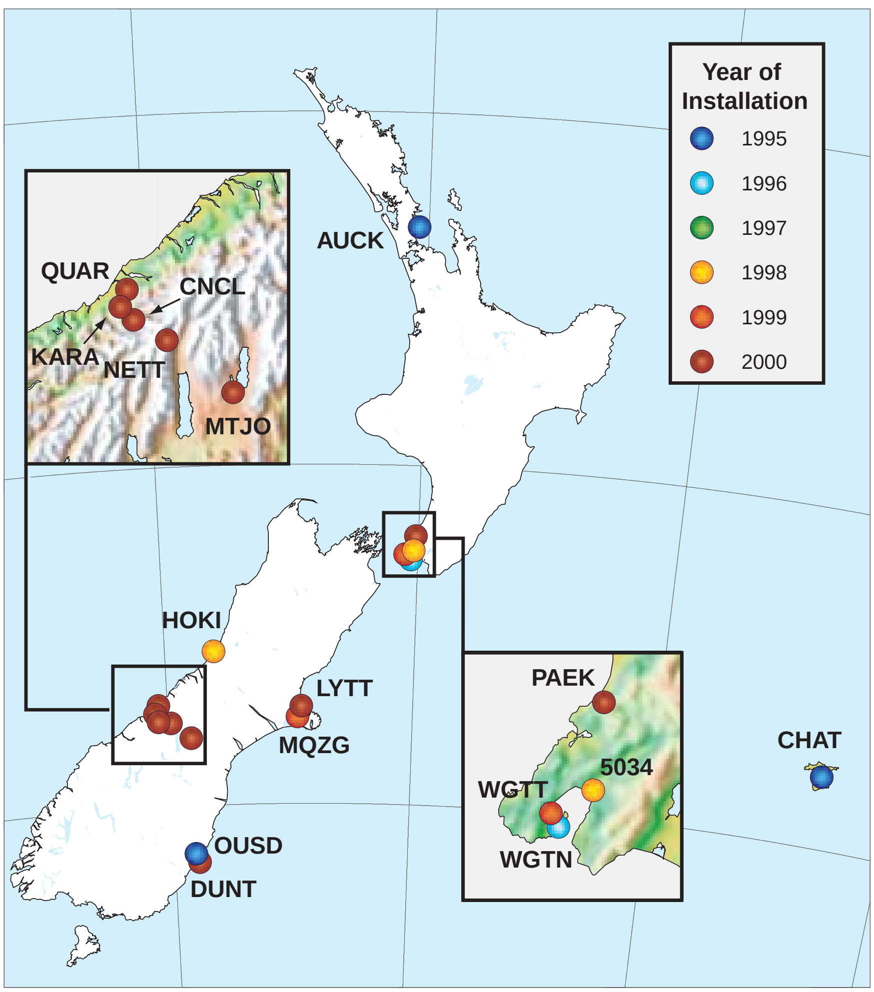

Figure 1. CGPS Array - December 2000

AUCK and CHAT

AUCK and CHAT are the original New Zealand IGS stations, installed in 1995 in partnership between the Institute of Geological and Nuclear Sciences (GNS), Land Information New Zealand (LINZ), JPL, and UNAVCO. These are the only New Zealand stations whose data are presently submitted to the IGS. Both stations have been operating with Turborogue SNR-8000 receivers since their inception, but we plan to upgrade both to Ashtech Z-12 CGRS receivers in 2001.

Sea Level Network

Since late 1999/early 2000, GNS and Otago University have operated CGPS receivers at three of New Zealand's longest-running tide gauges. These are stations DUNT, LYTT, and WGTT, and a fourth station will be established at the Auckland tide gauge in 2001. Funding for this network is from the New Zealand Foundation for Research, Science and Technology (FRST).

Southern Alps Network

The Southern Alps network (QUAR, KARA, CNCL, NETT, and MTJO) is primarily aimed at measuring the distribution of vertical motion across the Southern Alps in order to better understand processes of continental collision. The experiment started in February 2000 and will run at least 5 years. It is a joint project between MIT, the University of Colorado, Otago University, GNS, and UNAVCO. The primary funding is an NSF grant to Peter Molnar (with U.S. co-investigators Brad Hager and Tom Herring), with the New Zealand institutions funded by FRST and an Otago University Research Grant. As well as the continuous stations, a number of "semi-continuous" stations are operated for several months per year, mainly during the summer.

GNS Network

Five stations (WGTN, HOKI, 5034, MQZG, and PAEK) have been installed by GNS, sometimes in partnership with other institutions. HOKI was established in cooperation with Lamont-Doherty Earth Observatory of Columbia University, while PAEK was established in cooperation with the Geographical Survey Institute, Tsukuba, Japan. LINZ has contributed to the installation of several of the stations.

Otago University Station

OUSD is the longest-running CGPS station in New Zealand, dating from January 1995 some 8 months before AUCK and CHAT were established.

Near Real Time Precipitable Water

Most of the stations described above are downloaded hourly, and are processed to determine precipitable water with a delay of about 2 hours. These results may be found at www.gns.cri.nz/earthact/crustal/precip/gpspw.html.

References

Graeme Blick, Land Information New Zealand, Wellington, New Zealand.
gblick@linz.govt.nz

Paul Denys, Otago University, Dunedin, New Zealand.
pdenys@stonebow.otago.ac.nz

Mark Falvey, Victoria University of Wellington, Wellington, New Zealand.

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

C. Garcia, J.M. Dow, R. Zandbergen, J. Feltens, I. Romero

ESA/European Space Operations Centre
Darmstadt, Germany

Overall Hardware Configuration

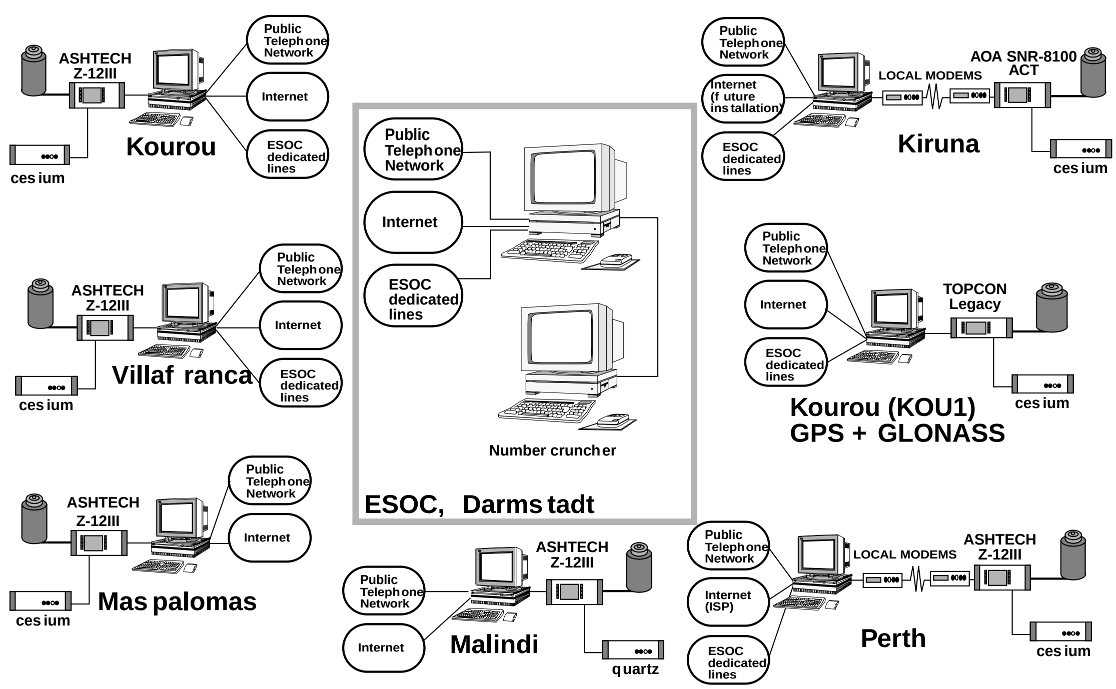

Figure 1 shows the configuration of the ESA stations by the end of 2000.

Receiver Performance

As it was reported in the IGS Network Systems Workshop, held in Annapolis 2-5 November 1998, the TurboRogues located at equatorial stations show many limitations in the cross correlation mode tracking during the solar maximum. The only solution is a replacement by new receivers.

Over the year 2000 ESOC has continued the plans to upgrade its network with receivers capable of tracking techniques with higher SNR than the cross correlation. ACT (AOA) and Z-tracking (Ashtech) receivers have been deployed to the tracking stations. It was a busy year with the following upgrades:

In Kiruna (KIRU) the receiver was upgraded to an AOA SNR-8100 ACT in September 2000.

In Kourou (KOUR) the TurboRogue was replaced by an ASHTECH Z-XII3 in March 2000.

In Malindi (MALI) the upgrade was delayed till April 2001 due to several problems with shipments arriving in bad condition to the African station.

Maspalomas (MAS1) was the first ACT upgrade in August 1999, but the upgraded receiver failed some months later and had to be replaced by an ASHTECH Z-XII3 in December 2000.

In Perth (PERT), due to the geographical location, the cross correlation receiver had an acceptable performance and the receiver was only replaced in 2001 after failure of the TurboRogue.

Villafranca (VILL) was upgraded to an AOA ACT receiver in July 2000. A similar situation to Maspalomas with a failure of the upgraded receiver some months later made necessary the replacement by an ASHTECH Z-XII3 by the beginning of 2001.

A Topcon Legacy combined GPS+GLONASS receiver was installed at Kourou (KOU1). A technical problem with the cable attenuation delayed the data distribution which is expected to start in 2001 to support IGS and IGLOS activities.

Communications

The communication from the ESA stations to the Control Centre at ESOC has been implemented based on the ESA permanent leased lines for those locations where they are available (Kiruna, Kourou, Perth and Villafranca) and based on dial-up modems where they are not. These lines are shared by other operational ESA projects and have a bandwidth limitation of 2400 baud. This rate is approximately twice the needed for 1 Hz receiver tracking and can be enough for data streaming but it is very tight if the data are packed in 15 minutes or 1 hour files.

To offer a better connectivity an effort has been undertaken to upgrade the stations with TCP/IP communications based on the Internet connectivity of the stations. The lines are not as reliable as the operational links, but accept higher throughput.

The new remote computers that support the receivers are Windows NT PCs with remote control for computer and receiver housekeeping. The operation is automatic and autonomous.

High Rate Data Capability

Thanks to the new Ashtech receivers and the new TCP/IP communications the ESA stations are able to produce 1 Hz data in subdaily downloads. It has been demonstrated in various high rate data collection campaigns like the HIRAC/Solarmax in April 2001.

The new Ashtech Z-XII receivers can internally store an download 1 HZ data. The AShtech receivers also do not present any problems in the second frequency tracking at equatorial stations caused by high ionospheric activity. The old TurboRogues where only capable of 0.33 Hz sampling by using the internal memory and CPU resources.

The Internet lines, developed for the bandwidth requirements of the web browsers, can download the 1 Hz data collected during one hour in a few minutes.

One-Hour Downloads

One-hour data of Kiruna, Kourou, Perth and Villafranca are available since September 1998. These stations have permanent leased data links to ESOC. The data flow has been continuos with only one hour latency during 1999 and 2000.

Maspalomas joined the hourly group in December 2000, at the beginning by using connectivity from a local Internet Service Provider and finally by using a 2 Mbits line of the station.

Malindi started the hourly downloads in 2001 using the Internet connection provided by the University of Rome at the San Marco station.

The hourly data are currently used for the computation of the ESA Rapid and Ultra Rapid products.

References

GPS-TDAF Stations Configuration Manual. Version 1.4, October 1999.

The GPS receiver Network of ESOC: Maspalomas, Kourou, Kiruna, Perth, Villafranca and Malindi. C. Garcia-Martinez, J.M. Dow, T. Martin-Mur, J. Feltens, P. Bernedo. 1998 Technical Reports. IGS Central Bureau.

ESA/ESOC IGS Analysis Centre Poster Summary. C. Garcia-Martinez, J.M. Dow, T. Martin-Mur, J. Feltens, P. Bernedo. 1998 IGS Network Systems Workshop.

Status Report of IGS Stations Monitored by GFZ

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Division 1
Kinematics and Dynamics of the Earth

Introduction

The improving of the data availability is in fact the most important and a permanent task in monitoring the IGS GPS-sites. Some IGS sites operated by GFZ were extended to meet the requirements of the GFZ Champ mission, showing the possibilities and limitations of the current concept. Effort was taken to add new sites to the IGS net.

Data Transfer

The software for transferring the data via FTP was improved. Regarding the Windows based GPS sites new software was developed to increase the transfer reliability and speed. The station KIT3 shows still poor data availability due to the remote location. We are now working on an internet solution at this site.

Champ Support

Some GPS sites, e. g. LPGS, were extended to work at higher sample rates. Higher sample rates with increased file sizes could result in increased latencies depending on the strength of the data transfer routes. Compromises had to be taken to meet both requirements, low latency and high sample rates.

New Station

The station ULBA located at the Ulaanbaatar Astronomical Observatory in the Mongolia is about to obtain the IGS status. This station is equipped with an radio modem link type WIMAN **/1/**, connecting the GPS site over a distance of about 10 km to the internet. Efforts were taken to find new partners for building up new GPS sites in Africa and first contacts are very promising.

References

Neumeyer J., Nischan Th., Ramatschi M., Status Report of IGS Stations Monitored by GFZ, http://igscb.jpl.nasa.gov/overview/99_tech_reports.html

Table 1: Status of IGS stations operated by GFZ (07/2001)

Station	Receiver	Download Software	Receiver Format	Operating System	Compression	File Size	Data link	Latency	Meteo Station
KSTU (Russia)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Hourly	Internet	<15 min	Yes
KIT3 (Uzbekistan)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Daily	Internet (offline)	~ 10 days	Yes
LPGS (Argentina)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Hourly	Internet	<15 min	No
OBER (Germany)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp	Hourly	Internet	<15 min	Yes
POTS (Germany)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp	Hourly	Internet	<15 min	Yes
ULBA (Mongolia)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Hourly	Radio link + Internet	<15 min	No
UNSA (Argentina)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Hourly	Internet	<15 min	No
URUM (China)	AOA SNR 8000 ACT	TrMonitor	Conan Binary	LINUX	ZIP	Daily	Modem + Internet (offline)	<2 h	No
RIOG (Argentina)	Ashtech Z 12	GBSS	Binary	Win / NT4	ZIP	Hourly	Internet	<15 min	No
ZWEN (Russia)	AOA SNR 8000 ACT	TrMonitor	Turbo Binary	LINUX	Tcomp + ZIP	Hourly	Internet	<15 min	No

NASA-Sponsored GPS Global Network Activities

D. Stowers
Jet Propulsion Laboratory, Pasadena, CA, USA

M. Jackson, O. Ruud
University NAVstar Consortium, Boulder, CO, USA

R. Khachikyan
Raytheon Systems Company, Pasadena, CA, USA

Activities in 2000

NASA supported IGS sites established in 2000/2001, and partner agencies:

NRIL Norilsk, Russia - RDAAC/IRIS
MOBN Moscaw/Obninsk, Russia - RDAAC
CHPI Cachioera Paulista, Brazil - INPE
MBAR Mbarara, Uganda - IRIS/Geological Survey and Mines Dept. of Uganda
MSKU Franceville, Gabon - IRIS/Universite des Sciences et Techniques de Masuku
DYR2 Diyarbakir, Turkey - MIT/ERL
YAKT Yakutsk, Russia - RDAAC/IRIS
RBAY Richards Bay, South Africa - Hartebeesthoek Radio Astronomy Observatory
RABT Rabat, Morroco - MIT/ERL
CHUM Chumysh, Kazakhstan - IVTAN

NASA supported IGS sites upgraded with modern receivers:

AREQ, CRO1, IISC, GALA, GOLD, GUAM, HRAO, MADR, SANT, TIDB, USUD

High-rate data available with global distribution:

Partnered ground support commitment for the CHAMP LEO mission, the IGS call for support for LEO missions in general, and real-time GPS data applications provided the impetus to expand the high-rate subnetwork to 25 (and growing) sites. In most cases, these sites provide both 1s data and what are now typical hourly and daily 30s RINEX file products.

Formats of data publicly available from ftp://bodhi.jpl.nasa.gov/pub/

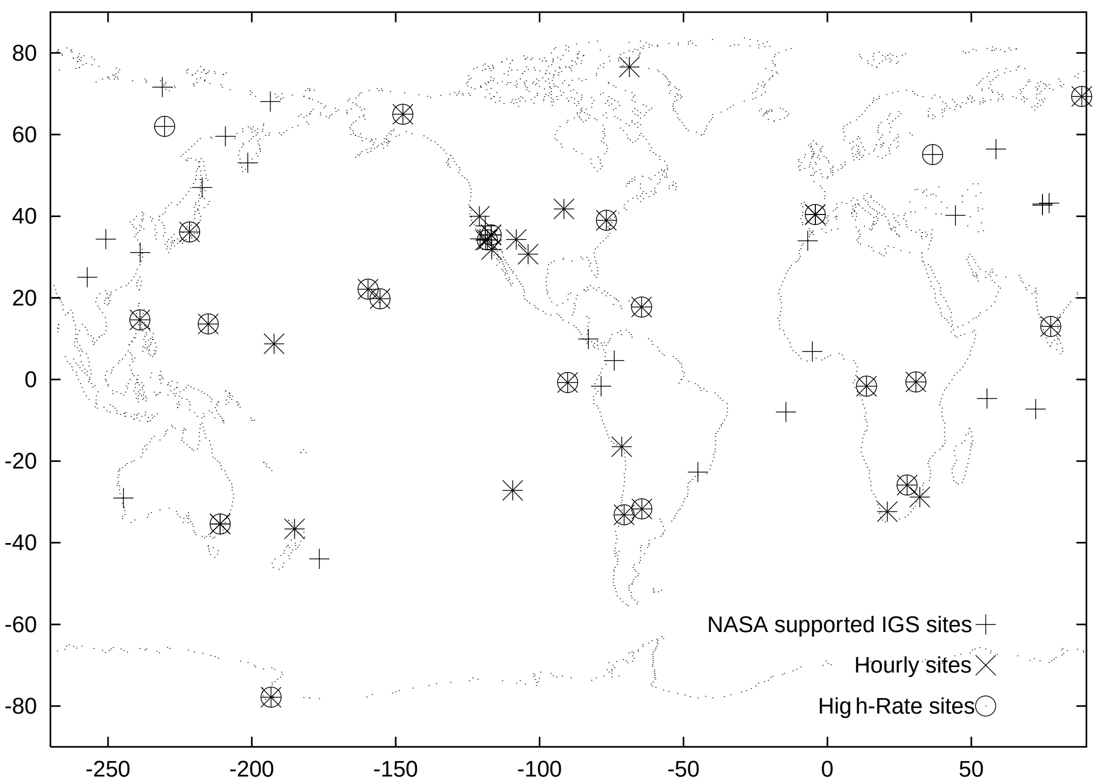
Daily 30s-samplerate RINEX
Hourly 30s-samplerate RINEX
15m 1s-samplerate compressed TurboBinary (GFZ tcomp utility);
CHAMP LEO support
15m 1s-samplerate CompactRINEX (Hatanaka/unix compressed);
IGS LEO Pilot Project format

Continued L2 troubles:

TurboRogues continue to have problems w/L2 tracking during solar maximum. A firmware fix did not materialize. An external fix running the TurboRogue receiver at 1s provides some improvement, but is not feasible at many locations. Receiver replacement has provided the best solution.

Y2K and other issues:

Other than some minor date formatting issues that were resolved almost immediately, and bit of a flurry to continue to provide continuous IGS support with a reduced number of Global Data Centers and an unusual number of key facility electrical power outages (unrelated to Y2K issues), this particular date rollover was largely uneventful.



* 1s data available + hourly 30s data available

NASA Supported IGS Sites

AOA1 ROGUE SNR-8000
+AREQ AOA SNR-8000 ACT
ARTU ASHTECH Z-XII3
ASC1 AOA SNR-8000 ACT
+AUCK ROGUE SNR-8000
BILI ASHTECH Z-XII3
BOGT non-operational
CASA ROGUE SNR-8000
CHAT ROGUE SNR-8000
CHPI ROGUE SNR-8000
CHUM ROGUE SNR-8000
+CIC1 ROGUE SNR-8000
*+CORD ROGUE SNR-8000
*+CRO1 ASHTECH Z-XII3
DGAR AOA SNR-8000 ACT
DYR2 ROGUE SNR-8000
+EISL ROGUE SNR-8000
*+FAIR AOA SNR-8100 ACT
*+GALA ASHTECH Z-XII3
*+GODE AOA SNR-12 ACT
+GOL2 ROGUE SNR-12 RM
*+GOLD ASHTECH Z-XII3
*+GUAM ASHTECH Z-XII3
HARV AOA SNR-8000 ACT
*+HRAO ASHTECH Z-XII3
IAVH (replaced by RABT)
*+IISC ASHTECH Z-XII3
+JPLM ROGUE SNR-8000
*+KOKB AOA SNR-8100 ACT
KUNM ROGUE SNR-8000
+KWJ1 AOA SNR-8100 ACT
+MAD2 ROGUE SNR-12 RM
*+MADR ASHTECH Z-XII3
MAGO ASHTECH Z-XII3
*+MBAR ASHTECH Z-XII3
MCM4 ROGUE SNR-8000
+MDO1 ROGUE SNR-8000
*+MKEA ASHTECH Z-XII3
*MOBN ASHTECH Z-XII3
MOIN non-operational
*+MSKU ASHTECH Z-XII3
+NLIB ROGUE SNR-8000
*+NRIL ASHTECH Z-XII3
NSSP ROGUE SNR-8000
PETP ASHTECH Z-XII3
+PIE1 ROGUE SNR-8000
*+PIMO ROGUE SNR-8000
POL2 ROGUE SNR-8000
+QUIN ROGUE SNR-8000
RABT ROGUE SNR-8000
+RBAY ROGUE SNR-8000
RIOP ROGUE SNR-8000
*+SANT ASHTECH Z-XII3
SELE ROGUE SNR-8000
SEY1 ROGUE SNR-8000
SHAO ROGUE SNR-8100
+SUTH ROGUE SNR-8100
THU1 ROGUE SNR-12 RM
+TID2 ROGUE SNR-12 RM
*+TIDB ASHTECH Z-XII3
TIXI ASHTECH Z-XII3
*+USUD ASHTECH Z-XII3
XIAN ROGUE SNR-8100
*YAKT ASHTECH Z-XII3
YAR1 ROGUE SNR-8100
YKRO ROGUE SNR-8000
YSSK ASHTECH Z-XII3

*Auxiliary Z-12 receiver (GODF) providing 1s data from GODE antenna/monument.
*Auxiliary Z-12 receiver (MCMZ) providing 1s data from MCM4 antenna/monument.
*Auxiliary Z-12 receiver (JPLT) providing 1s data from JPL Frequency Standard Test Lab
*Auxiliary Z-12 receiver (OKC2) providing 1s data from ARM Facility in Oklahoma

NRCan – GSC
Western Canada Deformation Array GPS Network
2000 Report

Michael Schmidt, Herb Dragert
Geological Survey of Canada, Natural Resources Canada

Introduction

The Western Canada Deformation Array (WCDA) is a regional network of continuous GPS stations operated by the Geological Survey (GSC) of Canada primarily for the study of crustal deformation in the Cascadia Subduction Zone. In addition two sites, DUBO and FLIN, (supported under a joint GSC – NASA/JPL research agreement), are operated as part of a continental postglacial rebound study involving the analysis of GPS data from various agencies. Absolute gravity measurements are carried out at a subset of eight of these sites. In 2000, the operation of station WHIT was transferred to the Geodetic Survey Division (GSD) of NRCan. The WCDA network grew by a number of new stations bringing the total number of sites up to 14. Of these, 10 are posted to the IGS. Data from all sites are available from the WCDA ftp server.

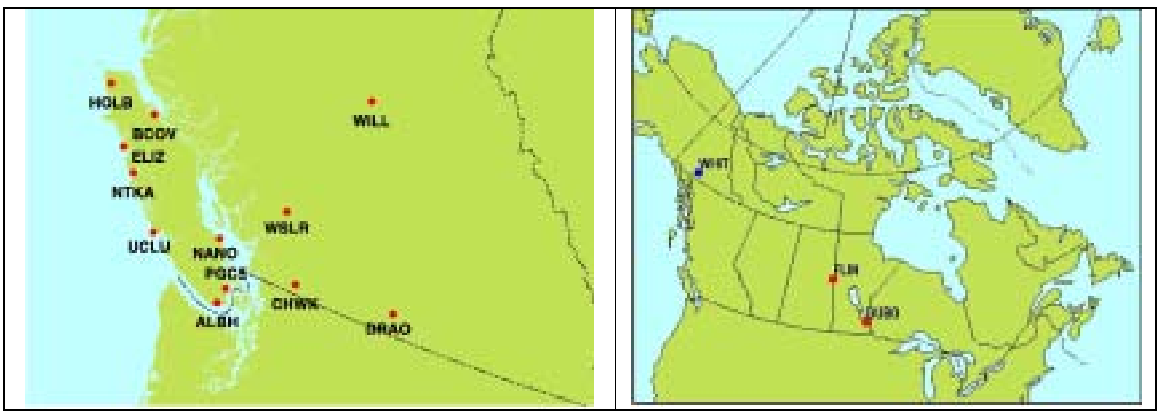


Figure 1: WCDA GPS Network

Data Retrieval, Validation and Distribution

No significant changes were made to the GPS data retrieval, validation and distribution systems in 2000. Data are retrieved on an ongoing automated basis. Data from the two IGS global sites, ALBH and DRAO are forwarded hourly to CDDIS. The remaining sites' data are distributed to the IGS in 24-hour files. All file distribution and posting on the WCDA server is in the compressed Hatanaka RINEX format. Data validation process continues to use three separate programs: GIMP, GPSPACE (both GSD/NRCan) and TEQC (UNAVCO).

GIMP provides arc-by-arc statistics including number of observations, data gaps, cycle slips, ionospheric and multipath parameters. GPSPACE uses either broadcast orbits or 'SP3' format orbits to calculate single point position, clock offset and clock drift. TEQC, in addition to providing data quality control, is also used to RINEX all WCDA data. Summary statistics from all three validation programs are tabulated in summary files used for evaluating site performance, generating plots, etc..

Metadata contained in the RINEX observation file headers are generated at the time of RINEX conversion based on time-stamped entries in station log files. UNIX-Hatanaka compressed RINEX files are posted on the WCDA FTP server and forwarded to CDDIS immediately after automated data retrieval and validation is complete. Data files and IGS site logs are available via the web (http://www.pgc.nrcan.gc.ca/geodyn) or via anonymous FTP from WCDA server: ftp://sikanni.pgc.nrcan.gc.ca

WCDA Site Upgrades:

The summary of site upgrades includes receiver, receiver firmware, antenna and dome changes carried out in 2000 and in effect as of Dec 31, 2000. Changes made subsequent to Dec 31. 2000 are not reflected in these tables.

Receiver Upgrades 2000

Three stations were upgraded to the AOA BenchMark ACT technology.

Site	Date Installed	Firmware Version
ALBH	15-MAR-2000	3.3.32.2N
WHIT*	11-JUL-2000	3.3.32.4
WSLR	AOA SNR-8000 ACT	3.3.32.3

Table 1: AOA BENCHMARK ACT GPS receiver installation
as of Dec. 31, 2000
* WHIT: operation transferred to GSD, NRCan Oct. 4, 2000

Firmware Upgrades 2000

Table 2 lists the receiver type and firmware changes carried out prior to December 31, 2000.

Site	Receiver Type	Date Installed	Firmware Version
ALBH	AOA BENCHMARK ACT	15-MAR-2000 18:18 UT	3.3.32.2N
DRAO	AOA BENCHMARK ACT	06-DEC-2000 22:36 UT	3.3.32.4
WHIT*	AOA SNR-8000 ACT	04-OCT-2000 00:00 UT	3.3.32.2N
WSLR	AOA SNR-8000 ACT	29-MAR-2000 21:53 UT	3.3.32.3

Table 2: Receiver Firmware: Date of Upgrade and Version Number
as of December 31, 2000
* WHIT: operation transferred to GSD, NRCan Oct. 4, 2000

Antenna / Dome Upgrades 2000

All WCDA sites are equipped with AOAD/M_T antennas. Several models of this antenna are used. Table 3 summarizes antenna changes and Table 4 dome changes made at WCDA sites.

Site	Antenna Type	Antenna Part Number	Change Effective
UCLU	AOAD/M_T	7490582-B	01-JUN-2000 23:00 UT
WSLR	AOAD/M_T	7490582-2	29-MAR-2000 21:53 UT

Table 3: Antenna and Changes, 2000
as of December 31, 2000

Site	Dome Type + RF screen	Change Effective
UCLU	SCIS + RF screen	SCIS Dome installed 01-JUN-2000 23:00 UT
WSLR	SCIS	SCIS Dome installed 29-MAR-2000 21:53 UT

Table 4: Antenna Dome changes, 2000
as of December 31, 2000

External Frequency (Clock) Changes 2000

Site	Clock Change	Change Effective
ALBH	Rubidium to Hydrogen Maser	06-OCT-2000 19:45 UT
NANO	Rubidium to Clock Steering	07-NOV-2000 17:08 UT
WSLR	Rubidium to Clock Steering	31-MAR-2000 17:20 UT

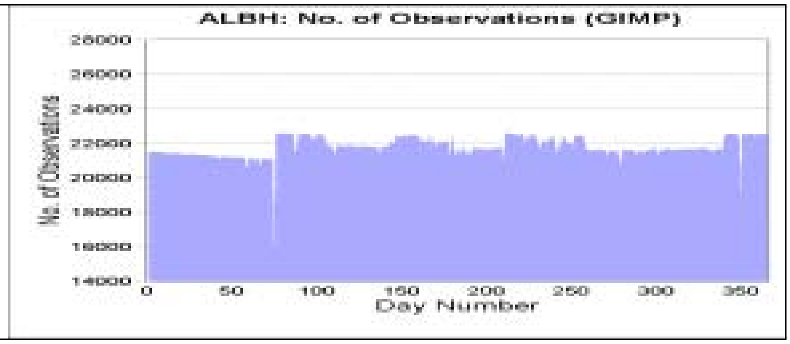
Table 5: External Frequency (clock) changes, 2000
as of December 31, 2000

WCDA IGS Global Sites

The following tables summarize the data collection status of WCDA IGS Global sites (ALBH, DRAO) as indicated by the total number of daily observations. The clock performance as derived from GPSPACE with IGS Rapid orbits is also indicated.

ALBH

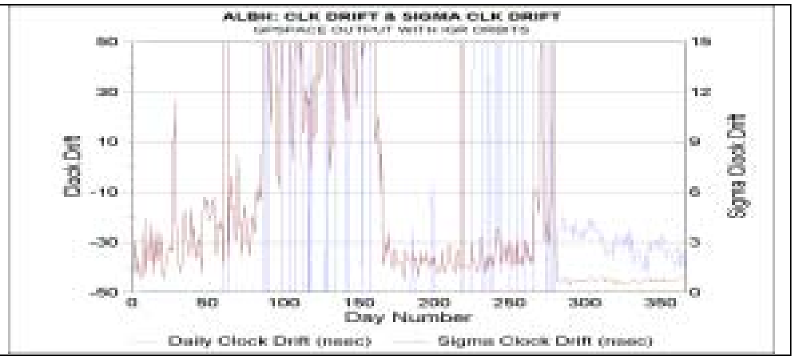
- upgrade to AOA BenchMark ACT D075 (8 ch to 12 ch)
- difference(s) in daily No. of data points due to changes in constellation;



ALBH

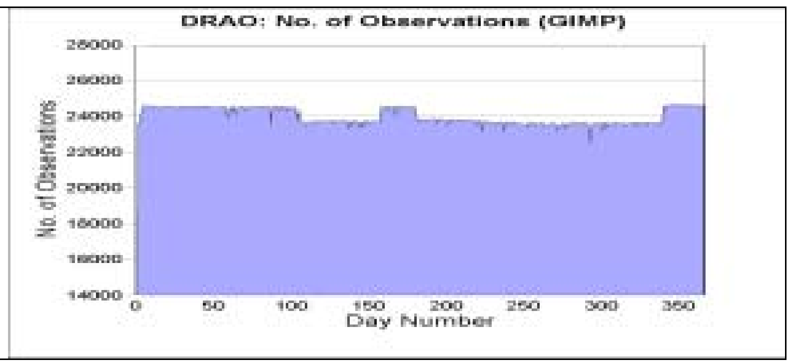
- Rubidium clock used until Oct. 6 (D280);
- Hydrogen Maser installed D280;

> Output from GPSPACE with Rapid Orbits;



DRAO

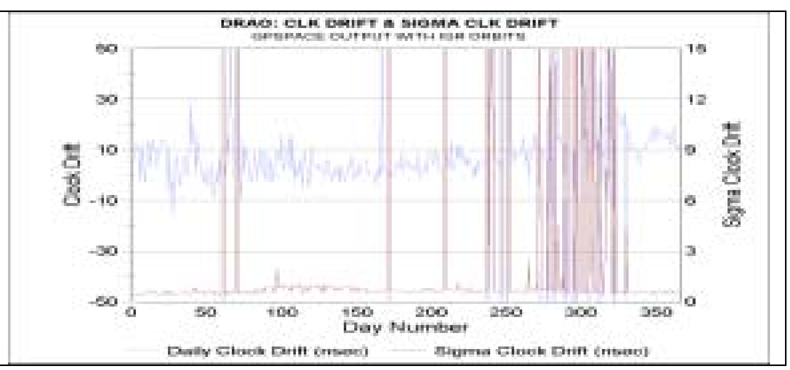
- difference(s) in daily No. of data points due to changes in constellation;



DRAO

- large number of apparent clock resets due to problem with receiver offloads causing receiver resets;
- problem resolved by firmware upgrade D341

> Output from GPSPACE with Rapid Orbits;



Complete site information is available at: http://www.pgc.nrcan.gc.ca/geodyn

Permanent GPS Tracking Station UPAD

A. Caporali
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(alessandro.caporali@unipd.it)

Presentation

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

Instrumentation

In 1997 the station operated with the TRIMBLE 4000SSE receiver and geodetic antenna with ground plane. In September 1997 new equipment included a TRIMBLE 4000 Ssi, choke ring antenna and the control software URS, under OS2. The local PC is configured as a FTP and WEB server. Since September 1999 the URS operates under the Operating system Windows NT4.

Data

Data production consists of :

- Real time differential corrections RTCM/RTK obtainable at free of charge at the phone number 049 8273442 (modem)
- Hourly files in compressed RINEX format. Compression is according to IGS standards (Unix+Hatanaka). Observation and Navigation files are available. Sampling time is 5 seconds.
- Hourly files in compressed RINEX format. Compression is according to IGS standards (Unix+Hatanaka). Observation and Navigation files are available. Sampling time is 30 seconds.
- Daily files in compressed RINEX format. Compression is according to IGS standards (Unix+Hatanaka). Observation and Navigation files are available. Sampling time is 30 seconds.

The FTP target hosts are, at this time:

1. University of Padova
2. Observatory Graz Lustbuehl, Austria
3. BKG, Frankfurt, Germany
4. GFZ, Potsdam, Germany
5. Italian Space Agency, Matera Space Geodesy Center, Italy

Figure 1: the antenna of UPAD

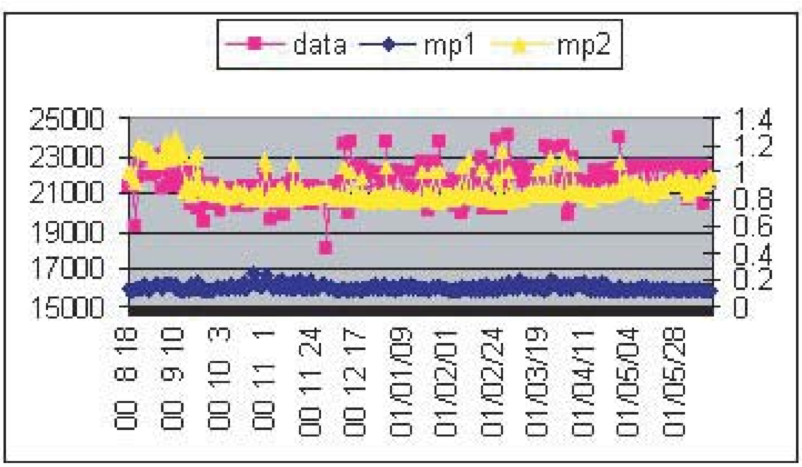

Figure 2: plot of total acquired data since August 2000, and code multipath (right y –scale, in meters)

Technical Report on LAMA IGS Station for Year 2000

L.W. Baran, J. Kapcia, P. Wielgosz

The IGS permanent station LAMA is located in Poland, 25 kilometres northwards from Olsztyn and 200 kilometres northwards from Warsaw, the capital city of Poland. It is maintained by the Institute of Geodesy of the University of Warmia and Mazury in Olsztyn. The station has carried out GPS observation within IGS since 1994 and also within EPN (EUREF Permanent Network). It is equipped (nowadays) with ASHTECH Z-XII-3 receiver, ASH700936F_C antenna, rubidium frequency standard and LAB EL meteo station.

In year 2000 the station experienced problem with its GPS antenna AOAD/M_T. The problem started about April 9, 2000. We got known about this situation when our station was excluded from EUREF weekly solutions due to large residuals on May 16, 2000. We were informed about the problem with over one month of delay, because of the availability of the EUREF combined solution. We did not get any information about low quality of LAMA observations from IGS. We know also that EPN management works to improve this situation in order to nearly real-time data quality checking (Takacs and Bruyninx, 2001). Anyway, we checked this problem and found out, that our antenna was tracking very few satellites (2-4 satellites less than nearby IGS/EPN stations). So we sent our AOAD/M_T antenna to repair and replaced it by ASH700936F_C antenna (with Ashtech radome) on October 6, 2000. Since then the station has operated without major problems. It is a pity we could not use the new antenna until October 2000. The change of the antenna caused a few millimetres shift in station coordinates.

On the basis of GPS observations collected at LAMA and other IGS/EPN stations we conduct studies, primarily on ionospheric TEC behaviour during geomagnetic storms and also on monitoring vectors connecting LAMA with several EPN stations for geodynamics purposes (Baran et al., 2000; Chenyakov et al., 1999).

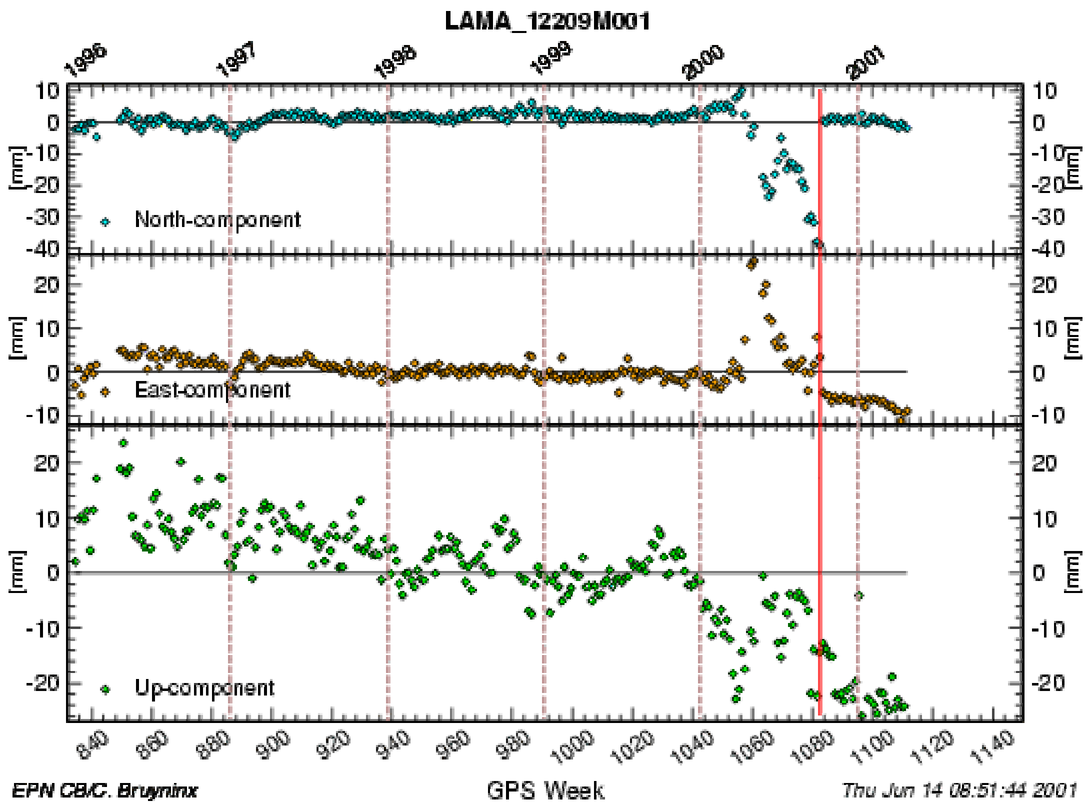

Fig.1 Changes in coordinate time series of LAMA station caused by malfunction and next replacement of GPS antenna (by www.epncb.oma.be/series/lama.html, C. Bruyninx).

References

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Chenyakov I.I., Shagimuratov I.I, Baran L.W. (1999) *High Latitude Measurements of Ionospheric TEC from GPS Signals*, Physics of Auroral Phenomena, Proceedings of the 22nd Annual Seminar, 23-26 March 1999, Russian Academy of Sciences, Kola Science Center, Polar Geophysics Institute, Apatity, pp. 14-17

Takacs B., Bruyninx C.: *Quality Checking the Raw Data of the EUREF Permanent Network*, Presented at the EUREF Symposium, May 16, 2001, Dubrovnik, Croatia

IGS

WORKING GROUPS/ PILOT PROJECTS/COMMITTEES

IGS / BIPM Time Transfer Pilot Project

Jim R. Ray

United States Naval Observatory, USA

Introduction

The IGS/BIPM Pilot Project to Study Accurate Time and Frequency Comparisons using GPS Phase and Code Measurements is sponsored jointly with the Bureau International des Poids et Mesures (BIPM). The project has been underway since early 1998, with the main goal being to investigate and develop operational strategies to exploit geodetic GPS methods for improved global availability of accurate time and frequency comparisons.

The respective roles of the IGS and BIPM are complementary and mutually beneficial. The IGS brings a global GPS tracking network, standards for continuously operating geodetic, dual-frequency receivers, an efficient data delivery system, and state-of-the-art data analysis groups, methods, and products. The BIPM and the timing laboratories contribute expertise in high-accuracy metrological standards and measurements, timing calibration methods, algorithms for maintaining stable time scales, and formation and dissemination of UTC.

Recent activities generally fall into the following areas:

- Workshop — Two days during the "IGS 2000 Analysis Center Workshop," held 25–26 September 2000 at the U.S. Naval Observatory, were devoted to the pilot project.
- Deployment of GPS receivers — The IGS network currently consists of about 250 permanent, continuously operating stations globally distributed. Of these, external frequency standards are used at ~38 with H-masers, ~23 with cesium clocks, and ~17 with rubidium clocks; the remainder use internal crystal oscillators. Table 1 lists the IGS stations currently located at timing laboratories. The former timing lab at the Technical University of Graz, TUG (GRAZ receiver) ended operations in 2000, while the NPLD and SPT0 stations are new. Figure 1 shows the locations of the stations.
- GPS data analysis — A new method to combine satellite and receiver clock estimates, both sampled at 5-minute intervals, was implemented officially by the IGS on 5 November 2000.
- Instrumental delays — The BIPM has demonstrated techniques to calibrate the instrumental biases of the Ashtech Z-XII3T receiver. Efforts are underway to measure the biases of similar receivers deployed at timing laboratories.
- Comparison experiments — Studies are underway comparing geodetic timing results with simultaneous, independent measurements using the common-view and two-way satellite techniques.

For further information, please refer to *http://maia.usno.navy.mil/gpst.html*.

Table 1. IGS Stations Located at BIPM Timing Laboratories (in 2000)

AMC2	AMC*	AOA SNR-12 ACT	H-maser	Colorado Springs, Colorado, USA
BOR1	AOS	AOA TurboRogue	Cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-maser	Brussels, Belgium
MDVO	IMVP	Trimble 4000SSE	H-maser	Mendeleevo, Russia
NPLD	NPL*	Ashtech Z-XII3T	H-maser	Teddington, UK
NRC1	NRC*	AOA SNR-12 ACT	H-maser	Ottawa, Canada
NRC2	NRC*	AOA SNR-8100 ACT	H-maser	Ottawa, Canada
OBER	DLR	AOA SNR-8000 ACT	Rubidium	Oberpfaffenhofen, Germany
PENC	SGO	Trimble 4000SSE	Rubidium	Penc, Hungary
SFER	ROA	Trimble 4000SSI	Cesium	San Fernando, Spain
SPT0	SP	JPS Legacy	Cesium	Boras, Sweden
TLSE	CNES	AOA TurboRogue	Cesium	Toulouse, France
USNO	USNO*	AOA SNR-12 ACT	H-maser	Washington, DC, USA
WTZR	IFAG	AOA SNR-8000 ACT	H-maser	Wettzell, Germany

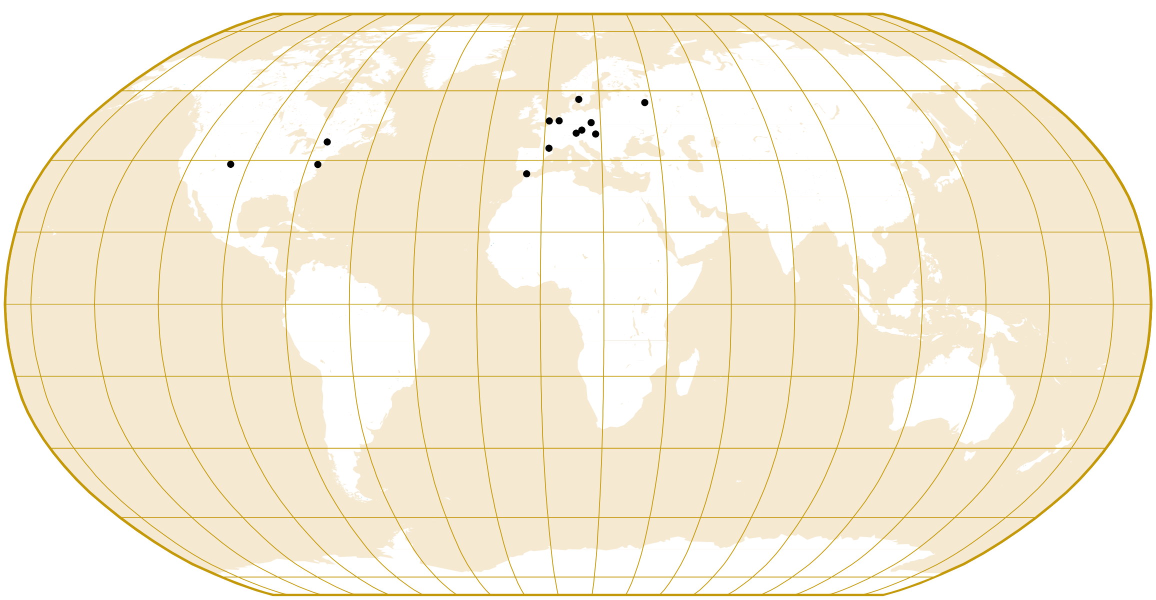

Figure 1. Locations of IGS stations at BIPM timing laboratories

Report of the Tropospheric Working Group

Gerd Gendt

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Product Generation

Since 1997 the IGS regularly generates a combined tropospheric product. It is based on the submission of the individual IGS Analysis Centers (AC), which compute their tropospheric estimates during or after the generation of the IGS final products. Since SIO has joined these activities in February 1998 all IGS ACs contribute to the combination. The product is the weighted mean of the total zenith path delay (ZPD) of the neutral atmosphere (Gendt, 1996). The individual AC biases are calibrated on a weekly basis. The product delay is 2 to 4 weeks. The standards for the analysis are converging, so six ACs have implemented the Niell mapping function, and elevation cut-off angles of 10, 15 and 20 degrees are used by 2 , 4 and 1 centers, respectively.

For more than 210 sites the product is available now (Fig. 1). Nearly 150 sites are used by three or more ACs, which allows to derive reasonable quality measures. The number and quality of the meteorological sensors is slowly improving (Figs. 2, 3). Up to now only 30 sites have reported meteorological data, typically about 25. Information on the quality of all sites to support the selection for new installations were compiled. Presently there are tendencies by some meteorological institutions to assimilate the ZPD directly into the numerical weather prediction (NWP) models. If this proves to be the final strategy then it will have an impact on the installation of meteorological sensors for the regional applications devoted to NWP. However, for sites used in climate studies, which is the case for the global IGS network, meteorological sensors are important, and the usual daily RINEX-met files are sufficient. Therefore IGS should strive to complete the installation of sensors in its global network.

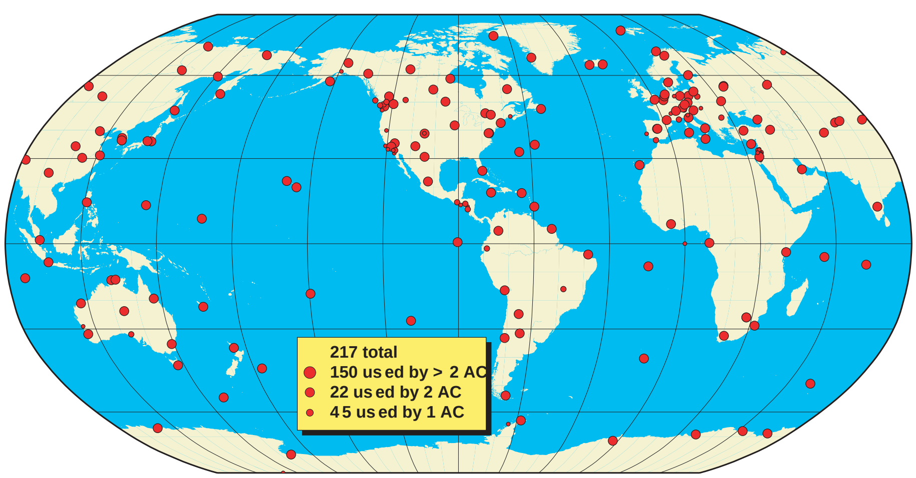

Figure 1. IGS Stations with Tropospheric Estimates

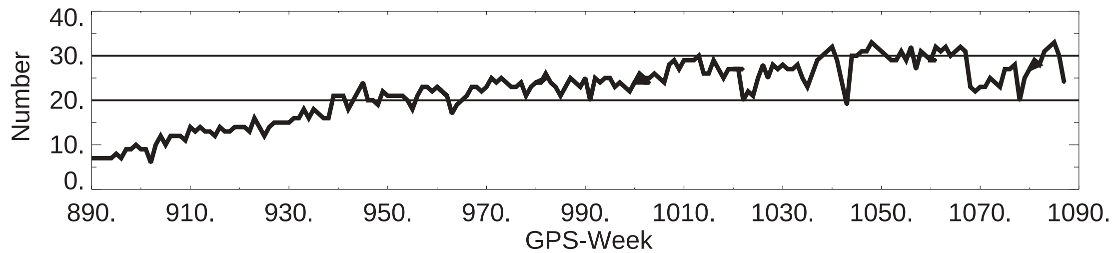

Figure 2. Number of sites with meteorological sensors

Product Quality and Validation

The quality of the product (internal consistency between ACs) is at the level of 3 to 5 mm in the ZPD, which corresponds to ≤ 1 mm in the water vapor (Fig. 4). The biases are even smaller. However, changes in the analysis parameters of the ACs can be seen in most cases in the series.

The histograms in Figure 5 reveal that for most sites the standard deviation is below the 4 mm level. Especially, CODE and SIO have pronounced peaks at 2 – 3 mm, caused by the fact that both centers use many sites in the denser parts of the network where the quality is significantly better than for the sparser parts (Fig. 3). Systematic effects in the biases can clearly be seen for CODE and SIO. The primary reason may be the different cutoff angles applied by both centers (10^o), where the weighted 10^o degrees of CODE seems to correspond to an effective angle of about 20^o.

Regular comparisons with co-located techniques were performed for Potsdam only. Here, a water vapor radiometer (WVR) operated by the German Weather Service is available. All AC GPS solutions monitor the fluctuations in the water vapor with high accuracy. The scattering is of the level of ±1 mm, the best agreement is for the combined series. All ACs have a negative bias of about –1 mm. The fluctuations in the biases are rather large over a longer time interval (~1 mm). The biases may have various reasons, e.g. the WVR itself (calibration) or GPS modeling deficiencies (antenna phase center patterns, mapping functions, satellite antenna offsets). Efforts to make an extensive comparison with globally distributed VLBI sites failed up to now, because older VLBI results had only archived the wet delay without the corresponding pressure values. Such validations should be done in future in a close cooperation with the IVS.

Resume

All IGS components contributing to the combined tropospheric IGS product are performing well. The product has reached a high quality and further investigations on a post-processed tropospheric product in a global scale are not planned. Therefore the activities of working group on this topic will be finished. The established procedures for the regular product generation will be continued, and GFZ agrees to perform the combination (see http://op.gfz-potsdam.de/S11/index_GPSS.html).

Presently near real-time (NRT) monitoring of water vapor is supported by IGS by providing global data, NRT orbits and its Ultra-rapid predictions (Fang et al., 2001). Although NRT activities are more suited to individual countries or regional organizations, where sufficient dense networks are operated, IGS plans to study the feasibility for an Ultra-rapid or even NRT global tropospheric product. Such a product, provided for a relative sparse network only, can be used for NRT quality control in regional network applications.

Up to now only a few users retrieve the IGS tropospheric products (looking into servers at CDDIS, IGN and GFZ). Hopefully, the interest of meteorological community in the product will grow in parallel with the acceptance of GPS products for NWP models. The IGS contribution should also be seen in the context of other activities like the establishment of a similar database (TROP-SINEX format) for Asia and Western Pacific by the Earthquake Research Institute, Tokyo, and the plan to generate a combined tropospheric product within EUREF.

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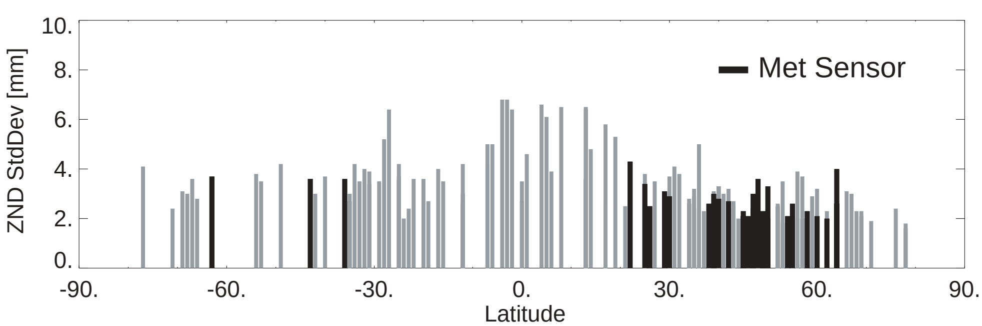

Figure 3. Mean standard deviation for IGS sites used by three or more Analysis Centers, sorted by latitude (mean over GPS weeks 1000 to 1087). Sites equipped with met sensors are marked.

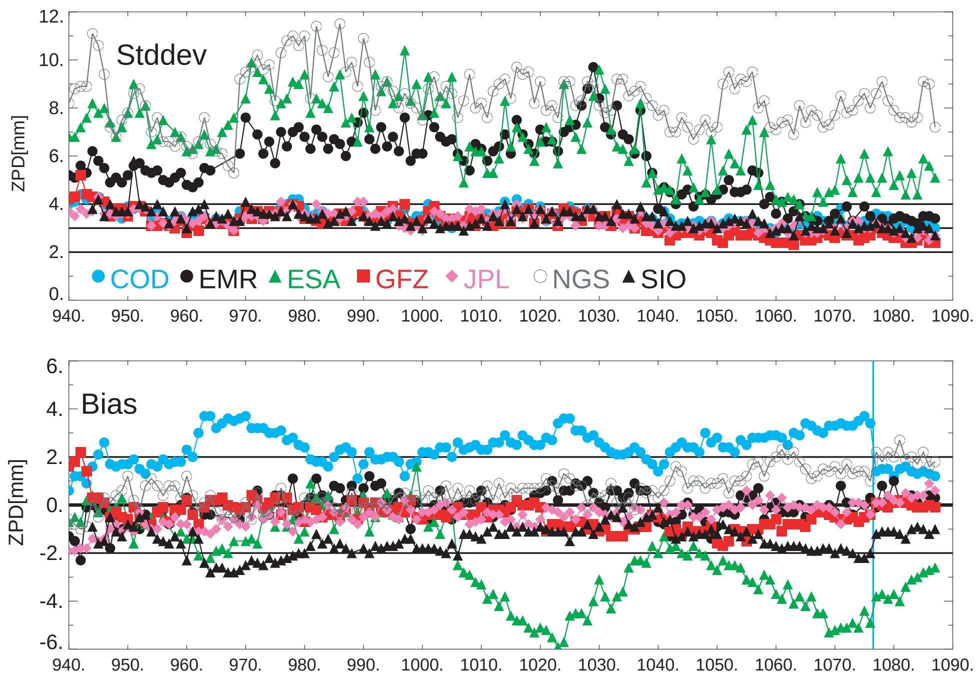

Figure 4. Difference in the zenith neutral delay between the individual GPS estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center.

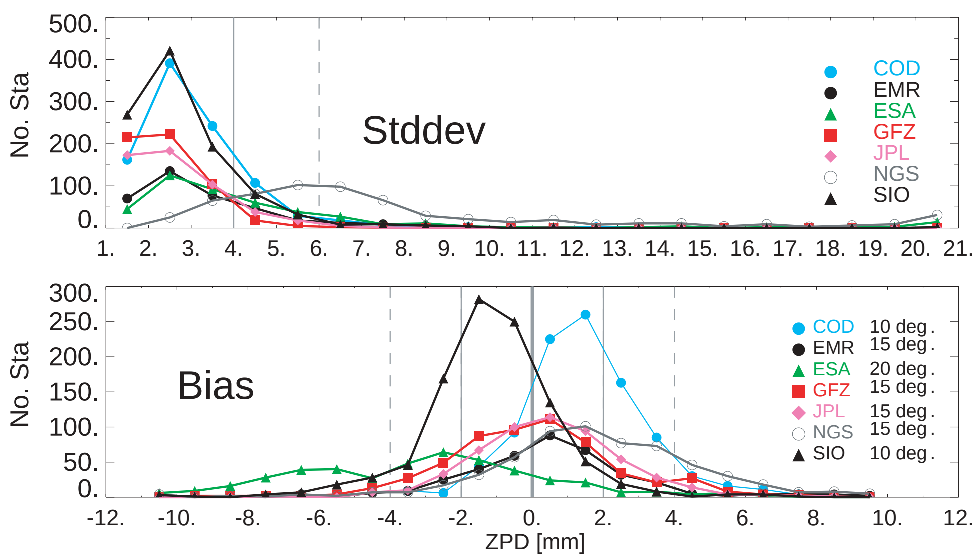

Figure 5. Differences in the zenith path delay between the individual GPS estimates and the IGS Combined Product. Histograms of standard deviation and bias for the GPS weeks 1080 to 1087.

2000 IGS Activities in the Area of the Ionosphere

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Introduction

The IGS Ionosphere Working Group (Iono_WG) is active since June 1998. The working group's most important short-term goal is the routine provision of global ionosphere TEC maps plus GPS spacecraft differential code biases (DCBs) with a delay of some days. The routine delivery of stations DCBs is in preparation and will be included soon. In the medium- and long-term, the development of more sophisticated ionosphere models and the establishment of a near-real-time service are the major tasks. The final target is the establishment of an independent IGS ionosphere model.

Five Ionosphere Associate Analysis Centers (IAACs) contribute with their products to the Iono_WG activities:

1. CODE, Center for Orbit Determination in Europe, Astronomical Institute, University of Berne, Switzerland.
2. ESOC, European Space Operations Centre of ESA, Darmstadt, Germany.
3. JPL, Jet Propulsion Laboratory, Pasadena, California, U.S.A.
4. NRCan, National Resources Canada, Ottawa, Ontario, Canada.
5. UPC, Polytechnical University of Catalonia, Barcelona, Spain.

It is the intent of this Technical Report to give an overview over the Iono_WG activities in 2000.

Routine Activities

Daily Ionospheric Total Electron Content (TEC) Information

Each IAAC delivers per 24 hours an IONEX file (Schaer et al., 1997) with 12 TEC maps containing global TEC information with a 2-hours time resolution and a daily set of GPS satellite DCBs in its header. The inclusion of ground station receivers DCBs is in preparation.

Weekly Comparisons

On Tuesday of each week the TEC maps from the different IAACs are compared for all days of the week before. These comparisons are done at ESA/ESOC. A weekly comparison summary is e-mailed to the "Iono_WG members" via IONO-WG mail.

Furthermore, the daily summaries, the daily IONEX files with the "mean" TEC maps & GPS satellite DCBs and daily TEC & DCB difference files with respect to the "mean" for each IAAC, and also plots of these maps, are made available to the "Iono_WG members" on ESOC's FTP account. The algorithm used in the comparison program is described in (Feltens, 1999 - Appendix A). This algorithm is currently being upgraded with a new weighting scheme, for more details (see next chapter "Improvement of the Comparison Scheme/Validations").

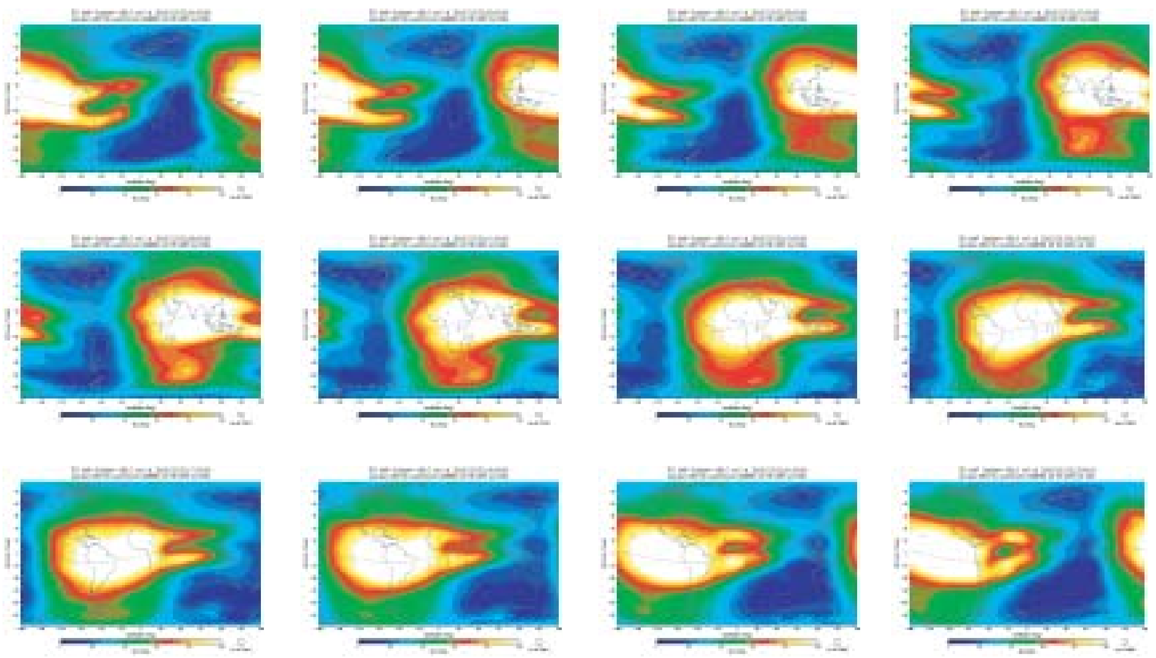

Figure 1: The IGS "weighted mean" TEC maps of 28 March 2000 in [TECU]
(1st row: 1^h, 3^h, 5^h, 7^h ; 2nd row: 9^h, 11^h, 13^h, 15^h ; 3rd row: 17^h, 19^h, 21^h, 23^h).

On the northern hemisphere the deviations of the different IAAC TEC maps from the IGS "mean" are under normal conditions 5 TECU or less. At the equator and on the southern hemisphere the situation is more problematic, because of gaps in the station coverage at these latitudes. However, the deployment of new IGS stations in these areas has reduced these gaps since 1999. Figure 1 above shows the sequence of IGS "weighted mean" TEC maps of 28 March 2000, a day during a period in the current solar maximum, when the TEC level was very high.

The day-by-day variations of the different IAAC DCB sets are normally less than 0.3 nanoseconds, sometimes 0.5 nanoseconds. IAAC DCB sets showing deviations of one 1 nanosecond and more with respect to the IGS "mean" are excluded from the comparison. According to a presentation of S. Schaer at the IGS Workshop, 27 - 29 September 2000, Washington, mean IAAC satellite DCB series show an agreement of about 0.1 nanoseconds. For his analysis Schaer took three months (GPS weeks 1065 - 1077) of daily satellite DCB sets from the IAACs IONEX files and computed from these daily values IAAC-specific mean DCB sets. The five mean DCB sets thus obtained were then compared with respect to each other and also with respect to an overall mean set (All). Table 1 below is an extract of Schaer's presentation and shows the obtained rms errors (in nanoseconds). When interpreting these numbers one has to keep in mind that some IAACs estimate their DCB sets together with their TEC maps, while others make separate program runs for this. Some IAACs introduce constraints in their DCBs estimation, while others do not.

Table 1: Agreement of the distinct IAACs satellite DCB sets in [nanoseconds] (according to S. Schaer).

	NRCan	***ESOC***	***JPL***	***UPC***	***All***
CODE	*0.122*	*0.106*	*0.110*	*0.370*	*0.094*
NRCan		*0.109*	*0.144*	*0.371*	*0.104*
ESOC			*0.118*	*0.373*	*0.095*
JPL				*0.393*	*0.117*
UPC					*0.296*

Improvement of the Comparison Scheme / Validations

The current comparison/combination algorithm is based on a pure statistical approach using weighted means. On the other hand, the methods used by the IAACs to model the ionosphere are very different. In order to achieve an objective weighting for a combination scheme the existing comparison/combination is currently upgraded: Based on two self-consistency methods proposed by NRCan and UPC, in which directly from GPS-observables derived TEC values are compared with corresponding TEC values interpolated from the IAACs TEC maps, new geographic-dependent weights will be computed and thus replace the old kind of weighting in the comparison/combination algorithm. A detailed description on how these two methods work can be found in (Feltens, 2000a; Feltens, 2000c; Hernandez-Pajares, 2000; Heroux, 1999).

Figure 2 below shows in form of histograms the results of an analysis made at UPC with TOPEX data for each of the five IAACs for the year 2000; the Number of TOPEX observations are shown on the ordinate and the differences {TEC(TOPEX) - TEC(GPS)} in [TECU] are shown on the abscissa. When interpreting these histograms it should be taken into account that, in these plots, a negative bias means that the estimated TEC with GPS (h < 20200 km) is greater than the TOPEX TEC (h < 1300 km). Then a positive bias means directly a mean underestimation of the TEC with GPS at least equal to the bias (the TOPEX accuracy seems to be 2 TECU).

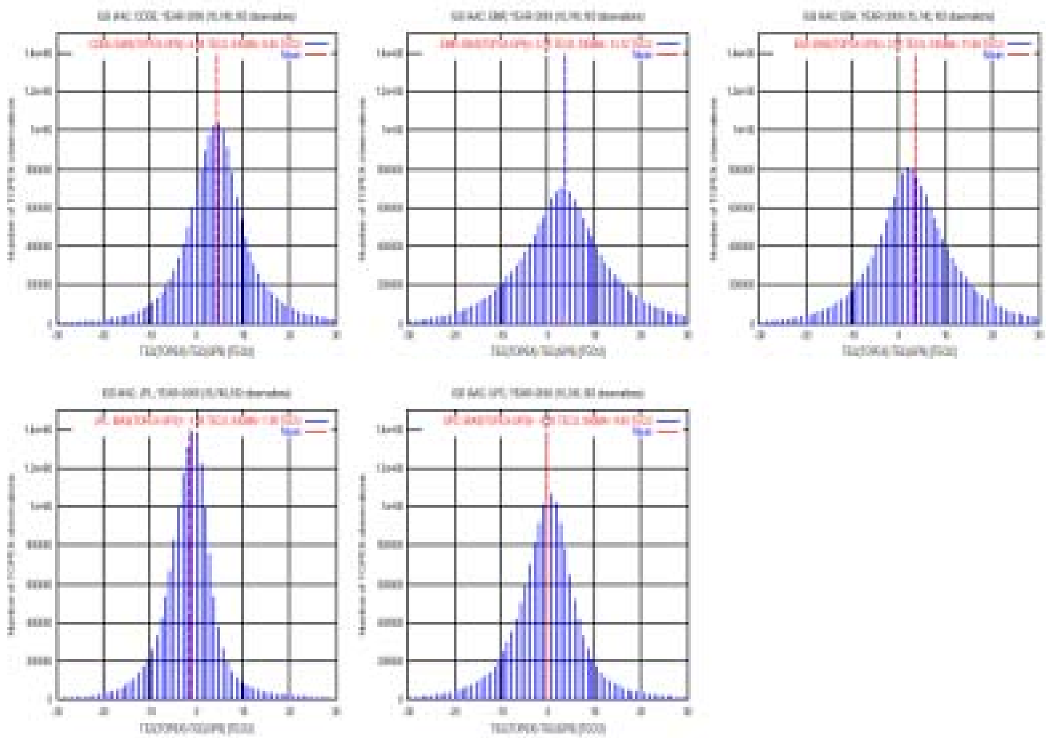

Figure 2: TOPEX- vs GPS-TEC for the year 2000 (figure made at UPC).

Special Activities

During events which are of special interest for the ionosphere community and for ionospheric research, the Iono_WG organizes special high-rate tracking campaigns with the global IGS ground stations network. After the Solar Eclipse Campaign on 11 August 1999, the preparations for a new high-rate campaign with the name "HIRAC/SolarMax" were started with an initiative of J. Feltens and N. Jakowski through IGSmail #3091 (Feltens, 2000b): the objective was to collect in April or May 2001 one week of global high-rate GPS/GLONASS data as a basis for analyses of ionospheric behavior under the current solar maximum conditions. Further details about the HIRAC/SolarMax campaign will then be a topic for the IGS 2001 Technical Report.

Future Tasks

As soon as the new weighting scheme is implemented into the comparison/combination program, it is intended to start with the routine delivery of a combined IGS ionosphere product.

Preparations are made to attach to the weekly comparison program runs validations by comparing IAACs model vertical TEC values with vertical TEC values derived from TOPEX (and Envisat, once launched) altimeter data. Another important aspect will be the reduction of the time deadline for ionosphere products delivery. The ionosphere is a very rapidly changing medium, and it must be the working group's intention to provide actual ionosphere models in short time frames - especially with regard to the current solar maximum.

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IGS LEO Pilot Project

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The Call for Participation in the IGS Low-Earth Orbiter (LEO) Pilot Project was announced in January 2000. It elicited a very strong response evident by the 26 proposals submitted to the Central Bureau. All components were represented (stations, data centers, Associate Analysis Centers, etc.), and the Governing Board accepted all the proposals at the June meeting at the U.S. Naval Observatory. The constitutional meeting to organize the project was planned for January 2001 at GeoForschungsZentrum (GFZ) in Potsdam, Germany. The CHAMP satellite launched successfully on 15 July. In November, after an initial commissioning phase of the satellite, members of the IGS LEO Pilot Project were provided with one day of CHAMP GPS, gravity, and magnetic field sensor data, as well as accelerometer and attitude data plus reference frame and data format descriptions. Data from the U.S.–Argentina mission SAC-C, which successfully launched on 21 November, are also available to the project. The benefits of a common ground-based infrastructure to serve upcoming multimissions cannot be overlooked.

The definition and operation of a robust, high-sampling-rate, low-latency subset of the global tracking network is progressing rapidly, and issues such as data formats, access, products, etc., will be discussed in more detail in 2001 when the project members have had opportunity to examine the space and ground data and produce preliminary results.

One of the key questions is the structure of the project, and in particular, identifying the Associate Analysis Coordinator for the project. Various groups will evaluate the inclusion of LEO data as a core element of the IGS. An assessment of the effects on the traditional IGS analysis products will be performed (GPS ephemerides, clocks, Earth orientation, and troposphere), as well as an assessment of the additional computational and data center burdens. There are clear potential benefits, but these are balanced by additional complexity. In the spirit of the IGS, the pilot project looks to provide a collaborative approach. The data from the satellites are generated by spaceborne, geodetic-quality GPS receivers designed by JPL. In addition to CHAMP and SAC-C, these flight receivers will be flown on board a number of upcoming missions — Jason-1, Gravity Recovery and Climate Experiment (GRACE), and ICESat.

It is clear that the next few years will provide interesting opportunities to explore the enhancement of the IGS through many applications projects. The LEO Pilot Project promises fertile cooperation, noting that by 2003 nearly a half dozen missions will be on orbit and available to the pilot project.

International GLONASS Service Pilot Project

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Introduction

Russia launched the first GLONASS satellites in late 1982. However, until the International GLONASS Experiment (IGEX-98) was conducted in 1998-1999, no coordinated international effort had been organized to collect and process GLONASS data. IGEX-98 created a global tracking network of stations with geodetic receivers, obtained increased laser tracking support from the satellite laser ranging community, generated a continuous archive of satellite observations, and produced post-processed precise orbits. As a result of continued interest in GLONASS, the IGS initiated a pilot project, the International GLONASS Service Pilot Project (IGLOS-PP), to exploit the GLONASS system as long as it remained viable.

A Call for Participation was issued in May 2000 with the following goals and objectives:

1. Establish and maintain a global GLONASS tracking network
2. Produce precise (10-cm level) orbits, satellite clock estimates, and station coordinates
3. Monitor and assess GLONASS system performance
4. Investigate the use of GLONASS to improve Earth orientation parameters
5. Improve atmospheric products of the IGS
6. Fully integrate GLONASS into IGS products, operations and programs.

A pilot project committee was formed consisting of Vladimir Glotov (Russian Space Agency), Ramesh Govind (Australian Survey and Land Information Group), Werner Gurtner (University of Berne, International Laser Ranging Service liaison), Arne Jungstand (EC Joint Research Centre and DLR), Angelyn Moore (IGS Central Bureau), Carey Noll (NASA Goddard Space Flight Center, Data Center Coordinator), James Slater (National Imagery and Mapping Agency, Chair), Robert Weber (University of Technology, Vienna, IGLOS Analysis Center Coordinator), and Pascal Willis (Institut Geographique National). In addition, the IGS Central Bureau initiated a new mail service, IGLOSMAIL, on May 25, 2000 for participants in the project.

The pilot service is based on the infrastructure already in place in the IGS for GPS. Tracking stations forward their data to regional and global data centers where the data are retrieved by Analysis Centers that compute precise orbits and other products. These products are then archived at global data centers for access by the user community.

Tracking Network

As of December 2000, there were 32 operational, dual-frequency tracking stations and 13 proposed stations in the IGLOS pilot project global tracking network. Most of the operational receivers are Ashtech Z-18 or JPS Legacy models. The remainder are 3S Navigation receivers. In conjunction with this, the International Laser Ranging Service has been coordinating laser tracking of three GLONASS satellites (in slot numbers 1, 15, and 24) as part of its routine schedule. The laser tracking takes advantage of laser retroreflectors that are on every GLONASS satellite.

Analysis Centers and Global Data Center

Two Analysis Centers, BKG and ESA/ESOC, have been computing precise orbits on a weekly basis using the receiver data from the tracking network. The Mission Control Center of the Russian Space Agency and the NERC Space Geodesy Facility in the United Kingdom have been computing orbits from the laser tracking data on an intermittent basis. After the BKG and ESA/ESOC orbits are produced, the IGLOS Analysis Coordinator computes a combined orbit at the University of Technology in Vienna.

Data and precise orbits are stored in the CDDIS global data center at NASA's Goddard Space Flight Center. Between August and November 2000, 28 organizations primarily from Austria, Germany, Russia and the U.S. retrieved IGLOS data from the global data center.

Precise GLONASS Orbits

Precise GLONASS orbits have been computed continuously by BKG and ESA for each day in 2000 for all the operational satellites. BKG uses the Bernese software, while ESA uses its GPSOBS/BAHN software. Orbit repeatability is generally in the 10-20 cm range (rms). The Analysis Centers also compute the time offset between GPS and GLONASS times, and estimate datum transformations between the GLONASS PZ-90 reference frame and the International Terrestrial Reference Frame using the GLONASS broadcast message. After the individual center orbits are released, a weighted combination of the two orbits is generated and made available through the CDDIS.

NERC has computed GLONASS orbits using SLR data alone and compared it with microwave receiver-based orbits. It has also compared laser ranges directly with ranges derived from the microwave receiver-based orbits. RMS differences between the laser and microwave orbits are approximately 10 cm radially and 50 cm in the along-track and cross-track directions.

Plans

Efforts during 2001 will be focussed on integrating the GLONASS receiver sites with the GPS sites in the IGS. Site log forms, data archives and analysis center software will be revised where possible to process combined GPS and GLONASS data. Stations will all have to meet IGS standards. Improved timeliness of orbit products will also be a goal. There is still some uncertainty regarding the GLONASS constellation and its long term reliability and maintenance. Nine satellites were operational in December, but without a new launch in 2001, this number will probably go down.