IGS

INTERNATIONAL

GPS

SERVICE

2001 - 2002 TECHNICAL REPORTS

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IGS Central Bureau

Jet Propulsion Laboratory
California Institute of Technology
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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 2001 / 2002 Technical Reports. Hard copies of each volume can be obtained by contacting the IGS Central Bureau at the Jet Propulsion Laboratory. This report is published in black and white. To view graphs or plots that use color to represent data trends or information, please refer to the online PDF version at http://igscb.jpl.nasa.gov/overview/pubs.html.

Preface

It is a somewhat humbling experience to be a user of IGS products. A moment's consideration reveals the huge global enterprise that goes into constructing a product such as the IGS precise ephemeris, so critical to achieving high-precision scientific results with GPS. These results are now considered routine, but were difficult or impossible to achieve 10 or 15 years ago. The main difference is IGS.

While the reader of a typical scientific article employing GPS data may be unaware of IGS' contribution, the author of that article is (or should be) fully aware of the key role played by IGS in the generation of his or her scientific results. In most scientific research articles, space does not permit the proper acknowledgment of the full scope of those contributions. My guess is that, on average, a minimum of several hundred people around the world who are affiliated with IGS have made key (but largely unsung) contributions to the work described in a typical geophysical research paper, including station installation and maintenance; maintaining Internet connections; archiving activities, data analysis at several facilities for production of satellite ephemerides, satellite clocks, and other products; improvement of geophysical models; development of new algorithms and software for data analysis; and comparison and validation of results. Without all these contributions by members of IGS, we simply could not do modern geodetic research.

Members of IGS have a shared global vision. They realize that by pooling data and ideas, the sum is much greater than the parts. IGS serves as a model of unselfish global cooperation, exploiting the Internet to bypass political and institutional boundaries, pumping vast amounts of data around the world in record time, and generating something important with it, to amazingly high technical standards. The goal of all this activity is to generate data products of unprecedented accuracy that facilitate a wide range of scientific and environmental applications. As we survey the state of the world in 2004, with its host of problems, the answer to at least a few of them seems obvious: act more like IGS.

IGS is a remarkable organization, and its members can be justly proud of their accomplishments on this 10th anniversary of its founding.

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IGS

E X E C U T I V E   R E P O R T S

IGS Governing Board 1999-2002

Christoph Reigber

GeoForschungsZentrum, Potsdam, Germany

Introduction

These two years continue to realize the collective success of the IGS. A key focus of both years has been the IGS Strategic Plan and the process for implementing actions to accomplish the objectives. The key parts of this plan refine the mission, long term goals and objectives of the IGS which are included here. The directions of the IGS as formulated in this plan promise productive and rewarding years to come in this unique global federation of the IGS.

Mission

The International GPS Service is committed to providing the highest quality data and products as the standard for global navigation satellite systems (GNSS) in support of Earth science research, multidisciplinary applications, and education. These activities aim to advance scientific understanding of the Earth system components and their interactions, as well as to facilitate other applications benefiting society.

Long-Term Goals and Objectives

The IGS strives to:

- Provide the highest quality, reliable GNSS data and products, openly and readily available to all user communities.
- Promote universal acceptance of IGS products and conventions as the world standard.
- Continuously innovate by attracting leading-edge expertise and pursuing challenging projects and ideas.
- Seek and implement new growth opportunities while responding to changing user needs.
- Sustain and nurture the IGS culture of collegiality, openness, inclusiveness, and cooperation.
- Maintain a voluntary organization with effective leadership, governance, and management.

The final document was approved by the Board in late 2001 and published in March of 2002. Separate copies are available from the Central Bureau.

Highlights

The table below indicates the significant events of the IGS and more are described in the submissions to this document and the Technical Reports.

IGS Significant Events 2001

January	R. Weber replaces T.A. Springer as IGS Analysis Coordinator, University of Bern
February	• LEO workshop, GeoforschungsZentrum Potsdam • First meeting of the IGS Real-Time Working Group, Co-Chairs named, M. Caissy, NRCan and R. Mullerschoen, JPL
Early 2001	IGS Predicted product terminated, IGS Ultra officially accepted which includes the prediction.
March	IGS Board establishes the International GLONASS Service Pilot Project, IGLOS-PP
March 9-17	CONSAS and AFREF Meeting in Capetown supported by the Central Bureau
March 25	*IGS Governing Board Meeting, Nice, France*
	TIGA Project established by the GB, Chaired by T. Schoene, GFZ
April	High Rate Tracking Campaign for Ionospheric research during solar eclipse
April 23-27	GLOSS meeting Hawaii joint with TIGA project
mid-2001	IGS Workshop Proceedings published externally: GPS Solutions: Analysis Center Workshop, September 2000 US Naval Observatory Physics and Chemistry of the Earth: Network Workshop of the IGS Oslo, Norway, Norwegian Mapping Authroity
September 1	*IGS Governing Board Meeting, Budapest, Hungary at the IAG General Assembly*
December 9	*IGS Governing Board Meeting, San Francisco, California*

2002 Significant Events

January	Ionosphere Workshop, ESA/ESOC, Darmstadt, Germany
Early - 2002	IGS Strategic Plan 2002-2007 Completed and Published
April	Ottawa Workshop – 'Towards Real-Time', Natural Resources Canada
April 11	*IGS Governing Board Meeting, Ottawa, Canada*
	Data Center Working Group established naming C. Noll as Chair
June	IGS Representation on the UN GNSS Action Team, Vienna
June 21	Marks ten years since IGS Pilot Project initiated
July	UN Regional GNSS Workshop, Lusaka, Zambia AFREF meeting
September 10	*IGS Governing Board Meeting, Potsdam, Germany*
December 10	*IGS Governing Board Meeting, San Francisco, California*
	•J. Dow elected to succeed C. Reigber as IGS Governing Board Chair • GNSS Working Group established with R. Weber as Chair • IGS/BIPM Pilot Project dissolved as timing activities become part of IGS official suite of products, K. Senior, US Naval Research Lab named timing Coordinator.

2001 Key Events

A major challenge to the IGS was met by Prof. R. Weber, who succeeded Prof. T. Springer as IGS Analysis Center Coordinator mid-term. This demonstrated the University of Bern's deep commitment to this task through 2002 and was greatly respected by everyone. In February, GeoForschungsZentrum organized a Low Earth Orbiter Workshop in Potsdam, Germany, which was co-hosted by the IGS. This was well attended and provided a venue to discuss the end-to-end aspects of LEO missions, particularly CHAMP, and their applications which include POD, gravity, atmospheric occultation, ionospheric tomography. Following the workshop, the first meeting of the IGS Real-Time Working Group was held in Potsdam to develop the charter and technical approach to building a real-time IGS sub-network and related processes. The IGS supported a campaign of the Ionosphere Working Group to collect and analyze high-rate data during the period of the total eclipse of the sun during April.

A new project called TIGA was established within the IGS to use GPS observations at tide gauge bench-mark stations in order to assess long-term sea level change. GPS observations will be used to remove the signals from coastal crustal deformation or subsidence from the long-term records. The TIGA has very challenging vertical measurement requirements that will span decades. The project has facilitated analyzing data from stations with high latency data availability – some collected only once per year from remote locations with no access to the internet.

The need for a continental reference system in Africa has been increasingly underscored and is termed AFREF. Discussions were held in Capetown, South Africa with Surveying and Mapping representatives from most of the southern African nations to discuss and plan a regional realization of AFREF and included representatives from the Central Bureau. See the report by Wonnacott in this annual report.

2002 Key Events

A true highlight of the year was a full workshop of the IGS titled 'Towards Real-Time' skillfully managed by the Natural Resources of Canada, host and local organizer in April. This was the first workshop in many years that brought all components of the IGS together and it was agreed that this was an excellent workshop. Proceedings of this Ottawa workshop are available at the IGS website. A workshop to discuss the status of the Ionosphere Working Group was held in January at ESA/ESOC in Darmstadt.

IGS became a member of a United Nations Action Team on Global Navigation Satellite Systems (GNSS) with the Central Bureau Director as the designated representative. This Team focuses on the use of GNSS especially in developing countries, and is chartered by the UN Office of Outer Space Affairs in Vienna to address various GNSS related issues. More progress is expected as the Team prepares its report for the 2004 UNISPACE conference.

The LEO mission GRACE launched successfully promising additional data for the LEO Working Group. At the December Governing Board meeting, my term as Chair of the IGS Governing Board was completed and Prof. John Dow of ESA/ESOC was elected to lead the

Board and the IGS. A proposal for the next Analysis Center Coordinator was also approved by the Board with Prof. Gerd Gendt, GFZ, to succeed Prof. Robert Weber, AIUB and Technical University of Vienna. This was unanimously approved based on technical expertise and committed support of GFZ. The expected transition period is set to be complete by mid-2003. A GNSS Working Group is set up with plans to position the IGS to take advantage of the future Galileo and modernized GPS. Due to all of these increasing demands on the data and product access, a Data Center Working Group was approved earlier this year. IGS timescale activities moved seamlessly from USNO to Naval Research Laboratory with continued expertise.

I have very much enjoyed working with the Board and the people of the IGS, and am convinced that the IGS will continue to flourish. I will remain on the Board until 2004, working on the strategic issues and the new project of the International Association of Geodesy: Integrated Global Geodetic Observing System (IGGOS).

Central Bureau Status and Perspective

Ruth Neilan

Director IGS Central Bureau
NASA/Jet Propulsion Laboratory
California Institute of Technology

The Central Bureau continues to promote the IGS organization, data and data products as setting the world standard for GPS/GNSS geodetic applications as outlined in the IGS Strategic Plan. The Central Bureau was responsible for the organization of the strategic planning process, preparation of all documents, and the editing and publication of the plan. This was a major activity and the Board's consensus on the plan is a significant milestone in the evolution of the IGS. The Central Bureau is responsible for the day-to-day management of the Service. With 200 organizations in over 80 countries and a ground network of ~350 stations, this requires daily interfaces on many different levels globally. The separate summary of the IGS Network Coordinator is included in this annual report and demonstrates the vital technical tasks of the Central Bureau. The CB is also responsible to arrange and organize all Board activities and is involved in the supporting the planning and logistics of all IGS workshops and meetings.

In 2001-2002, the CB focused effort on outreach to other nations to garner participation in the IGS for a mutual benefit. Continued discussions with principals of China's 'Crustal Motion Observation Network of China' (CMONOC) at the China Seismological Bureau (CSB) demonstrate their deep interest in becoming more involved with the IGS. Similarly in Africa, the CB has been active in 2000 and 2001, to further the concept of a continental reference system for Africa – 'AFREF', taking part in meetings and discussions in Capetown. The initiative is being embraced by principal people within Africa, a key requirement for the long-term viability of a reference frame realization.

The CB began working with the United Nations Office of Outer Space Affairs (UN/OOSA) to assist in the planning of the regional series of UN/GNSS workshops, with the objective to obtain broader international participation in these meetings. In particular, a key workshop took place in Lusaka, Zambia in July 2002 where many people from throughout Africa were present. One of the sessions of the workshop was devoted to unifying the African continental reference frame (AFREF) and was very well attended. The IGS exhibit was displayed and nearly all handout materials evaporated due to keen interest. One of the main problems facing Africans is the ability to interface with the international community and this was seen as an opportunity for them to make connections that help to build up their base of sustainable technology.

This year the IGS published workshop proceedings in conjunction with outside publishing companies as a variant on CB publications: GPS Solutions published the proceedings from the 2000 Analysis Center Workshop (some copies are available from the CB); and Physics and Chemistry of the Earth published the IGS Network Workshop proceedings joint with 'Towards Operational Meteorology', the European COST 716 Action "Exploitation of Ground-Based GPS for Climate and Numerical Weather Prediction Applications". These are excellent proceedings, however, copyright issues preclude their posting to the IGS website which limits the availability of information, especially to the wider global community.

The CB continues to improve efficiencies with very limited resources and staff and looks forward to working with the GB to accomplish one of the objectives of the strategic plan, '*to strengthen and stabilize the Central Bureau'*.

ANALYSIS CENTER REPORTS

2001/2002 Analysis Coordinator Report

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Introduction

This report complements the Analysis Activities Report given in the IGS Annual Report 2001/2002 (Weber, 2003). A summary of the most important model changes and IGS Analysis Activities in 2001/2002 will be presented.

IGS 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 shows the estimated quality of the provided data sets at the end of year 2002.

Table 1: Quality of the IGS products as of December 2002
(for details see http://igscb.jpl.nasa.gov/components/prods.html)

Products / Delay	Ultra-Rapid/ Real Time	Rapid/ 17 hours	Final/ 13 days	Units
Orbit (GPS)	15.0	5.0	3.0	cm
Satellite Clocks	5.0 (predicted)	0.1	0.05	ns
Station Clocks		0.1	0.05	ns
Orbit (GLONASS)	----	----	25.0	cm
Polar Motion		30.0	0.05	mas
LOD			20.0	μs/d
Stations h/v			3.0/6.0	mm
Troposphere			4.0	mm ZPD

IGS Final Orbits

Figure 1 shows the weighted orbit RMS (WRMS) of the Final Analysis Centre solutions with respect to the combined IGS final orbit products from 1994 until end of 2002. The graphic nicely demonstrates past and still ongoing improvements in modelling satellite orbits. Most Analysis Centres and also the IGS rapid orbits (IGR) have reached the 3-6 centimeter 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 measurements to the GPS satellites PRN 5 and PRN 6.

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

Year	COD	EMR	ESA	GFZ	JPL	NGS	SIO	IGR
Final 2002	2	4	6	2	3	8	5	2

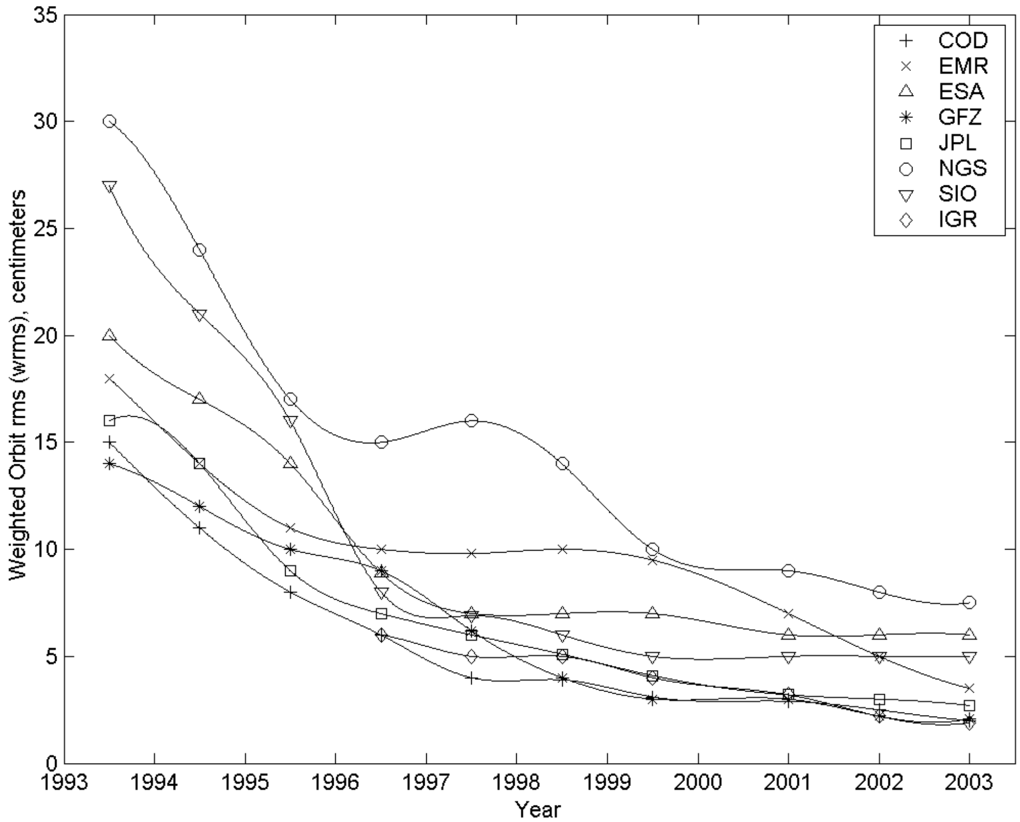

Figure 1: Weighted orbit RMS (WRMS) of the Analysis Center and the IGS Rapid (IGR) orbit solutions with respect to the IGS final orbits; WRMS values were smoothed for graphical representation

Detailed Information concerning quality and availability of Precise Glonass orbits is provided in the report of the International GLONASS Service – Pilot Project (this Volume).

IGS Rapid Orbits

The IGR-orbit is routinely compared to the IGS orbit. Although not entering with any weight in the Finals orbit combination the IGR orbit turns out to be as close to the IGS orbit as the best final AC solutions or even closer (1-2cm; see Table 2).

Table 3: 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	USN
Rapid 2002	3	5	8	5	4	8	6	3

Table 3, along with Figure 2, show the weighted RMS (mm) of the individual AC solutions with respect to the IGS Rapid orbit in 2002. For display purposes the values of the Rapid Combination summaries are smoothed using a sliding 7 day window. The orbit consistency ranges between 3-8 cm, which are quite small numbers having in mind the latency of only 17 hours causing a relatively low amount of available tracking data.

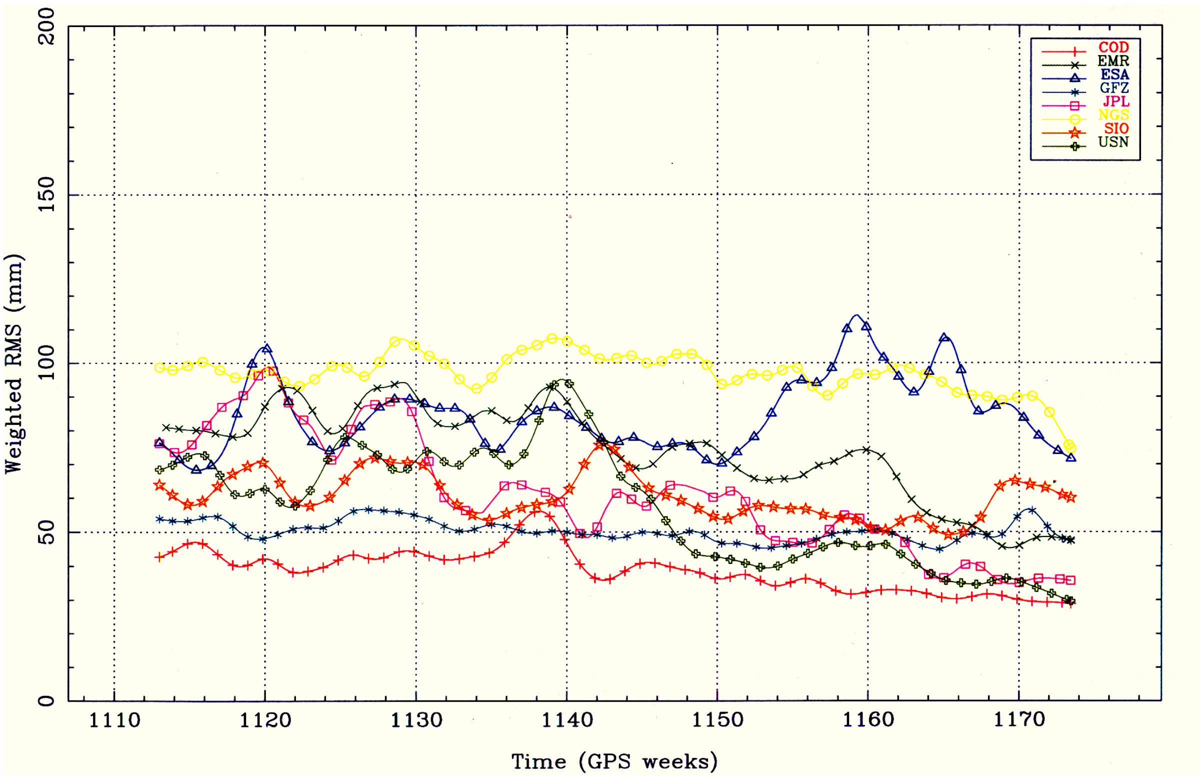

Figure 2: Weighted orbit RMS (WRMS) of the Analysis Center Rapid orbit solutions and the IGR orbit solutions with respect to the IGS final orbits (mid 2001 until mid 2002)

IGS Clock Combination

The consistency of the final AC clock solutions is at the 0.05 ns level, the consistency of the rapid clock solutions slightly better than 0.1 ns (see Figure 3). The combined final and rapid solutions provide satellite and station clock information with a temporal spacing of 5 minutes. An even higher resolution (30 seconds) is recommended, and foreseen to be provided in the near future. This will put a remarkable additional computation load at the ACs.

The basic clock combination proofed to be a very robust process. After combination the IGS combined clock products are aligned to GPS time (broadcast satellite clock corrections) on a daily basis. This procedure sometimes fails due to jumps of the reference clock of individual AC's. Moreover the alignment introduces significant daily discontinuity errors up to a few nanoseconds. To mitigate the problem the IGS clock products will be aligned to the UTC time scale in the near future (see Senior et al., 2001)

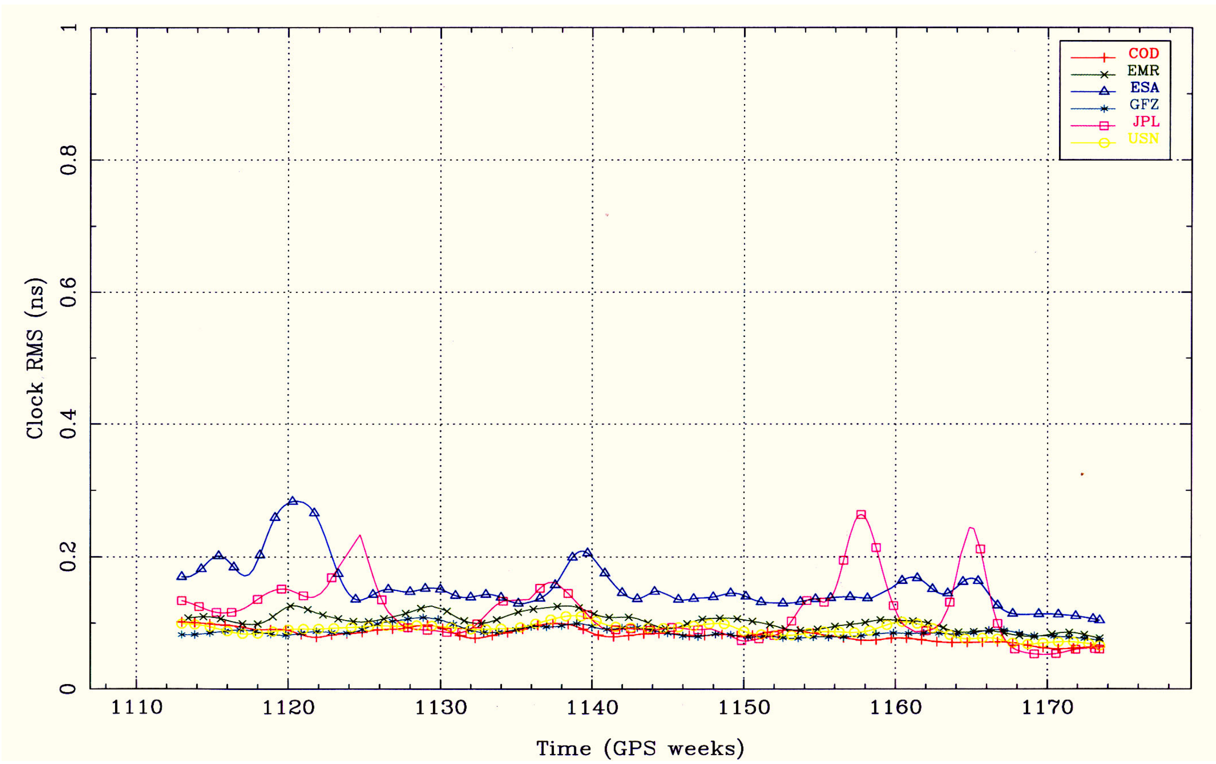

Figure 3: Clock RMS (ns) of the individual AC satellite clock solutions with respect to the IGS Rapid clocks (mid 2001 until mid 2002).

Reference Frame

Since December 2001 (GPS-Week 1143) all IGS products are based consistently on the IGS Reference Frame realization (IGS00) of the ITRF2000. To perform this task the unconstrained weekly combined IGS-SINEX solution of station coordinates/velocities and ERP's is aligned by minimum datum constraints to IGS00, based on a list of 54 reference stations with high quality positions/velocities in ITRF2000. Previous to the combination also the individual orbit solutions are rotated by means of a spatial similarity transformation to this common frame. IGS reference frame products are available in SINEX format and issued by the IGS Reference Frame Coordinator on a weekly basis. Detailed information can be obtained from (Ferland, 2001) or from the weekly IGS SINEX Combination Reports (e.g. Ferland, Hutchison, 2001).

Earth Rotation Parameters

Although the IGS final combination establishes another weighted erp-file based on orbit quality, the 'official' IGS pole series stem from the weekly SINEX combination performed at NRCan. IERS comparisons show an agreement between IGS and IVS solutions at the 0.1mas level for polar motion (PM) and 0.1ms for Length of Day (LOD). It has to be stated that Bulletin B erp-series are dominated by VLBI although there are differences at the same level (0.1mas,0.1ms) between IVS solutions using different observation networks. IGR erp-series be given a heavy weight in the Bulletin A combination and are therefore close (0.05mas PM, 0.1ms LOD) to the Bulletin series. An IERS recommendation, passed at the IERS Workshop in Munich (November 2002), encourages all IGS AC's to provide in addition to polar motion and LOD also nutation rate series.

Atmosphere Sounding Products

Detailed Information concerning quality and availability of IGS Atmosphere Sounding Products is provided in the reports of the relevant Working Groups (this Volume).

IGS Ultra Rapid Products

In October 1999 the GFZ Analysis Centre provided the first ultra rapid products. These products, delivered every 12 hours (two times per day), 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 six different Analysis Centres. Currently IGU orbits are used in an increasing number of applications, e.g. for the derivation of ground-based GPS meteorological parameters used in numerical weather prediction or in regional GNSS Reference Network solutions used for RTK surveying.

IGU Orbits

The orbit consistency level, characterized by the weighted orbit RMS (WRMS) of the observed part of ultra rapid Analysis Center solutions with respect to (w.r.t.) the combined IGS Ultra-Rapid Orbit (IGU) ranges from 10-25 centimetres (see Figure 4). The predicted part of the IGU compares to the IGR orbit at the 30 cm level.

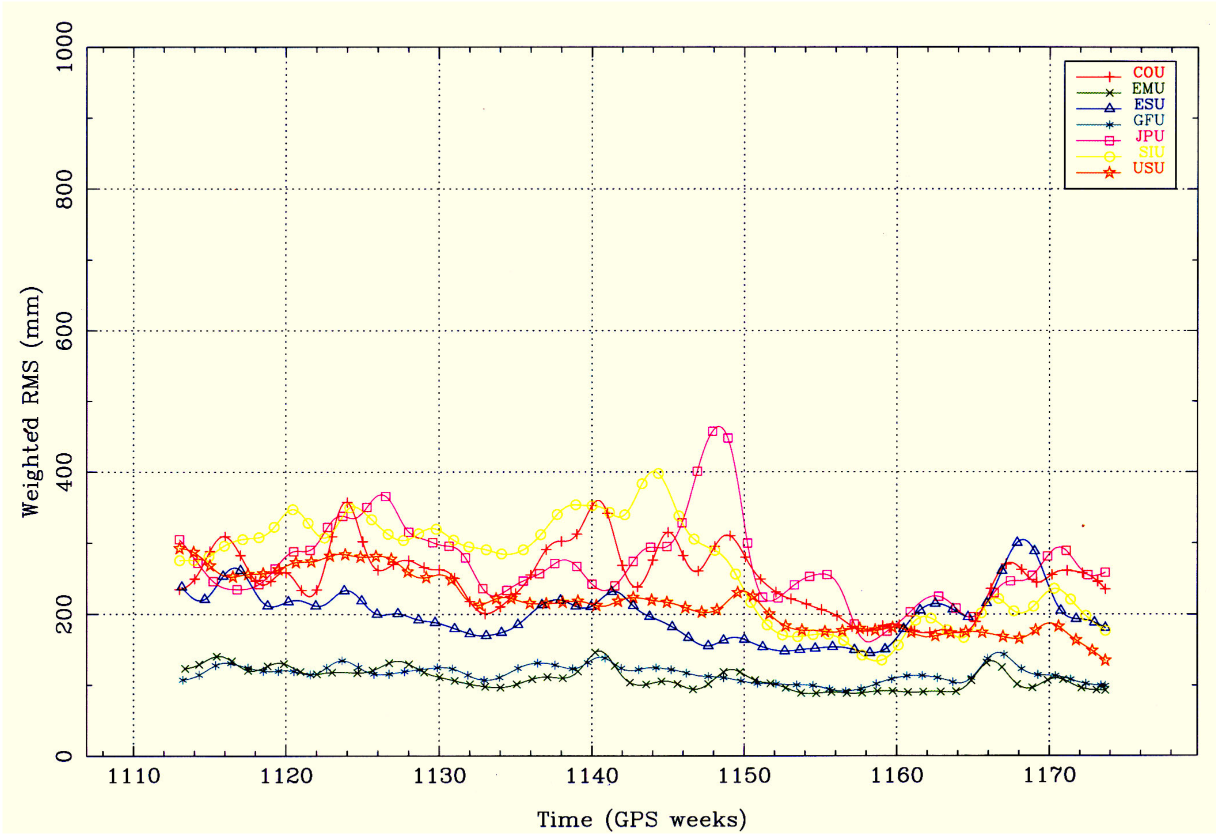

Figure 4: Weighted orbit RMS (WRMS) of the Analysis Center Ultra Rapid orbit solutions with respect to the IGS Rapid orbits (mid 2001 until mid 2002)

IGU Satellite Clock Corrections

As mentioned above, the IGU orbits and clock corrections are the result of a weighted averaging process, currently based on individual submissions of 6 IGS Analysis Centres. Most of these solutions contain 24 hours of observed clock corrections consistent with the provided orbits and 24 hours of clock extrapolation. We were interested in a rough estimate of the overall quality of the individual AC clock submissions. A raw comparison of the observed and the predicted clock-offsets w.r.t. the combined IGS Rapid clock solution is given in Figures 5 and 7. The calculations are based on the clock information given in the sp3-product files with a time resolution of 15 minutes. Thus the time axis in these diagrams cover 96 epochs over a day (E1-E96).

Raw clock differences usually reflect the clock offset and the clock drift of clock 2 w.r.t. reference clock 1. In contrast to the combined IGS Rapid clock product (linearly aligned to GPS-time) the reference clocks used in AC solutions are steered to a very stable clock at one of the tracking sites or to a weighted assembly of hydrogen masers located in timing laboratories around the world. A clock-offset and the clock-drift are common to all reported satellite clocks. In addition clock-differences may reflect radial orbit differences (per satellite) of the corresponding ephemeris, which propagate into the clock solutions. For the observed 24 hours part these differences induced by the orbits usually range up to a few tenth of a nanosecond (1 ns = 30 cm).

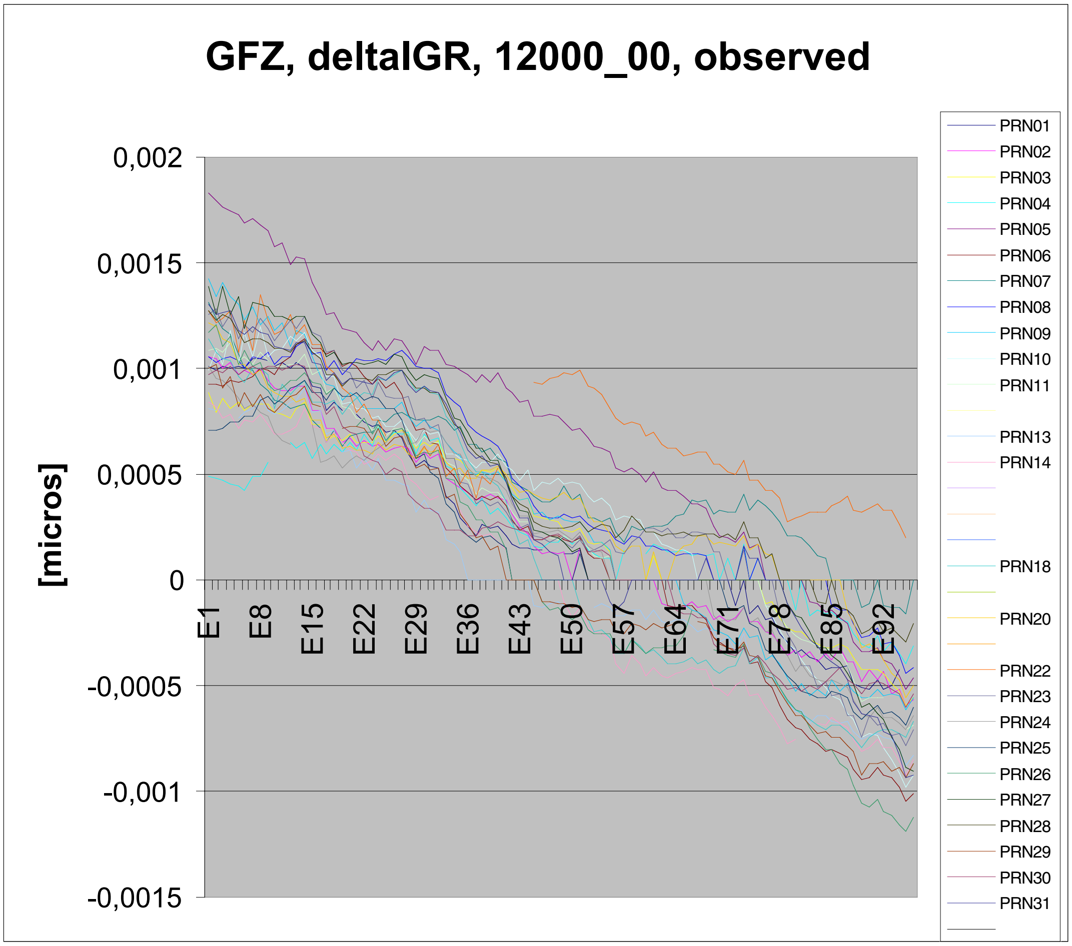

Figure 5: observed 24 hours of GFZ ultra rapid satellite clock solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 0.

In a second step the rms of the offset and drift reduced clock differences was calculated. These differences reflect solely high order polynomial or periodical deviations.

As demonstrated in figures 5 and 6 the rms of observed satellite clocks typically range from 0.1 ns to about 0.4 ns. This result might be a little disappointing when compared to IGS Final or IGS Rapid clocks which are of a higher quality by a factor of 2-3. However, we should keep in mind that Ultra Rapid products are based on a relatively small quantity of immediately available tracking data.

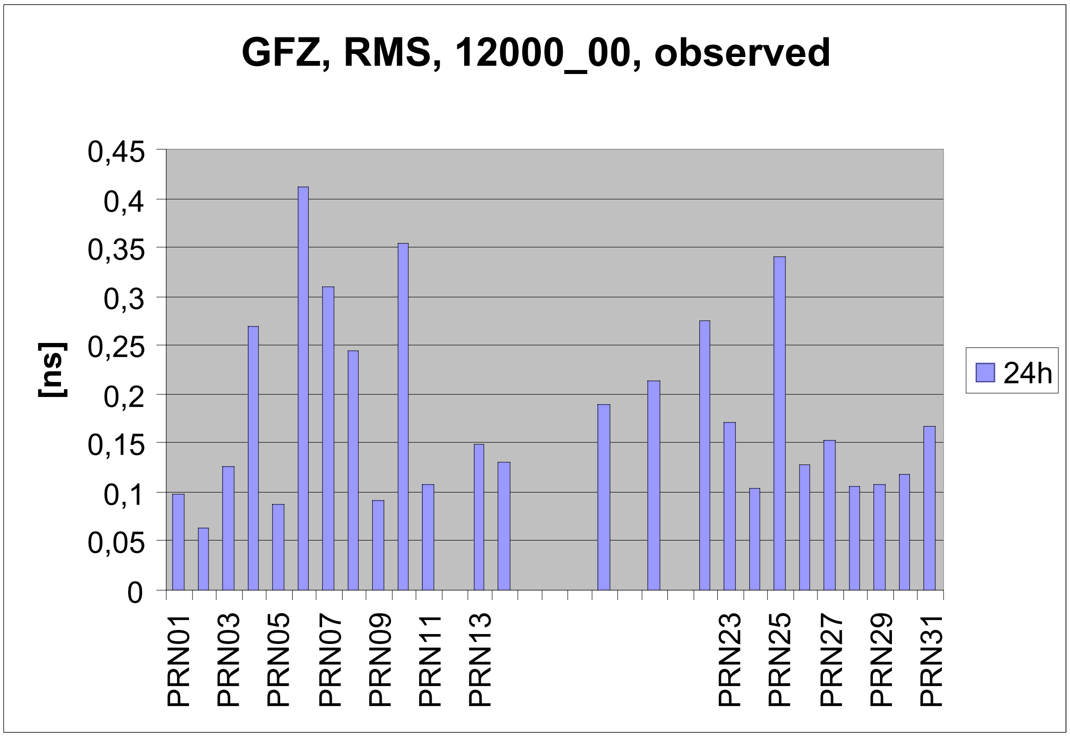

Figure 6: Satellite clock rms of GFZ observed Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 0.

When inspecting the 24 hours period of clock prediction we find a complete different scenario. While the clock-differences of the observed part normally populate a small band of 1-2 ns, the values within the predicted part diverge substantially (see Figure 7). Another outcome of the diagram is, that obviously some satellite clocks are more difficult to predict then others. Usually clock predictions over 12 hours are good to ±3-4 ns, depending on the stability of the satellite clock (type of clock) and the prediction model. Unfortunately extrapolations of 12 hours or more are sometimes wrong by 10 –20 ns.

For the predicted part, the clock rms is calculated in different intervals as shown in figures 8a-d. The intervals start at 0.00 GPST with the first predicted clock offset and last for 3, 6, 9, and 12 hours, respectively. Again the clock differences have been reduced for an offset and a drift in advance. As expected the rms-values increase in most cases with the length of the interval. A series of steady growing bars reflect a significant quadratic or periodic behaviour of the satellite clock. The satellite specific clock rms for the predicted interval of 3 hours is typically at the +/-1ns level growing up to +/-2 ns for the 6 hours interval. At the end of an 12 hours interval the rms of worse behaving clocks may reach +/-10ns or more. For comparison the AC-solutions from CODE, EMR, ESA and GFZ presented in figures 8a-d coincide in time but not in scale.

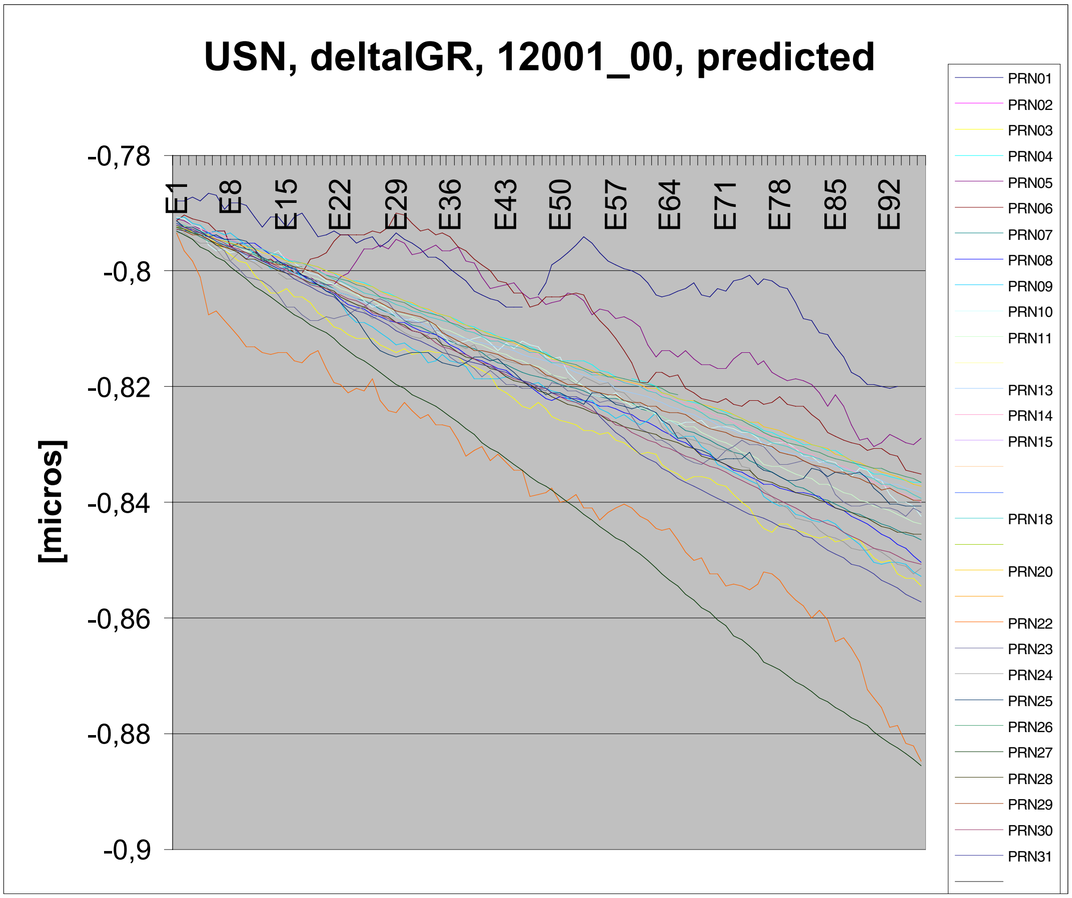

Figure 7: predicted 24 hours of USNO ultra rapid satellite clock solution w.r.t. combined IGS Rapid clocks / GPS-week 1200, day 1.

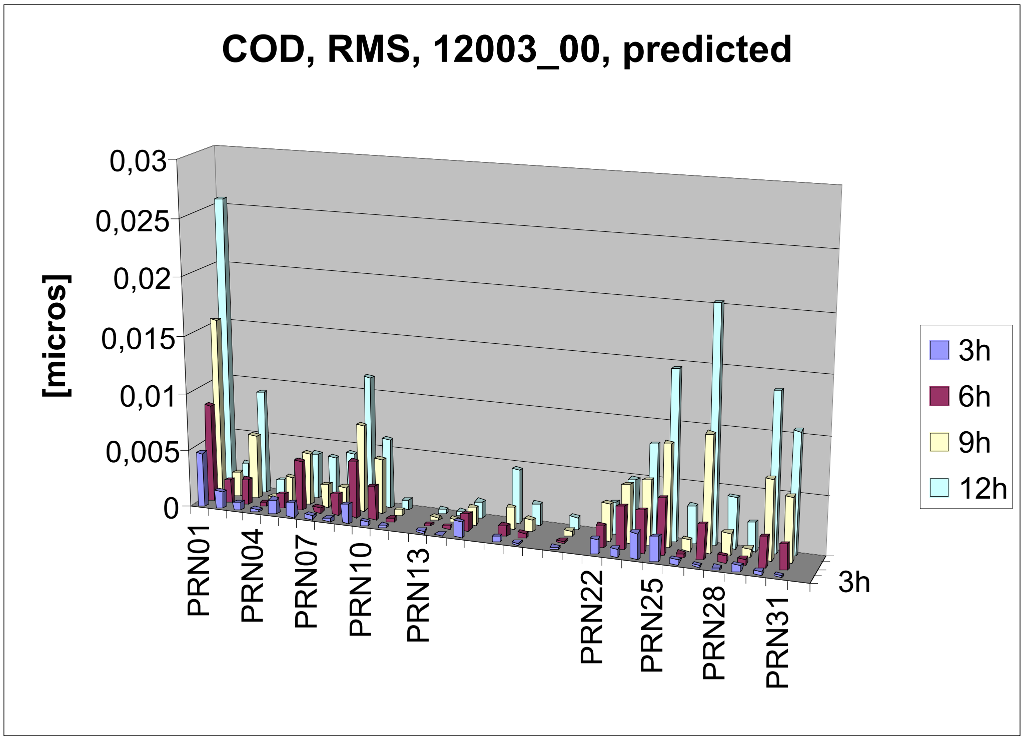

Figure 8a: Satellite clock rms of COD predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

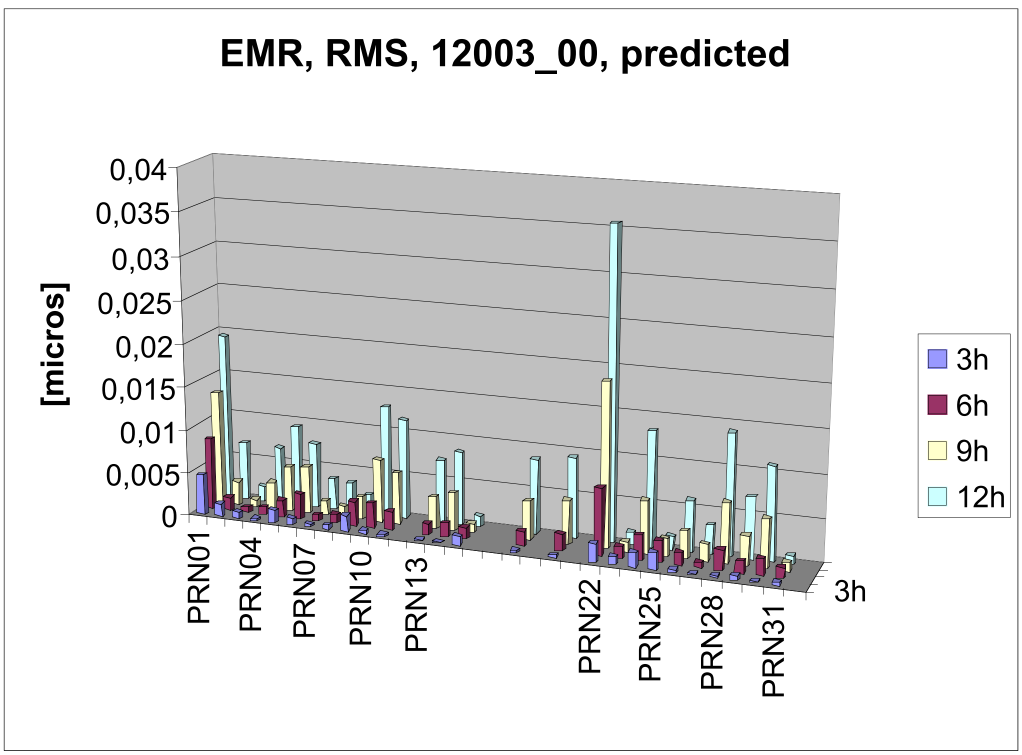

Figure 8b: Satellite clock rms of EMR predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

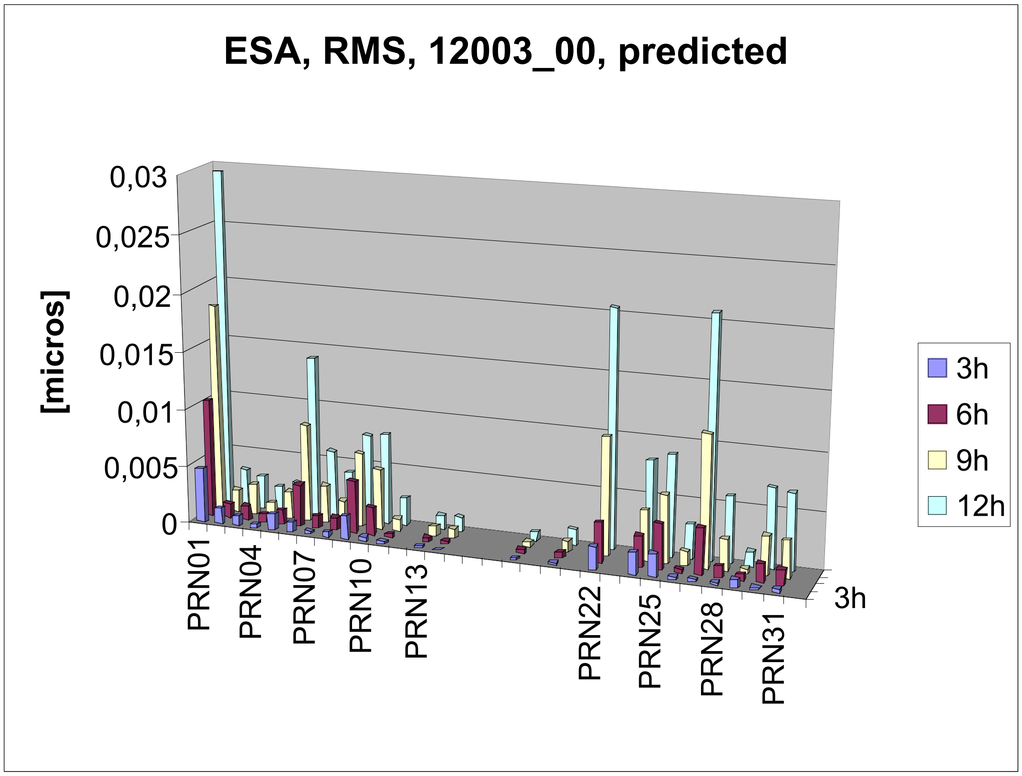

Figure 8c: Satellite clock rms of ESA predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

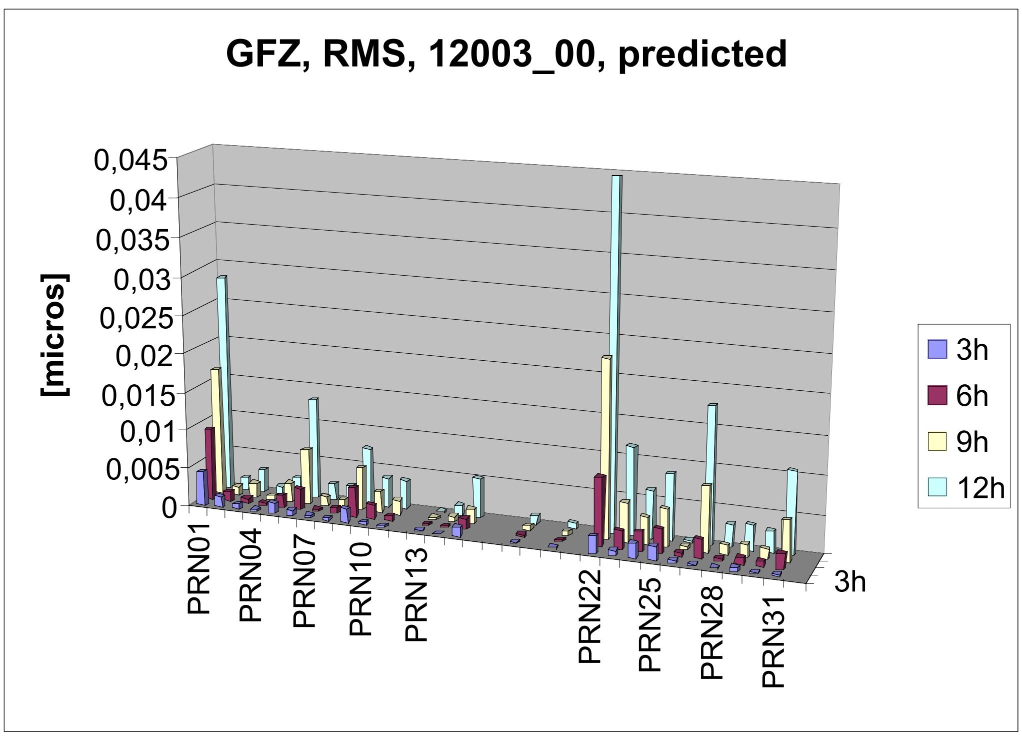

Figure 8d: Satellite clock rms of GFZ predicted Ultra-Rapid solution w.r.t. combined IGS Rapid clocks / GPS-week 1203, day 0.

The presented comparisons are carried out routinely since GPS Week 1151 (February 2002). Graphics and statistics are posted regularly at
http://www.hg.tuwien.ac.at/forschung/satellitenverfahren/igs.htm

Unfortunately the Ultra-Rapid Orbit Combination suffers frequently from a remarkable number of satellites missing in the AC – submissions (about 10-15%) due to modelling problems. The situation is illustrated in figure 9 covering the period from March 2001 until March 2002. The figure is based on ultra-rapid comparison log-files issued twice daily. Submitting 100% of the satellites would stand for submitting all tracked satellites. The scheme might be too pessimistic cause missing full submissions due to time or internet restrictions also reduce the score. On the other hand satellites which are forwarded by less than 3 centers (and are therefore rejected from the combination) increase the score of the submitting AC. Within the period March 2001-March 2002 about 85% of the tracked satellites passed the combination (about 3-4 missing satellites (out of 28) per IGU update). In the second half of 2002 the situation improved and the number of satellites excluded in the IGU orbits went down to 1-2 satellites per submission. The average percentage of satellites provided in the IGU-orbits with an accuracy better than 20cm could be enhanced to over 90% end of 2002. Satellite orbits with reduced accuracy were still rejected from the combination.

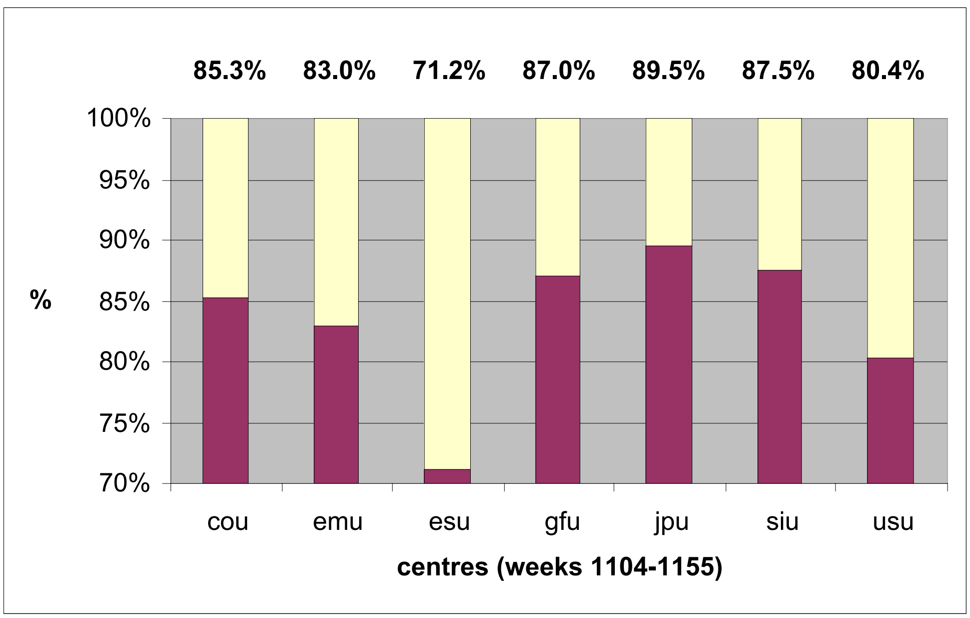

Figure 9: Percentage of satellites submitted within the AC's Ultra Rapid Orbit File (March 2001 until March 2002)

In April 2002 the IGS Analysis and Network Workshop 'Towards Real Time' took place in Ottawa. A number of recommendations were passed aiming at short- and medium-term improvements of the IGS products. Concerning the Ultra Rapid Products it is envisaged to shorten the prediction periods and thus to improve the orbit and clock quality significantly due to more frequent updates (e.g. 3 or 6 hourly updates). A more comprehensive report of this successful meeting comprising the official list of workshop recommendations has been made available via http://igscb.jpl.nasa.gov/mail/igsmail/2002/msg00183.html .

SP3- Format Update

It has been demonstrated that the old SP3 standard format for exchange of satellite orbits and clock corrections lacks of flexibility e.g. to characterize sufficiently the variable accuracy of the given data points within the IGU-orbits or to discriminate between observed and predicted data points. Therefore a new format update, labelled SP3c, has been developed under the direction of Steve Hilla from NGS (Hilla, 2003). Data exchange in SP3c format among AC's started on Dec,1st, 2002, the start of distribution of IGS Combined SP3c files will be early in 2003. A comprehensive description of the new format can be obtained via ftp://igscb.jpl.nasa.gov/igscb/data/format/sp3c.txt .

Summary and Outlook

Early in 2003 Gerd Gendt from GFZ Potsdam started his term as the new IGS Analysis Coordinator. Within a few months the IGS combination software package has been successfully installed at GFZ Potsdam. Although some Analysis problems could be solved in 2002 there are still a number of open questions to tackle.

So future activities will certainly focus on

- the implementation of more frequent updates of IGS Near Realtime products (IGU's)
- the real time dissemination of IGS data and products
- the implementation of the new IAU 2000 Resolutions comprising an updated nutation and precession model as well as the paradigm of the non rotating origin
- the implementation of new IERS Conventions,
  (e.g. subdaily ERP model, see Kouba, 2003a)
- the adoption of a new realigned (UTC) clock time scale
- the full integration of GLONASS data and products within the IGS product lines
- the stabilization of the varying IGS TRF scale e.g. by introducing new antenna calibrations
- the delivery of a really unconstrained GNSS 'technique-specific' combined coordinate solution to IERS

Finally, I want to wish the new IGS ACC Gerd Gendt and his team all the best for the upcoming years.

Acknowledgements

I want thank all people within the IGS and all components of the IGS for their support and cooperation over the past two years. My special thanks have to go to Remi Ferland, Jim Ray and Jan Kouba for a large number of email-discussions and their invaluable scientific support in questions concerning the reference frame and the clock products. Moreover I have to thank the CODE IGS team in Berne, in special Urs Hugentobler, Stefan Schaer and Rolf Dach, for a lot of discussions concerning improvements in the combination software, for maintaining the operating system and for looking after the combination during a huge number of weekends.

Moreover the author wishes to thank Veronika Bröderbauer for the preparation of the Ultra-Rapid Clock Comparisons and for the maintenance of the related Web-Site. Last but not least, I am very much indebted to my colleague, Elisabeth Fragner for her invaluable help. During the past two years she spent countless hours at my side in operating the IGS product combination software.

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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 Associate Analysis Centers (GNAAC) provide quality control.

The weekly AC solutions include estimates of weekly station coordinates and daily ERPs. The ACs currently process weekly data from between 40 and 140 stations They 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. The weekly combined station coordinates are accumulated in a cumulative solution containing estimated station coordinates and velocities at a reference epoch.

This year activities also included the implementation of the IGS realization of ITRF2000. All the proposed additions/changes are in the Southern Hemisphere, with the main objective being to improve the reference frame (RF) station distribution. In South America, two new stations were added while two old ones were removed. Three other stations were also added; one on Ascension Island in the Atlantic Ocean, one on Diego Garcia Island in the Indian Ocean and one in Australia.

The group also participated to two IERS activities; namely, the definition of the SINEX version 2.0 and some analysis of the stability of ERP's. The objectives of the SINEX version 2.0 extensions were to accommodate the requirements of other techniques and the inclusion of the normal equations for multi-techniques combinations.

Introduction

Station coordinates and velocities, Earth Rotation Parameters (ERP) and geocenter products are generated within the Reference Frame Working Group (RFWG) (Kouba et. al., 1998). These products also influence the combination of the GPS satellite ephemeredes and clock products. Since February 27, 2000 (GPS Week 1051), the AC coordinator aligns the orbit products to the weekly SINEX cumulative combinations, thus ensuring IGS products consistency. The weekly

SINEX combination is available within 12 days (Thursday) of the end of each GPS week. The ERPs are included in the weekly SINEX combination along with the station coordinates. The combination uses all the available covariance information.

The IGS RFWG contribution to the International Terrestrial Reference Frame (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 RFWG contribution to ITRF2000 was provided in November 2000 and included 167 stations (Ferland, R. 2002). For the period of GPS weeks 0837 (January 21, 1996) and 0977 (October 3, 1998), the weekly combined solutions from JPL, MIT and NCL Global Associates Analysis Centers (GNAAC) were used in the cumulative solution. Since GPS week 0978 (October 4, 1998), the seven ACs (COD, EMR, ESA, GFZ, JPL, NGS and SIO) are used in the combination, while the GNAACs are used to control the quality of the weekly combination (Table 1). The IGS contribution took the form of a cumulative solution that included data between GPS weeks 0837 and 1088 (January 21, 1996 – November 18, 2000). The IGS realization of ITRF is accomplished with a subset of stations of the IGS network. For the realization of ITRF2000, 54 high quality stations were selected. (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 their precise code and phase observations. Data used to realize an IGS ITRF will also be subsequently contributed to the IERS combination process to generate ITRF at future epochs.

Table 1. IGS Analysis and Associate Analysis Centers

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 (up to 00/09/09)

Weekly SINEX combination

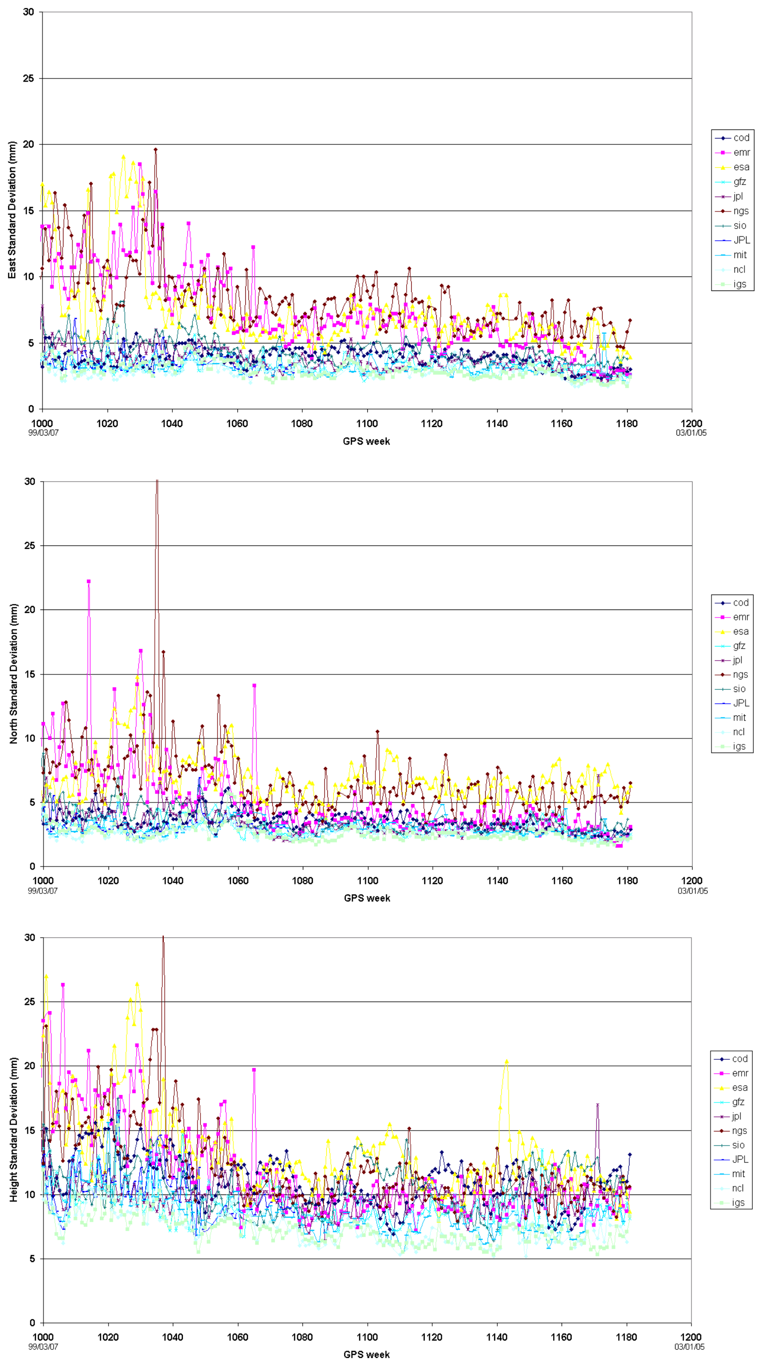

Figure 1. North, east and height stations residuals standard deviation between the AC, GNAAC and IGS weekly solutions and the IGS cumulative solution.

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 (June 6, 1999) the weekly combination also includes daily ERP (pole position and rate, calibrated length of day (Mireault et al. 1999)) and since GPS week 0978 (October 4, 1998) weekly apparent geocenter estimates. The cumulative combination is updated every week with the latest weekly combination. The alignment of the weekly and cumulative solution is done using a set of reference frame stations (see the next section). Since GPS week 1000 (March 7, 1999), weekly comparisons between the IGS weekly and the cumulative solution show standard deviations of about 3 mm horizontally and 6-8 mm vertically. Figure 1 shows the standard deviation of the weekly station coordinates residuals between the ACs GNAACs and IGS with respect to the IGS cumulative solution. Gradual improvement is apparent especially in the height component. The bandwidth of the deviations is also decreasing, indicating a better level of agreement between the various solutions.

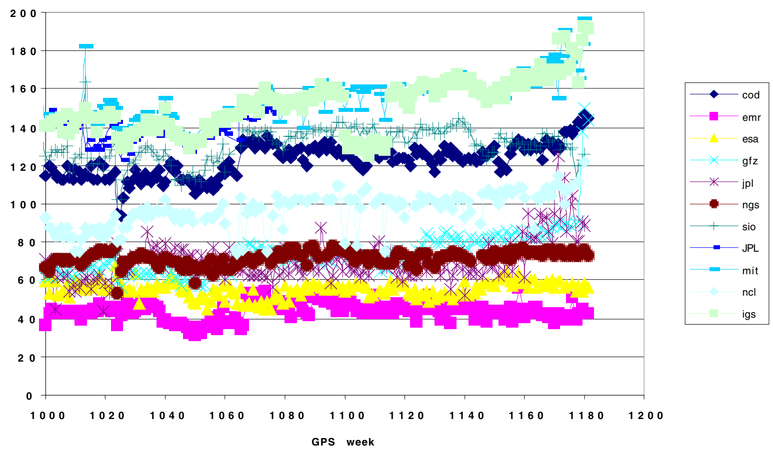

Figure 2. Number of Stations in the Weekly AC, GNAAC & IGS SINEX Solutions

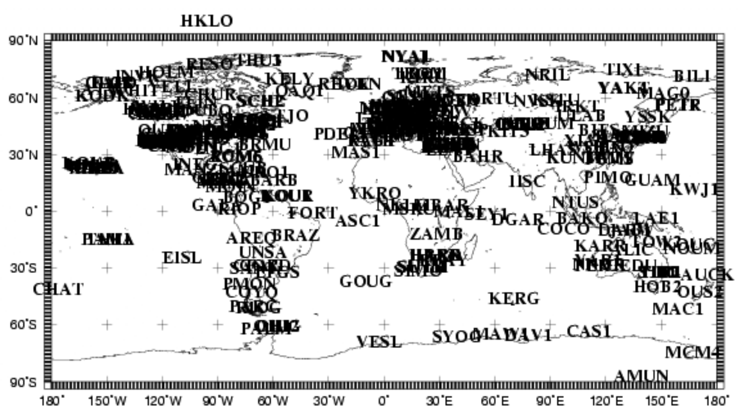

Figure 3. Stations in the "extended" Cumulative Solution

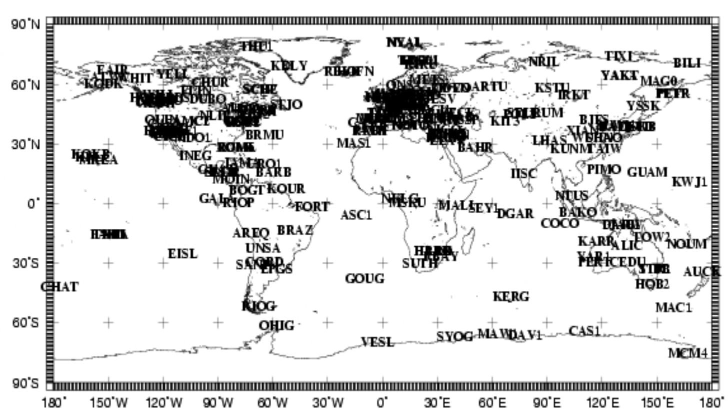

Figure 4. Stations available in the Cumulative Solution

Equipment, local environment and processing changes are the causes for a number of discontinuities in the station coordinate time series. Those are also visible in the residual time series after linear. Comparisons done in the past between the weekly and cumulative solution statistics have indicated that non-random effects account for up to 30% of the residuals signature. Discontinuities, which tend to affect mainly the height, are generally caused by either blunders, equipment or processing changes.

The number of operational stations is steadily increasing. The number of stations processed and submitted by the ACs is also increasing. In the IGS weekly combination, the number of stations increases on average by one station per month. Due to ongoing changes in the stations selected by the ACs in their processing, the number of stations in the cumulative solution increases at rate of almost two stations per month. Figure 2 shows the evolution in the number of stations included in the weekly ACs, GNAACs and IGS combined SINEX solutions. The ACs currently process about 40 and 140 stations weekly.

The weekly combined solution now exceeds 180 stations. All the weekly station coordinate estimates provided by the AC are currently combined and made available. The "extended" cumulative solution generated from these weekly combinations currently includes over 340 stations (Figure 3). Of those, 215 stations with reliable information are included in the IGS SINEX Combination (Figure 4). Cumulative solutions for over 120 stations are not yet releases for the following reasons: they are missing essential info such as dome #, site logs; they cover a short time span (e.g. < ~1 year) which prevent reliable velocity estimation; or they are located in geographical areas that are already well covered (e.g. North America and Europe).

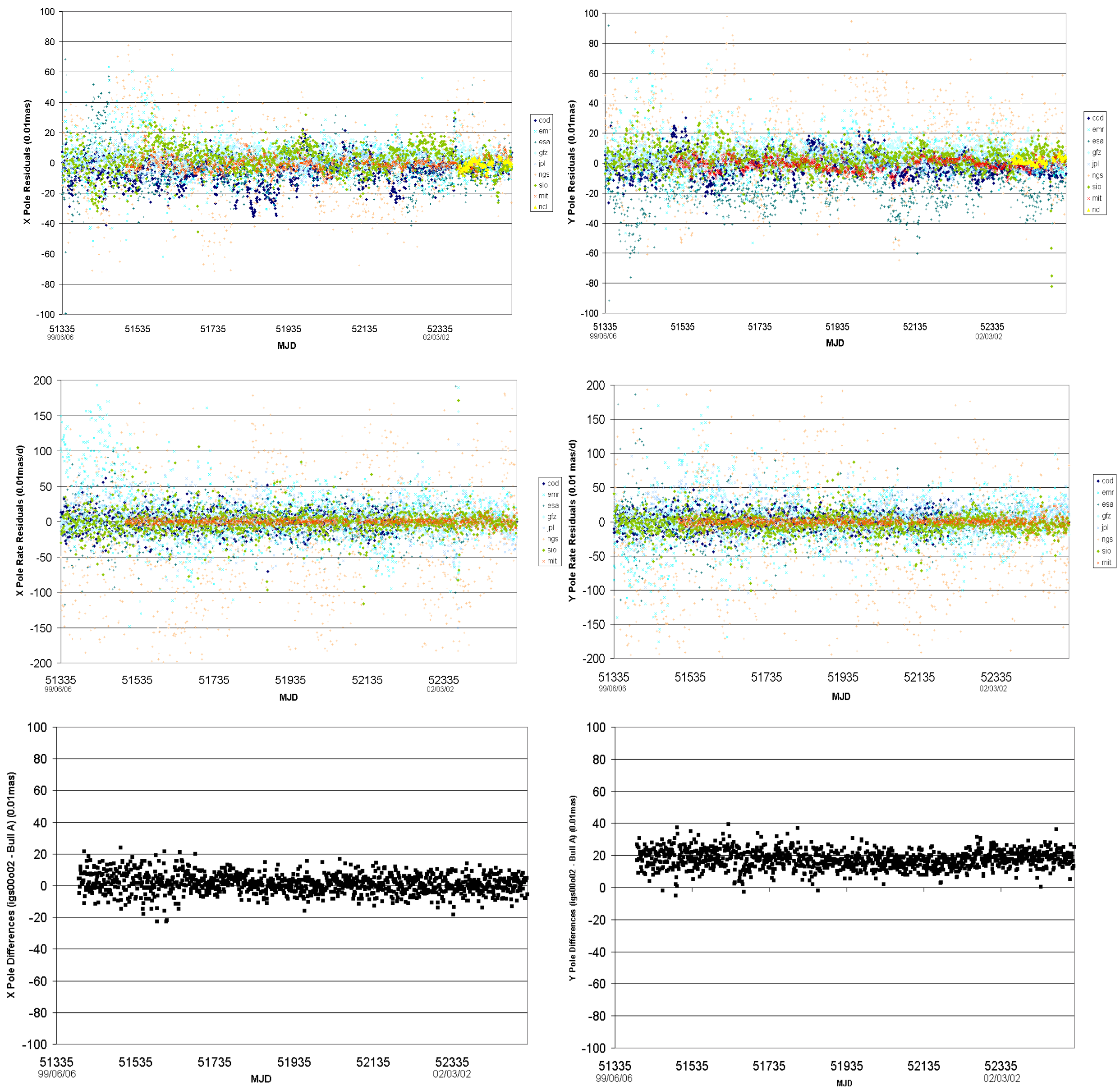

Figure 5. Daily X Pole, Y Pole (top), X Pole Rate, Y Pole Rate (middle) differences between the combined solution "igs00p02" and the AC & GNAAC estimates. Daily X Pole, Y Pole (bottom) differences between the combined solution "igs00p02" and the Bulletin A.

The daily ERPs are combined in the weekly SINEX solution along with the station coordinates by making use of all covariance information. The best AC pole positions 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 5 show the daily residuals time series 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. Note that the IGS combined solution and the Bulletin A are not independent, since the AC solutions contribute significantly to Bulletin A. The Bulletin A daily estimates were linearly interpolated to match the corresponding epochs of the IGS combined values. Small differences between the AC combined pole and pole rates are due to differences in processing strategy (e.g.: different weighting and rejection criterion). Independent daily ERPs using a different weighting 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 0.06mas (0.10mas/d) which is similar to the differences with respect to Bulletin A (bias removed) (0.07mas & 0.17mas/d). The GNAAC NCL analysis center has also started combining the pole positions as well as the LOD.

Implementation of ITRF2000

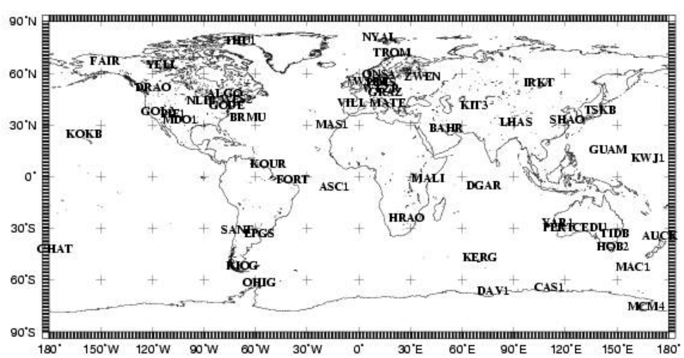

Figure 6. IGS00 Reference Frame Stations

ITRF2000 (Altamimi, 2001) was made available in the spring of 2001. 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. The IGS cumulative solution submitted to ITRF, was an edited solution extracted from IGS00P46.snx. The solution included the GPS weeks 0837 to 1088. The ACs/GNAACs (COD, GFZ, JPL, NGS, NCL) also provided their global cumulative solutions that are also included in ITRF2000. The "IGS00" realization of ITRF2000 was extracted from the cumulative solution "IGS01P37.snx" GPS week 1131 (September 9-15, 2001). After an analysis of the performance of the reference frame stations used for IGS97, it was decided to remove two stations and add five new ones. The station BRAZ was removed because it had been providing timely data for only a few weeks during the previous 12 months. Station AREQ was removed due to an earthquake that caused a significant discontinuity on June 23, 2001 ($\Delta\varphi$= -34cm, $\Delta\lambda$ = -47cm, Δh= - 2cm). In an attempt to compensate for removal of BRAZ and AREQ from the reference frame stations list, stations LPGS and RIOG, both in Argentina, were added. Both stations were contributing quality and timely data; their coordinates time series were also stable. RIOG was also collocated with DORIS. Stations at ASC1 (Ascension Island) and DGAR (Diego Garcia Island) were also added. These stations are also contributing to strengthen the reference frame network around Africa. Alternatives on the African continent were considered (e. g.: NKLG& YKRO), but, their track record was considered too short for reliable velocity estimate. One more station (CEDU) was added in Australia. See Figure 6 for a map of the IGS00 Reference Frame stations.

Table 2. Transformation Parameters from IGS (ITRF97) to IGS (ITRF2000) at December 02, 2001

At Dec 02, 2001	Translations			Rotations			Scale
	TX (mm)	TY (mm)	TZ (mm)	RX (mas)	RY (mas)	RZ (mas)	S (ppb)
(1 sigma)	-4.5 (4.1)	-2.4 (5.0)	26.0 (7.5)	-0.024 (0.092)	-0.004 (0.099)	-0.159 (0.076)	-1.451 (0.27)
Rate (/y) (1 sigma)	0.4 (1.7)	0.8 (1.9)	1.6 (2.8)	0.003 (0.038)	-0.001 (0.040)	-0.030 (0.034)	-0.03 (0.12)

Although, the ITRF97 and ITRF2000 are supposed to be aligned, there are some small transformation parameters between their IGS realizations mainly due to network effects. Based on the 49 common stations between the two IGS realizations of ITRF, the estimated transformation parameters (3 translations, 3 rotations, 1 scale and their respective rates) from IGS (ITRF97) to IGS (ITRF2000) are given in Table 2. The change from IGS97 to IGS00 was made on GPS week 1143 (December 2, 2001).

As part of an IERS analysis campaign, several strategies to realize ITRF2000 were analyzed to evaluate their effects on the ERP's. The strategies included different sub-networks and weighting schemes. The strategies were tested on two years of IGS weekly SINEX combinations. Comparisons have shown that the impact of the different strategies on the ERP's never exceeded 0.03 mas.

The differences between the ITRF2000 and IGS00 reference frame stations have position RMS of (0.5mm, 0.7mm, 2.5mm) and velocity RMS of (0.6mm/y, 0.8mm/y, 1.7mm/y) in the north, east and height directions.

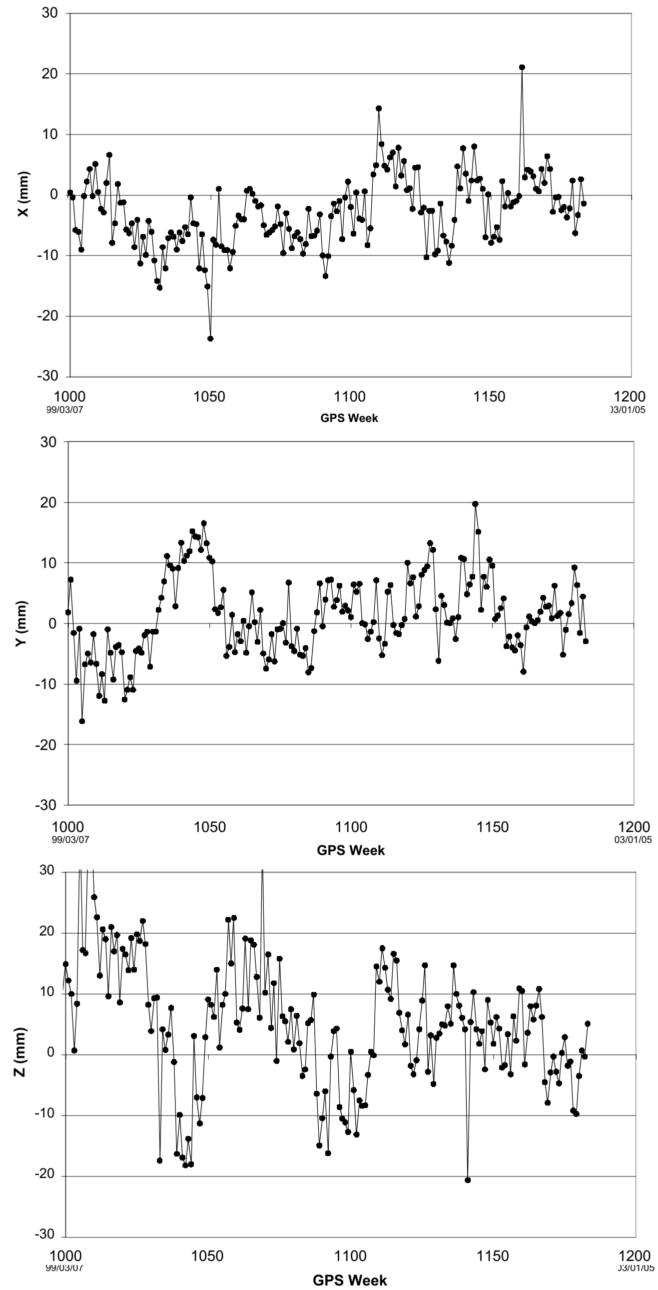

Figure 7. Apparent Geocenter Weekly estimates with respect to current IGS realization of ITRF2000.

Figure 7 shows the weekly apparent geocenter position. Linear regression analysis on those time series indicates that there may still be some small drift in all 3 components of the apparent geocenter (2.0 +-0.8 mm/y, 1.5 +-0.9mm/y, -3.7 +- 1.4 mm/y).

Summary

The IGS cumulative solution now contains about 340 stations among which 215 are made available weekly. This is considered sufficient for ITRF densification purposes. The IGS realization of ITRF uses a subset of the IGS cumulative solution. This improves the internal stability and consistency of the weekly product alignment. Tests with different realizations of ITRF2000 have indicated that the effect on the ERP's never exceeded 0.03mas. The use of the 7 ACs and the 2 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 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/). Also thanks to J. Kouba and P. Heroux for reviewing this report.

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Time Series Combination of Station Positions and Earth Orientation Parameters

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Abstract

CATREF software developed to generate ITRF solutions was enhanced in order to rigorously combine station positions (and velocities) together with Earth Orientation Parameters (EOP). It is also well adapted for time series combination of station positions and EOP's. We present in this paper some comparative analysis of available time series solutions provided in SINEX format from 4 techniques: VLBI, SLR, GPS and DORIS.

Introduction

Up to now, the ITRF, ICRF and EOP are determined separately and consequently their consistency is difficult to assess. Since some 5 years ago, several analysis/technique centers started to make available time series of daily/weakly/monthly solutions of station positions and daily EOP provided in SINEX files. Time series combination becomes interesting since it allows, in particular, detecting and monitoring all kind of variations and discontinuities in station positions. Moreover, the inclusion of EOPs in the ITRF combination allows to improve consistency between IERS products.

Combination model

The initial model implemented in CATREF software allows simultaneous combination of station positions and velocities. A large description could be found in (Altamimi et al. 2002). Assuming that for each individual solution *s*, and each point *i*, we have position X_s^i at epoch t_s^i and velocity $\dot{X}_c^i$, expressed in a given TRF *k*.

The combination consists in estimating:

- Positions X_c^i at a given epoch t_0 and velocities $\dot{X}_c^i$, expressed in the combined TRF *c*,
- Transformation parameters T_k at an epoch t_k and their rates $\dot{T}_k$, from the combined TRF *c* to each individual frame *k*.

The general combination model is given by the following equation:

$$\begin{cases} X_s^i = X_c^i + (t_s^i - t_0) + T_k + D_k X_c^i + R_k X_c^i \\ \qquad + (t_s^i - t_k)[\dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i] \\ \dot{X}_s^i = \dot{X}_c^i + \dot{T}_k + \dot{D}_k X_c^i + \dot{R}_k X_c^i \end{cases} \qquad (1)$$

Using pole coordinates x_s^p , y_s^p and universal time UT_s as well as their daily time derivatives $\dot{x}_s^p$, $\dot{y}_s^p$ and LOD_s, the corresponding equations are:

$$\begin{cases} x_s^p = x^p + R2_k \\ y_s^p = y^p + R1_k \\ UT_s = UT - \frac{1}{f} R3_k \\ \dot{x}_s^p = \dot{x}^p + \dot{R}2_k \\ \dot{y}_s^p = \dot{y}^p + \dot{R}1_k \\ LOD_s = LOD + \frac{\Lambda}{f} \dot{R}3_k \end{cases} \quad (2)$$

where f = 1.002737909350795 is the conversion factor of UT into sideral time. Considering LOD =, $\Lambda_0 \frac{dUT}{dt}$ is homogenous to time difference, so that Λ_0 = 1 day in time unit.

Note that the link between EOP and TRF is ensured upon the 3 rotation angles $\dot{R}1$, $\dot{R}2$, $\dot{R}3$, and their time derivatives.

In order to precisely define the datum of the combined frame minimum constraints equations were implemented in CATREF software, allowing to express the combined solution in any external frame. For more details concerning equations of minimum constraints and their practical use, see for instance Altamimi et al., (2003).

Data Analysis

Input Data

- VLBI: 24h-session sinex files over 1990-2003, provided by Goddard Space Flight Center (GSFC) VLBI Group, using the terrestrial reference frame of gsfd001 (IVS, 2003),
- SLR: weekly solutions over 1999-2002, provide by Italian Space Agency (ASI) , (Luceri, 2003),
- GPS: Official IGS weekly combined solutions over 1999-2003 (Ferland, 2003), and JPL weekly solutions over 1996-2002 available at IGS, (Heflin et al., 2003),
- DORIS: IGN-JPL weekly solutions over 1993-2003, by IGN-JPL, (Willis, 2003).

Analysis Strategy

The analysis strategy applied currently to times series combination is as follows:

- Remove original constraints and apply minimum constraints equally to all constrained solutions
- Use as they are the minimally constrained solutions

- Perform per-technique combinations (TRF + EOP), all expressed in ITRF2000 using equations of minimum constraints. At this step the per-technique combinations are obviously free from any local ties.
- Identify and reject outliers and properly handle discontinuities, using break-wise approach
- Combine the per-technique combinations adding local ties in collocation sites
- Estimate variance components and iterate as necessary.

Analysis Results

From the per technique combinations we extracted the geocenter estimates for SLR/ASI, GPS/JPL and DORIS/IGN-JPL time series as illustrated in Figure 1. These geocenter estimates are in fact weekly translation components (over the period of the available data) with respect to ITRF2000 origin, being aligned to the center of mass. While geocenter motion assessment is still a research area, we could mention that, according to Figure 1, SLR results seem to be less scattered than GPS and DORIS. Figure 1 shows also that unlike T_z component, T_x and T_y components are stable in time, with some seasonal variations. To have an idea about the magnitude of these seasonal variations, Table 1 lists the values of the annual amplitude of the geocenter components computed by:

$$dx(t) = A.cos(2\pi f(t-t0) + \phi) \qquad (3)$$

where *dx* designates one of the three geocenter components: *Tx, Ty, Tz*. *A* and ϕ are annual amplitude and phase, respectively, and (f = 1) is the frequency in cycles per year. The SLR seasonal variations of the geocenter components seem to be more reliable than GPS and DORIS. Figure 1 depicts also the scale time variation for the above 3 solutions, converted in mm over the equator, showing no significant drift in time, while DORIS solution exhibit a shift of about 2 cm compared to ITRF2000. Figure 2 illustrates the daily scale variation of GSFC VLBI results, over approximately 10 years, showing less scatter from 1997 on, no significant drift and roughly zero mean with respect to ITRF2000. However we may distinguish some annual variations of about 3 mm amplitude.

Table1. Annual amplitude of geocenter components (mm)

Solution	T_x	T_y	T_z
SLR/ASI	2.2	3.6	3.2
GPS/JPL	4.1	7.2	15.8
DORIS/IGN-JPL	6.9	4.4	16.0

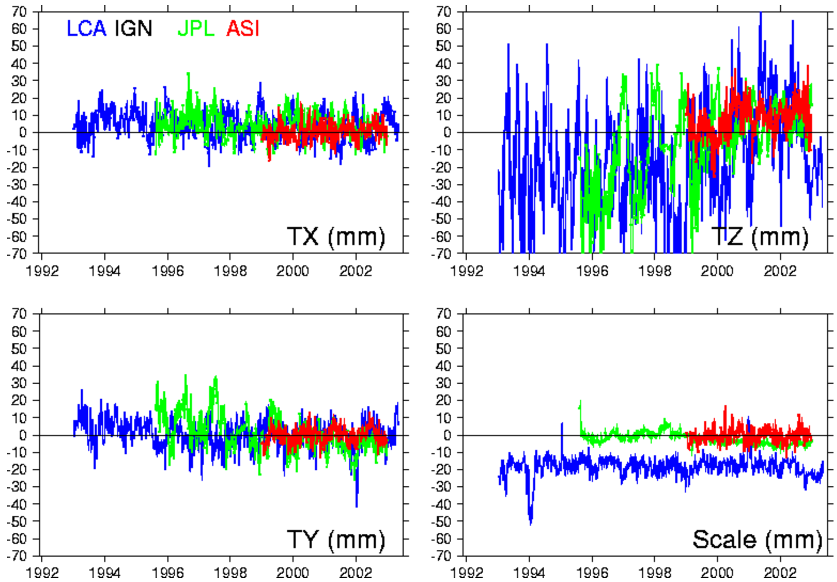

Figure 1. Origin and scale variations with respect to ITRF2000 for DORIS/IGN-JPL, GPS/JPL and SLR/ASI

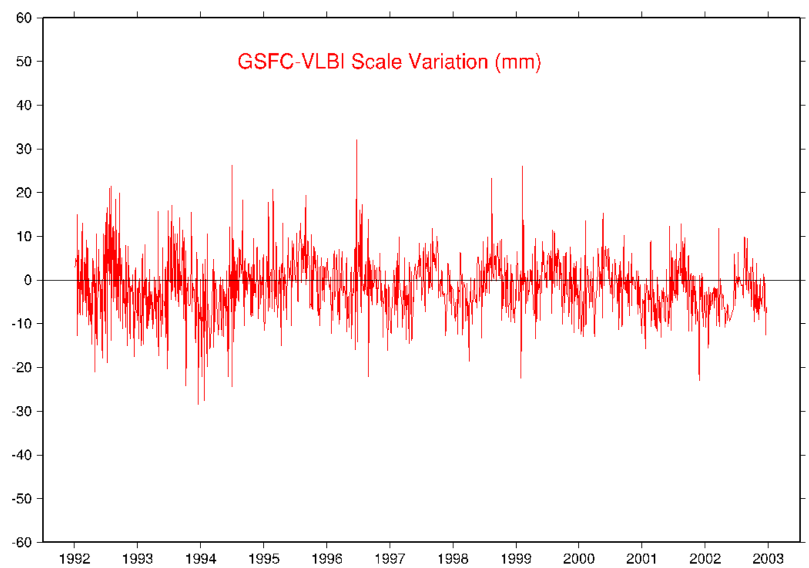

Figure 2. Daily GSFC VLBI scale variation w.r.t. ITRF2000

As results from the per technique combination, Figure 3 shows the polar motion post fit residuals (in *mas*) and Figure 4 shows the post fit residual of polar motion rates (in *mas*/yr.) and LOD (in *ms*/yr.) per technique. Moreover, Figure 5 (courtesy from D. Gambis) illustrates differences between EOP values resulted from the combination test and the IERS series C04.

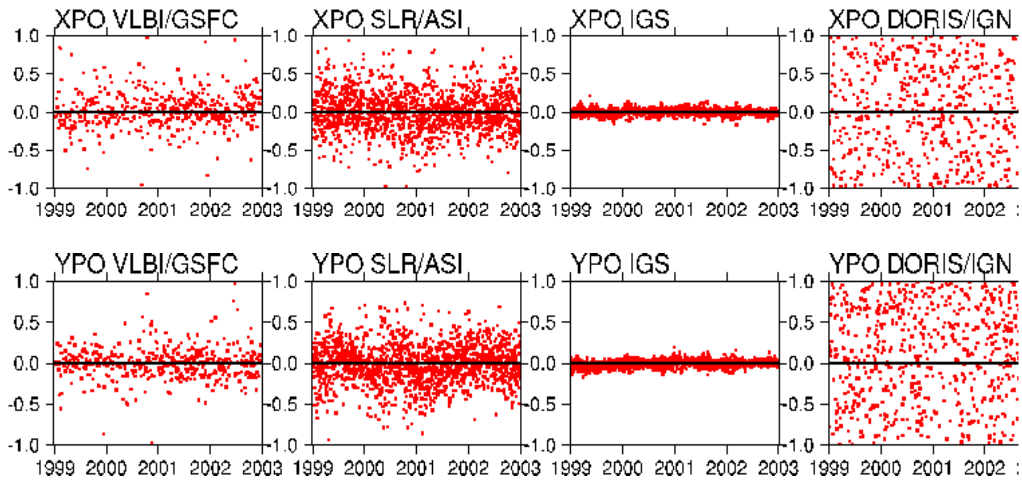

Figure 3. Post fit residual of Polar motion per technique (*mas*)

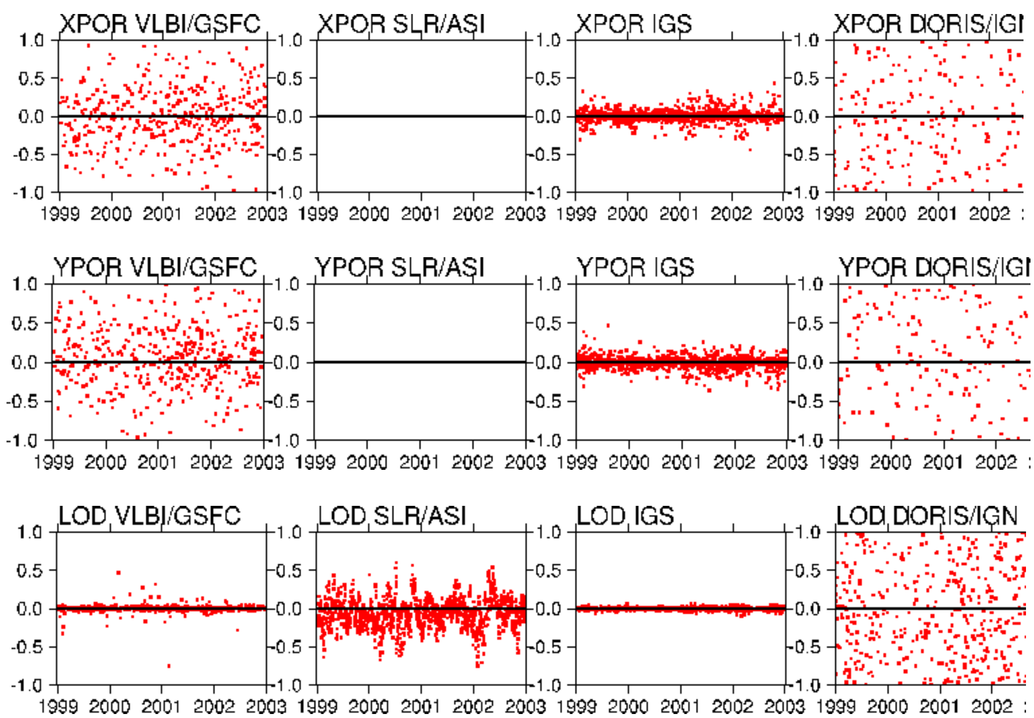

Figure 4. Post fit residual of Polar motion rates (*mas*/yr.) and LOD (*ms*/yr.) per technique

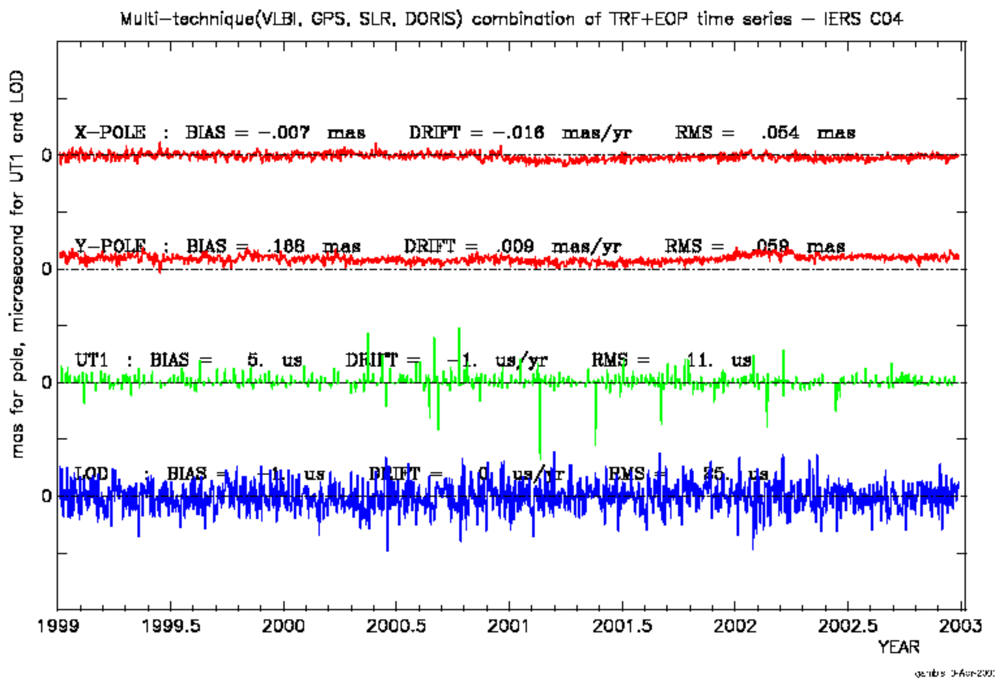

Figure 5. EOP differences with IERS C04 (*mas*) (plot courtesy from D. Gambis)

Conclusion

The EOP IGS results appear to dominate the other technique results. This is mainly due to the fact that the IGS solution is already a combination of 7 analysis centers, whereas the others are provided from one analysis center per technique. In addition, the IGS EOP estimates are based on continuous observations from more than 200 sites homogenously distributed. From Figure 5, it clearly appears that there is a bias in the y-pole component of about 170 micro-arc-second between IERS EOP series C04 and ITRF2000.

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IGS

ANALYSIS CENTERS

CODE IGS Analysis Center Technical Report 2002

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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 (swisstopo), 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 development version of the Bernese GPS Software [Hugentobler et al., 2001].

This report covers the time period from January through December 2002. 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 in previous years are described in earlier CODE annual reports [Rothacher et al., 1995, 1996, 1997, 1998, 1999, Hugentobler et al., 2000, 2001].

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 50 stations of a sub-network of a European permanent network are processed on a daily basis. Weekly coordinate solutions in SINEX format are regularly delivered to EUREF (European Reference Frame, Subcommission of IAG Commission X).

In 2002, no real ultra-rapid orbits were computed at CODE. The solutions delivered to the IGS by CODE were pure predictions on the basis of our daily rapid orbit solutions (i.e., NRT hourly data is not yet considered). Nevertheless the quality of the orbits is entirely competitive with other AC orbit products. The orbits are delivered to the IGS for comparison and are excluded from the IGS ultra rapid orbit combination process but still treated for comparison purposes. The computation of ultra-rapid solutions based on hourly observation data is foreseen for 2003.

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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 info)
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

Changes in the Routine Processing

The major changes implemented in the CODE routine analysis within the year 2002 are listed in Table 3. For details we refer to the IGS analysis questionnaire of CODE available at the IGS CB.

Table 3: Modifications to the CODE processing strategy accomplished between January 2002 and December 2002 (and important changes in 2001).

Date	Doy/Year	Description of Change and Impact
23-Aug-01	231/01	Estimation of horizontal troposphere delay gradient parameters (one set per day and per station). Change of elevation cut-off angle from 10 deg to 3 deg.
20-Sep-01	252/02	Use of a modified single-layer ionosphere model mapping function (approximating the JPL extended slab model mapping function).
10-Oct-01	280/01	Increase of spatial resolution of global ionosphere maps from harmonic expansion 12x12 to 15x15.
09-Dec-01	338/01	Switch from IGS97 to IGS 2000 for the definition of the datum.
13-Jan-02	009/02	Implementation of effect of the Moon's penumbra on orbits.
13-Mar-02	069/02	Earth potential coefficients considered up to degree/order 12.
13-Mar-02	069/02	Start to provide receiver DCB information in IONEX format.
18-Mar-02	074/02	Revised ambiguity resolution strategy.
27-Mar-02	076/02	GIM results for the middle day of a 3-day solution are considered.
07-May-02	124/02	Start to distinguish between three receiver classes (P1/P2, C1/C2, C1/P2) in clock, ionosphere, and wide lane ambiguity resolution procedures. Consider "Trimble 4700" no longer as C1/C2 but as C1/P2 receiver.
08-May-02	123/02	Improved P1-C1 bias values are retrieved from an additional clock estimation step but are based on ambiguity-fixed double differences conforming with the Melbourne-Wübbena linear combination.
09-Jul-02	187/02	Maximum number of stations in final analysis increased from 120 to 150.
29-Oct-02	301/02	Network condition deactivated in rapid analysis. Datum definition done by constraining fiducial sites (3mm)
14-Nov-02	314/02	All orbit products are written in SP3c format.
15-Nov-02	307/02	All IONEX products with 13 2-hourly ionosphere maps. Piece-wise linear (instead of constant) functions are used for representation in the time domain.

Starting with GPS week 1143 the datum of the station coordinates is defined using IGS00, the IGS realization of ITRF2000. In order to further densify our solutions the maximum number of stations was increased from 120 to 150 for the final analysis starting with doy 187/2002. Starting with doy 301/2002, the datum for the rapid analysis is no longer defined by a no-net rotation constraint on the coordinates of fiducial sites but by constraining the fiducial sites with 3 mm. Important for assuring the quality of our products was the complete revision of the ambiguity resolution scheme in both, final and rapid analysis (see below).

Several improvements concern ionosphere products and differential code biases (P1-P2 as well as P1-C1). More details are given below. Since November 14, all orbit products (including intermediate precise orbit files) are written in the new SP3c format.

Refined Ambiguity Resolution

Resolving initial carrier phase ambiguities seems to be essential not only for determination of high quality station coordinates but also for orbital parameters. This is supported by Figure 1 in an impressive manner. During about three weeks of the end of 2001 (doy 290-312), ambiguity fixing as part of our rapid analysis was – by mistake – deactivated. The figure shows the smoothed weighted rms for each IGS AC rapid orbit solution with respect to the IGS-combined orbit product. The arrow indicates the significant increase of CODE's orbit rms for the ambiguity-float solution.

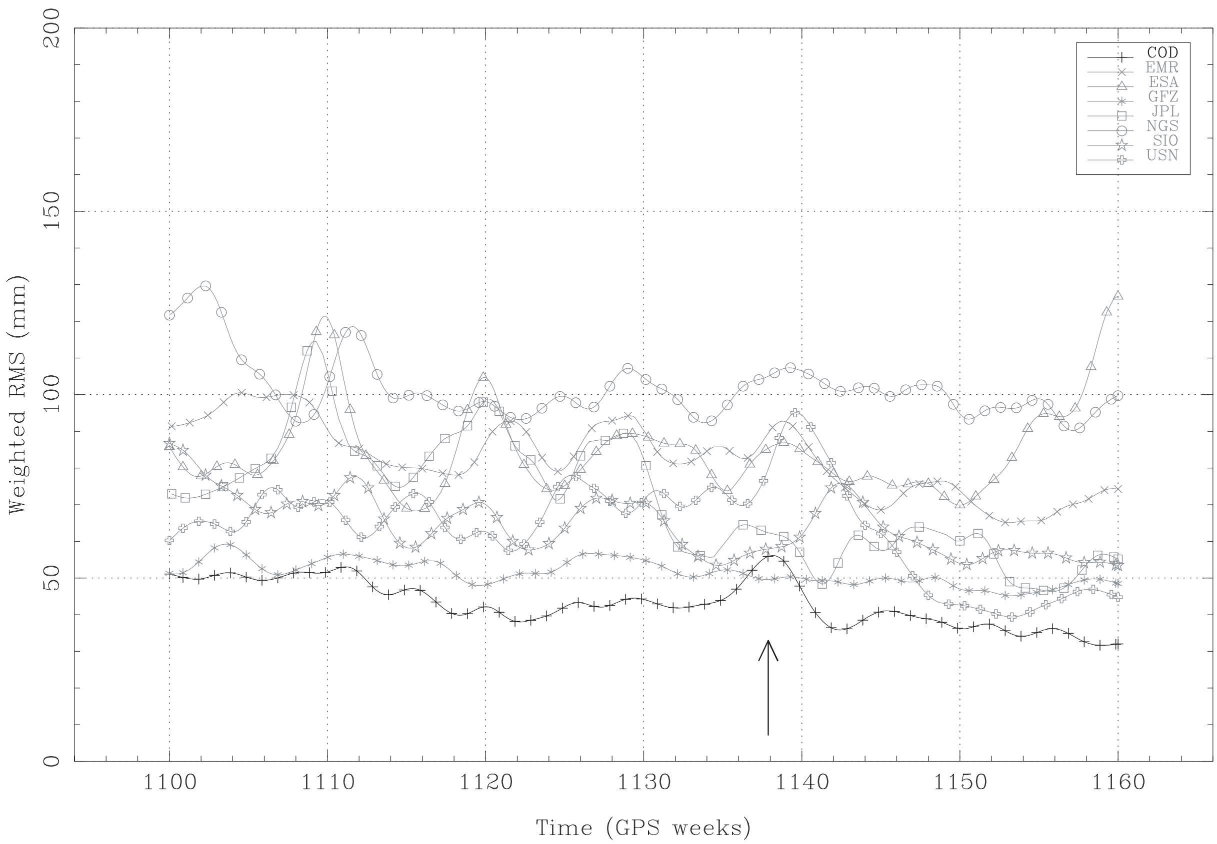

Figure 1: Smoothed weighted rms for each IGS Analysis Center rapid orbit solution with respect to the IGS-combined orbit product. The arrow indicates the period during which ambiguity resolution was by mistake deactivated at CODE.

Motivated by this unintentional experiment we reviewed our ambiguity resolution strategy for the final as well as for the rapid analysis. In March 2002 (doy 074) we activated a completely revised ambiguity resolution scheme for the final analysis. In a cascade of steps we attempt to fix ambiguities for baselines up to 6000 km length:

a) In a first step the widelane ambiguities are solved using the Melbourne-Wübbena strategy, followed by fixing of the corresponding narrowlane ambiguities. The procedure is applied in two iterations. In a boot-strapping step baselines up to 3000 km length are considered, in the final iteration baselines up to 6000 km length are processed.

b) In a second step, unresolved ambiguities on baselines up to a length of 2000 km are fixed using the quasi-ionosphere-free (QIF) strategy.
c) A subsequent step solves widelane and narrowlane ambiguities (relying on phase data only) up to a maximum baseline length of 200 km.
d) Finally, ambiguities on very short baselines (up to 20 km length) are resolved directly on the two carriers.

Assuming that the fraction of resolved (widelane) ambiguities on a specific baseline can be decomposed as the product of performance factors for the two receivers involved, quality indicators for the receivers in a network can be derived. Results show a broad range of such receiver or receiver type specific quality factors. Some receiver types may be found regularly at the upper end of the scale while others show a poor performance for widelane ambiguity resolution. A third class of receivers show a large range in quality factors for individual receivers of one and the same type. Due to the potential sensitivity of the results no rating of receiver types is provided here.

Estimation of Satellite and Receiver Clock Parameters

At CODE, a large number of IGS receivers is considered in the GPS clock estimation process. The final analysis is based on about 120 stations while the rapid analysis typically includes 90 stations. This can be achieved by doing the analysis in three global station clusters and subsequently combining the resulting satellite and receiver clock offsets. Effort was put into the algorithm to get an optimum distribution of stations in the different clusters. The clock offsets are aligned to GPS broadcast time and are referenced to that receiver clock that exhibits the smallest rms difference in a linear fit.

The clock zero-difference processing is based on the results from the double-difference analysis. Satellite orbits as well as determined station coordinates and troposphere parameters are considered fixed in the clock solution. Coordinates and troposphere parameters for additional stations are solved for in the zero-difference analysis.

Ionosphere

During winter 2001/2002 the solar activity passed its maximum. Mean vertical TEC values up to more than 60 TECU could be observed occasionally, one order of magnitude higher than the minimum mean value during solar activity minimum in 1996. When highest peaks were observed in the mean TEC, auroral phenomena could be observed even in Switzerland. To convert line-of-sight TEC into vertical TEC, a modified single-layer model mapping function approximating the JPL extended slab model mapping function is adopted since September, 2001.

Since doy 076/2002 (GPS week 1158) the CODE final GIM results correspond to the results for the middle day of a 3-day combination analysis solving for 37 times 256, or 9472 vertical TEC parameters and one common set of satellite and receiver DCB constants. In this way, discontinuities at day boundaries can be minimized. Furthermore, a time-invariant quality level is achieved. This model change was announced in IGS Mail 3823.

Starting with doy 307/2002 (GPS week 1191), all provided CODE IONEX files include 13 VTEC maps. The first map refers to 00:00 UT, the last map to 24:00 UT (instead of 01:00 and 23:00 UT, respectively). The time spacing of the maps (snapshots) is still 2 hours. Due to the fact that each new daily file contains ionospheric information covering not only 22 but 24 hours, data interpolation becomes more user-friendly. This model change was announced in IGS Mail 4162.

Determination of Differential Code Bias Values

As part of the ionosphere parameter estimation process, P1-P2 DCB values are determined for all active GPS satellites and for about 200 IGS stations. The daily repeatability of these parameters is of the order of 0.1 ns. Monthly P1-P2 DCB solutions are available as of October 1997. In order to ensure that the precise clock information is fully consistent to P1/P2 code measurements, P1-C1 code biases are accounted for as of GPS week 1057. Although the size of P1-C1 bias values is approximately three times smaller than that of P1-P2 values, these biases are still significantly detectable. Based on ambiguity-fixed double differences conforming with the Melbourne-Wübbena linear combination we are doing a kind of "finishing" of the P1-C1 bias retrievals coming from the undifferenced analysis. These P1-C1 bias values, provided since doy 123/2002, have a day-to-day repeatability of the order of 30 picoseconds.

Starting with doy 069/2002, receiver DCB information is provided in CODE IONEX data.

To verify the tracking technology for the different receivers a procedure was developed which safely identifies the receiver class. The procedure is based on the differing code bias corrections for appropriate linear combinations of the carriers and provides reliable results even based on GPS tracking data of a single day. In several cases the tracking technology for new receivers could be determined and were afterwards confirmed by the receiver manufacturers. A file containing the tracking types for the receivers commonly used within the IGS is maintained and made available at http://www.aiub.unibe.ch/ download/BSWUSER/GEN/ RECEIVER.

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

GPS Satellites in Moon’s Penumbra

GPS satellites periodically pass through the penumbra of the Moon. Eclipsing phases may occur when the angular distance between the Moon and the Sun is less than about 4.5 degrees which is the case close to the New Moon phases in the vicinity of the nodes of the lunar orbit with respect to the ecliptic plane. As a consequence, eclipses occur two times per year for four (in rare cases only three) successive New Moons. The Moon’s penumbra sweeps the GPS satellite constellation in about 17 hours. On average, 9 satellites are affected by the shadow. It is worth mentioning that up to 20 eclipses on a single day could be observed since 1997. The mean duration of the partial eclipses is 45 minutes; durations of up to 2.5 hours may occur in exceptional cases. In the last seven years only three total eclipses of GPS satellites by the Moon occurred and lasted for up to 50 seconds.

Until January 13, 2002, our software did not take into account the Moon's penumbra for the computation of the radiation pressure acting on the satellites. The accuracy of the GPS satellite orbits, however, reached a level where this effect could no longer be neglected. Experiments showed that the orbit rms difference for satellites passing through partial eclipse may reach 10 cm, an unacceptable large value in view of the accuracy reached by the IGS orbits. Starting with doy 009/2002, all CODE products are based on the improved orbit model.

Kinematic and Dynamic Orbit Determination for Low Earth Satellites

The AIUB is participating in the IGS LEO Pilot Project. In the context of the Ph.D. thesis of Heike Bock a set of programs were developed allowing for an efficient and robust kinematic and reduced-dynamic orbit determination for LEOs based on GPS tracking data. The procedure is based on a precise point positioning generating positions from code observations and position differences from phase differences from one epoch to the next. The phase epoch-differences eliminate the phase ambiguities allowing for an efficient epochwise processing. Positions and position differences are combined to high precision positions in a second step.

GPS orbits are introduced as fixed while high rate clock corrections (30 sec) 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. With the POD procedure an orbit accuracy of about one decimeter can be reached. The limited accuracy is due to neglected correlations between epoch differences. The built-in data screening algorithms makes the procedure, however, very robust and allows for a quick check of the data quality for a LEO and the rapid generation of a good a priori orbit for a procedure providing an orbit accuracy in the centimeter range. The procedure was successfully tested using observations from CHAMP and SAC-C [Bock et al., 2000].

In a follow-up Ph.D. work by Adrian Jäggi the focus is put on the rigorous GPS data processing for spaceborne GPS receivers as well as on the improvement of dynamic orbit models and stochastic orbit parameterization.

First tests for a combined processing of GPS ground tracking and LEO receiver data using double differenced observations were performed to approach the question on the impact of a combined processing [Hugentobler et al., 2002b]. The fast motion of a LEO and the correspondingly large number of ambiguity parameters required (typically 800 per day) causes an increase of the computation effort for the inclusion of a single LEO which is much higher than for an additional ground station. Simulations show, as expected, an impact in particular on the geocenter coordinates.

Tests using tracking data from JASON-1 orbiting at a higher altitude than CHAMP are foreseen for 2003. In addition the inclusion of GPS tracking data originating from LEO satellites is intended for the generation of global ionosphere maps. CHAMP orbits at a sufficiently low altitude to be sensitive to about 2/3 of the impact of the ionosphere as seen by a ground station for tracking data acquired above the local horizon.

Outlook

In the near future, developments are foreseen in various fields eventually resulting in a further increased accuracy of the products generated by CODE for the IGS. Significant effort is expected in regard to the switch to absolute antenna phase patterns for the GPS satellite constellation and the IGS ground receivers. A thorough investigation on the impact of this step on orbits and terrestrial frame is intended.

Studies of GLONASS orbits as well as of the data availability within the IGLOS tracking network are underway. As soon as the global data from combined receivers is available rapidly enough, a fully combined processing of GPS and GLONASS orbits is foreseen. It is planned to start delivering "real" ultra rapid orbits based on hourly RINEX data. High-rate (30-second) GPS satellite clock corrections based on a phase consistent interpolation of our 5-minutes clocks may be expected as final as well as rapid products.

Further improvements in the LEO data processing will be made, including studies on combined processing of ground receiver and LEO tracking data. LEO observations are intended to be included for the generation of global ionosphere maps.

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The ESA/ESOC IGS Analysis Centre Annual Report 2002

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Introduction

This Report gives an overview of the ESOC Analysis Centre activities and a presentation of the IGS activities at ESOC during the year 2002.

This year the ESOC AC activities have continued uninterrupted and have consolidated with the timely delivery of all the products part of the IGS and participation in several of the IGS Working Groups and Pilot Projects. There have been no major changes to the routine processing during 2002, only some small changes to the processing strategies as outlined and described below.

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 five days. Information is available on the website: http://nng.esoc.esa.de/gps/gps.html

Changes and Activities in 2002

These have been the changes to IGS activities at ESOC during 2002:

Jan 2002 *GLONASS processing*: Changed terrestrial reference frame to ITRF2000, based on the IGS2000.SNX file generated by the IGS for the core stations, together with the use of the GPS fixed orbits which had been switched to ITRF2000 a few months back.

May 2002 *Ultra-Rapid processing*: Switched processing to use only RINEX data for 48 hours, no fixed positions from previous sp3 files were further used.

Nov 2002 *IGS processing*: switched all orbit submissions to the SP3c format to comply with the new IGS standard.

Dec 2002 *IGS processing*: Changed the processing during satellite eclipses from excluding the data during eclipse periods and introducing a manoeuvre at the eclipse exit to leaving all the data in and not including a manoeuvre at the eclipse exit.

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 clock biases
- Final GLONASS Orbits plus clock biases
- Rapid GPS Orbits plus clock biases
- Twice Daily Ultra-Rapid GPS Orbits plus clock biases
- 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 final ionospheric files in IONEX format
- Weekly combined IGS ionosphere IONEX files; ESOC is the IGS Ionosphere Associate Combination Center (IACC)
- 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: 30 to 35 stations

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 undifferenced, 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-free 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:

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http://nng.esoc.esa.de/
http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn
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Ultra-Rapid Processing

The processing has changed minimally by removing the sp3 orbits as pseudo-observations. In the past the Ultra-Rapid has used a number of days of fixed orbits as pseudo-observations before the RINEX data arc. This practice would stabilise the orbit solutions when there were few stations available with current data. At this time the hourly data availability is such that for the Ultra-rapid processing there is always more than enough RINEX data to produce very good estimated orbits and thus to predict the orbits into the future with a high degree of accuracy.

Eclipse Data Processing

During satellite eclipses the ESA/ESOC processing used to exclude the data and estimate a manoeuvre at the eclipse exit. The exclusion of the data over the eclipse period was done to simplify the estimator calculations in fitting the data. The eclipse manoeuvre was included to try and absorb some of the unmodelled behaviour when the satellites reacquire the sun. These two strategies made the ESOC solution both incomplete and discontinuous. Incomplete since we cannot calculate clock biases when no data is processed so none where included in the clock solution for around one hour (Figure 1). The orbit solution was also subject to discontinuities, which appeared as large peak differences when comparing to other orbit solutions.

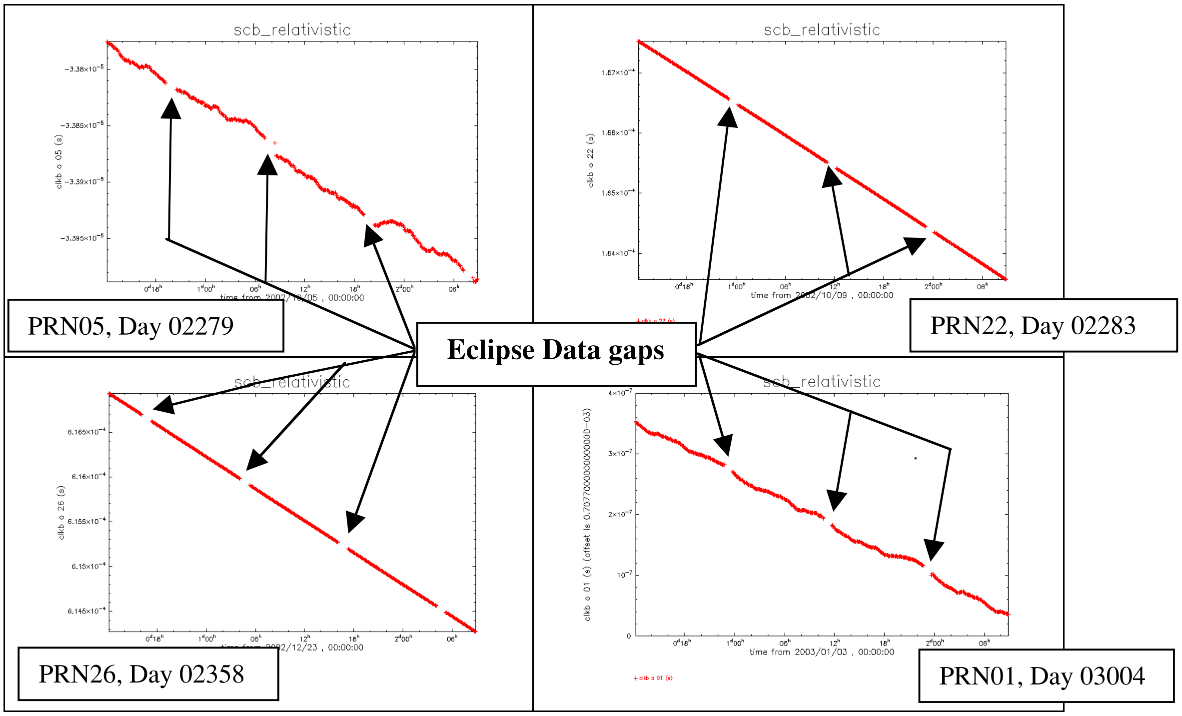

Figure 1: Clock bias values showing data gaps due to eclipse data exclusions.

Towards the end of 2002 and early 2003 the new strategy of including all the data all the time and NOT including eclipse manoeuvres was tested, validated and implemented.

GLONASS Processing

GLONASS processing at ESOC has continued during 2002 as it had done during 2001.

A change implemented during 2002 in the GLONASS processing has been to switch to the ITRF2000 as had been done for all the other IGS operations a few months earlier.

During 2002 the processing continued using the complete 9-parameter Solar Radiation Pressure (SRP) model for the GLONASS satellites; this had been a change for testing purposes from the 5-parameter model used up to 2001 (Romero et al., 2002). The processing was stopped after the summer of 2002 due to manpower problems and was later resumed without loss during 2003.

Figure 2 shows the weighted orbit comparisons between the solutions from CODE, BKG, MCC (Mission Control Centre, Moscow) and ESOC versus the GLONASS combination up to the time of writing. CODE orbit contributions ceased during 2000. The ESOC weighted comparison to the combination has stabilised at an error level of around 10 to 15 cm.

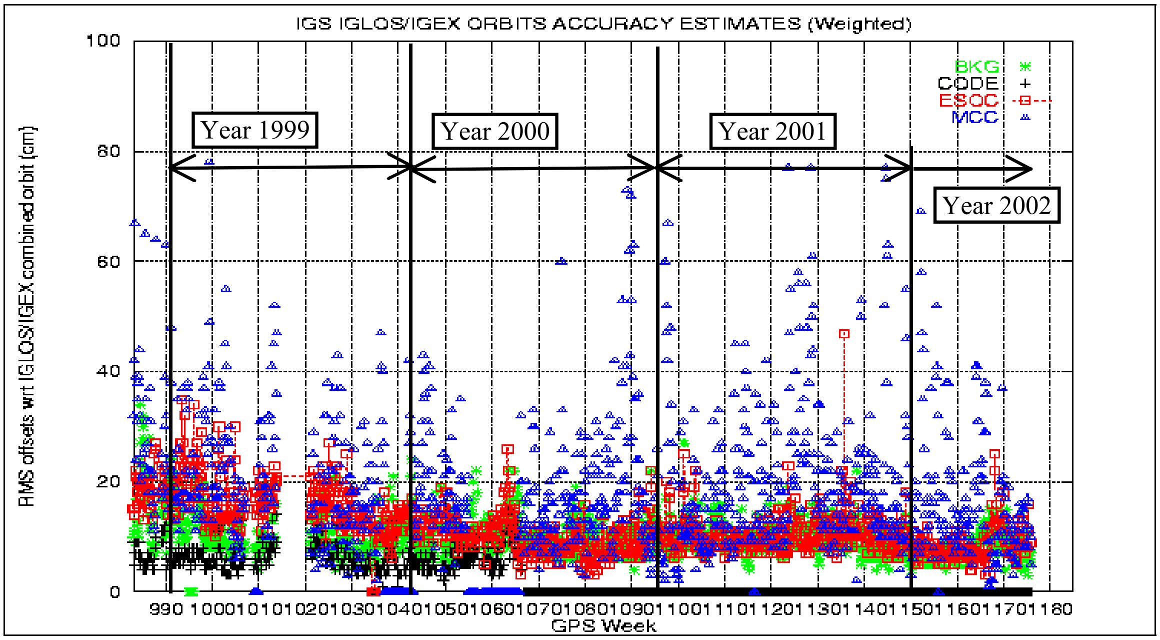

Figure 2: IGLOS/IGEX AC weighted orbit comparisons versus the combination.

Ionosphere Processing

Routine processing of ionospheric Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 2002.

The ionosphere processing in final mode continued with the rapid orbits. The number of ground stations used was increased to about 180. The daily routine ionosphere processing in 2002 was 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 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. This run is the official ESOC contribution to the IGS Ionosphere Working Group to be part of the combination.
3) A Chapman profile model is fitted to the TEC data, where h0 is estimated as a global constant. This run is made for test reasons and theoretical studies.
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.

Beyond the routine processing of our own TEC maps, ESOC has also chaired the IGS Ionosphere Working Group (Iono_WG) from 1998 to 2002, before transfer of the chairmanship to Dr. M. Hernandez Parajes. As part of these activities, ESOC was responsible for the weekly comparisons of Iono_WG products as IGS Ionosphere Associate Combination Centre.

LEO Activities

The activities of the ESOC Analysis Centre for the IGS LEO Pilot Project over 2002 have concentrated on implementing LEO processing capability in the available POD systems, using the data from CHAMP. Because ESOC also coordinates the Pilot Project itself, please refer to the Chapters on the LEO Pilot Project for more information, or consult the igsleo website at nng.esoc.esa.de/igsleo.html

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, station network solutions and EOPs. In the area of LEO POD significant efforts are underway to completely redesign the LEO calculations. All the processes will be streamlined further and the GPS-TDAF will be improved for more efficient and independent operations, paying particular attention to the GLONASS processing to make it more efficient and to reconsider the processing of GPS and GLONASS orbits together.

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Dow, J.M., Feltens, J., Garcia, C., Romero, I., The ESOC IGS Analysis Centre, *1998 IGS Technical Report*, R. Neilan, A. Moore, K. Gowey, eds., Pasadena CA, Jet Propulsion Laboratory, 1999.

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GFZ Analysis Center of IGS - Annual Report for 2002

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Summary

The changes introduced during 2002 and early 2003 are summarized in Table 1. They were focused on the improvement in the product quality and in the robustness of the analysis strategy.

Table 1. Changes in the analysis strategy

Week	Date	Description
1168	2002-05-30	Introduction of new single site data cleaning strategy
1172	2002-06-23	Use of UT1 instead of UT1R
1174	2002-07-07	Loosing the a-priori orbit sigma during its eliminations from the SNX-file (old: ~0.1 m resp. m/d new: ~ 1 m resp. m/d)
1179	2002-08-11	Extension of used IGS network to 150 stations via cluster strategy
1184	2002-09-19	Rapid products with concatenation of two days
1189	2002-10-20	Introduction of new sp3c-format
1202	2003-01-19	Introduction of ambiguity fixing into Rapid analysis
1214	2003-04-13	Enlargement of network (~50 station) for Rapid analysis

Data Cleaning

The data are cleaned iteratively by scanning the post-fit residuals from the network solution. The number of iterations needed for obtaining a clean data set depends heavily on the quality of the GPS data the procedure start with, as large cycle slips will bias the residuals in the network solution. To speed up the clean procedure a single station data clean strategy is implemented as described by Blewitt (1990) to flag and repair as many cycle slips as possible before starting the network analysis. It is well known that the method fails when the pseudo range observations are not good enough. This is unfortunately true for a number of stations as our network is extended to more than 150 sites. Rapid ionosphere changes can also lead to erroneously removal of good observations. To overcome those problems, we reduce the geometric effect from the ionosphere-free phase observation and fit the difference between satellites piece by piece for data without SA clock dithering. The rms and the residuals of the fitted observations give an additional quality index along with wide-lane and ionosphere change for making a decision on the observation quality. The new software has been introduced into our routine data processing since May 30, 2003. For non-SA data the remaining cycle slips detected in the later iterative procedure are in average no more than 4% of all the cycle slips over all the 150 stations and their values are rarely larger than 1 cycle in L1 wavelength. This is especially effective for our ultra-rapid and rapid processing where precise satellite clock information is not yet available for cleaning the data station by station using the precise point positioning technique as it is done for the Final analysis.

Rapid Products

Whereas the quality of the GFZ Final orbits has reached a level of 2 cm during 2001 the quality of the GFZ Rapid products with 5 to 6 cm has not improved significantly throughout the last years. Therefore efforts were made to utilize elements from the Final analysis also here. One orbit-stabilizing factor in the Final analysis is that three-day orbits are used to get the best orbit solution for the middle day, avoiding orbit problems at the day boundaries. For the Rapid orbit two days were concatenated and the second day is taken as the product. However, the most visible progress in the orbit quality was gained by the introduction of the ambiguity fixing (Fig. 1). This was feasible because the robustness of the ambiguity fixing was improved recently so that it could be introduced into the automated analysis for the Rapid products.

Additionally, the selected station set was enlarged from ~35 to ~50 so that the realization of the reference frame will be less effected by the available station data.

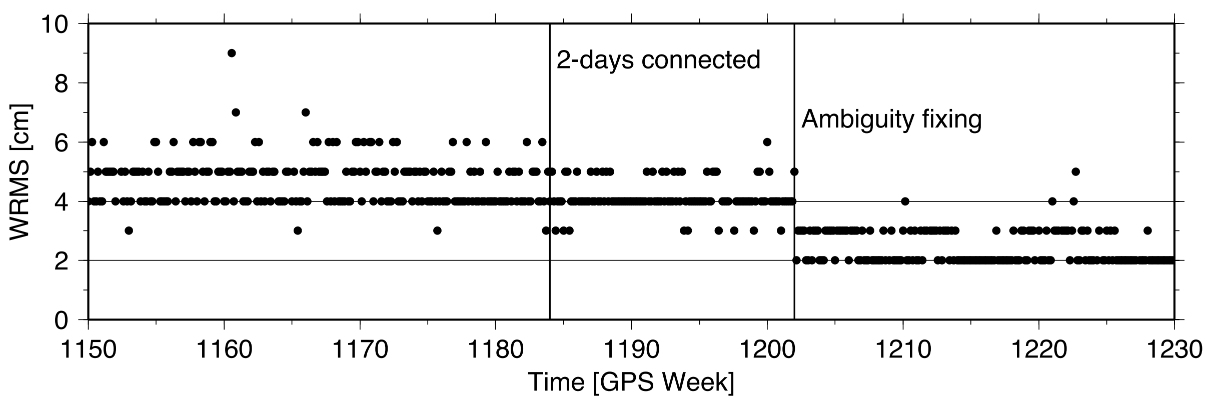

Fig. 1. Quality of the various GFZ satellite orbit products taken from the official combinations reports

Final Products

To extend our IGS final network, we process data in a cluster mode for saving computer time and overcoming computer memory limitation. We divided all the stations to be processed into several clusters. Each cluster includes no more than 80 stations. That is for the moment the most economic station number for EPOS running on our mainframe computer. A set of common stations is necessary to be included in each cluster as the reference network for connecting the clusters. Each cluster is processed independently similar to usual GFZ final data processing strategy by calling standard EPOS procedures. The cluster (named 'IGS base') for generating IGS orbit and clock is processed at first, so that its products can be used for cleaning the data of the other clusters by scanning precise point positioning residuals. Each cluster provides a normal equation with station coordinate, orbit and earth rotation parameters. Daily normal equations of several clusters are combined together to generate a daily normal equation with all station coordinate and unique orbit and earth rotation parameters for further processing. With this strategy we enlarged our IGS network to about 150 stations and integrated TIGA stations into our routine data processing effectively.

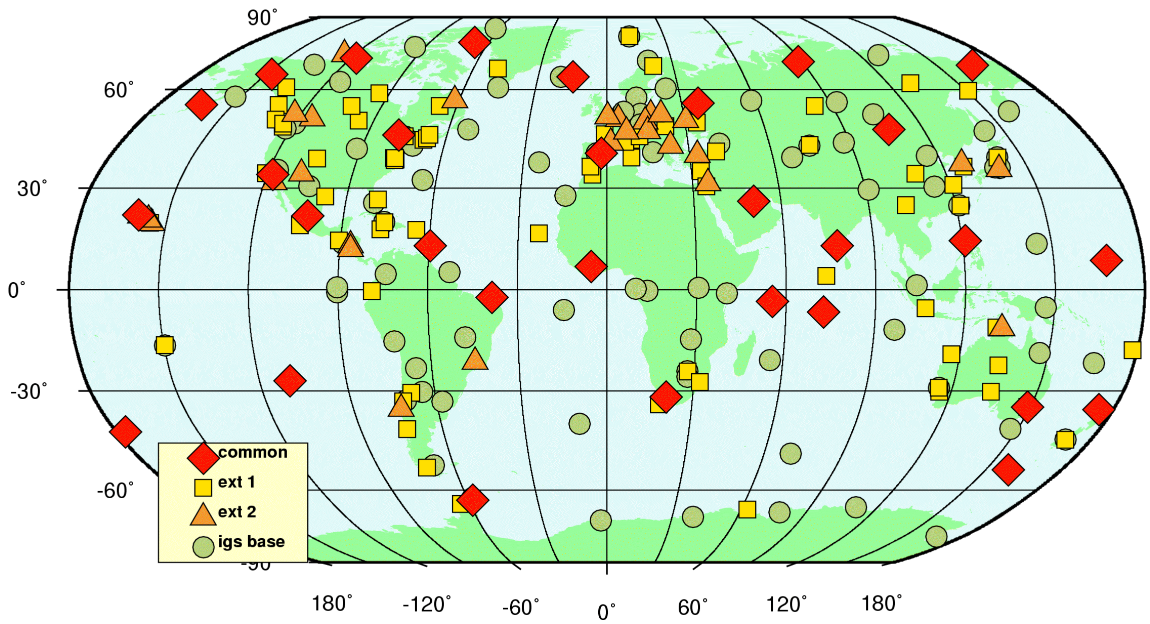

Fig. 2. IGS station distribution and cluster definition, common stations are included in all clusters

There are 4 clusters now in our routine data processing, the 'IGS base' cluster, one TIGA cluster and two IGS extended clusters (named 'ext1', 'ext2'). Figure 2 shows the station distribution of the IGS clusters (the TIGA cluster is shown in Fig.4). To produce a daily solution for IGS or TIGA by normal equation combination, the corresponding cluster solutions are chosen. To generate the IGS solution the clusters 'IGS base', 'ext1' and 'ext2' are combined and to get the TIGA solution the clusters 'IGS base', 'ext1' and TIGA are used. The common stations are included in all clusters.

We combine 3 daily solutions with appropriate orbit constraint at the day boundaries and output a 3-day normal equation for generating weekly products. The final IGS weekly SINEX solution is obtained by combing seven 3-day normal equations. Fixing the station coordinates and earth rotation parameters to the values in the weekly solution, we repeat the 3-day combination to get the consistent final orbit for each day. With station coordinate, ERP and orbit fixed to the value we got in the last step, we solve for clock again from observation to get the clock estimates submitted to IGS. For the moment, only the 'IGS base' cluster is used for final clock estimation.

The solution quality obtained by the new cluster strategy can be seen in Figure 3. The difference to the weekly combined IGS solution has slightly improved by about 1 mm for all components and is approaching ±1 mm and ±4 mm in the horizontal and vertical components respectively.

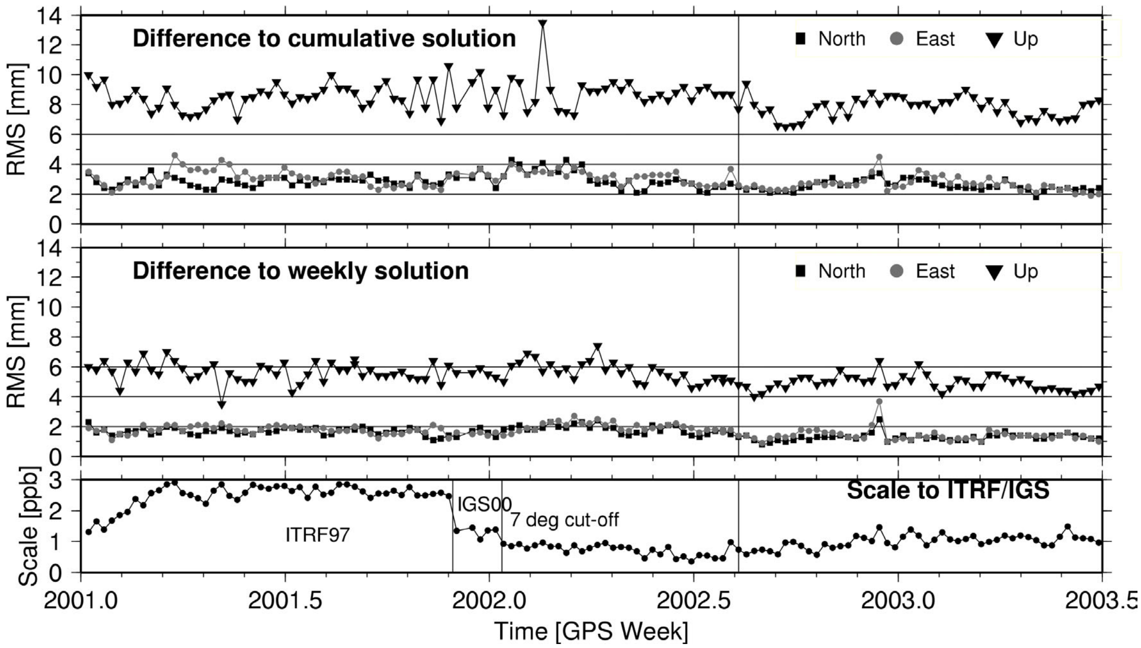

Fig. 3. Quality of GFZ station coordinate solutions extracted from the IGS SINEX combination reports. Since August 2002 the cluster solution strategy was introduced.

TIGA Data Processing

For the TIGA project, an additional cluster, the TIGA cluster, is defined and processed following the same cluster strategy mentioned above. There are about 80 stations for the moment and Figure 4 shows its distribution. The final TIGA solution comes from combining the TIGA cluster and two IGS clusters as already mentioned. To keep the data set as complete as possible, GPS raw data retrieval is carried out by scanning all TIGA related data centers before starting the job for a day.

At the moment, GFZ is operating three TIGA processing chains. The first chain, with 1-week latency and in parallel with the GFZ/IGS data processing, starts from 2002.0. The second chain, with 460-day latency starting from processing GPS week 1112, is dedicated to TIGA as a permanent routine service. The weekly SINEX solutions are available at ftp://ftp.gfz-potsdam.de/pub/transfer/kg_igs/igstiga/solutions/. The last chain, the backward processing planned to trace back to year 1994, is carried out with a 4-week time step to get a quick look of the time series. This chain started from processing the data of year 2001 and year 1997 is nearly finished now. For consistency, the IGS clusters are reprocessed with the state-of-the-art data processing technique.

To validate the results, the solutions are compared with official IGS solutions and other TIGA AC solutions routinely. Figure 5 gives the rms of the station coordinate differences between the official IGS and the GFZ TIGA weekly solutions (for about 200 weeks) and the number of common stations compared. From Figure 5, the coordinate consistency is ±1 to ±4 mm, and ±5 to ±10 mm in horizontal and vertical directions respectively.

Daily solutions are generated to obtain time series for estimating vertical velocities of TIGA stations. To improve the accuracy of velocity estimation, we are considering applying seasonal variation correction caused by mass loading redistribution derived from geophysical data.

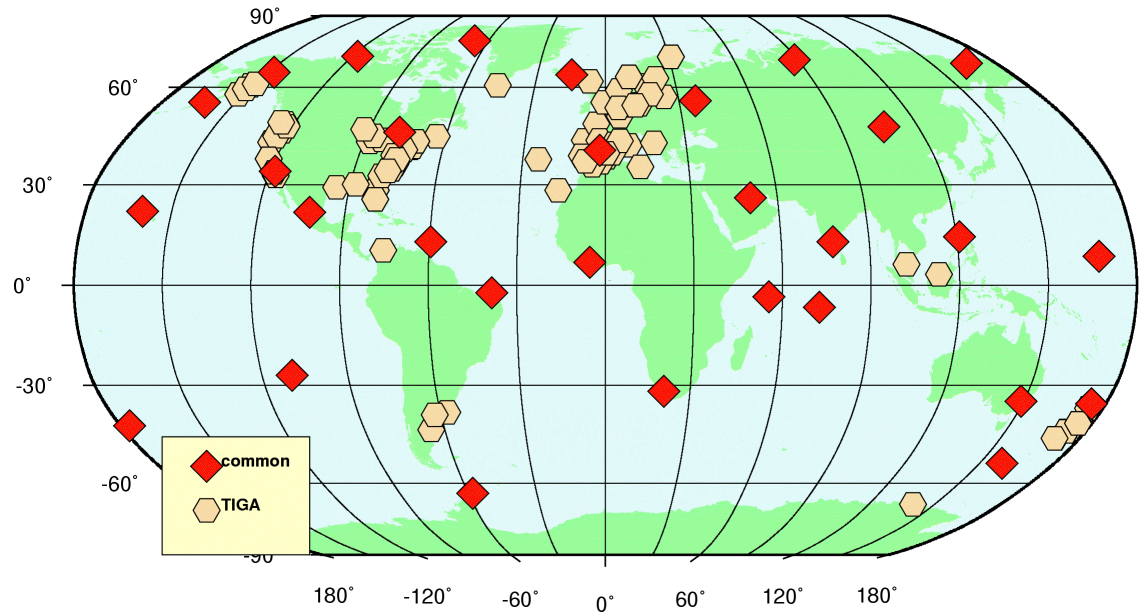

Fig. 4. Geographic distribution of TIGA stations

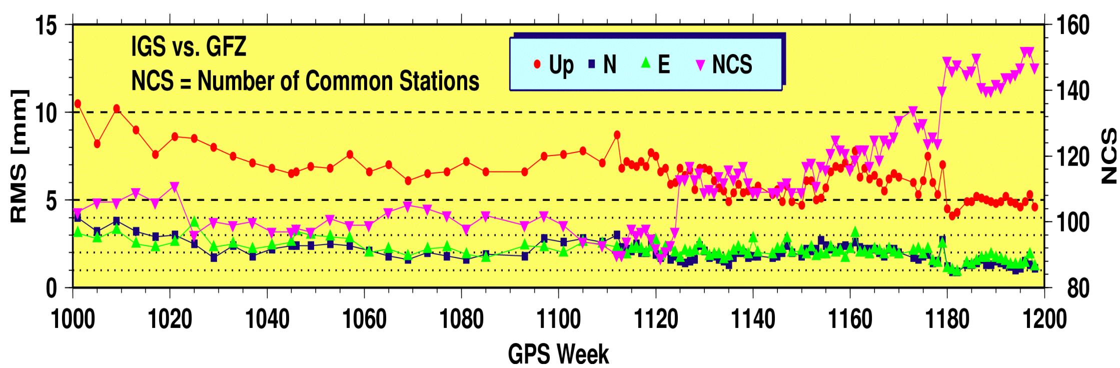

Fig. 5. Comparison between the GFZ/TIGA and the official IGS weekly solutions

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JPL IGS Analysis Center Report, 2001-2003

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Summary

Three GPS orbit and clock products are currently provided by JPL for consideration by the IGS. Each differs in its latency and quality, with later results being more accurate. Results are typically available in both IGS and GIPSY formats via anonymous ftp. Current performance based on comparisons with the IGS final products is summarized in Table 1. Orbit performance was determined by computing the 3D RMS difference between each JPL product and the IGS final orbits based on 15 minute estimates from the sp3 files. Clock performance was computed as the RMS difference after subtracting a linear trend based on 15 minute estimates from the sp3 files.

Table 1: Product Quality

Products	Delivery	Orbit	Clock
Final-Flinn	Weekly	5.2 cm	5.8 cm
Rapid	Daily	7.4 cm	6.2 cm
Real-Time	Every 15 minutes	17.7 cm	14.6 cm

Recent Improvements

Strategy improvements are listed in Table 2. Preparation for a new GIPSY release resulted in 80 station tracking capability, use of RCS (revision control system) for configuration control, an upgrade to Red Hat 9 (RH9), use of the gcc 3.2.2 compiler, and a new version of qfront. These improvements have led to our longest period of 4-cm orbit overlaps ever as shown in Figure 1.

Table 2: Strategy Updates

Action	Date
new qfront which calls clockprep, PvsCA, and teqc	09/14/03
RH9, RCS, gcc 3.2.2	08/10/03
Increase from 60 to 80 sites	04/20/03
Create sp3c files	02/16/03
Extra digit in sp3 files	10/20/02
Use USN1 and AMC2 reference clocks without alignment	09/23/02

Table 2: Strategy Updates (cont'd)

Action	Date
Ocean loading upgrade - FES02 [1]	07/23/02
Extra digit in jpl.txt files	07/14/02
New hi-rate clock process	06/17/02
Extra digit in eci files	05/27/02
Increase Flinn tracking network from 42 to 60 sites	04/07/02
Ocean loading upgrade - FES99 [2]	03/03/02
New ITRF2000 nominal coordinate database	01/09/02
Expand Flinn high rate clocks from 27 to 30 hours	01/20/02
ITRF2000 / IGS00 reference frame	12/02/01
IERS2000 tidal models	08/29/01
Tighten edit window to 2 m and 2 cm for range and phase	05/06/01

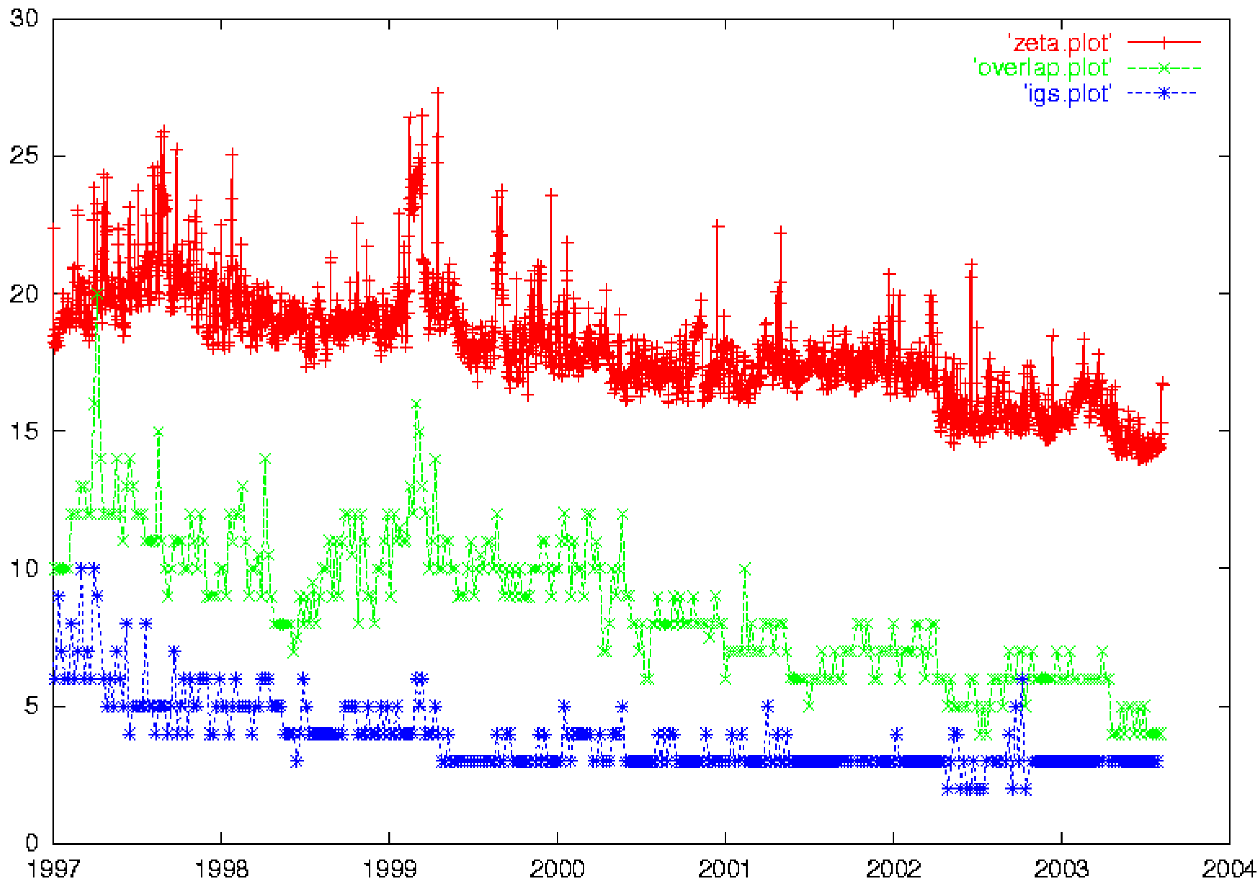

Figure1: Performance Metrics

Figure 1 shows the three main metrics used for monitoring performance; (1) zeta in hundreds of km is representative of the site distribution density, (2) three-dimensional orbit overlaps from day to day in cm, and (3) one-dimensional IGS orbit comparisons in cm. All metrics have improved over time. There is a significant correlation between tracking site distribution and orbit quality.

Flinn orbits and clocks are used in the analysis of data from NASA (and other) flight projects, including the ocean altimetry mission JASON and the gravity mission GRACE. Flinn orbits and clocks are also used to compute point positions for hundreds of terrestrial GPS sites around the world. Figure 2 shows the growth of point positioning over time from roughly 20 sites per day in 1991 to more than 600 sites per day in 2003. JPL currently computes time series for the IGS, SCIGN, CORS, NBAR, and PANGA networks. These time series provide insight into global plate motion, post-glacial rebound, seasonal loading, co- and post-seismic deformation due to earthquakes, and interseismic strain accumulation related to seismic hazards in active boundary zones such as Southern California. The current global velocity field is illustrated in Figure 3.

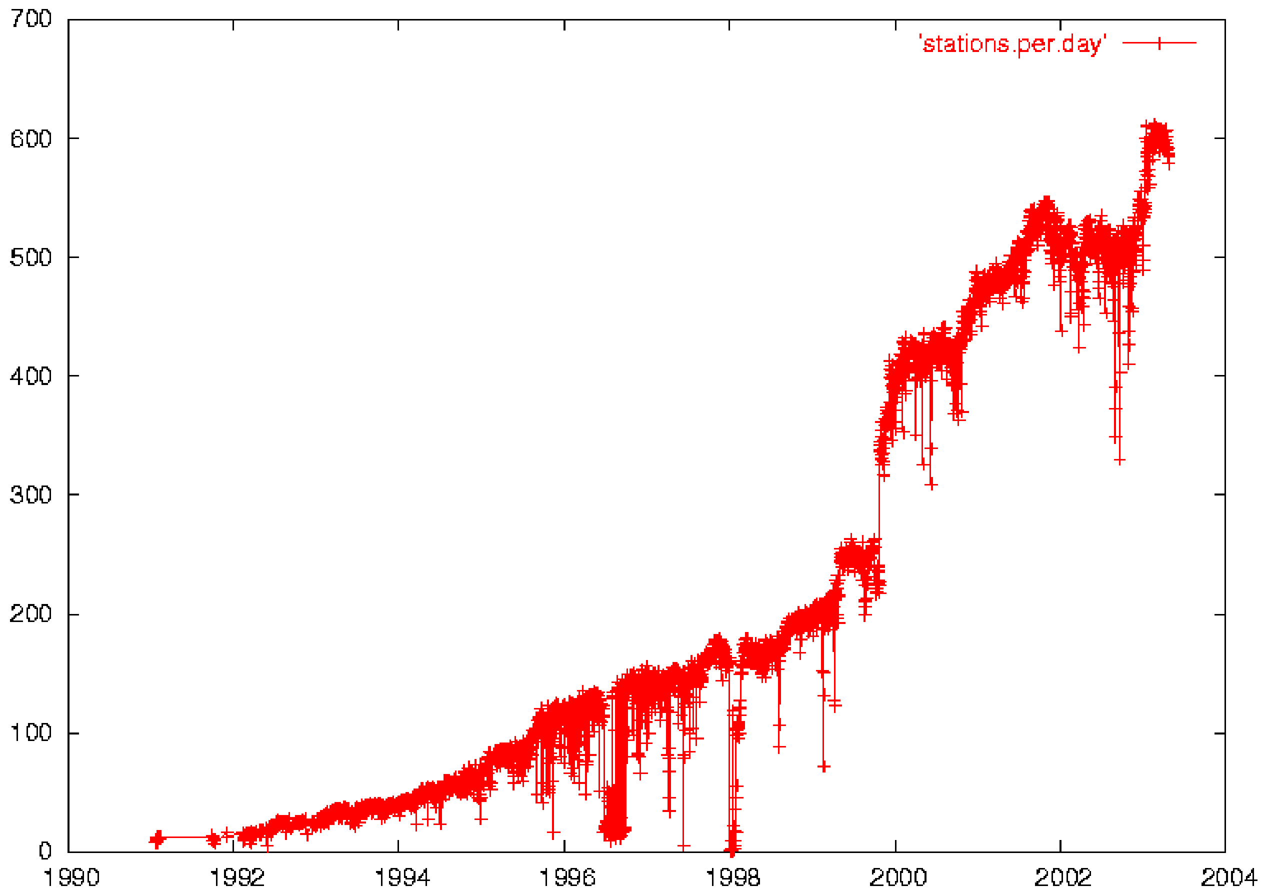

Figure 2: Point Positions Per Day

Products

Various products are made available via ftp and http as listed in Table 3. There are three major orbit and clock products. Orbit estimates can be found in the IGS format .sp3 and .yaw files as well as in the GIPSY format .eci, .yaw or .yaw_rates, and .shad or .shadow_events files. Clock information can be found in the IGS format .clk and .sp3 files and in the GIPSY format .gps_clock and .tdpc files. Tropospheric estimates can be found in the IGS format .tro files.

Earth orientation information is contained in the IGS format .erp files and the GIPSY format TPNML and tpeo.nml files. Post-processing based on Flinn products is used to derive our final time series of polar motion, length of day, geocenter, scale, and site position [3].

Table 3: Product Files

Real-Time Products

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ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/15min
jpl12322.clk.Z
jpl12322.sp3.Z
jpl12322.tro.Z
jpl12322.yaw.Z
2003-08-19.TPNML.Z
2003-08-19.eci.Z
2003-08-19.gps_clocks.Z
2003-08-19.shadow_events.Z
2003-08-19.yaw_rates.Z

Rapid Products

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ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/RapidService/orbits
jpl12321.clk.Z
jpl12321.erp
jpl12321.sp3.Z
jpl12321.sp3c.Z
jpl12321_pred.sp3.Z
jpl12321_pred_pc.sp3.Z
2003-08-18.DONE
2003-08-18.PREDICT
2003-08-18.TPNML.Z
2003-08-18.TPNML.predict.Z
2003-08-18.eci.Z
2003-08-18.eci.predict.Z
2003-08-18.eci.predict.edited.Z
2003-08-18.frame
2003-08-18.gps_clocks.Z
2003-08-18.shadow_events.Z
2003-08-18.yaw_rates.Z

Table 3: Product Files (cont'd)

Final-Flinn Products

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ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/jpligsac/1230
jpl12300.clk.Z
jpl12300.sp3.Z
jpl12300.sp3c.Z
jpl12300.tro.Z
jpl12300.yaw.Z
jpl12307.erp.Z
jpl12307.snx.Z
jpl12307.sum.Z

ftp://sideshow.jpl.nasa.gov/pub/gipsy_products/2003/orbits
2003-08-09.eci.Z
2003-08-09_nf.eci.Z
2003-08-09.tdpc.Z
2003-08-09_nf.tdpc.Z
2003-08-09tpeo.nml.Z
2003-08-09tpeo_nf.nml.Z
2003-08-09.frame
2003-08-09.shad.Z

Time Series

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http://sideshow.jpl.nasa.gov/mbh/series.html - web page with links to tables, plots, and ftp areas

ftp://sideshow.jpl.nasa.gov/pub/mbh/point - IGS, SCIGN, CORS, NBAR, and PANGA
ftp://sideshow.jpl.nasa.gov/pub/mbh/filtered - ambiguity resolved, regionally filtered SCIGN
ftp://sideshow.jpl.nasa.gov/pub/mbh/stacov - ambiguity resolved SCIGN stacov files

Time series are given as three ASCII files SITE.lat, SITE.lon, and SITE.rad containing the time in years, estimate in cm, sigma in cm, site, component, and date. Stacov files contain X, Y, Z estimates in m, sigmas in m, and correlations.

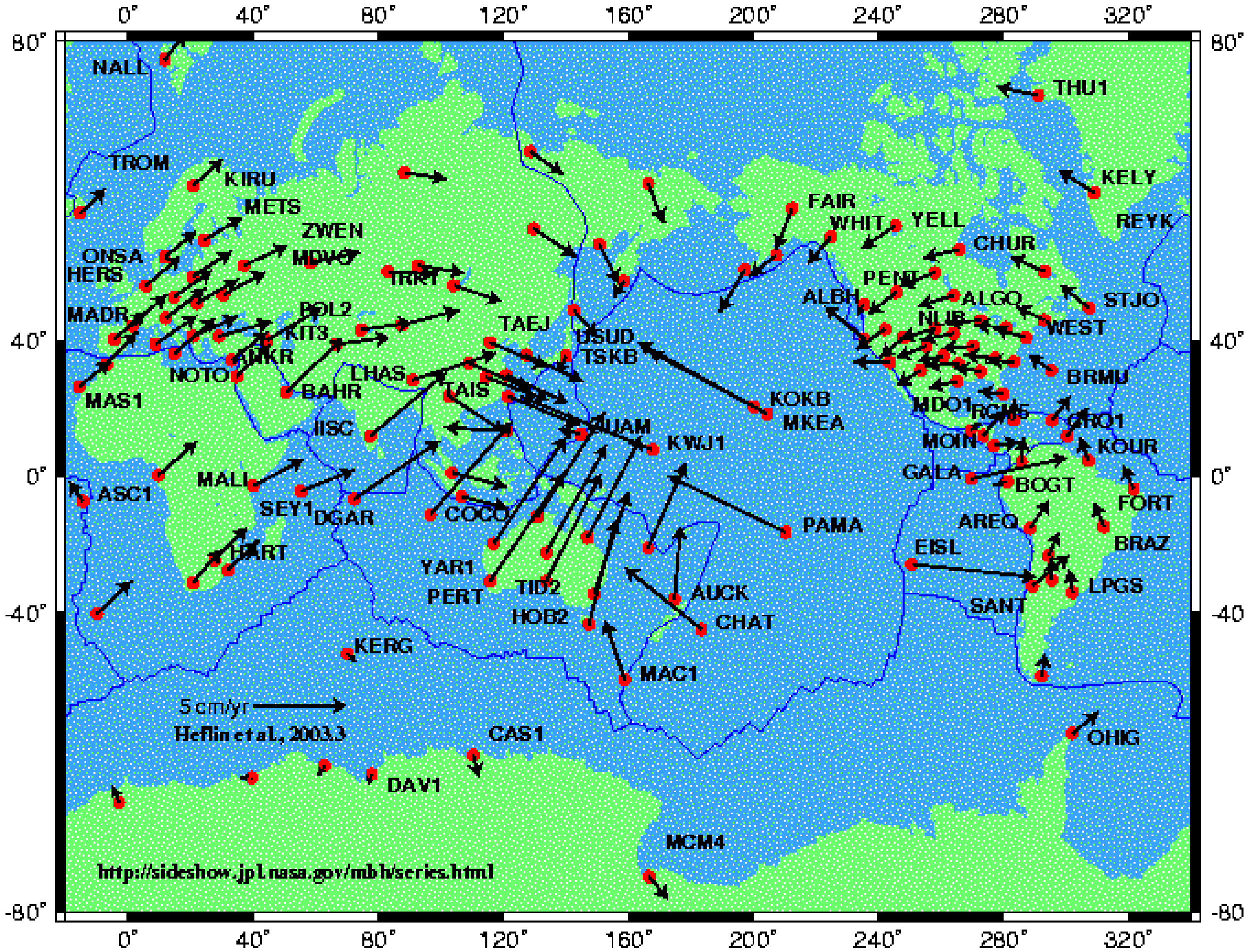

Figure 3: Global GPS Velocity Field

Acknowledgment

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Lefevre, F., F. Lyard, C. Le Provost, and E. J. O. Schrama, *Journal of atmospheric and oceanic technology,* 19 (9), 1345-1356, 2002.

Comparison of a GPS-defined global reference frame with ITRF2000
Heflin, M., D. Argus, D. Jefferson, F. Webb, and J. Zumberge, *GPS Solutions,* Volume 6, No. 1-2, pp. 72, 2002.

GPS Orbit and Earth Orientation Parameter Production at NOAA for 2002

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, William H. Dillinger, Jim Ray, Stephen Hilla

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 60-70 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

A few minor software enhancements were made during 2002. PAGES/GPSCOM, both developed at NGS, remain the software tools used for orbit production. During 2002, additional options were added to PAGES to allow for weighting by satellite and elevation angle; these options continue to be tested. Changes made to the preprocessing programs resulted in improved cycle slip fixing and the ability to reject data sets where the receiver had a runaway channel. Since the beginning of 2000, NGS has modelled deformations driven by ocean tidal loading using the Schwiderski model (Schwiderski 1983). On December 2, 2001 NGS, along with the other Analysis Centers, switched from the IGS97 reference frame to the IGS realization of the ITRF2000 reference frame (IGS00). Beginning with GPS week 1194 (November 24,2002) NGS began sending its final product to the IGS in the new SP3-c format.

Product Evaluation

Figure 2 shows the daily RMS differences between the NGS and IGS final ephemerides for the year 2002 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. Figure 3 shows the daily RMS differences between the NGS and IGS rapid ephemerides. The subplots are defined in the same way as Figure 2. On average over all 2002, NGS EOP match the National Earth Orientation Service Bulletin A values at: X pole -0.181 +/- 0.221 milliarcseconds and Y pole 0.143 +/- 0.209 milliarcseconds. The NGS software only uses double difference carrier phase as an observable and does not attempt to recover a UT1 time series.

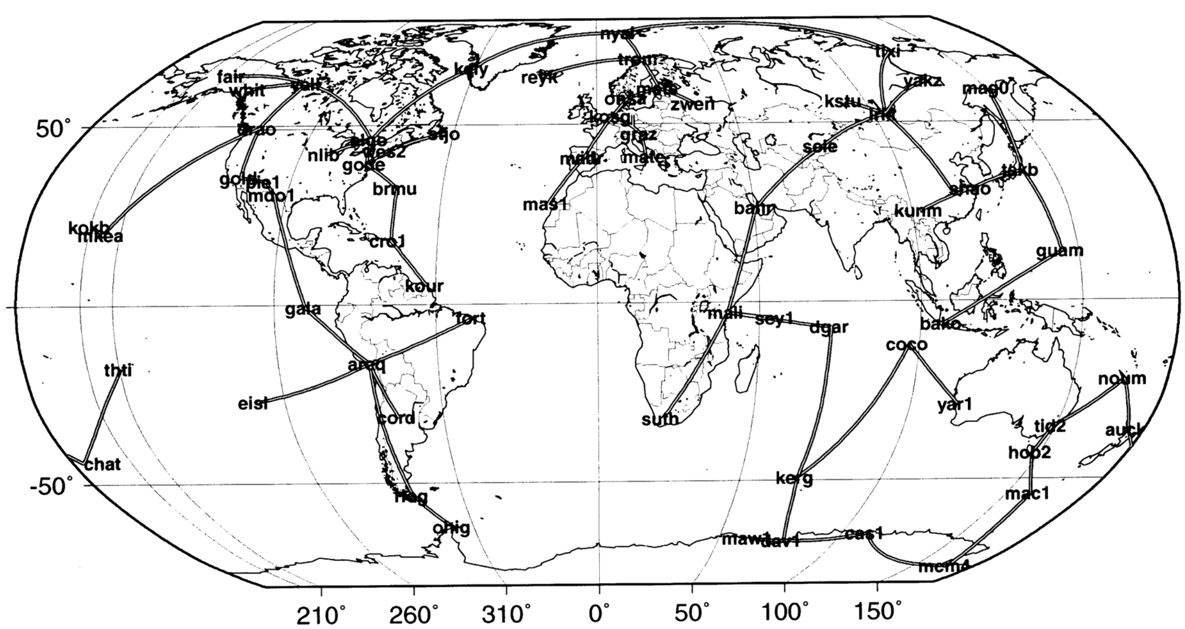

Figure 1.

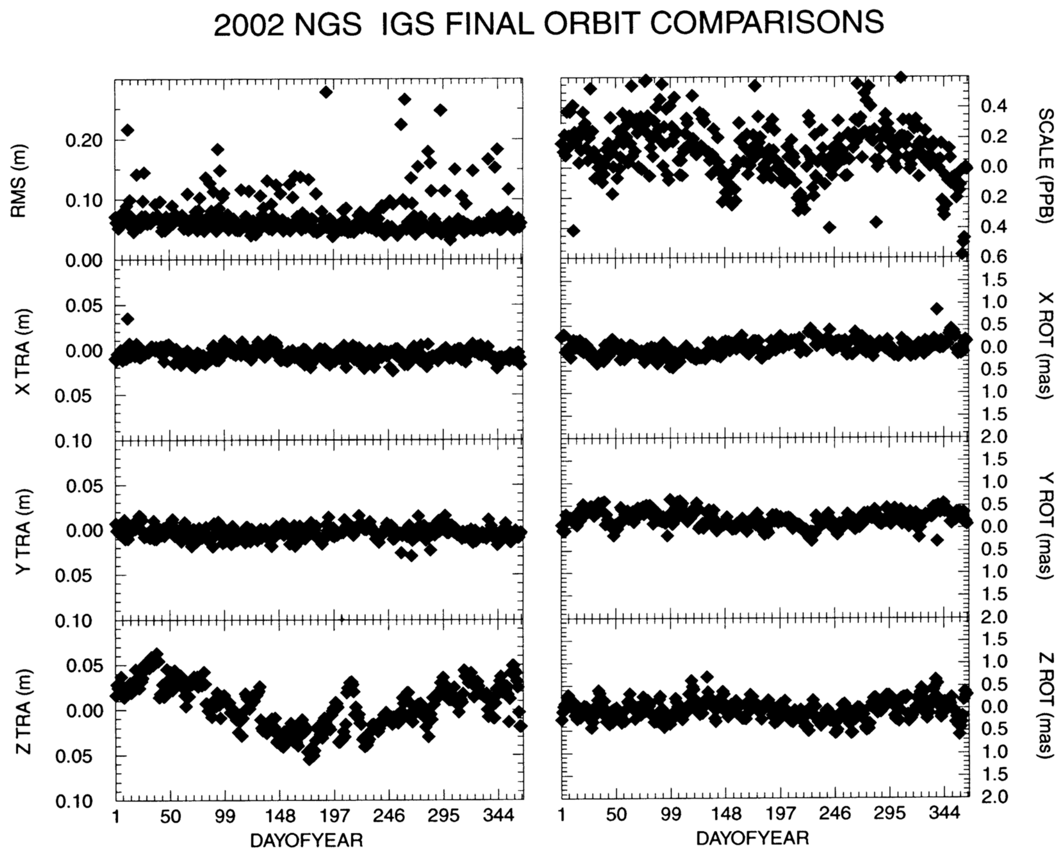
2002 NGS IGS FINAL ORBIT COMPARISONS
RMS (m)
X TRA (m)
Y TRA (m)
Z TRA (m)
SCALE (PPB)
X ROT (mas)
Y ROT (mas)
Z ROT (mas)
DAYOFYEAR
1 50 99 148 197 246 295 344

Figure 2

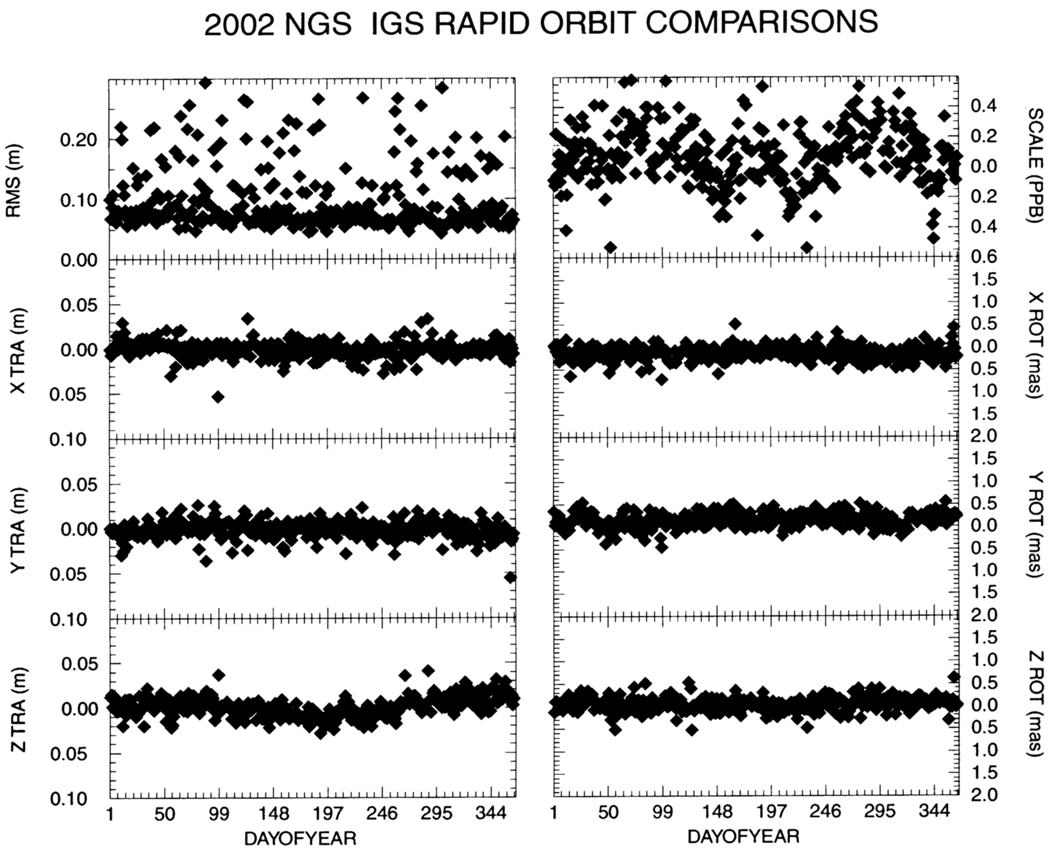

Figure 3

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 6-8centimeters

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 7-10 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)

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NRCan IGS Analysis Center Report for 2002

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During 2002 in addition to its continued contribution of GPS products to the IGS, NRCan had the pleasant task of organizing and hosting the first combined Network, Data and Analysis Center IGS Workshop. In 2002 NRCan was also able to improve the quality of its Rapid and Final orbit estimation. The pages that follow document the major changes to the strategies and software use by NRCan to generate the various products contributed to the IGS.

NRCan Final and Rapid Products

In 2002 NRCan continued to estimate Rapid and Final products using JPL's GIPSY-OASIS version 2.6 software as described in ftp://igscb.jpl.nasa.gov/igscb/center/analysis/emr.can. Table 1 lists several changes made to the NRCan strategy based on IGS recommendations. Table 1 also lists modifications made in order to improve the consistency and reliability of the Rapid and Final solutions.

Table 1: Final/Rapid Processing Strategies Modifications

GPS Week	Modification
1150	Adoption of new set of <P1-C1> bias values (v2.4) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1153	Adoption of new set of <P1-C1> bias values (v3.0) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1165	Implementation of Rapid station clock estimation using precise point positioning (fixing emr rapid orbits and clocks) to augment our Rapid station clock solution. This strategy allows for estimation, and contribution to the IGS Rapid Timescale Product (IGRT) of station clock values for all IGS stations with stable frequency standards.
1167	Implementation of Final station clock estimation using precise point positioning (fixing emr final orbits and clocks) to augment our Final station clock solution. This strategy allows for estimation, and contribution to the IGS Final Timescale (IGST) of station clock values for all IGS stations with stable frequency standards.

1167	Implementation of ambiguity fixed solution for both Rapid and Final products.
1190	Re-aligned NRCan Final UT1-UTC value to VLBI derived value (Bulletin A) on day 0 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1191	Re-aligned NRCan Rapid UT1-UTC value to VLBI derived value (Bulletin A) on day 3 and then resumed NRCan's normal daily estimation procedure for UT1-UTC.
1195	Adoption of new sp3c orbit format.
1197	Adoption of new set of <P1-C1> bias values (v3.2) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.

Ambiguity Resolution

During 2002 ambiguity resolution was implemented for both the Rapid and Final product estimation. Ambiguity resolution was implemented for the NRCan Final products estimation starting with GPS week 1167 day 0 and for the Rapid estimation starting with GPS week 1167 day 3. Improvements made by JPL in GIPSY-OASIS v2.6 as well as improved hardware implemented by NRCan in late 2001 finally made ambiguity fixing feasible. Under the current hardware and software configuration, ambiguity fixing increases the processing time by 1-2 hours for a Rapid solution and 2-3 hours for a Final solution. However the Rapid solution was contributed to the IGR combination more than 95% of the days in 2002 compared to only 79% in 2001 due to improved pre-processing techniques used for data screening. Resolving ambiguities significantly improved the consistency of the Rapid and Final solutions with respect to IGS. Figure 1 shows the Rapid orbit daily rms with respect to the IGR combination. Figure 2 shows the Final orbit rms with respect to the IGS combination. Developments are underway to further increase the consistency of NRCan Rapid and Final products in 2003.

NRCan Ultra Rapid Products

Processing Strategy and Changes

In 2002, NRCan continued the development and delivery of its Ultra Rapid Products (EMU). The most important improvement in 2002 was the introduction of the Ultra Rapid satellite clocks starting on October 31. Our Ultra Rapid overall strategy has not changed. Orbits and Earth Rotation Parameters (ERP) are still estimated first followed by the estimation of satellite clocks. For the satellite clocks, GPS data for the last 24 hours are gathered and processed at a 15-minute rate. Only 30 to 33 stations can be process due to CPU time limitation. Station selection is mostly based on the longest time span. EMU orbits and ERPs are held fixed and station coordinates (IGS2000) are constrained to their apriori standard deviation. Finally, satellite and station clocks along with hourly station TZDs and real ambiguities are estimated. The 24-hr estimated satellite clocks are then fitted and propagated using the following function:

$$CLK_{PRN} = A_{PRN} + B_{PRN}\Delta t + C_{PRN} SIN(D_{PRN}\Delta t + E_{PRN}) \quad (1)$$

where: A_{PRN} is the offset
B_{PRN} is the drift
C_{PRN} is the amplitude
D_{PRN} is the frequency fixed at $\frac{1}{12hr}$ for all PRN
E_{PRN} is the phase shift
Δt is the time

Equation (1) is then used to generate the 24-hr satellite clock predictions needed. The major changes to our Ultra Rapid processing strategy in 2002 are listed in Table 2. The reader is referred to previous IGS Technical Reports for more details on the processing strategy used.

Table 2. Modifications to NRCan Ultra Rapid processing strategy in 2002.

Date	**Doy**	**Description of Changes**
Apr. 24, 2002	114	Use of 10 degree elevation cutoff angle.
May 06, 2002	126	Use of 5 degree elevation cutoff angle.
Jun. 14, 2002	165	Station selection improved. It now uses some QC values such as the hourly number of observations and gaps.
Jul. 4, 2002	185	Inclusion of marginal satellites.
Oct. 31, 2002	304	First Ultra Rapid clock submission.
Dec. 1, 2002	335	Adoption of new sp3c orbit format.
Dec. 20, 2002	354	Adoption of new set of <P1-C1> bias values (v3.2) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.

Results

This section shows the comparison of NRCan Ultra Rapid orbits, clocks and ERP products (EMU) with respect to the IGS Ultra Rapid (IGU). Six graphics are presented covering year 2002. Figure 3 shows the orbit RMS, Median RMS and Weighted RMS (WRMS) with respect to IGU (estimated and predicted portions not separated). Spikes can still be seen in the orbit RMS and WRMS plots. This indicates that NRCan (and other ACs at times) had problems modeling some satellite orbits and acknowledging it. Figure 4 shows the clock RMS with respect to IGU over a 48-hour period (i.e., estimated and predicted portions not separated). The graphic basically shows the overall quality of the predicted clocks since their precision is much worse than the precision of the estimated clocks. The quality of the estimated part is of the order of 0.2 to 0.4 ns (not shown here). Two spikes can be noticed on November 27 and December 22. The first one is not real since one AC's clock solution had a reference clock jump not acknowledged in the Ultra Rapid Combination resulting in high clock RMS for all ACs. The second one is real and was related to some processing problems with PRN26. Figures 5 and 6 show the Translations, the Rotations and Scale for EMU with respect to IGU. Figures 7 and 8 show the pole (Xp, Yp, Xp_{rate}, Yp_{rate}) and LOD comparisons with respect to IGU for both the estimated and predicted portions of EMU respectively.

Future Work (Ultra-Rapid)

In the near future, we will investigate the feasibility of estimating satellite orbits and clocks every hour instead of every 3 hours. If possible, we would also like to implement the estimation of satellite clock corrections every 5 minutes instead of 15 minutes. This would greatly benefit the Precise Point Positioning (PPP) users. It's also our intention to at least try to acknowledge badly behaving satellites that are not presently detected as they can cause serious problems to some users.

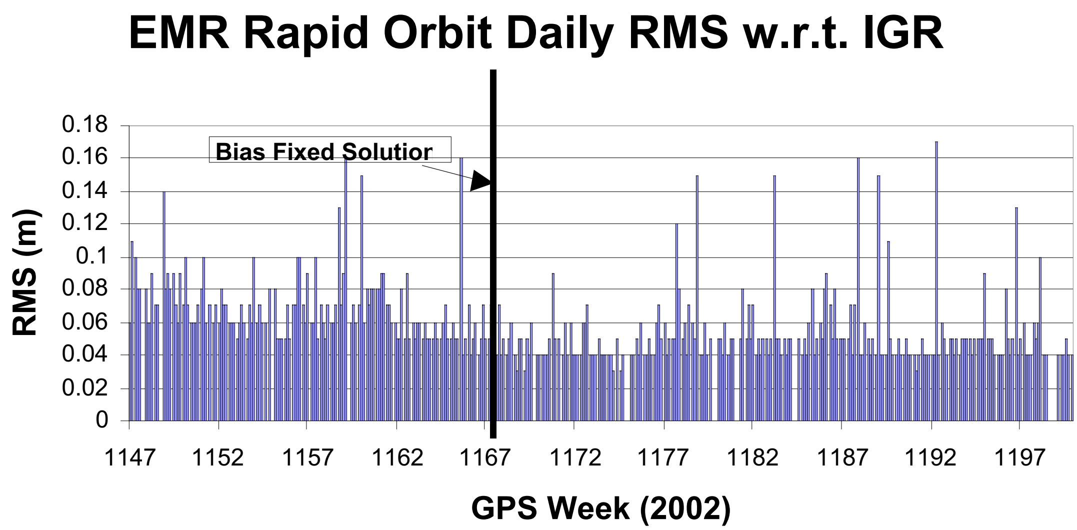

Figure 1: NRCan (EMR) Rapid orbit daily RMS w.r.t. IGR for year 2002

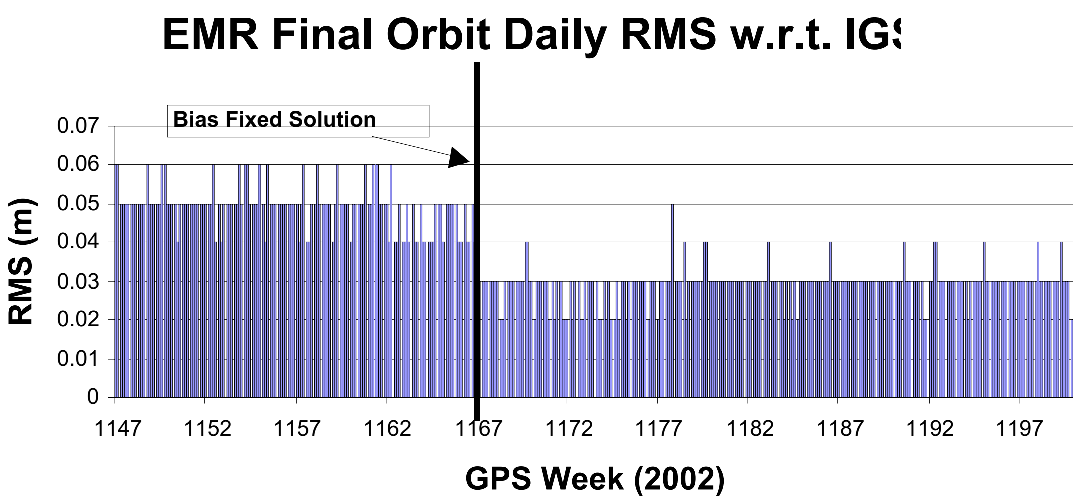

Figure 2: NRCan (EMR) Final orbit daily RMS w.r.t. IGS for year 2002

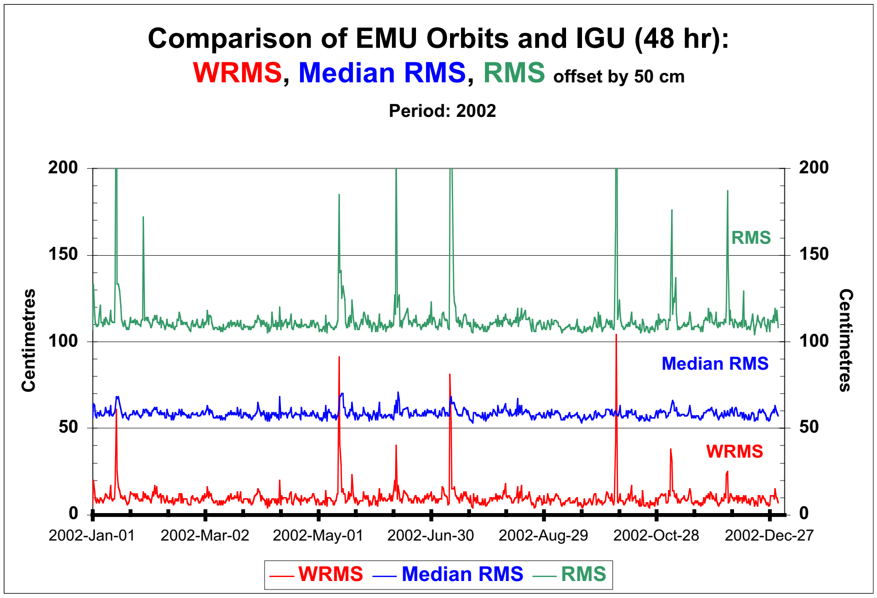

Figure 3: Comparison of EMU Orbits and IGU for 2002 (48-hour Orbit): **WRMS**, **Median RMS** and **RMS**, each offset by 50 cm.

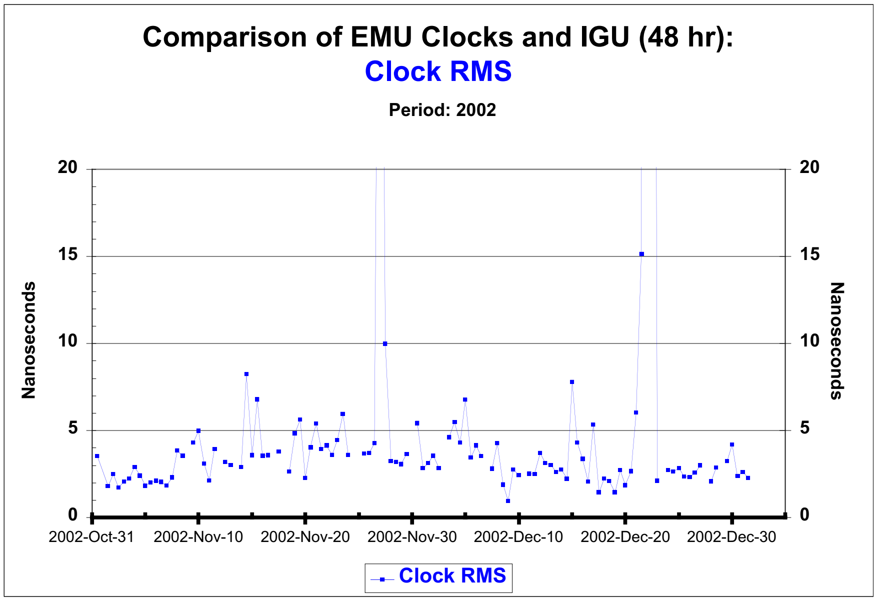

Figure 4: Comparison of EMU Clocks and IGU for 2002 (48-hour Clocks): **RMS**.

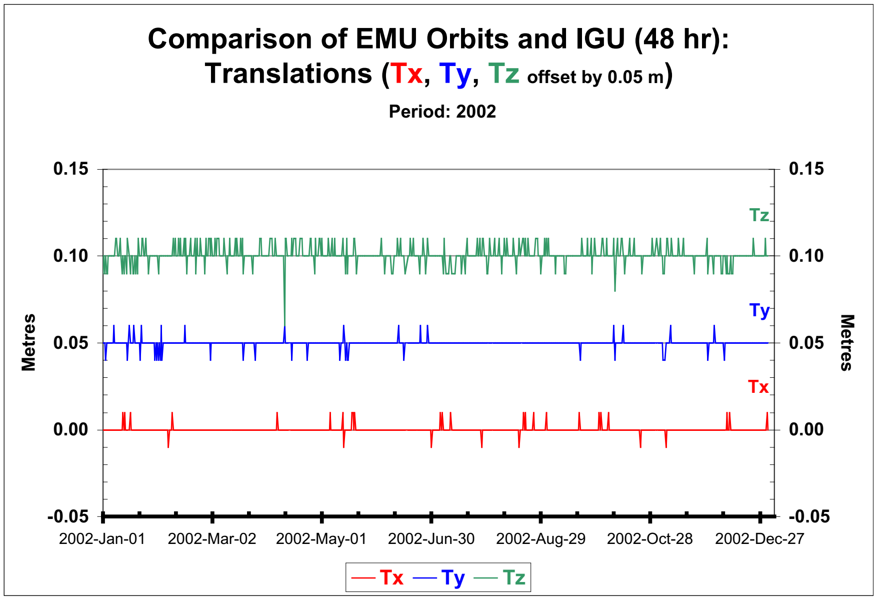

Figure 5: Comparison of EMU Orbits and IGU for 2002 (48-hour Orbit): **Translations Tx, Ty** and **Tz**, each offset by 0.05 m.

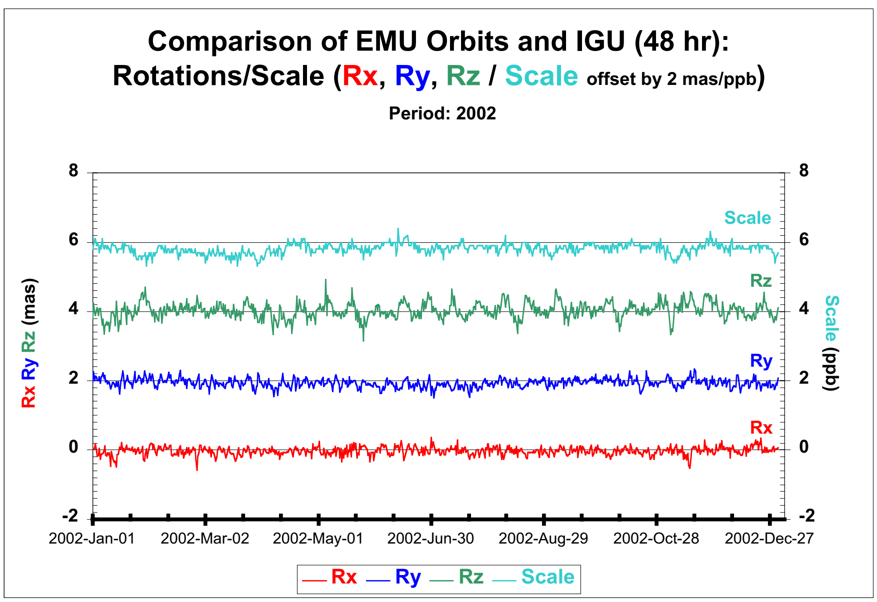

Figure 6: Comparison of EMU Orbits and IGU for 2002 (48-hour Orbit): **Rotations Rx, Ry**, **Rz** and **Scale** each offset by **2 mas**, **2 mas**, **2 mas** and **2 ppb** respectively.

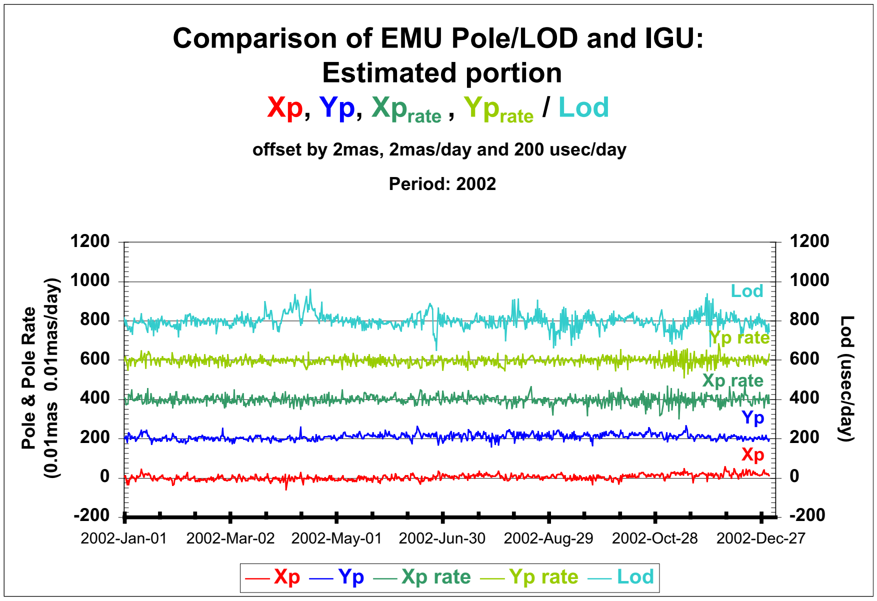

Figure 7: Comparison of EMU Estimated Pole/LOD and IGU for 2002: **Xp**, **Yp**, **Xp$_{rate}$**, **Yp$_{rate}$** and Lod, each offset by **2 mas**, **2 mas**, **2 mas/day**, **2 mas/day** and **200 usec/day** respectively.

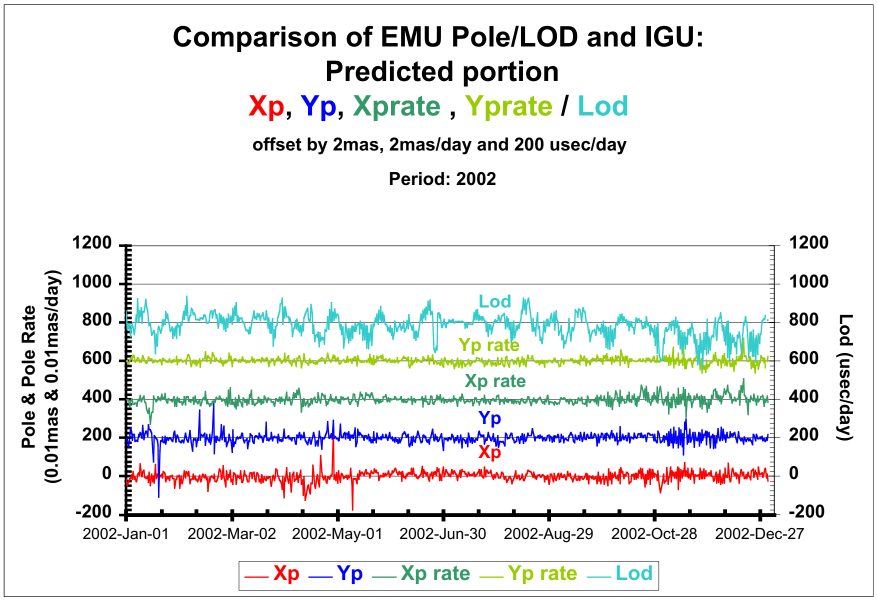

Figure 8: Comparison of EMU Predicted Pole/LOD and IGU for 2002: **Xp**, **Yp**, **Xp$_{rate}$** , **Yp$_{rate}$** and **Lod**, each offset by **2 mas**, **2 mas**, **2 mas/day**, **2 mas/day** and **200 usec/day** respectively.

SOPAC 2002 IGS Analysis Center Report

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Introduction

The Scripps Orbit and Permanent Array Center (SOPAC) at the Scripps Institution of Oceanography (SIO) has been producing precise satellite orbits, Earth Orientation Parameters, and station positions since 1991 when the Permanent GPS Geodetic Array (PGGA) project was initiated in southern California. SOPAC has been an analysis center from the inception of IGS.

This report covers the activities between 2000 and 2002, and will focus on SOPAC's GPS analysis strategy, changes in the software/procedure, and a review of some of the results.

Products Submitted and Served

SOPAC provides both processed products as well as observation data products (see companion SOPAC global data center report) accessible through anonymous ftp at (ftp://garner.ucsd.edu) and http (http://garner.ucsd.edu/), with explanatory information on our webpage (http://sopac.ucsd.edu/).

There are four types of processed products that SOPAC contributes to IGS at three latency levels. The products are summarized in Figure 1 and Table 1.

Analysis Procedure

SOPAC "final" solutions are based on daily sessions in distributed mode, that is, we divide the global network into sub-networks. During the period 2000-2002, three sub-networks were used (see Network Configuration below). Once the daily solutions are produced for a given GPS week, the loosely constrained solutions are fed into a weekly combination analysis, in which the orbits, EOP, and site positions are tied to a designated reference frame by constraining the positions of a group of selected core sites.

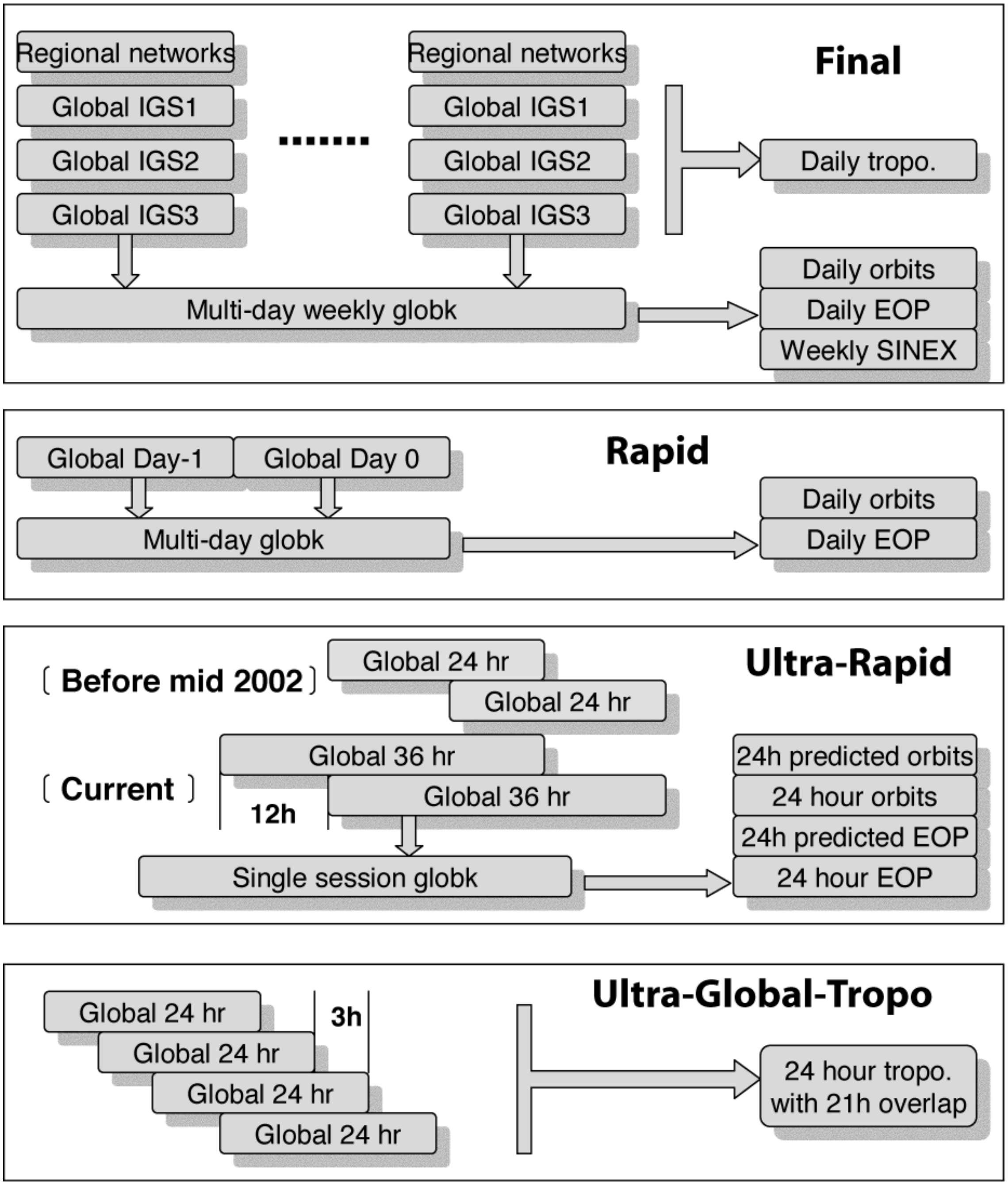

Figure 1. Flow chart for SOPAC final, rapid, ultra rapid processing and products.

SOPAC "rapid" solutions are based on multi-day solutions, that is, current day and previous day. The original two sub-network scheme, maximum 26 sites each, has been replaced by single network, up to 36 sites, since late 1999. This change was based on the evaluation of the orbit /EOP performance and the consideration of processing efficiency.

After the introduction of IGS ultra rapid products from GPS week 1075, SOPAC has contributed its 00h and 12h hourly orbit solutions. This process is based on a single 24-hour session using data from a single network of up to 38 sites.

SOPAC also contributes to the IGS near real-time global tropospheric delay product using a sliding window scheme. 24-hour session data from 40+ selected sites are processed every 3 hours with a latency of about 2 hours.

The main processing engines are GAMIT [*King and Bock*, 2002] and GLOBK [*Herring*, 2002].

The related software version changes and the applied model parameter changes for the above solutions are summarized in Table 2. More detailed processing parameters, models applied [*McCarthy*, 1992, 1996; *Beutler et al*., 1994; *Springer et al*., 1998; *Bar-Sever*, 1996; *Dong and Bock*, 1989; *Niell*, 1996, *Wu et al*., 1993] and processing strategies remained unchanged and have been reported in a previous SOPAC annual AC report [*Fang et al*., 1998]. The ocean loading model used is based on the *Scherneck* [1991] model.

Since all products are defined with respect to the global reference frame, the choice of core sites and the constraints on their positions and velocities play an important role in data processing. The constraint histories for final and rapid solutions can be found on the SOPAC webpage.

Network Configuration

For SOPAC final solutions, the global sites are grouped into 3 sub-networks: IGS1, IGS2, and IGS3, of 50+ sites each (Figure 2). IGS3 mainly includes the IGS defined core stations. Since there is a high concentration of global stations in Europe, some of the ‘global’ stations are grouped into SOPAC’s EURO regional sub-network. Figures 1-3 show the basic network configurations for IGS1, IGS2, and IGS3. The sites in the maps include all sites processed within 2000 and 2002 time frame. Since the sites in each network have been adjusted from time to time, the detailed history of site inclusion and exclusion can be found in the constraint history plots.

Reprocessing of IGS Products

SOPAC has completed the reprocessing of its entire data holdings (starting in 1991) including both global and regional networks [*Nikolaidis*, 2002; *Bock et al*., 2003]. We now have a consistently analyzed data set and all SOPAC data products are referenced to ITRF2000 [*Altamimi et al*., 2002]. Web-based interfaces have been developed to facilitate users access to the IGS products and their derivatives. See, for example, http://sopac.ucsd.edu/cgi-bin/refinedJavaTimeSeries.cgi; http://sopac.ucsd.edu/processing/coordinates/).

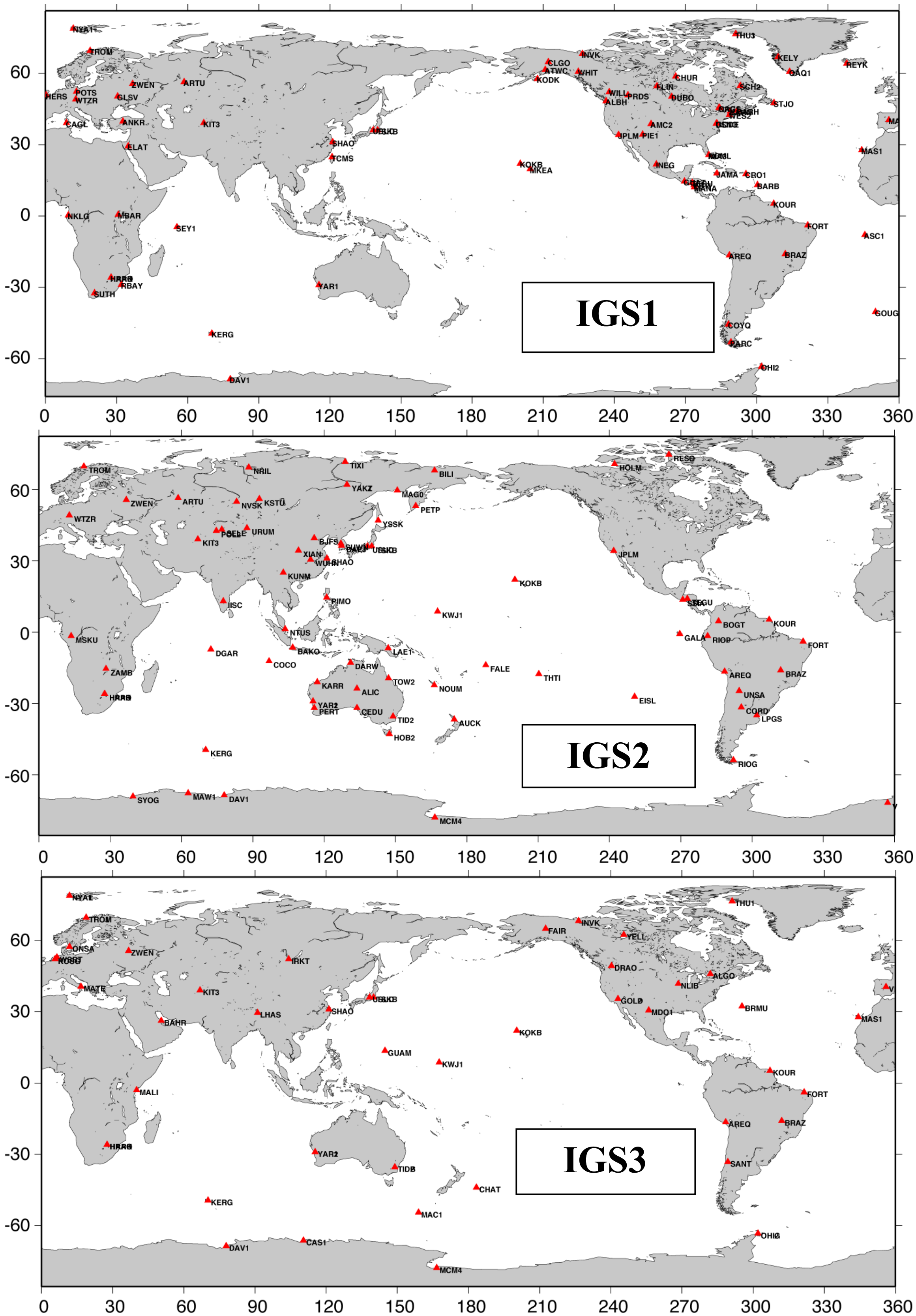

Figure 2. Site distribution of sub-networks for SOPAC final solutions (2000-2002).

Table 1. SOPAC IGS products (2000-2002)

Type of Product	Latency	File Format	*Description*
Final Products	4-8 days	siowwwwn.sp3	Daily precise orbits
		siowwww7.erp	Weekly EOP (pole, UT1-UTC, LOD)
		siowwww7.snx	Weekly SINEX files
		siowwwwn.tro	Hourly tropospheric delay updated daily
		siowwww7.sum	Weekly processing summary
Rapid Products	18 hours	sirwwwwn.sp3	Daily rapid orbit solutions
		sirwwwwn.erp	Daily rapid EOP solutions
Ultra Rapid Products	2 hours	siuwwwwn.sp3 *siuwwwwn_hh.sp3	24 hr estimated + 24 hr predicted orbits
		siuwwwwn.erp *siuwwwwn_hh.erp	24 hr estimated + 24 hr predicted EOP
		siowwwwn_hh.tro	Hourly tropospheric delay updated ever three hour

Latency is defined as the time period from product delivery to the end time of the observation session used in the data processing.
* new naming convention after the product update frequency changed from daily to every 12 hour.

Table 2. Reference frame, tidal model applied, and software version change history for SOPAC products (2000-2002)

	Reference frame		Pole tide/Ocean tide		GAMIT version		GLOBK version	
Final	2000 001	Itrf97	2000 001	No/No	2000 001	9.93	2000 001	5.05
					2000 122	9.92	2000 122	5.03
					2000 170	9.93	2000 170	5.04
			2000 331	Yes/Yes	2000 331	9.94	2000 331	5.05
	2001 302	Itrf00						
	2001 340	Itrf00U						
					2001 364	9.95		
							2002 055	5.06
Rapid/ Ultra Rapid	2000 001	Itrf97	2000 001	No/No	2000 001	9.93	2000 001	5.05
					2001 004	9.94		
	2001 345	Itrf00U						
					2001 363	9.95		
			2002 008	Yes/Yes				
							2002 035	5.06

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USNO IGS Associate Analysis Center Annual Report for 2002

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Summary

USNO contributed rapid, ultra-rapid and tropospheric products to the IGS during 2002. The development of a new way to assign weights to satellite orbits, combining the orbits produced from different approaches, and the introduction of multiple data arc processing to the estimated part of the ultra-rapid solutions were major activities during 2002. The acquisition of a new HP Unix workstation allowed USNO to upgrade to GIPSY/OASIS 2.6, and increase the number of sites processed in both the rapid and ultra-rapid solutions.

Changes to Routine Analysis

Table 1 shows the changes to USNO's routine analysis in 2002. The basic strategy remained unchanged for the rapid solutions. The most important changes to the rapid solution strategy were made to the post-processing scripts. Comparisons between the USNO rapid solutions and the preceeding IGS ultra-rapid combinations provide the accuracy codes for the sp3 orbit files. In addition, the orbit files from two computers which use slightly different approaches, and different versions of GIPSY/OASIS, were merged using the accuracy codes to indicate appropriate weights. Our use of GIPSY/OASIS 2.5 has a tendency to produce poor orbits for one or two satellites per solution with no indication of a problem in the formal errors. The satellites with poor orbits were not necessarily the same on the two computers. Therefore, merging orbits using appropriate weights could, and did, mitigate this problem. GIPSY/OASIS 2.6 is a much improved product and produces far fewer poor orbits.

The initial strategy used for the estimated part of the ultra-rapid solutions was merely a scaled-down version of the strategy used for the rapid solutions. In 2002, one computer was switched to multiple data arc processing. This approach achieves greater speed by processing data in three-hour arcs, thus permitting USNO to increase the number of sites used from 27 to 34. The strategy used on the new HP Unix was to process a single solution with more sites rather than two sequential solutions with fewer sites.

Slabinski's modification of the CODE radiation force model continues to be used for the predicted part of the ultra-rapid orbits. A satellite's parameter values which are used in the model are adjusted, as required, so that the model predictions match the observed secular perturbations to the GPS orbit. Orbit prediction is difficult for certain older "problem" satellites because of an attitude control thruster firing every ~2 days which causes large deviations in the satellite position from the predicted values. These "problem" satellites have been given very low weight so that the typical 30 m RMS prediction error following a thruster firing makes a negligible contribution to the weighted RMS ultra-rapid prediction error. Efforts to move the

Ultra-rapid prediction software to the new workstation were frustrated by a FORTRAN compiler error that was not uncovered until year's end.

Table 2 lists the products that were submitted to the IGS in 2002. For more details regarding the computational strategy see the USNO Analysis Strategy Summary at ftp://igscb.jpl.nasa.gov/igscb/center/analysis/usno.acn.

Table 1: Changes to rapid and ultra-rapid solutions.

2002-01-03	Implemented the use of comparisons of USNO orbits with IGS ultra-rapid combined orbits to set accuracy codes for rapid solutions. Implemented the mergers of sp3 rapid orbit and Earth orientation parameter files from two different computers.
2002-01-16	"Problem" satellites PRN 15, 17, 21, 23, and 29 were automatically assigned very low weight in ultra-rapid orbit files.
2002-01-20	Implemented new <P1-C1> pseudorange bias values.
2002-02-08	The GIPSY program spx2eci was modified to include sub-daily terms in the Earth orientation parameters when transforming IGS determined Earth-fixed positions to inertial space for use in a trajectory fit for ultra-rapid predictions.
2002-02-13	Updated cc2noncc routine.
2002-03-28	Added 15 more sites for clock solutions using precise-point positioning.

Table 1: Changes to rapid and ultra-rapid solutions (Cont'd)

2002-03-14	Implemented the use of comparisons of USNO orbits with IGS ultra-rapid combined orbits to set accuracy codes for ultra-rapid solutions. Implemented the merging of sp3 ultra-rapid orbit and Earth orientation parameter files from two different computers.
2002-06-26	First submission of multiple data arc processing results in the estimated part of the ultra-rapid solutions.
2002-06-18	Full implentation of the use of secure shell for the transmission of ultra-rapid solutions to the IGS.
2002-09-07	First submission of rapid solution which contained results from the new workstation utilizing GIPSY/OASIS 2.6 and 40 sites per solution.
2002-10-02	First submission of an ultra-rapid solution whose estimated part contained results from the new workstation utilizing GIPSY/OASIS 2.6 and 40 sites per solution.
2002-12-01	Began submission of version 'c' of sp3 orbit files to the IGS.

Table 2: USNO products provided to the IGS for GPS week/day wwww/d.

File Name	Frequency	Contents
usnwwwwd.sp3	daily	Estimated GPS satellite positions and clock corrections at 15 minute intervals
usnwwwwd.erp	daily	Estimated Earth orientation parameters
usnwwwwd.clk	daily	Estimated satellite and receiver clock corrections at 5 minute intervals
usuwwwwd.sp3	twice daily	Estimated GPS satellite positions and clock corrections for 24 hours + predicted satellite positions and clock corrections for 24 hours at 15 minute intervals
usuwwwwd.erp	twice daily	Estimated and predicted values of Earth orientation parameters
usuwwwwd.zpd	every three hours	Estimated total zenith tropospheric delay at 30 minute intervals

Performance

Statistics for the USNO rapid orbit and clock solutions are shown in Table 3. The mean and median for the daily values of the weighted root mean square (WRMS), median (MEDI) and clock root mean square (CLK RMS) taken from the IGS Rapid Combinations are given. In addition, the mean and median for the number of receiver clocks per solution, and the number of days that submissions were successfully made are listed. The numbers of receiver clocks per solution for 2001 are reckoned from the introduction of precise-point positioning to augment the number of receiver clocks per rapid solution. The average number of receiver clocks is 69.4 with a median of 75. The values in Table 3 shown significant improvement in all statistics.

Table 3: Rapid solution statistics.

		GPS Orbits WRMS (cm)	GPS Orbits MEDI (cm)	Satellite CLK RMS (ns)	Number of clocks per solution	Number of days submitted
2001	mean	6.9	4.8	0.100	69.4	347
	median	6	5	0.10	75	
2002	mean	3.7	3.6	0.075	91.2	358
	median	4	4	0.07	98	

Statistics for the USNO ultra-rapid orbit and clock solutions are shown in Table 4. The mean and median for the daily values of the weighted root mean square (WRMS), median (MEDI) and clock root mean square (CLK RMS) taken from the IGS ultra-rapid orbit comparisons are given.

In addition, the numbers of successful twice-daily submissions are listed. Note that the satellite clock statistics refer to the prediction performance, not observations of the clocks. The values in Table 4 show significant improvement from 2001 to 2002 in the quality of the orbit solutions, particularly in the WRMS.

Table 4: Ultra-rapid solution statistics.

		GPS Orbits WRMS (cm)	GPS Orbits MEDI (cm)	Satellite CLK RMS (ns)	Number of twice-daily submissions
2001	mean	45.1	18.9	5.356	641
	median	31	17	4.88	
2002	mean	21.1	13.8	5.196	650
	median	15	13	4.63	

IGS

ASSOCIATE ANALYSIS CENTERS

IGS

GLOBAL NETWORK ASSOCIATE ANALYSIS CENTERS

The Newcastle GNAAC Annual Report for 2001-2002

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The GNAAC at University of Newcastle continued activities with submissions of weekly G-network and P-network SINEX files. The analysis procedure outlined previously (Davis & Blewitt, 2000; Nurutdinov et al., 2000) remained unchanged throughout the years 2001-2002. The IGS97 realization of ITRF97 has been used to constrain the solutions for GPS weeks 1065-1142. Starting with GPS week 1143 it has been replaced with IGS00 realization of ITRF2000. Combined solutions for Earth Rotation Parameters (X_p, Y_p, LOD) have been produced starting with week 1159.

G-network Results

A-network SINEX data from all seven global analysis centres (COD, EMR, ESA, GFZ, JPL, NGS, SIO) were processed. The appearance of a station in a minimum of three solutions defines a global station for 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 the P-network along with global stations. During 2002 an average of 116 global and 84 regional stations appeared in the weekly P-network what is higher than during 2001 (103 global and 75 regional stations) and 2000 (100 and 60 respectively).

The loose G-network solution (GNET) is estimated from block of normal equations composed of each de-constrained A-network. The corresponding covariance matrix is augmented to remove Helmert rotation parameter constraints. This solution is constrained later to the CORE network, consisting of 51 stations of IGS97 or 54 stations of IGS00, for the months Jan-Nov 2001 or Dec 2001-Dec 2002 respectively.

Figure 3 shows the weighted RMS of residuals for each weekly A-network solution after Helmert transformation to the weekly loose G-network solution. Values for weighted RMS are in the region 2-9 mm describing repeatability of the G-network estimates.

Figures 4 through 7 show the translational parameters for 7-parameter Helmert transformation from deconstrained AC and GNET solutions to CORE network.

The effect of introducing of IGS00 realisation of ITRF2000 in December 2001 instead of IGS-97 realisation of ITRF-97 used before is seen clearly from Figure 9. Mean values of the scale parameter of the Helmert transformation from AC solutions to the IGS CORE network became 1.5-4 times smaller.

P-network Results

The creation of the P-network is based on the G-network and the weekly input R-SINEXes from the RNAACs. A minimum of three global and one regional stations is required for inclusion of a solution in the P-network. In the “attachment” method of network combination the G-network is not allowed to be perturbed by the R-networks. Figure 8 shows of the RMS residuals of station coordinates after 7-parameter Helmert transformation of the deconstrained R-network to the G-network.

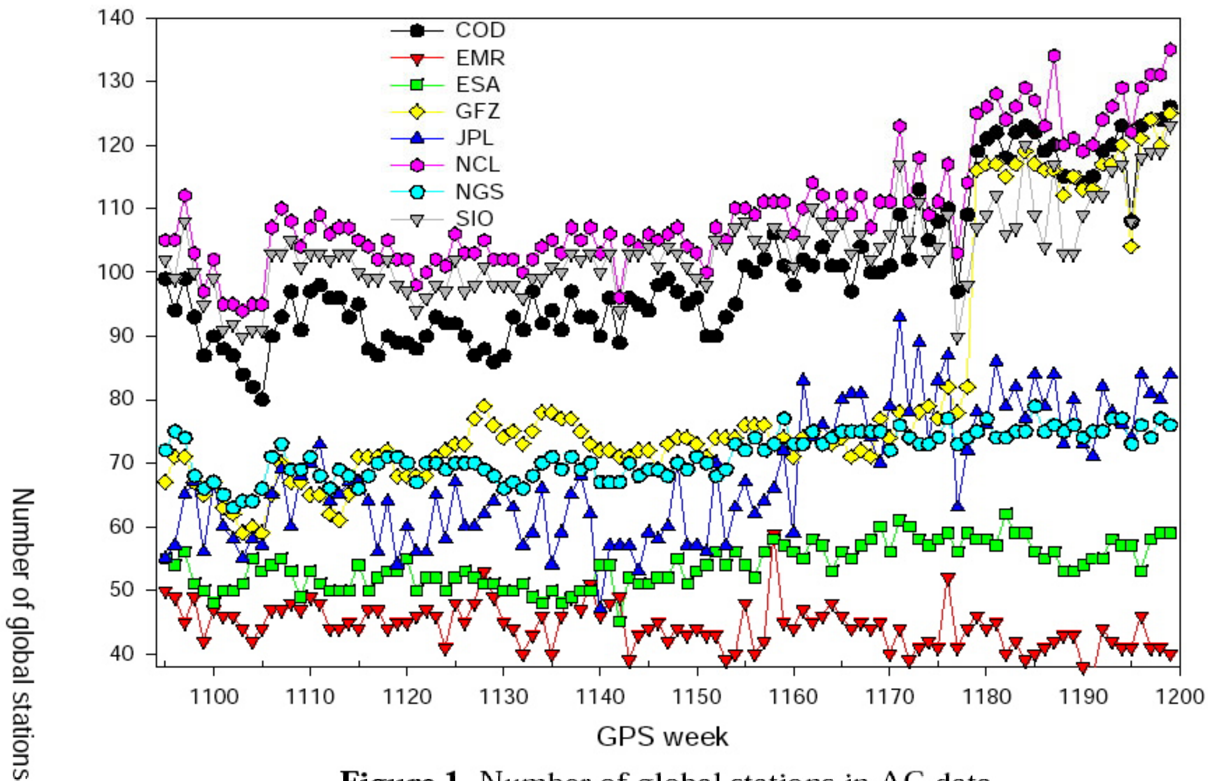

Figure 1. Number of global stations in AC data

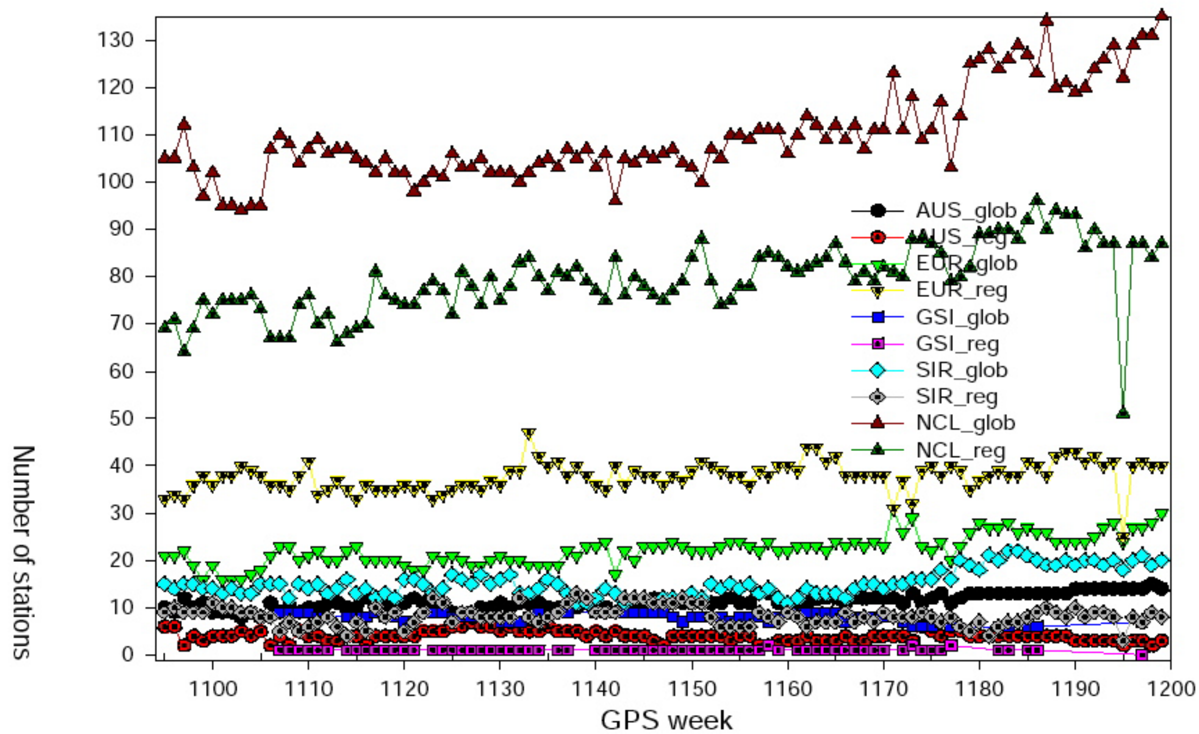

Figure 2. Number of global and regional stations in RNAAC and P-network solutions

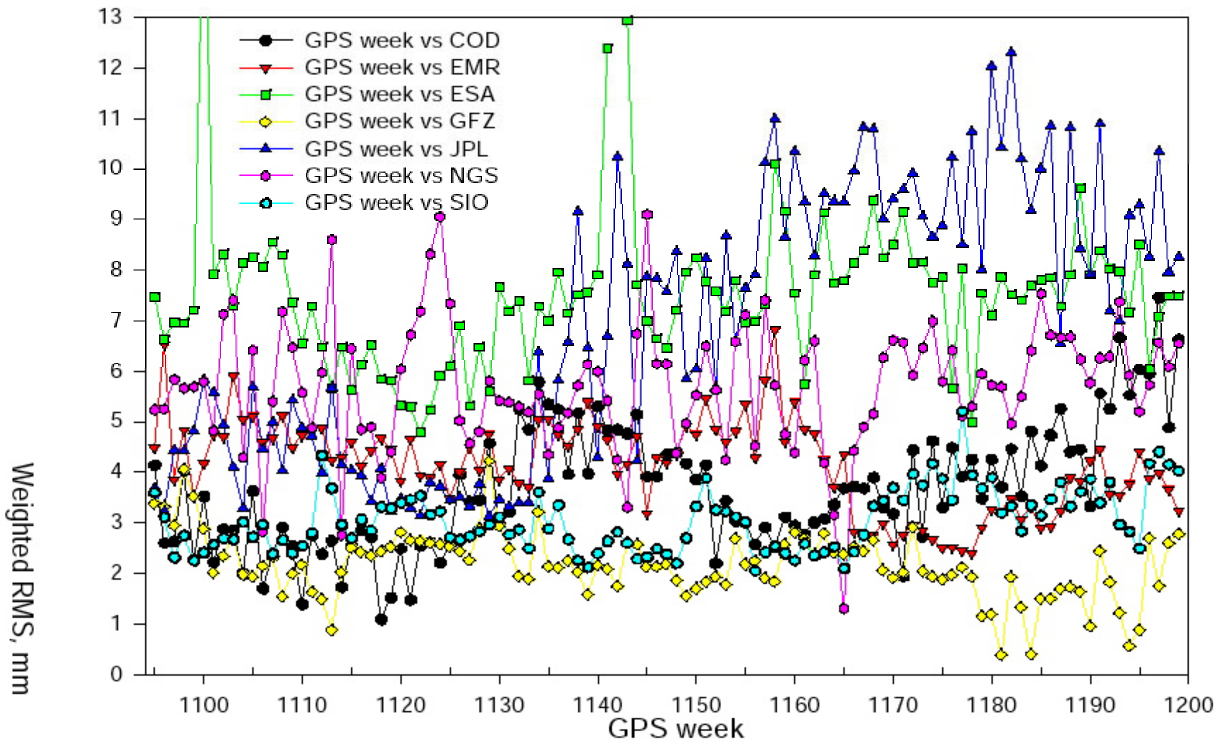

Figure 3. Weighted RMS of residuals for AC network transformation to loose NCL G-network

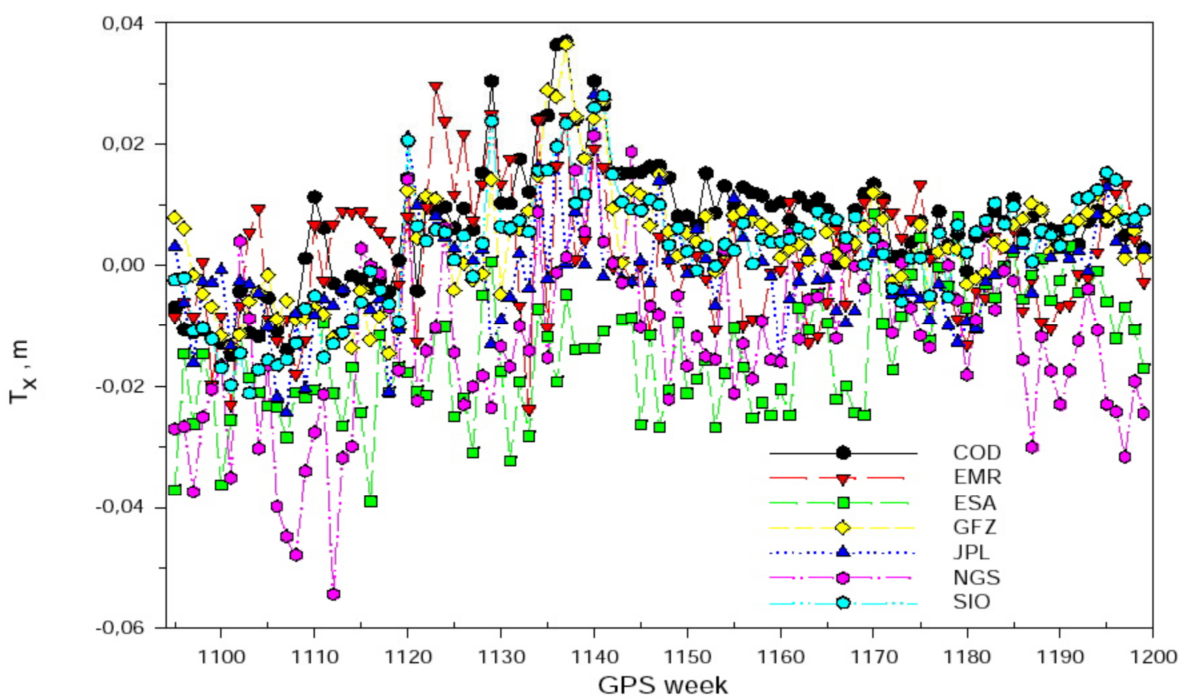

Figure 4. Time series of T_x transformation parameter for the ACs to ITRF

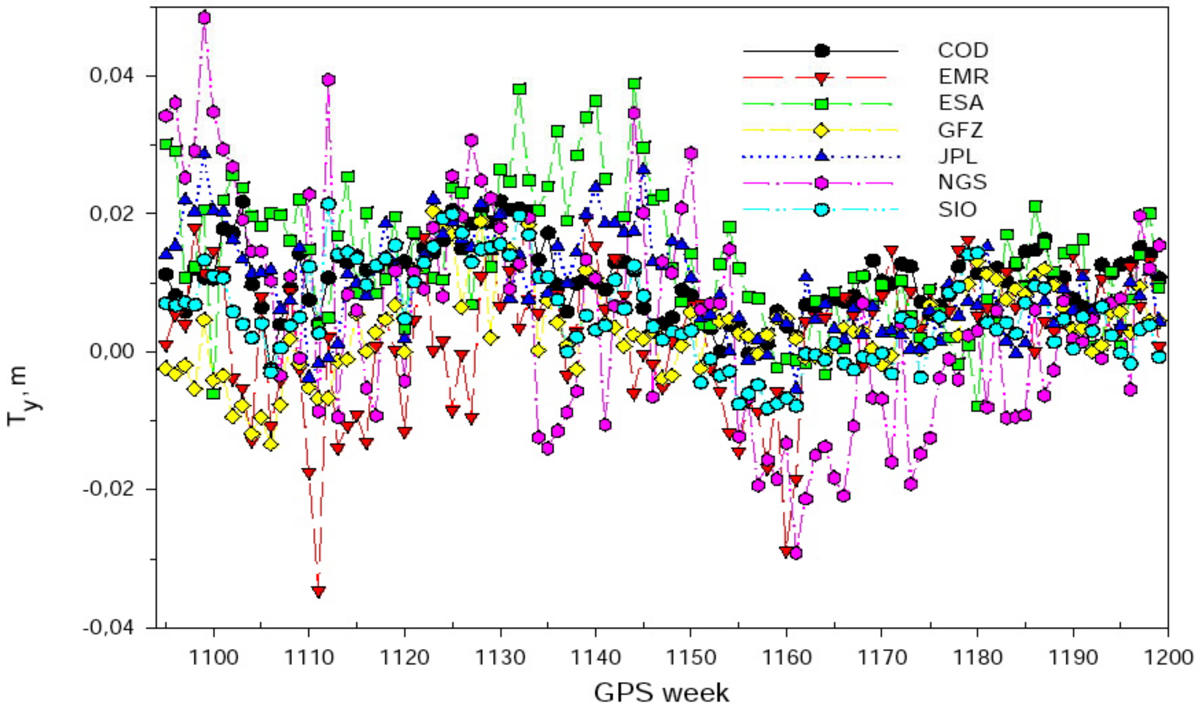

Figure 5. Time series of T_y transformation parameter for the ACs to ITRF

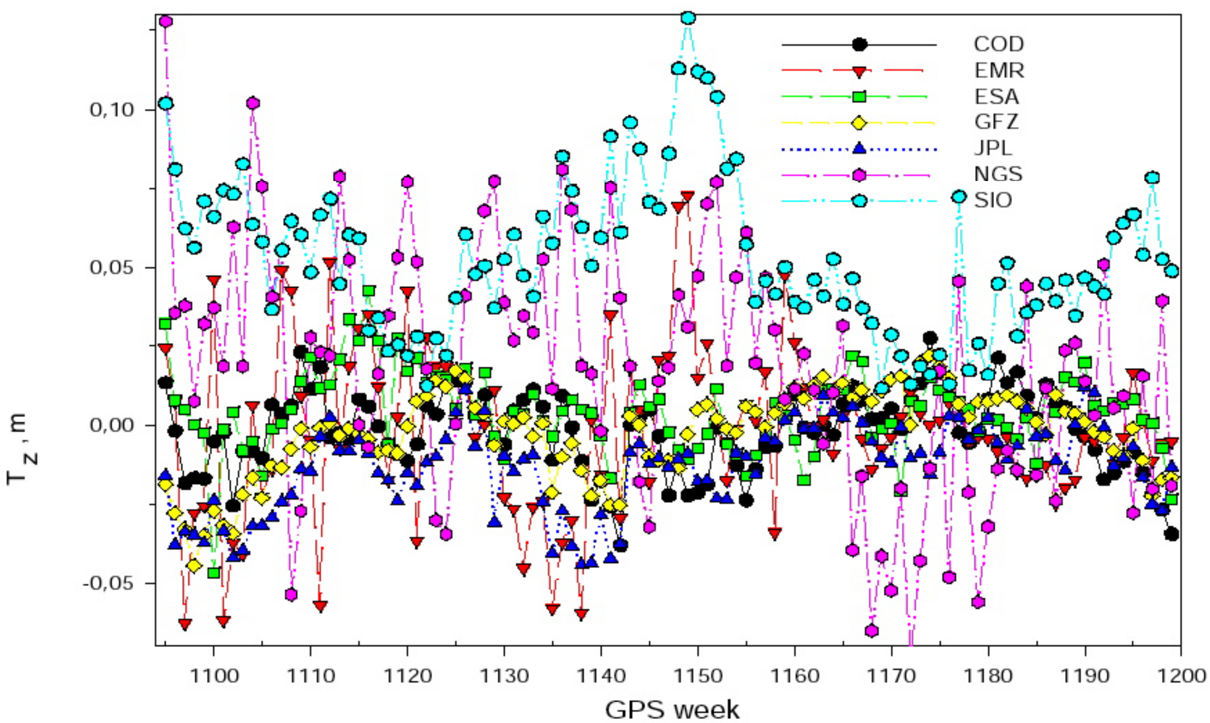

Figure 6. Time series of T_z transformation parameter for the ACs to ITRF

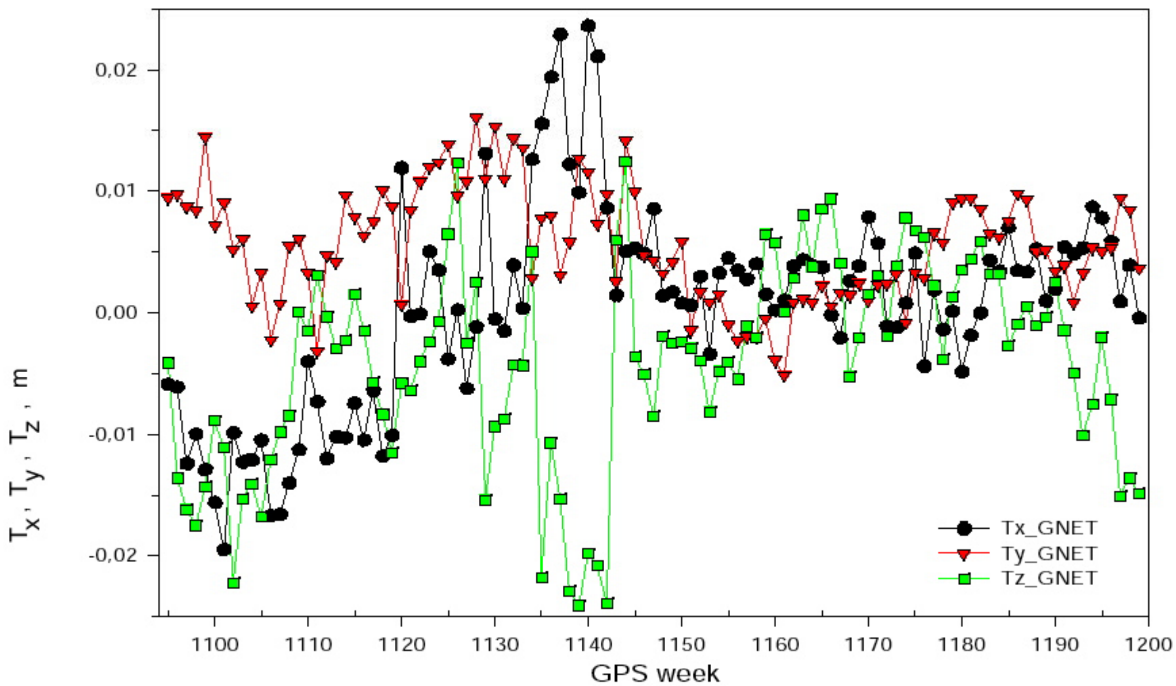

Figure 7. Time series of T_x, T_y, T_z transformation parameters for the NCL GNET to IGS

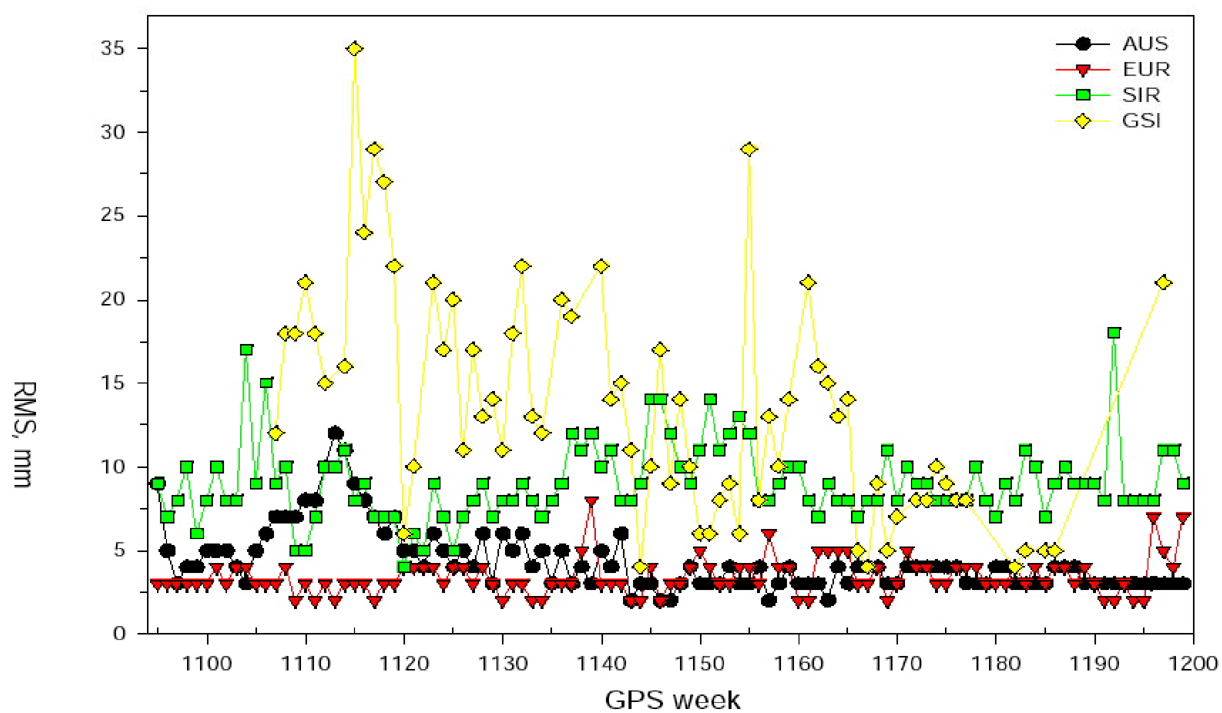

Figure 8. RMS of residuals for RNAAC R-network transformation to loose NCL G-network

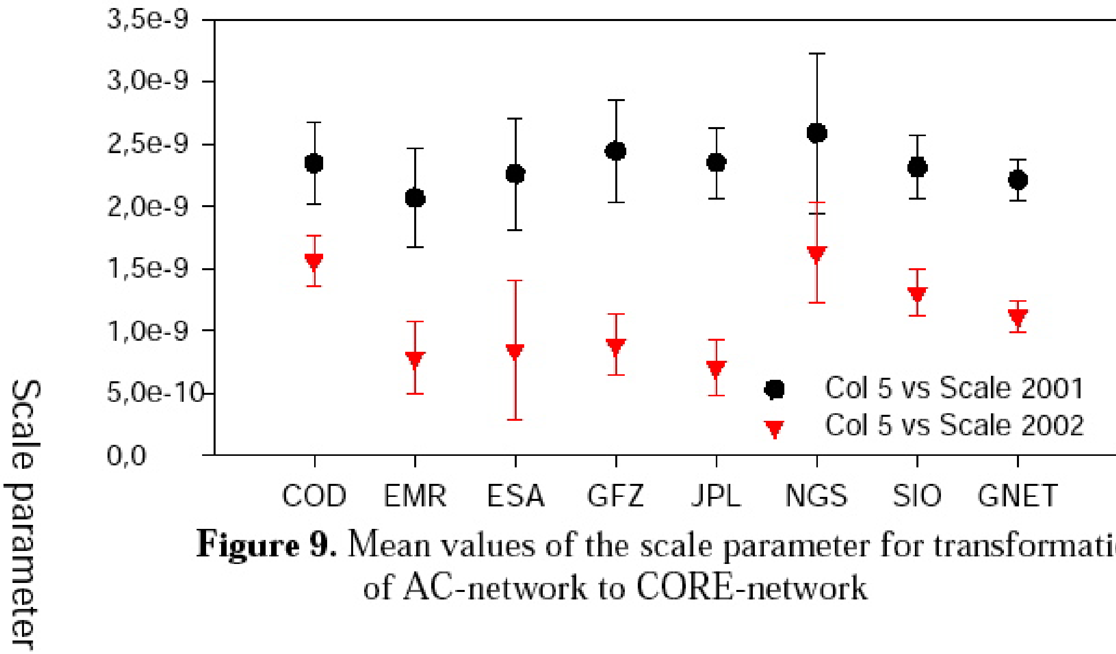

Figure 9. Mean values of the scale parameter for transformation of AC-network to CORE-network

Other Activity

NCL GNAAC P-sinex solutions over a five-year interval have been used to detect seasonal variations of station coordinates and geocentre position (Blewitt *et al.*, 2001a, 2001b). Contribution of seasonal interhemispheric (degree 1) mass transfer to variation in global mean sea level and nonsteric static ocean topography has been calculated, using published GPS results for seasonal degree-1 surface loading from the global IGS network (Blewitt & Clarke, 2003).

An online SINEX-checking facility to assist ACs in submitting SINEX files has been created at http://ucscgi2.ncl.ac.uk/~nkn3.

Summary and Outlook

The GNAAC at University of Newcastle continued to submit weekly G-network and P-network SINEX files to IGS. In the 2003, the Newcastle GNAAC continues to submit combined solutions to IGS. The TANYA software is developing further (Blewitt et al, 2000).

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MIT T2 Associate Analysis Center Report 2001-2002

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Abstract
We discuss the analysis of the 2001-2002 combined solutions generated from the SINEX files submitted by the IGS analysis centers. We highlight the changes to the analysis procedures reported in previous annual reports. Analysis of our combined solutions shows mean fits to the up to 49, and on average 43, IGS reference sites in the P041 solution of 3.0 mm. For the G-SINEX combinations the median root-mean-square (RMS) repeatability in north, east, and height are 1.5, 1.6 and 5.4 mm, respectively for 256 sites. For the P-SINEX combinations, the median RMS repeatabilities are 1.6, 1.8, and 6,0 mm, respectively for 376 sites. The root mean square (RMS) scatter of the differences between daily pole position and IERS Bulletin A values is 0.08 milli-arc-seconds (mas) for both X- and Y-pole position. However, there are mean differences in Y-pole position of 0.39 mas (2001.0) and a rate of –0.09 mas/yr. The RMS scatters of the differences in polar motion rates are 0.09 mas/day for both components. For length-of-day (LOD), the RMS difference to Bulletin A is 0.023 milliseconds (ms).

Analysis Procedure Changes

As reported previously [*Herring*, 1996,1997, 2000], two analyses are performed each week. One of these analyses uses the IGS Analysis Center (AC) weekly A-SINEX files to generate a combined G-SINEX file, and the other uses the Regional Analysis Center (RAC) R-SINEX files combined with the G-SINEX file to generate weekly P-SINEX files. During 2001 and 2002, the G-SINEX files contain 256 sites that were used more than 10 times during the two years and 118 sites that were used at least 100 times. The corresponding values for the P-SINEX files are 376 and 118 sites, respectively. The G- and P-SINEX analyses are performed with 2 and 7 weeks delays.

The basic procedures we use are documented in the weekly summary files submitted with the combined SINEX files. During the 2001-2002 interval, we used the IGS realization of ITRF97 as given in IGS00P41_RS51. After GPS week 1125, we stopped using AREQ in the frame definition and variance factor calculations because of 0.5 m displacement of the site due to a nearby earthquake. After week 1110, we stopped applying a pole correction to the SIO SINEX files because they started to apply the correction in their weekly analyses. We continue to update the G- and R-SINEX files based on differences between the header information and the igs.snx file.

Deconstraining AC SINEX files

All of the IGS analysis centers now submit either loosely constrained SINEX files (JPL, SIO) or SINEX files with minimum constraints applied (EMR, GFZ, NGS, COD and ESA). For this latter group of analysis centers we add to their covariance matrix a rotational deconstraint with variance of $(10\ \text{mas})^2$. This additional matrix is generated by computing the full covariance between station coordinates and Earth orientation parameters for rotations about each axis with $(10 \text{ mas})^2$ variance. The GFZ analysis center is applying constraints to the center of mass position. After week 1098, add a translation deconstraint matrix to this center's SINEX file so that the center of mass position of the combined SINEX file is not artificially constrained..

There are problems with desconstraining some the existing P-SINEX (regional SINEX) files. These analyses are performed with IGS orbits and earth orientation parameters fixed and usually have tight constraints on the sites from the G-SINEX files that are used to tie the regional networks to the global frame. For the EURREF SINEX files, the removal of the constraints applied does not appear to generate a loosely constrained solution (i.e., the standard deviations of the position estimates is still a few millimeters even after a nominal deconstraining to one meter. The regional SINEX files, after deconstraining them and re-aligning to one reference system still show discontinuities when there is a large change to the IGS system. We are sill investigating how to best account for these residual constraints. The net effect is that that P-SINEX files are not as useful as they could be in densifying the global reference system.

Earth Rotation Parameter Estimation

We carry forward into the SINEX combinations the estimates of Earth rotation parameters. In our combination we allocate elements in the Kalman filter state vector for the Earth orientation parameters (value and rate of change) for each day of the week centered at 12:00 UTC. The stochastic variations in these parameters are treated as a combination of a random walk (process variance 1 mas^2/day for pole position, and 0.066 ms^2/d of UT1) and integrated random walk (0.1 $\text{mas}^2/\text{day}^3$) for pole position and 0.007 ms^2/day^3 for UT1). The initial values at the start of the week are assumed to have variances of $(100 \text{ mas})^2$ for pole position, $(10 \text{ mas/day})^2$ for polar motion rate, $(6.7 \text{ ms})^2$ for UT1 and $(0.67 \text{ ms})^2$ for length of day. We ignore the values of UT1 given in the input SINEX files, i.e. the estimates of UT1 in our combined SINEX files are the IERS Bulletin A values at the start of week and integration of LOD for later days in the week.

We apply corrections to the submitted SINEX for some centers. For JPL, prior to January 1, 2000, we treat the input LOD as being regularized even through it is not given as LODR. For all dates, we reverse the sign of LOD since the submitted values appear to be the time derivative of UT1. For GFZ, we reverse the sign of UT1 since it appears to be given as UTC-UT1. (This latter change has little effect because we do not use the UT1 values).

Analysis Of Combined Solutions

Our analysis of 2001-2002 combined SINEX files examines the internal consistency of these combinations and their agreement with IGS97. In figure 1 we show for each weekly combination, the RMS agreement between the IGS977 reference sites. The list and number of sites used each week is given in weekly summary. This RMS is computed from the combination of the north, east, and height differences after a translation, rotation, and scale are removed from the weekly combination. In computing the RMS, the height is down-weighted by a factor of 3, i.e., we construct a weight matrix with the heights given one-tenth the weight of the horizontal components.

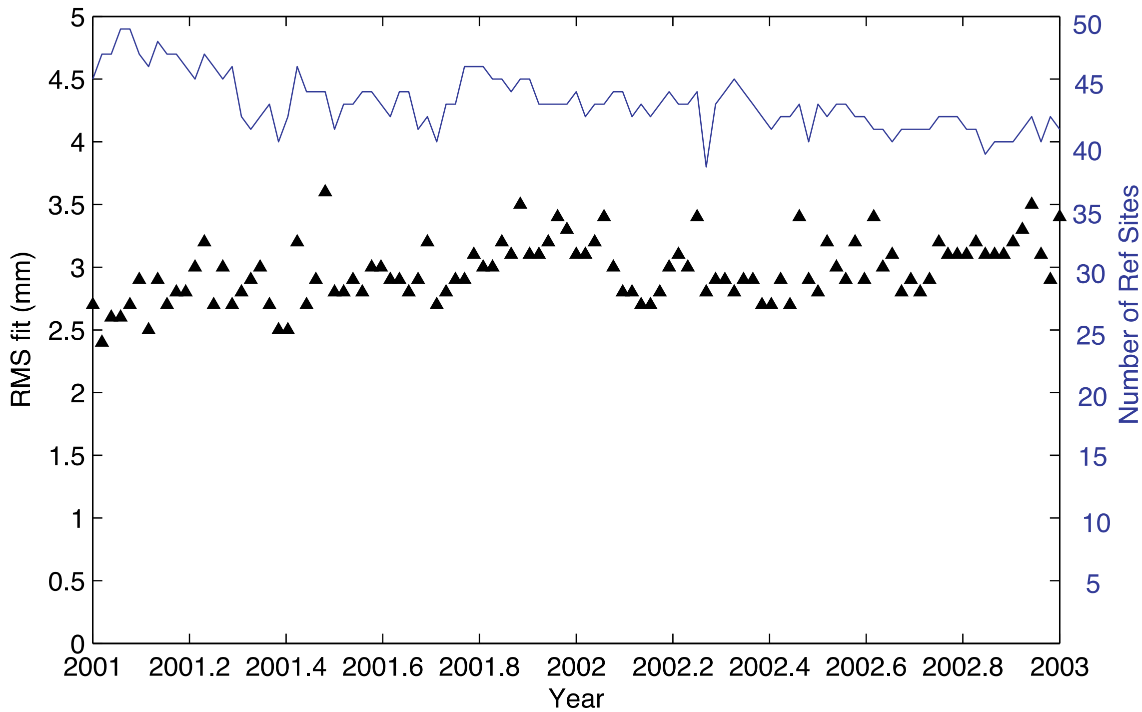

Figure 1: RMS fit of the weekly combinations to the up to 49 IGS97 reference sites. The mean RMS fit is 3.0 mm with a mean of 43 stations form the reference site list used.

In Figure 2 we show the differences in the pole position estimates between the MIT G-SINEX combination and IERS Bulletin A. The significant difference here is the offset and a mean rate of change between the Y-pole position and evolution given by the IGS97 station coordinate and velocity reference system and IERS Bulletin A. The LOD differences to Bulletin A do show any particular systematic behavior and have an RMS difference of 0.023 ms. The observed offset and drift in the Y-pole position presumably arises from differences in the IGS97 system site positions and velocities and those implicit in the IERS system.

In Figure 3, we show the positions of the sites in the G- and P-combinations. The time series of the position estimates can be found at http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC. The IGS weekly combination produced by Natural Resources Canada (NRCan) is updated weekly on this site. The time series from the other IGS centers shown are only updated occasionally. The statistics of the position residuals, after removal of linear trends, are given in Table 1. Analyses of the residuals do show offsets in the time series that are thought to arise from the residual effects of constraints on the solutions that cannot be completely removed. More detailed analysis of this problem is required at the moment.

We also make available Matlab based tools for the analysis of the IGS combined solution. These tools are available at http://www-gpsg.mit.edu/~tah/GGMatab. On the MIT IGS AAC web page a compressed tar file is available that contains the IGS weekly time series in a format suitable for use with these tools (http://www-gpsg.mit.edu/~tah/MIT_IGS_AAC/igsw/igsw.tar.Z)

Table 1: Distribution of the root mean square (RMS) scatters of the position estimates after removal of a linear trend for the North, East and Height components for the G- and P-SINEX combinations. Values shown are the RMS scatters below which either 50, 70 or 90% of the sites lie.

Component	G-SINEX Combination (256 sites)			P-SINEX Combination (359 sites)		
	50 % (mm)	70% (mm)	95%(mm)	50%)mm)	70% (mm)	90% (mm)
North	1.5	1.9	3.6	1.7	2.4	4.2
East	1.6	2.0	3.5	1.9	2.4	6.5
Height	5.4	6.5	10.6	6.0	7.7	13.8

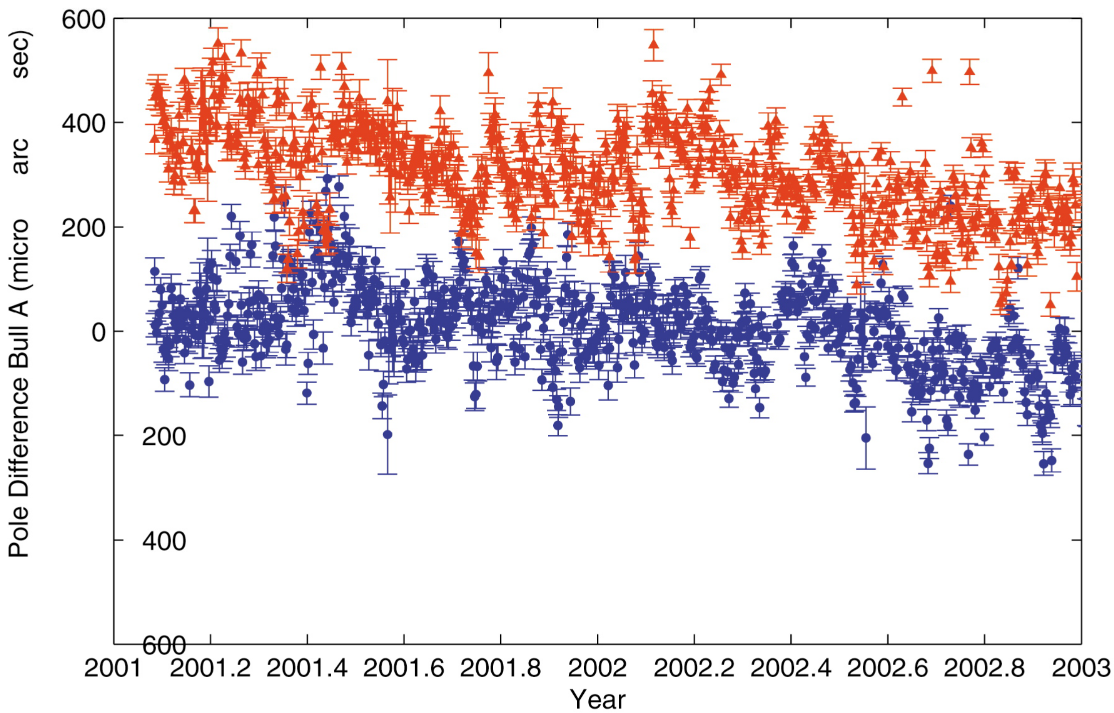

Figure 2: Differences between the X-pole (blue circles) and Y-pole (red triangles) position estimates from the MIT G_SINEX combination and IERS Bulletin A. The RMS differences after removal a mean X-pole offset of 0.003 mas and a Y-pole offset of 2001.0 and trend of 0.39 mas and –0.09 mas/yr are both 0,08 mas. The mean and RMS difference for LOD (not shown) are 0.008 ms and 0.023 ms.

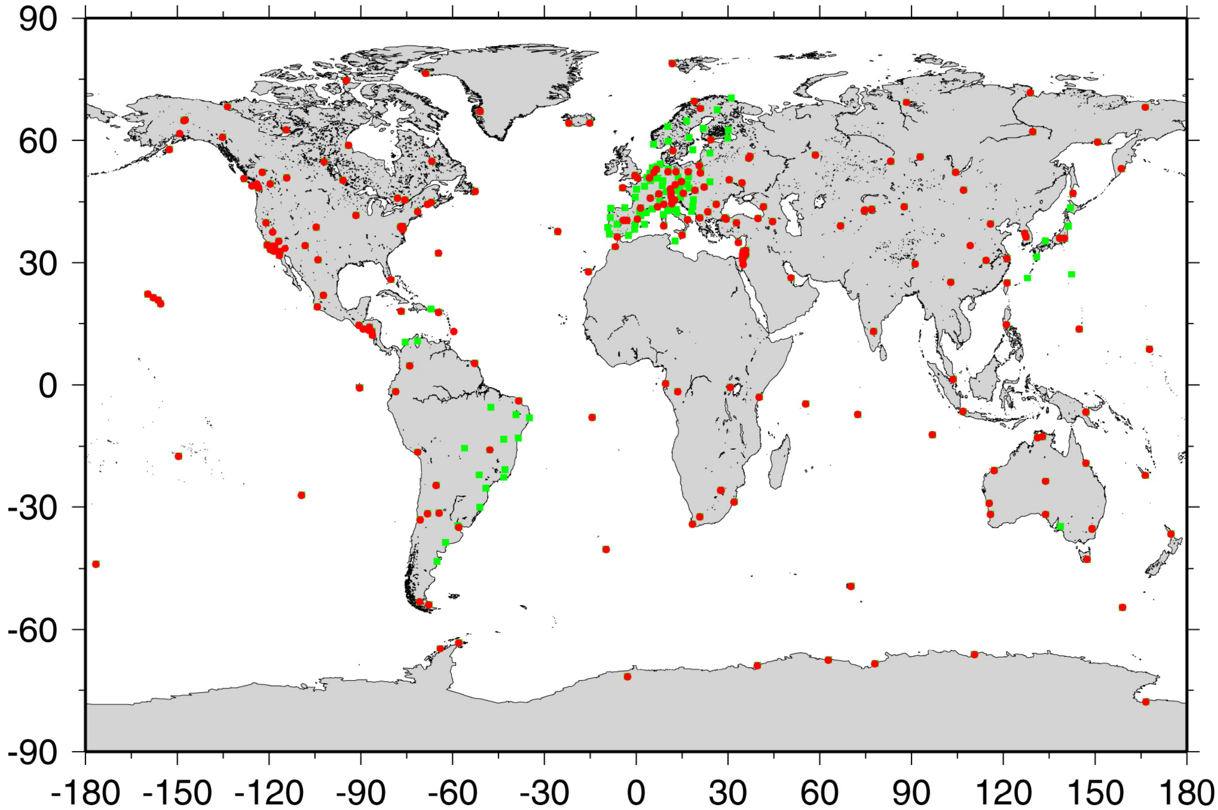

Figure 3: Global distribution of sites used more than 10 times between 2001 and 2002 in the G-SINEX (red circles) and P-SINEX (green squares) combinations. There are 246 sites in the G-SINEX files and 315 sites when the G- and P-SINEX files are combined.

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IGS

REGIONAL NETWORK ASSOCIATE ANALYSIS CENTERS

The EUREF Permanent Network in 2002

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Introduction

The EUREF Permanent Network (EPN) consists of GPS tracking stations, data centers and analysis centers organized following a similar hierarchy as the IGS and based on voluntary contributions.

Growth of the Tracking Network

The EPN tracking network has continued to operate successfully during the year 2002, integrating 10 new stations in its network (see Figure 1):

AMMN*	Amman, Jordan			IGS		
BOGI	Borowa Gora, Poland	H		IGS	GL	M
LPAL	La Palma, Canarian Islands, Spain	H				
LROC	La Rochelle, France		TG	IGS		
PULA*	Pula, Croatia	H				
MORP	Morpeth, UK	H		IGS		
MIKL	Mykolaiv,Ukraine			IGS		
NYIR	Nyirbator, Hungary	H				
QAQ1	Qaqortoq, Greenland	H		IGS		M
SPT0	Boras, Sweden	H		IGS	GL	

With:

H	= Hourly data submission
TG	= ***Collocated with tide gauge***
IGS	= Included in the IGS network
GL	= GPS/GLONASS station
M	= Collocated with meteorological instrument
*	= Station is presently not active

The total number of EPN stations reached 137 at the end of 2002; about 58% of them deliver hourly data.

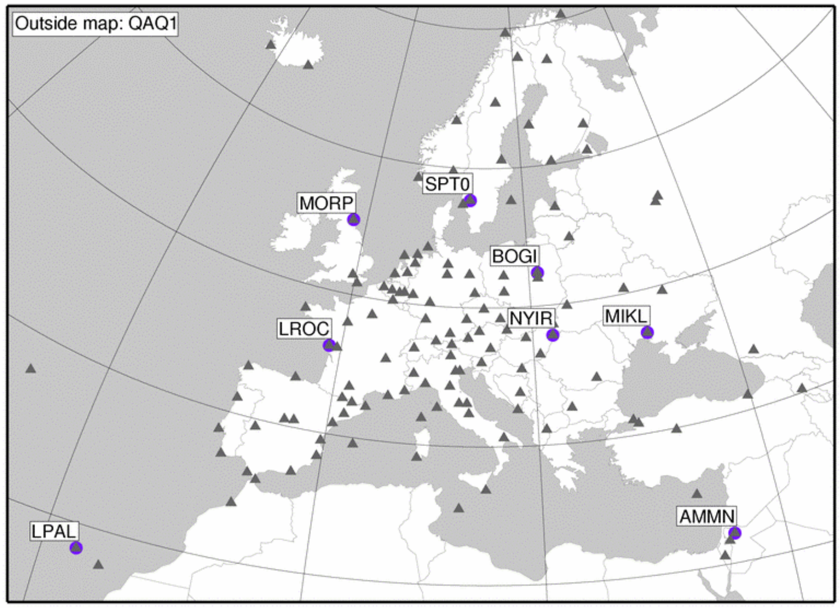

Figure 1: EPN tracking network (status Dec. 2002), stations denoted with circles joined the EPN in 2002.

Data Flow

During 2002 the problem of generating daily files from hourly ones was discussed. Daily files could be generated from hourly files to avoid the heavy traffic after midnight at the data centres. A minor problem is to avoid the sending of the same data twice. Comparing the size of a compressed RINEX file to other sources only the amount of 200 images or 50 MB a day will be saved. In 2003 some rules for creating daily files by concatenating hourly ones have been established.

There were some problems concerning the method of transfer by ftp. New ftp programs tend to transfer data in passive mode, which is sometimes rejected or restricted by the servers of the data centres. The reason is that both active and passive mode creates a security hole either in the uploading or receiving machine. Since anonymous ftp is the most comfortable and most general way to transfer data automatically one should stay to this method. However, during the next years a solution should be found which could replace the anonymous ftp and its use of lower port numbers. Because such a replacement affects the whole chain from the station managers over the data centres to the users downloading data, several platforms, like unices, Linux, Windows and Mac OS, have to be considered.

EUREF-IP Pilot Project - Real-time GNSS Data via Internet and Mobile IP Networks

Due to the increased capacity of the Internet, applications which transfer continuous data-streams by IP-packages, such as Internet Radio or Internet Video-on-Demand, have become well-established services. Growing mobile IP-Networks like GSM, GPRS, EDGE, or UMTS furthermore allow the mobile use of these real-time services. Compared to Multimedia applications, the bandwidth required for streaming GNSS data is relatively small. As a consequence, the global Internet can be used for the real-time collection and exchange of GNSS data, as well as for broadcasting derived differential products.

EUREF decided in June 2002 to set up and maintain a real-time GNSS infrastructure on the Internet using stations of its European GPS/GLONASS Permanent Network EPN. Although today's primary objective is to disseminate RTCM corrections over the Internet for precise differential positioning and navigation purposes (see *Resolution No. 3 of the EUREF symposium in Ponta Delgada, June 5 - 8, 2002*), various other applications are in sight like real-time orbit determination and ionosphere or troposphere parameter estimation.

A pilot project was established called EUREF-IP (IP for Internet Protocol). This real-time GNSS data service uses a new dissemination technique called "Networked Transport of RTCM via Internet Protocol" (Ntrip). Ntrip stands for an HTTP application-level protocol streaming GNSS data over the Internet. Currently about 110 data streams are available through EUREF-IP Ntrip Internet Broadcaster. Most of the stations generate pseudorange corrections (DGPS), other streams include carrier phase information (RTK) or raw measurement data. Seven real-time data streams are part of the EUREF-IP pilot project, the others are generated by various networks in Europe and US, among these about 15 European IGS stations. Currently no worldwide concept exists for GNSS Real-Time data dissemination. For the future it would be desirable to coordinate the efforts of EUREF-IP and IGS Real-Time Working Group.

The Broadcaster's Internet connection handles a maximum of 1000 users simultaneously. Some of the data streams are available for demonstration purposes and thus are accessible without authentication/authorization. For receiving protected data streams, the user needs a user-ID and a client password.

For receiving the real-time data the program "GNSS Internet Radio" is available for MS Windows, Windows CE and Linux operating systems. This client program is designed to run on a PC, Laptop or Pocket PC. It handles all communication through HTTP and transfers the received GNSS data to a serial or IP port supporting a networking software or DGPS/RTK application.

Further information at: http://www.epncb.oma.be/projects/euref_IP/euref_IP.html

Data Analysis

The EPN continued to apply the proven method of combining the EPN sub-network solutions as computed by Local Analysis Centres (LACs) into one official EPN solution. The Slovak University of Technology Bratislava, Slovakia (EPN abbreviation: SUT) joined the group of LACs at GPS week 1182 (September 2002) and increased the number of LACs to 16.

An IGS initiative of regional networks densifications has been presented at the IGS 2002 workshop in Ottawa, Canada. Various methods of datum definition for the densification of the global IGS polyhedron by regional networks were discussed. In order to contribute to this initiative, the EPN Analysis Coordinator (AC) started to generate two new EPN solutions.

- The first solution fixes all station coordinates of the weekly IGS global network solution and combines the IGS and the EPN networks only solving for the non-IGS stations of the EPN. The solution is generated routinely since GPS week 1136.

- The second test solution has been generated routinely since GPS week 1149 and combines the cumulative IGS global solution with a cumulative EPN solution following the datum definition strategy of the first test solution.

The EUREF TWG decided at a meeting in March 13 and 14, 2002 not to publish the results of these two test solutions as long as there is no clear recommendation for the datum definition by the IGS. It is important to save the users from too many different solutions, as was stressed at this meeting. However, the results of these solutions are available for scientific comparisons on request and they are used for internal consistency checks.

Since Dec. 2002, new guidelines for EPN Analysis Centres have been issued (http://www.epncb.oma.be/guidelines/guidelines_analysis_centres.html). Next to the general guidelines for the EPN AC's, they include information for new local analysis centres as well as an historical overview of all processing options.

Time Series Special Project

The basic aim of the Special Project is the monitoring of the EPN time series, in order to identify and eliminate the outliers and offsets present in the original EPN weekly combined solutions. Adding this information back to the original time series the estimated site velocities, especially for the height component can be substantially improved. The monitoring is based on the so-called *standard EPN time series* produced by C.Bruyninx and G.Carpentier at the EPN CB. These time series are used for the identification of time series inconsistencies related to equipment change at the sites. Then the found offsets are estimated in a separate run of the Bernese ADDNEQ program. The procedure is repeated offset-by-offset, where the previously estimated offset is introduced into the processing.

The retrospective analysis has been completed in 2002, than the offset and outlier database is being maintained periodically. Although the newly appearing offsets can be easily identified the reliable offset estimation can be done only with a few months delay. The main product of this work is the '*improved EPN time series'* published and periodically updated at the EPNCB website. The set of estimated offset values and outlier periods, which is collected in the Bernese format STACRUX.EPN file is being made also public and being published at the Time Series section of the EPNCB website October, 2003. Another product is a set of velocities, which are estimated by the Bernese ADDNEQ program based on the cumulative solution of the improved weekly EPN combined SINEX files. The estimated velocities are also published at the EPNCB. The height component velocities have been compared to VLBI and levelling solutions and gave good agreement.

Troposphere Special Project

The objective of the EPN Special Project "Troposphere Parameter Estimation" is the generation of a EUREF-troposphere product. A weekly combined troposphere solution for all sites included in the EUREF Permanent Network is computed. The Special Project started in June 2001 (GPS week 1110). Since GPS week 1143 all Local Analysis Centres have been participating. Besides some changes of processing options for the standardization of the analyses and improvement of the results in GPS week 1130, two changes have been introduced into the troposphere parameter estimation concerning the constraining of the weekly coordinate solution to ITRF and the fixing of the weekly coordinate solution during the final estimation of the daily troposphere parameters. These steps showed a significant reduction of the weekly mean biases between the combined solution and the individual solutions below 3-4 mm in Zenith Total Delay values.

Two institutions have been performing the combination of the individual solutions, GeoForschungsZentrum Potsdam and Bundesamt für Kartographie und Geodäsie, Frankfurt. The differences between the two solutions are below 0.2 mm in Zenith Total Delay for the mean bias with a standard deviation of ± 0.5-0.6 mm. More about the combination procedure and detailed results are presented in (Soehne and Weber, 2002).

Starting with GPS week 1203, the EUREF troposphere combination has been contributing to the IGS combination of Zenith Total Delay values. Since the IGS combination has a stringent timeliness a preliminary EUREF troposphere combination is calculated every week with all individual solutions arrived so far. The reason for the weekly mean bias of ~ 2-4 mm ZTD of the EPN solution is probably that the EPN solution is a regional solution whereas the other contributing solutions are global solutions (Soehne and Weber, 2003).

Network Coordination

Similar to the IGS, the EPN changed site log format on June 11, 2002. In addition, automated site log tests and submissions through e-mail have been introduced.

In 2002, the following items were added to the website of the EPN Central Bureau (http://www.epncb.oma.be/):

- Daily updated web-pages with an overview of metadata errors going back to mid 1998
- On-line papers related to the EPN activities (http://www.epncb.oma.be/papers.html)
- EPN coordinate time series expressed in the ITRS and ETRS89 (http://www.epncb.oma.be/series.html)

Due the growing number of IGS stations in Europe, the EPN TWG decided that from March 2002 on, IGS stations located in Europe, should separately apply to join the EPN (see http://www.epncb.oma.be/guidelines/procedures_becoming_station.html), instead of being automatically included in the EPN, as was done in the past.

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Soehne, W., Weber, G. (2002): “EUREF Troposphere Combination at BKG – First Results and Improvements“, Proceedings of the COST Action 716 Workshop “Exploitation of Ground-Based GPS for Meteorology”, January 28-29, 2002, GeoForschungZentrum Potsdam

Soehne, W., Weber, G. (2003): “Progress and status of the EPN Special Project ‘Troposphere Parameter Estimation’”, Proceedings of the EUREF Workshop, June 04-07, 2003, Toledo (in press)

Geoscience Australia RNAAC – 2002 Annual Report

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Introduction

The RNAAC function of routinely processing all stations in the Australian Regional GPS Network (ARGN) continued during 2002. The weekly combined SINEX result files were submitted to the Crustal Dynamics Data Information System (CDDIS).

Station Network

The station network processed by the Geoscience Australia (GA) RNAAC as at December 2002 is shown in Figure 1. Fifteen of the nineteen stations in this network are operated by GA. The stations AUST, NNOR, PERT and TIDB are owned and operated by other agencies.

Commencing GPS week 1174 site NNOR was added to the solution. Commencing GPS week 1194 site MOBS was added to the solution.

Data Analysis and Results

The Bernese GPS Software version 4.2 (Hugentobler, Schaer and Fridez 2001) was used for the GPS data processing. Daily solutions were computed using the following strategy:

- L3 double differenced phase observable.
- No resolution of integer ambiguities.
- Elevation cut-off angle of 10°.
- Elevation dependent observation weighting.
- 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 TIDB or YAR2).

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 were tightly constrained to the station coordinates from the IGS00 realisation of ITRF2000 at the following IGS reference stations; CAS1, CEDU, DAV1, HOB2, MAC1, PERT, TIDB and YAR2.

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

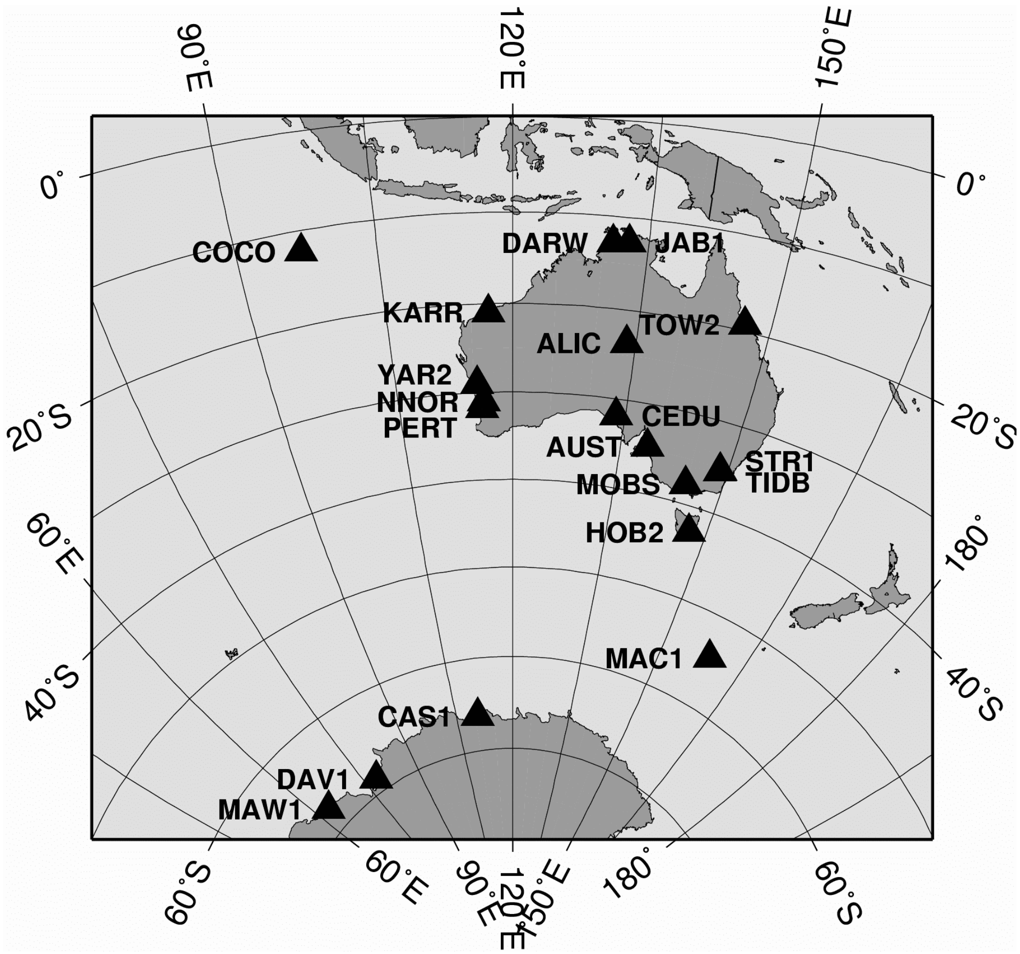

Figure 1. Geoscience Australia RNAAC station network as of 31 December 2002

Other GPS data processing and analysis activity at GA include:

- IGS GPS Tide Gauge Benchmark Monitoring Project as a type A analysis centre.
- The South Pacific Sea Level & Climate Monitoring Project.
- Asia Pacific Regional Geodetic Project (annual observation campaigns).
- Australian South West Seismic Zone monitoring project.
- South Australian Seismic Zone monitoring project.

References

Hugentobler, U., Schaer, S. and Fridez, P. (eds.), Bernese GPS Software Version 4.2, Astronomical Institute, University of Berne, 2001.

GSI RNAAC Technical Report 2002

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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). The network for the GSI's analysis consists of 10 IGS global sites (Figure 1a) and 7 domestic GPS sites (Figure 1b).

Outline of Processing

Coordinates and covariance are generated in daily basis using GAMIT version 9.95 and they are combined with GLOBK version 5.04 to generate weekly solutions with loose constraint.

The specification of the analysis is as follows;

Final IGS orbits and Earth orientation parameters are applied.
Measurement elevation cut-off angle of 20 degrees
Data rate of 30 secs for single-day adjustments.
Tropospheric zenith delays are estimated every 3 hours.
Station coordinates estimated, applying a priori sigma of ~10m.

Since the 1145th week, we've input the data from YAR2 instead of YAR1 due to the trouble with YAR1 reported in IGS mail No. 3884.

Current State

The standard deviation of GSI RNAAC weekly solution is shown in Figure 2. The results of the latter half year seem to be stable.

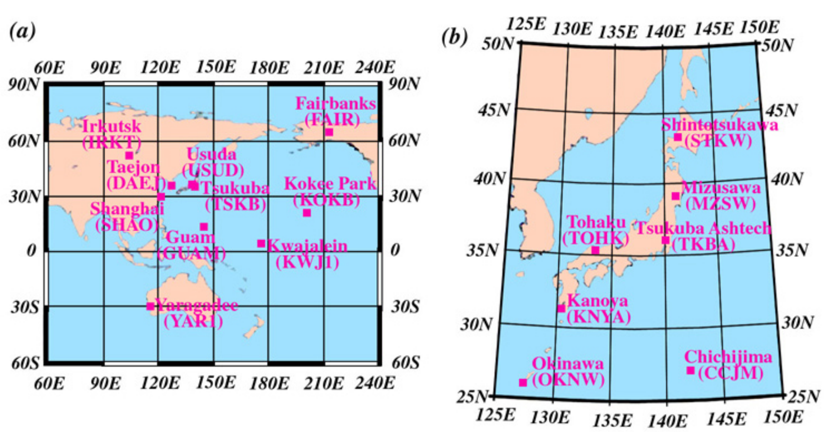

Figure 1. GPS observation sites for GSI RNAAC analysis
(a) IGS global sites (b) domestic sites

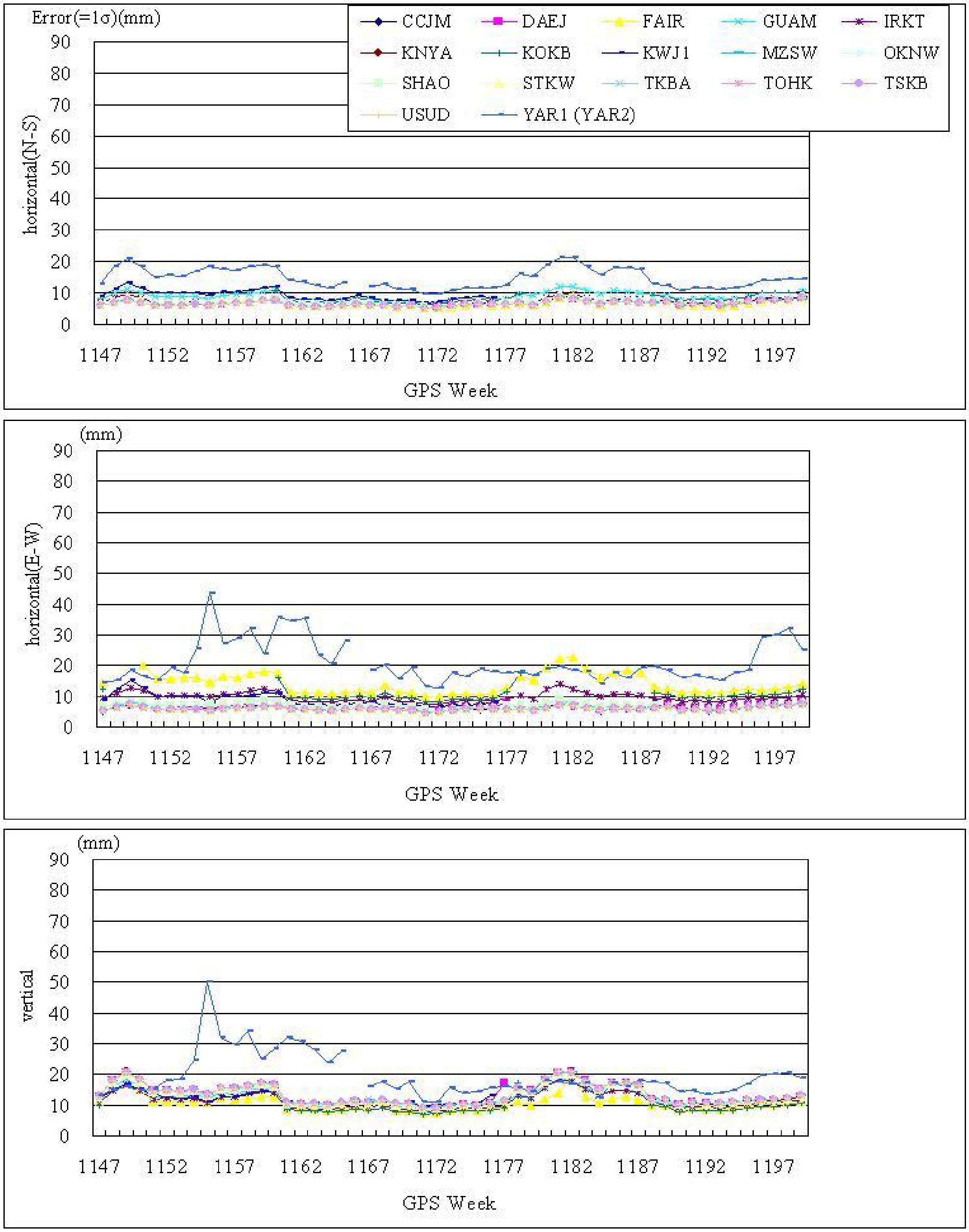

Figure 2.Standard Deviation of GSI RNAAC weekly solution

Annual Report 2002 of IGS RNAAC SIR

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Abstract

Changes in the RNAAC SIR station network and a new solution for coordinates and velocities are presented in this report. Additionally the impact of an earthquakes near Manzanillo (Mexico) on the weekly coordinate solutions and the velocity estimates are shown. The processing strategy is updated to include the influence of ocean loading.

Station Network

End of 2002 the network of IGS RNAAC SIR consisted of 62 GPS stations, 19 of them are regional stations (see fig.1). New global IGS stations are Key Biscayne (AOML)/USA, Ensenada (CIC1)/Mexico, Freetown (FREE)/West End (BHMA) on Bahamas, Santiago de Cuba (SCUB)/Cuba, and Concepcion (CONZ)/Chile, the GPS instrument of the German Transportable Integrated Geodetic Observatory (TIGO). New regional stations are Crato (CRAT)/Brasil, and Mar del Plata (MPLA)/Argentina.

Solutions

From GPS week 1156 onward the ocean loading effects are considered in the weekly solutions of IGS RNAAC SIR. At the International Symposium on recent Crustal Deformation in South America and surrounding areas (IAG), Oct. 21-25, 2002 in Santiago de Chile the new solution of coordinates and velocities was presented. Fig.1 shows this solution DGFI02P01 which covers the time period from June 30, 1996 to August 31, 2002. It is compared with ITRF2000 and the geophysical solution NNR NUVEL-1A. Again the solution is based on weekly SINEX files generated by the IGS RNAAC SIR. The velocities are given in figure 1 only for stations with more than one year of observations.

As already shown in the annual report for 2001, earthquakes are monitored in the region of the RNAAC SIR. An earthquake with significant displacements on the station Manzanillo (MANZ) was detected. The co-seismic and post-seismic displacements are shown in figures 2 and 3.

Conclusion

It becomes more and more clear that we have to consider seriously the proper modelling of episodic events like earthquakes which cause large displacements at the IGS RNAAC SIR stations as shown for the GPS sites San Salvador and Arequipa (see annual report 2001), and Manzanillo in 2002.

Including the effects of ocean loading has strengthened the daily solutions so that the repeatability from day to day processing is below one cm for the North and East components, and about one cm for the up component. The accuracy of the new velocity estimates of the solution DGFI02P01 increased due to more observation data, and for some more stations velocity estimates could be generated.

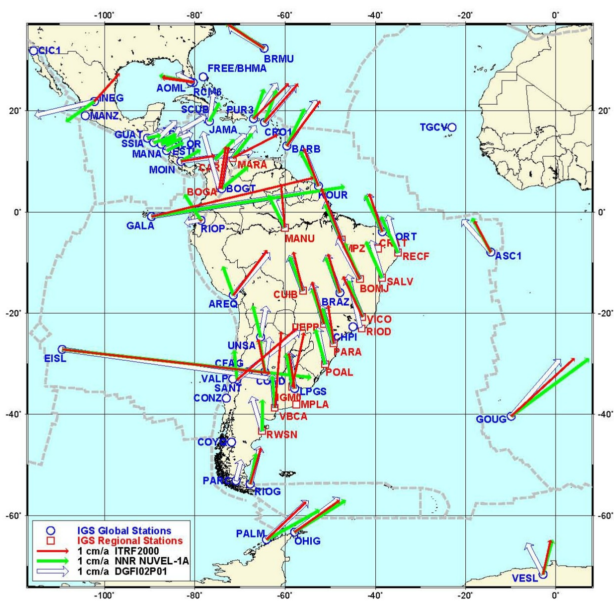

Figure1: IGS RNAAC SIR network and horizontal velocities of solution DGFI02P01 compared with ITRF2000 and NNR NUVEL-1A

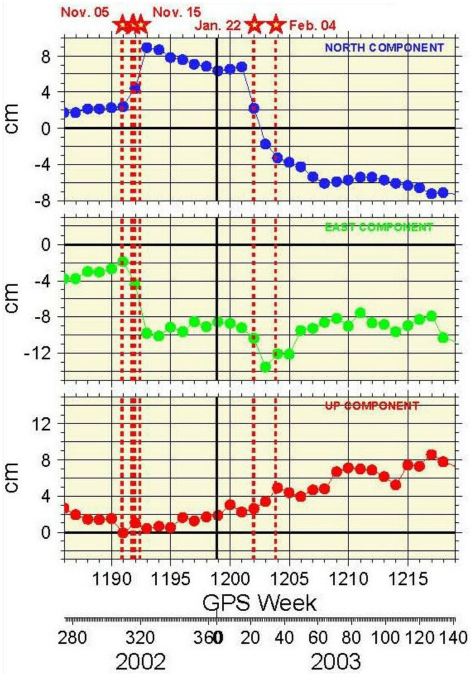

Fig.2 (above): Weekly variations of Station MANZ positions due to earthquakes near Manzanillo

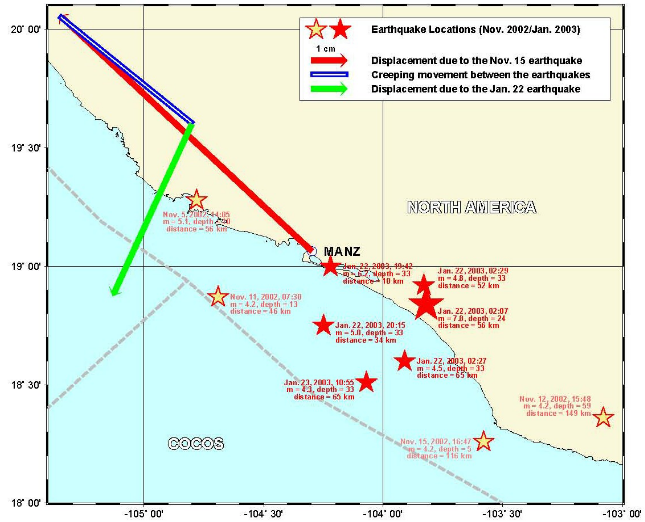

Fig.3 (above): Earthquake locations near Manzanillo and resulting displacements to site MANZ

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USGS: United States Geological Service, National Eartquake Information Center (http://neic.usgs.gov/neis)

D A T A C E N T E R R E P O R T S

IGS

GLOBAL CENTERS

CDDIS 2002 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 2002 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 UNIX server. 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 400 Gbytes of on-line disk space is devoted to the storage of daily GPS tracking data and products. GPS data since 1995 and IGS products since 1992 are available on-line.

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. Nearly forty of these IGS data centers make data available to the CDDIS from selected receivers on a daily (and in some cases hourly and/or sub-hourly) basis. The CDDIS also accesses the archives of 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. Over 87K station days from 313 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.2002*. Table 1 below summarizes the types of GPS data archived at the CDDIS.

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. These metadata are utilized to generate various reports on data holdings and data latency.

The CDDIS daily GPS tracking archive consists of observation (in both RINEX and "compact" RINEX format), 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 2002, the CDDIS archived data on a daily basis from an average of 280 stations. One reason for the large increase in stations is that as of June 11, 2002, GPS+GLONASS receiver data were archived in what was previously a GPS-only directory structure in the CDDIS archive. This new archive structure for the IGS regional and global data centers was mandated by the Central Bureau under recommendation from the IGLOS-PP. In 2002, the CDDIS GPS archive of daily GPS data files totaled over 31 Gbytes in volume (compact RINEX format only); this figure represents data from over 87K observation days. Of the 280 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.

At this time, the CDDIS on-line archive of daily GPS data contains data from January 1995 through the present. Prior to mid-2002, 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. However, in recent weeks, the GPS data are typically only available in compact RINEX format due to severe disk space constraints on host *cddisa.gsfc.nasa.gov*.

The majority of the data delivered to and archived in the CDDIS during 2002 was available to the user community within six hours after the observation day. Nearly sixty percent of the data from the global sites delivered to the CDDIS were available within three hours of the end of the observation day.

Hourly GPS Data Files

Since 2000, many IGS operational/regional data centers transmit hourly data files to the global data centers. 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. In 2002, approximately sixty percent of these hourly data files were available to the user community within twenty minutes of the end of the hour. Over 160 sites (both GPS and GLONASS+GPS) transmitted hourly data files to the global data centers in 2002.

The site-specific ephemeris data files for each hour are decompressed and then appended to a single file that contains the orbit information for all GPS satellites for the day up through that hour. This merged ephemeris data file, named *hourddd0.yyn.Z* (where *ddd* is the day of year and *yy* is the year), is then copied to the daily subdirectory in the hourly filesystem (*/gps/nrtdata/yyddd*). At the end of the day, this file is copied to the corresponding subdirectory under the daily filesystem (*/gps/gpsdata/yyddd/yyn*) and renamed to *brdcdd0yyn.Z*. Users can thus download this single daily file instead of all broadcast ephemeris files from the individual stations.

<u>High-Rate GPS Data Files</u>

In May of 2001, the CDDIS began the archive of high-rate (typically one-second) GPS data in support of the IGS Pilot Project for Low Earth Orbiting (LEO) Missions. The data are made available to the CDDIS from four principal sources, JPL, GFZ, NRCan, and ESA as well as other operations centers (e.g., ASI, GOPE, UNB, etc.). The RINEX data are archived in files containing fifteen minutes of data using the filenaming convention *ssssdddhmi.yyt.Z* where *ssss* is the monument name, *ddd* is the day of year, *h* is the hour (a-z), *mi* is the minute (00, 15, 30, 45), *yy* is the year, and *t* is the file type (d, m, n). On average during 2002, the CDDIS archived high-rate data from 52 sites totaling approximately 250 Mbytes per day, and a total of 90 Gbytes for the year.

Meteorological Data

The CDDIS currently receives meteorological data from over fifty sites. 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.

LEO GPS Data

The CDDIS proposed to serve as a data center supporting the IGS Pilot Project for Low Earth Orbiting (LEO) Missions in 2000. In 2002, the CDDIS established an archive of space-borne GPS receiver data from selected missions (e.g., SAC-C and CHAMP); future missions supported will include Jason-1, GRACE, and ICESat.

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. 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 2002. Furthermore, a new product, the IGS ultra-rapid combination (designated IGU) were made available twice daily. 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.

The CDDIS also continued to archive combined troposphere estimates in directories by GPS week (i.e., */gps/products/wwww/trop,* where *wwww* is the GPS week number). Global ionosphere maps of total electron content (TEC) from the IONEX AACs were also archived in subdirectories by day of year (i.e., */gps/products/ionex/yyyy* where *yyyy* is the four-digit year). The CDDIS archived products generated by the individual analysis centers contributing to the IGS LEO Pilot Project (LEO-PP). Thirteen AACs have thus far submitted products for review by the LEO-PP analysis coordinator; these files are archived in subdirectories by AAC within filesystem */gps/products/leopp*.

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 (both daily and high-rate) 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* and *ftp://cddisa.gsfc.nasa.gov/pub/reports/igshrdata*. The CDDIS also maintains an archive of and indices to IGS Mail, Report, Network, and other IGS-related messages.

GLONASS Data and Products

During 2002, the CDDIS continued as a global data center for GLONASS data and products in support of the IGLOS-PP Call for Participation issued in 2000. The CDDIS archived GLONASS data from over fifty sites. As of June 2002, data from GPS+GLONASS receivers are archived within the GPS directory structure to improve data retrieval for the user community; data from GLONASS-only receivers continue to be archived in the */igex/data* filesystem. GLONASS products from three analysis centers (BKG, ESA, and MCC) as well as the Analysis Coordinator (at the Technical University of Vienna) were also made available to the public. GLONASS products are accessible via anonymous ftp in the filesystem */igex/products*.

System Usage

Figures 1 through 3 summarize the monthly usage of the CDDIS for the retrieval of GPS and GLONASS data and products for 2002. Figure 1 illustrates the amount of GPS and GLONASS data retrieved by the user community during 2002, categorized by satellite (GPS or GLONASS) and type (daily, hourly, high-rate). Nearly forty million files were transferred in 2002, with an average of over three million files per month. Furthermore, nearly 170K GPS product files were retrieved each month from the CDDIS; less than 1,000 GLONASS product files were retrieved each month. Figures 2 and 3 illustrate the profile of users accessing the CDDIS IGS archive during 2002. Most accesses were through network gateways, which did not yield sufficient information about the user. Figure 3 displays the usage information by geographic region; the majority of CDDIS users are from hosts in North America.

Publications

The CDDIS staff attended several conferences during 2002 and presented papers on or conducted demos of their activities within the IGS, including:

- Noll, Carey E. “2001 IGS Data Center Reports”, 2001 IGS Annual Report (submitted in 2002)
- Noll, Carey E. “CDDIS 2001 Global Data Center Report”, 2001 IGS Technical Report (submitted in 2002)
- Noll, Carey E., “The CDDIS Data Center – NASA’s Space Geodesy Data Archive”, <u>EOS Transactions American Geophysical Union</u>, May 2002.

- Noll, Carey E. "Current Status of IGS Data Centers" IGS Network, Data, and Analysis Center Workshop, Ottawa, Canada, April 2002, in press.
- Noll, Carey E. and Maurice Dube. "The IGS Global Data Center at the CDDIS – an Update" IGS Network, Data, and Analysis Center Workshop, Ottawa, Canada, April 2002, in press.

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

The AlphaServer 4000 computer supporting the CDDIS has been operational for over five years. In 2003, a Linux-based system (and backup server) will be procured. Over four terabytes of RAID storage and a dedicated tape backup system will also be purchased for this new computer facility. Migration to the Linux operating system will begin in late 2003.

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	E-mail:	*Carey.E.Noll@nasa.gov*
NASA GSFC	WWW:	*http://cddisa.gsfc.nasa.gov/cddis_welcome.html*
Greenbelt, MD 20771		*http://cddis.nasa.gov*

Acknowledgments

The author would once again like to thank the Raytheon Information Technology and Scientific Services (RITSS) contractor staff, Dr. Maurice Dube, Ms. Ruth Kennard, and Ms. Laurie Batchelor. The recognition and success of the CDDIS in many international programs is significantly helped by their continued dedicated, consistent, professional, and timely support of its daily operations.

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Table 1: GPS Data Summary

Data Type	Sample Rate	Avg. No. Sites/Day	Avg. Volume/Day	Total Volume/Year	Data Format	Available On-line
Daily GPS	30 sec.	260 (1)	90 Mb	31 Gb	RINEX and compact RINEX (2)	Since 1995 (3)
Hourly GPS	30 sec.	160 (1)	70 Mb	350 Mb	Compact RINEX	Last 5 days
High-rate GPS	1 sec.	50	250 Mb	90 Gb	Compact RINEX	Since May 2001
LEO GPS	10 sec.	2 (4)	2 Mb	750 Gb	Compact RINEX	Since 2002

Notes: (1) Includes data from GPS+GLONASS sites
(2) Amount of non-compact RINEX data available on-line dependent upon available disk space
(3) Some older data migrated to temporary disk areas until more disk space available; data since 1992 archived in CDDIS
(4) Indicates number of LEO satellites

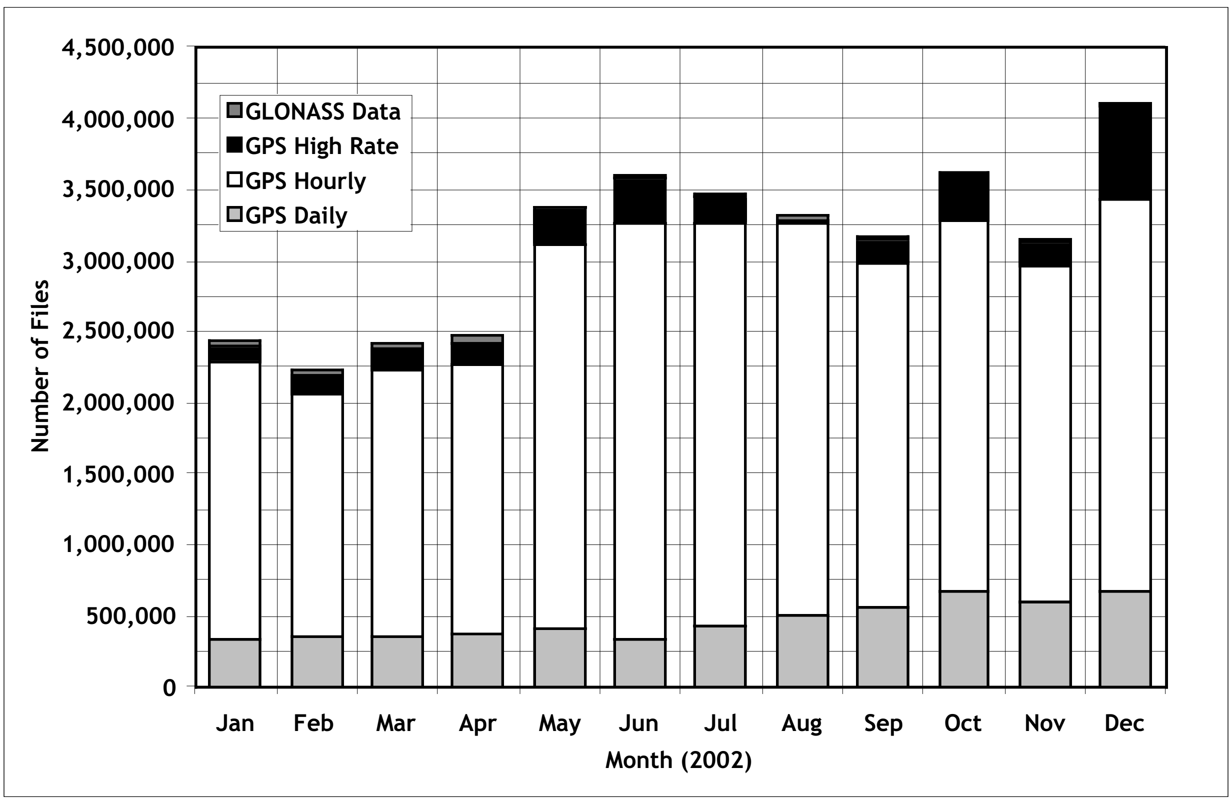

Figure 1: Number of GPS data files transferred from the CDDIS in 2002

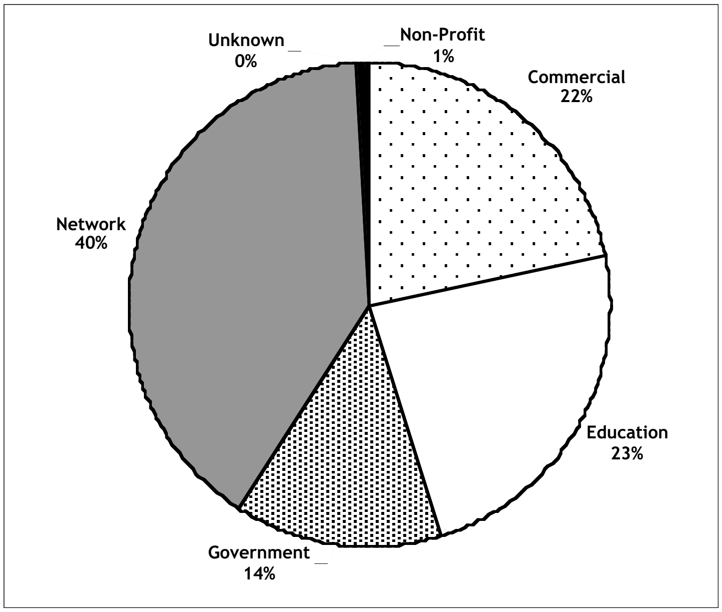

Figure 2: Distribution of IGS users of the CDDIS in 2002

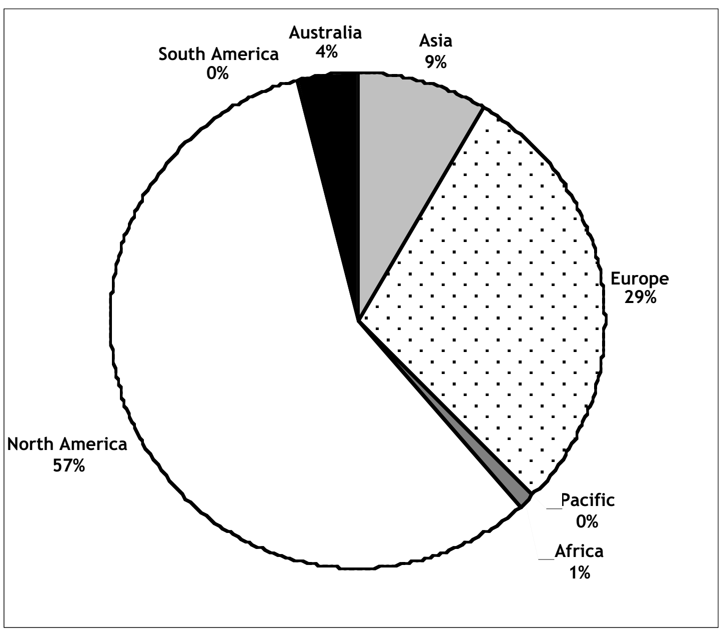

Figure 3: Geographic distribution of IGS users of the CDDIS in 2002

IGN 2002 Global Data Center Report

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Introduction

The *Institut Géographique National* (IGN) has been involved in IGS since its beginning through the *Laboratoire de Recherche en Géodésie* (LAREG). For a long time, a single person has administrated IGN Global Data Center (GDC): Loïc DANIEL. Since May 1st 2001, Edouard GAULUE has been appointed to assist him in his mission as IGS services around data kept growing (new stations, products and data transfer strategies, web developments). Here is a summary of IGN GDC activities from September 2001 to December 2002.

Service Overview

As a global data center, the IGN server gets observation files from regional and operational data centers and product files from analysis centers. All collected files (since 1997) are accessible to the user community through anonymous FTP. Moreover IGN also mirrors the central bureau directory for administrative reasons.

History

Hardware

IGN GDC has been working on a VAX/VMS machine until 1997. Many of the files obtained during this period had been archived on magneto-optical disks (75 Gb) that we expect to restore soon. In 1997, this server has been changed to an HP D230 machine running HP-UX. At the same time, the service moved to the *Ecole Nationale des Sciences Géographiques* (ENSG) equipped with a 2 Mb/s bandwidth Internet link. Five years later, due to the addition of external disks, a CD jukebox and a saving-robot, this machine has grown from half a cubic meter to 3. It has also become a little obsolete. Two machines have been ordered at the end of 2001 and should be delivered in 2003. In February 2002, the bandwidth of the ENSG has raised to 10 Mb/s.

Online service

In the middle of 2001, the FTP server has been refurbished taking into account a new stations (and name changes) and new products. In 2002, a new web site has been developed but it had to remain on a test server because of the delay in the delivery of the new servers.

Due to everyday service, our first 150 CDs jukebox accessible online is today more than half-full (about 90 Gb). In addition to the jukebox, 25 Gb are reserved for data storage on the server hard disks. Files online on hard disks represent about 200 days. After this time a CD is burned and stored in the jukebox from which data are still accessible online.

Service availability in 2002

In 2002, the IGN GDC FTP service has not experienced an interruption exceeding 3 days. Most of the interruptions were due to (i) our Internet provider during the bandwidth change, or (ii) the lack of space on the server. In fact, the principal difficulty we had to deal with in 2002 came from the continuous increasing delay concerning our new machines arrival.

How Does IGN GDC Work?

A diagram presenting the operating mechanism of the IGN IGS global data center server is given in Figure 1.

IGN GDC stores information about partner FTP sites in a MySQL database. In the meantime, using an automatic procedure on sitelog it also gets information concerning station sites. A third table links stations and centers according to the different information sources IGS provide and IGN GDC policy. This table gathers the station observations files (as well as navigation, meteorological and quality checks) for each center. For products, filenames are directly store with partner FTP sites information. Every night, based on these information, a "mirror configuration file" is generated for each partner data center.

This file is then processed by the so-called "mirror" program. This program questions the distant site and compares it to the local one before starting transfers. Files arrive directly in the public area. This procedure is the same for data centers which "put" data to IGN GDC: the distant site in this case is their local deposal directory at IGN. More information concerning the mirror program is displayed on Figure 2.

All mirroring tasks are scheduled using the CRON system. Moreover tasks are placed in specified queues depending of their aim to avoid download conflicts and control server overload.

Once in public area, automatic files scanning is done either for IGS community through check import or to feed our database. The "file" table is then used for statistical analysis, building data and products holding reports and web requests.

IGN Policy

Near Real Time (NRT) data

As NRT data doesn't need to be archived, IGN GDC tries to get data from a maximum number of stations (about 100 in 2002).

Observation files

Due to the server limitation, we prefer not to deal with more than 150 stations. A new policy will be defined when new machines will be in place. In 2002, priority is first given to regional stations (coming mainly from IFAG, CNES and ORSTOM) and then to global station. A few other stations have been dealt on request.

From May 2001 to the end of 2002, the number of processed stations rose from 70 to 150.

Product files

In 2002, IGN GDC tried to deal with more product files, taking into account new ultra rapid products. Moreover ionospheric and tropospheric data are always accessible in special tropo and iono directory.

GLONASS

No GLONASS data has been processed since the end of 2001. It has been decided at the Ottawa workshop to improve IGEX services by gathering observations and products in the same directories than IGS. All the IGN GLONASS services will be refurbished and implemented in 2003.

DORIS

Since December 2002, IGN has become a global DORIS data center. This event implied a transfer of the service to another server. Concerning observation, IGN DORIS GDC is just a mirror of the CDDIS archive. Concerning products, everything as been done to propose IGS-like services.

IGN GDC Usage in 2002

Incoming files

Figure 3 displays the average delay for incoming daily observation files in 2002. We can point out that 2/3 of the files arrive in less than 3 hours and 3/4 in less than half a day.

Figure 4 displays the same information for NRT data. One can notice that data arrival at IGN is in fact largely driven by the scheduled time in the CRON. The first scan of remote data centers begins approximately 10 minutes after the beginning of each hour and lasts 10 minutes. The next scan (for "*retardataires*") starts 45 min past the hour. The last files of the day (x files) follow a particular schedule for administrative reason. That explains why download begins 30 minutes after the end of the day.

Figure 5 and 6 show mean delays for data or products download at IGN GDC according to their origin. The delays for incoming observation are rather short. The mean delay for IGS final products arrival at IGN was about 17 to 18 days in 2002.

Outgoing files

Figure 7 and 8 show general statistics on observation and data downloads from IGN server. On the observation graph, the three first months show an unusual download: someone was downloading identical observation files 64 times a day. Nevertheless we can remark a systematic trend during spring and summer months certainly due to the global activity.

Figure 9 shows downloads and associated average transfer rates grouped by Internet domain. We can notice a particularly good connection to Luxembourg an Switzerland certainly due to our provider connection.

Future Development

In 2003, the IGN GDC activity will critically need its new computers to function properly. This would be the opportunity to completely rethink its procedures and use newer and better tools. Servers should be running under debian Linux distribution and should provide a MySQL 4.x database and a PHP-apache web server. Those machines will be shared with the permanent French geodetic GPS array. They should in term work in a mirroring scheme, one in Paris and the other one in Marne-La-Vallée with a heart-bit connection. Load balancing will have to be considered.

IGN GDC would also like to participate in real time transfer experiments. Contacts have been taken in Ottawa and at AGU to move towards this objective.

Last, IGN GDC will have its new web site online. Figure 10 displays a screenshot of what it could look like. Some modules are already operational but lots of work still has to be done until official opening. In relation to this topic, the IGN GDC team is interested to exchange on topics related to XML and particularly by the way to introduce this technology in IGS documentation.

Contacts

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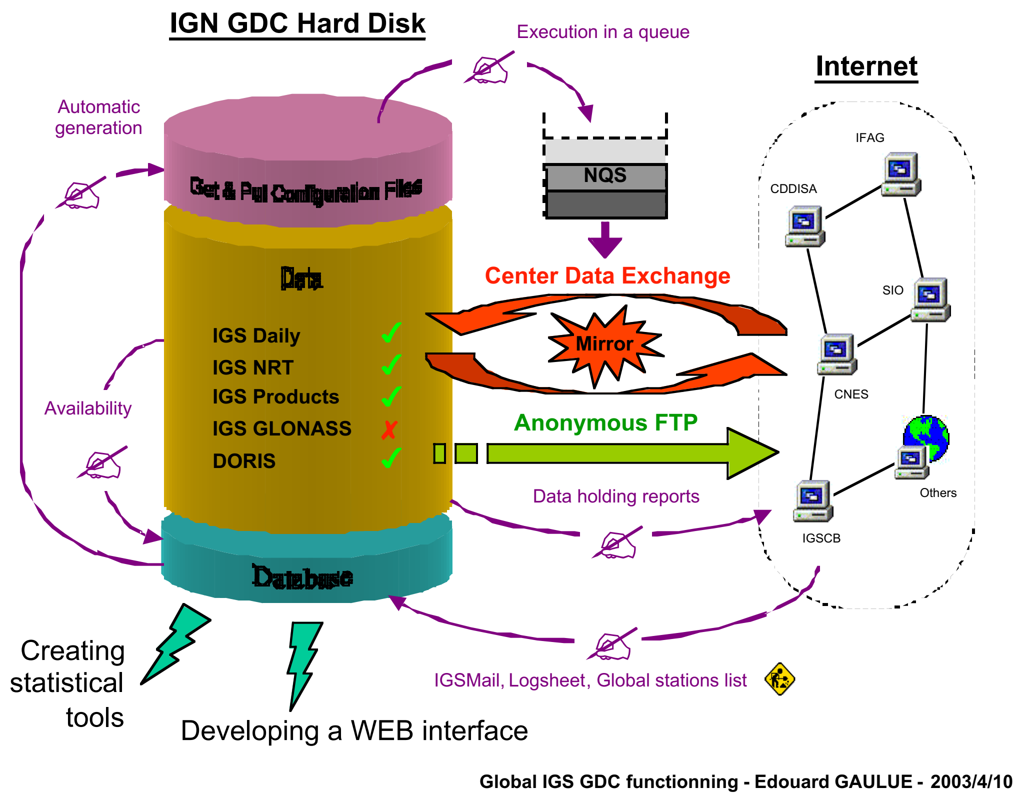

Figure 1. Global IGS GDC Functioning

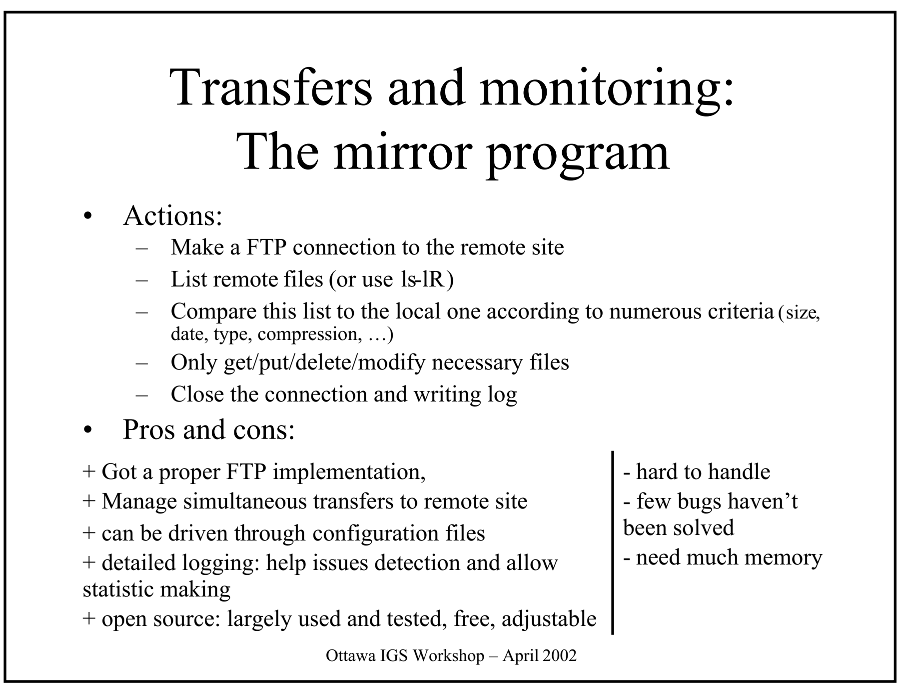

Figure 2. Mirror Program

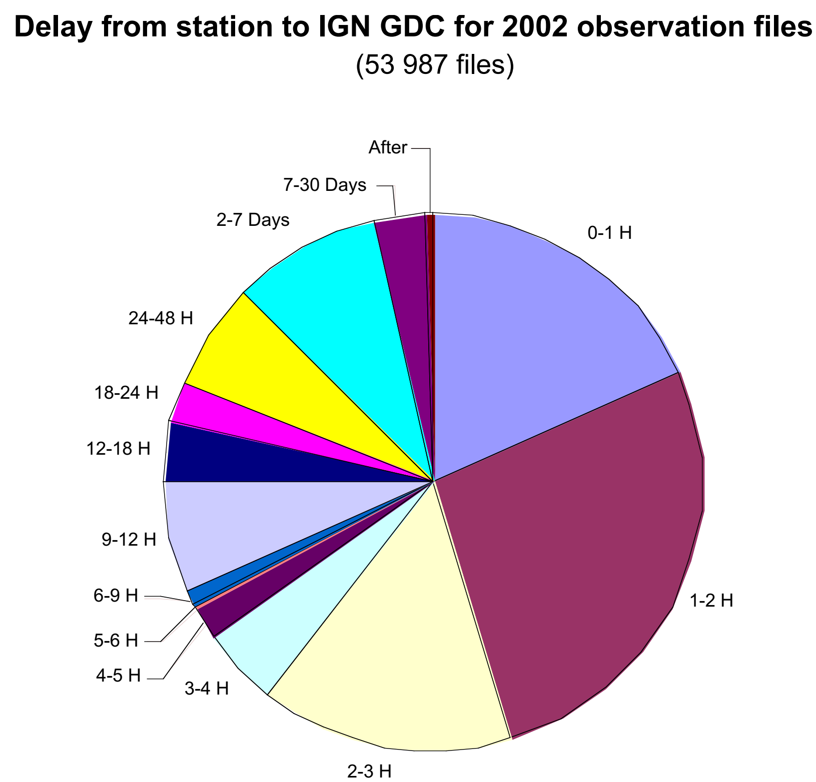

Figure 3.

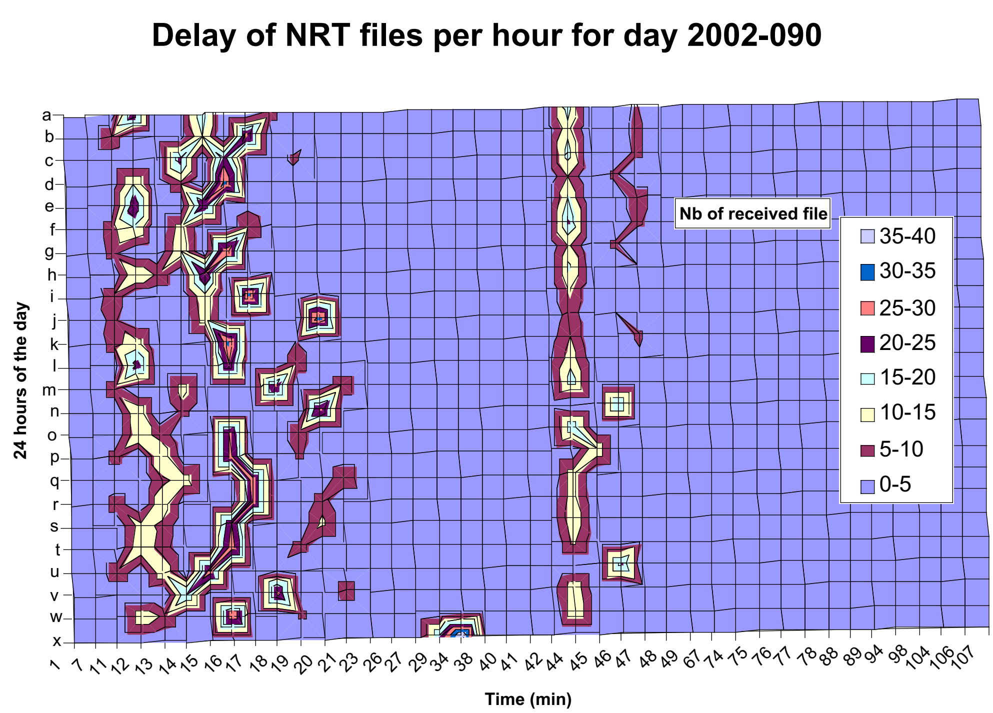

Figure 4.

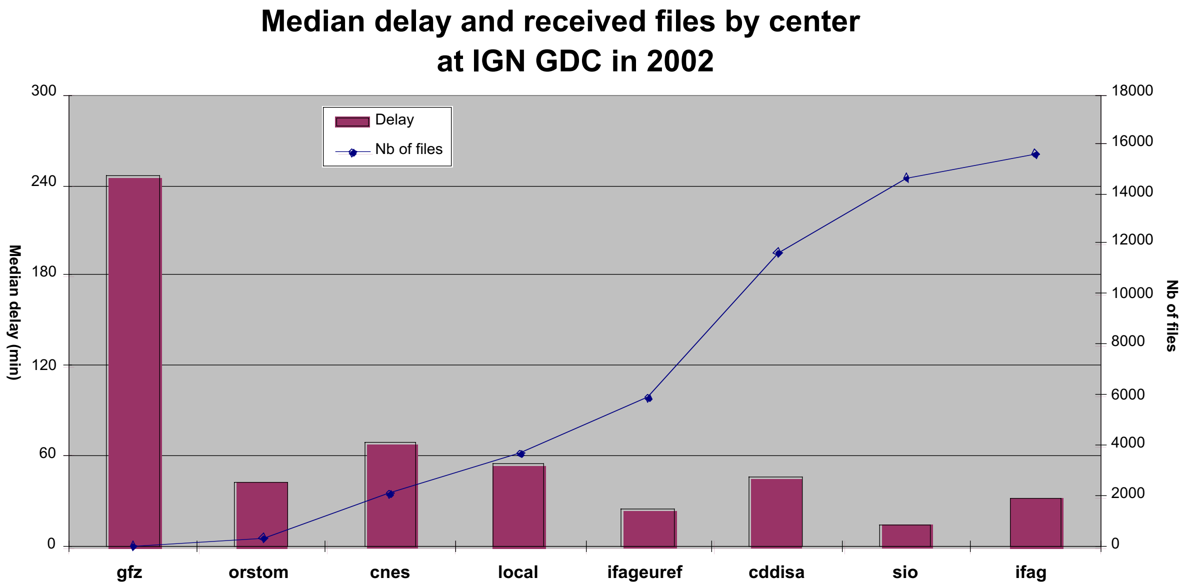

Figure 5.

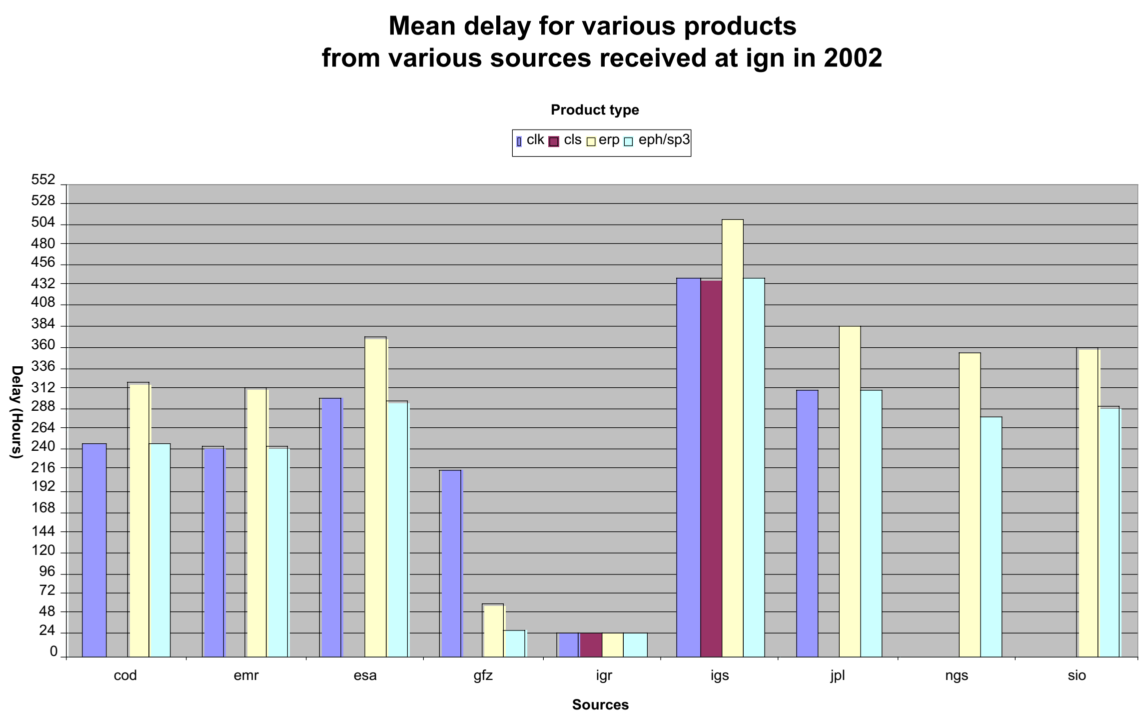

Figure 6.

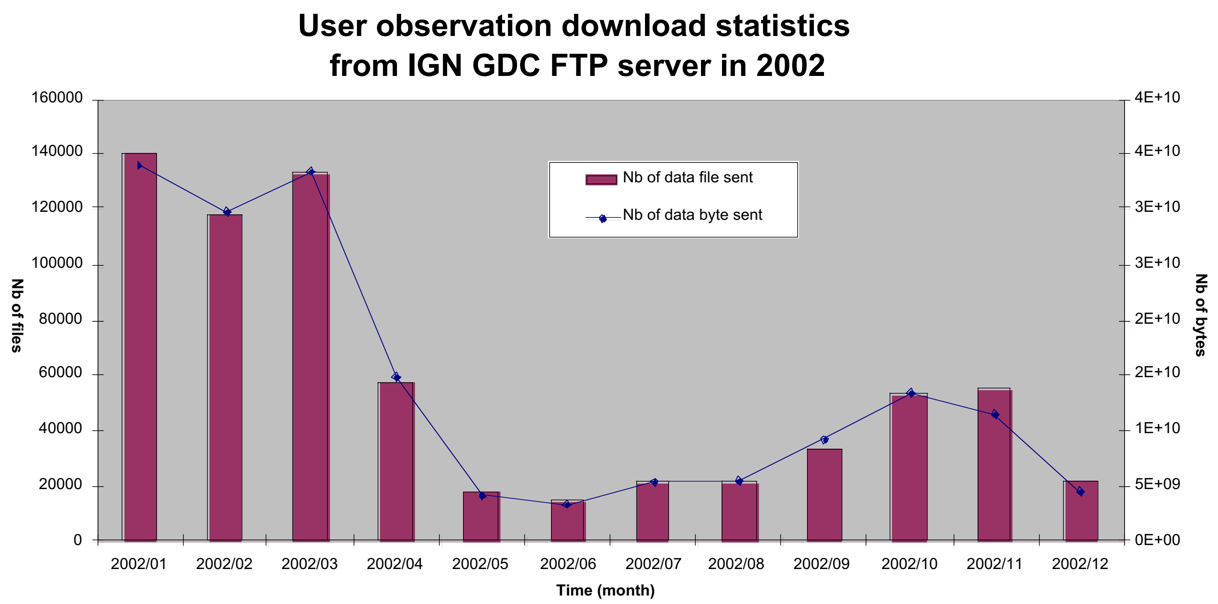

Figure 7.

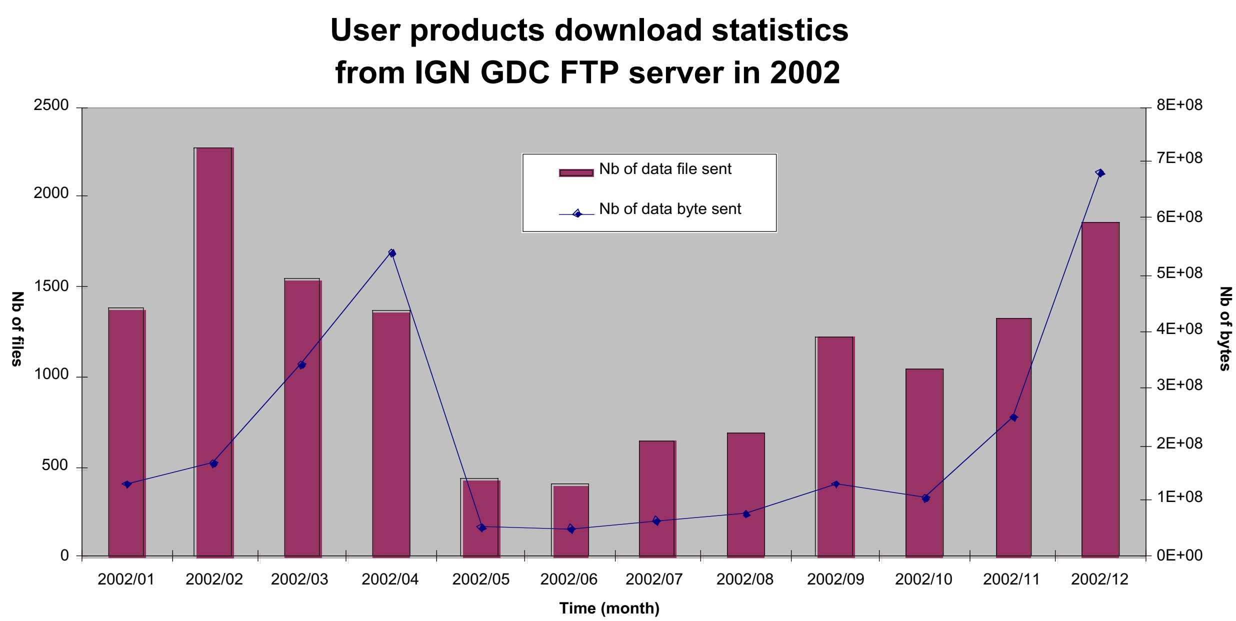

Figure 8.

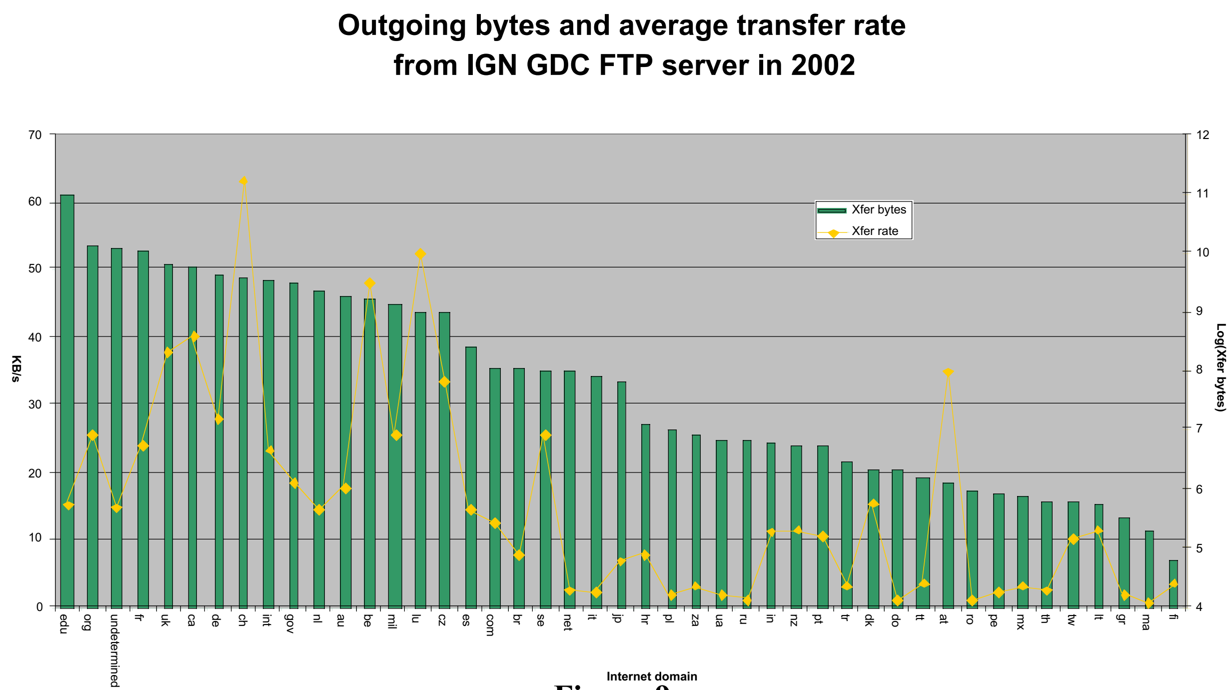

Figure 9.

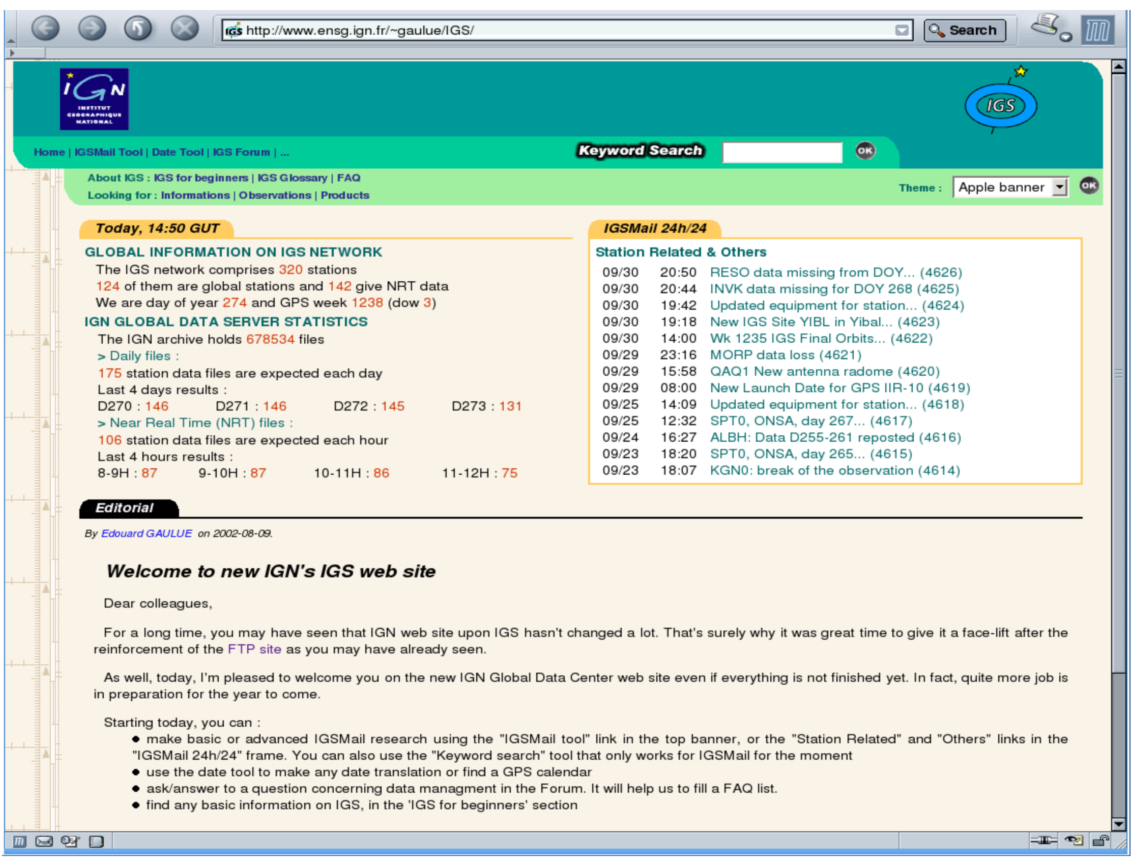

Figure 10.

SOPAC 2002 IGS Global Data Center Report

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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 for the IGS since its inception in 1994. SOPAC is responsible for the collection, archival, analysis and publication of high-precision continuous GPS data to support the global GPS community. SOPAC's two primary functions, archival and analysis of GPS-related data and data products, serve the interests of the IGS in addition to a number of other complementary SOPAC activities, including: the Southern California Integrated GPS Network (SCIGN), the National Geodetic Survey, the California Spatial Reference Center (http://csrc.ucsd.edu), NOAA's Forecast Systems Laboratory (FSL), and UNAVCO, Inc.

Some of the most noteworthy SOPAC activities in 2002, of interest to the IGS, included:

- Increase in the number of continuous GPS stations archived on a daily basis to over 1100.
- Increase in the number, scope, and function of interactive user applications, with a strong emphasis on analytical utilities such as GPS timeseries modeling and "any epoch" station positions using precise models.
- Development of GPS Seamless Archive (GSAC) for UNAVCO.
- Increase in physical archive storage to over 4 TB, spread across a dozen hosts and several different types of filesystems.
- Addition of primary/secondary dual online copies of most historical data on SOPAC archive (logical mirrors).
- Addition of several new hosts for GPS data archival and analysis.
- Centralized management of parallel archiving routines by SOPAC's Archive Data Manager (ADM) as well as numerous efficiency and participatory ADM improvements including RINEX file quality-checking, GSAC support and fault tolerance

Archive Content and Access

The SOPAC public GPS archive currently contains nearly 5 TB of on-line data, of which over 3 TB are primary copies. Included in this collection are real-time, 1 Hz GPS data files (24 hour maximum latency), near real-time GPS data files (from minute-level latency), daily GPS RINEX files, related GPS analysis products, GPS site information logs, software, and an assortment of other data files related to the use of GPS data.

The comprehensive age range of files in this collection stretches from 1990 (and sometimes earlier) to one hour ago, all of which are immediately available to the public through anonymous ftp (ftp://garner.ucsd.edu), as well as http (http://garner.ucsd.edu/).

Though the bulk of SOPAC's data collection and archiving activities involves recent data, occasionally older data and/or products are collected or generated. In these instances the files are added to the SOPAC archive as soon as possible, and are subject to the same open data policy as all other data files at SOPAC. This policy includes all data served via ftp or http from the above-mentioned servers, includes no restrictions on data acquisition and is intended to provide public users with the easiest means of collecting data on both a regular and irregular basis. Other than making appropriate acknowledgements[1] for data acquired from SOPAC there are no access restrictions on any data from the SOPAC archive.

GPS Observation Data Files

On a daily basis SOPAC is now archiving RINEX data files for over 1100 continuous GPS stations from around the world (see Figure 1), including the global IGS network (part of SOPAC's role as Global Data Center for the IGS). This number has steadily increased over the past several years, and most likely will continue to increase in the near future. A significant portion of SOPAC's public archive is dedicated to the storage and provision of data files associated with the Southern California Integrated GPS Network (http://www.scign.org); SOPAC is the primary data archive for the SCIGN network, a network comprised of over 250 continuous GPS stations spread throughout Southern California and Baja California, Mexico.

RINEX data files are divided into three primary directories on ftp://garner.ucsd.edu, /pub/rinex (observation), /pub/nav (navigation) and /pub/met (meteorological). Raw GPS data files are located under /pub/raw (daily and sub-daily sessions), as well as /pub/highrate/cache/raw (realtime raw data). For a complete list of data and data products available from the SOPAC public archive see http://garner.ucsd.edu/.

[1]Wherever applicable SOPAC strongly suggests acknowledging the source of data or products acquired from SOPAC. In particular data associated with the Southern California Integrated GPS Network (SCIGN), with UNAVCO, or the IGS, shall require acknowledgement of the variety listed at http://sopac.ucsd.edu/dataArchive/dataPolicies.html.

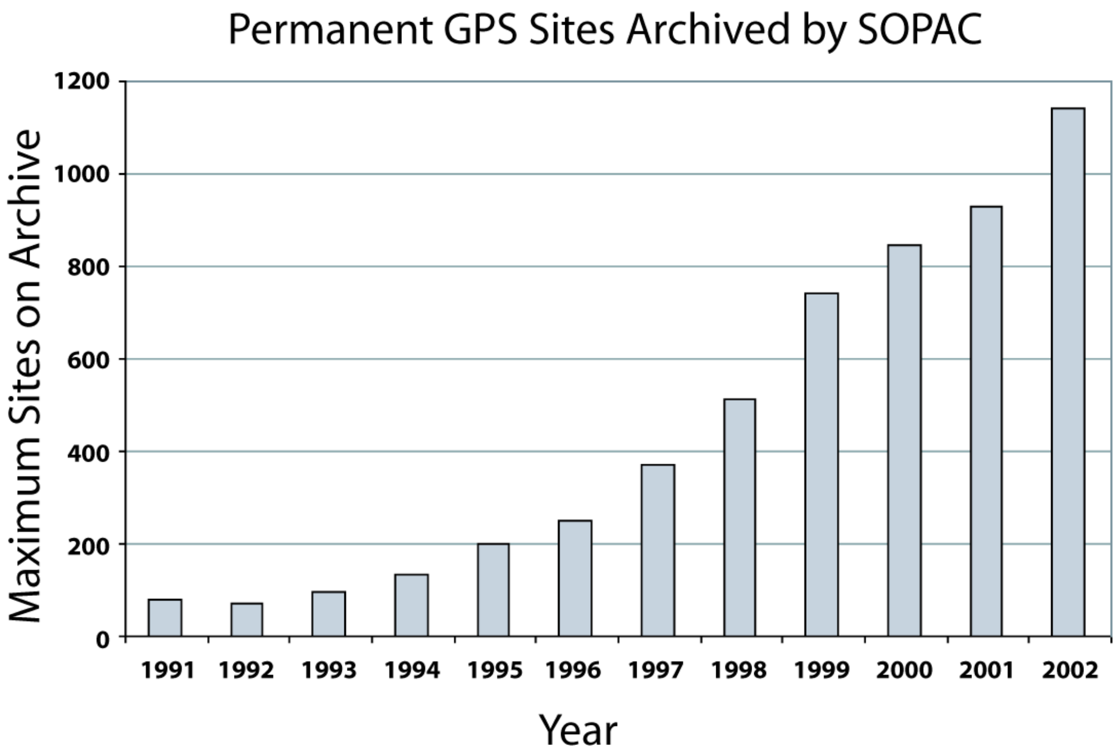


Figure 1. In 2002 the number of continuous GPS sites for which SOPAC archived data increased to nearly 1200.

GPS Analysis Products

In addition to RINEX and raw GPS data files, GPS products from all IGS analysis centers, including SOPAC (SIO), are available from SOPAC's public archive. These include combined, rapid and predicted orbits, Earth Orientation Parameters, tropospheric estimates, and SINEX solutions. Data required for the GAMIT/GLOBK processing software are also available online.

Weekly products have a latency of 4 days. SIO's predicted and rapid orbits are available within 18 hours from the end of the previous observation day. The IGS combined, rapid and predicted orbits are available within 22 hours from the end of the previous day.

Raw site time series generated from SOPAC's daily and weekly GAMIT/GLOBK processing are archived. Modeled time series from SOPAC's refined model are also available. Outliers and model site parameters, such as site offsets, are included. All time series products are available for download as tar files.

Please refer to our analysis center report in this volume for more information.

Archive Usage

In 2002 the total number of FTP transfers (from the SOPAC public archive) by both public and private users, locally and from around the world (Figure 2) more than doubled from 2001, approaching nearly 16 million in all (~ 7 million in 2001). Increasing slightly from 2001, the total number of unique hostnames/clients accessing the SOPAC archive via ftp topped 8000 (Figure 3). Overall, the vast majority of files transferred to these 8000 client machines were RINEX Observation, Navigation and Meteorological files - 14 million in all (Figure 4).

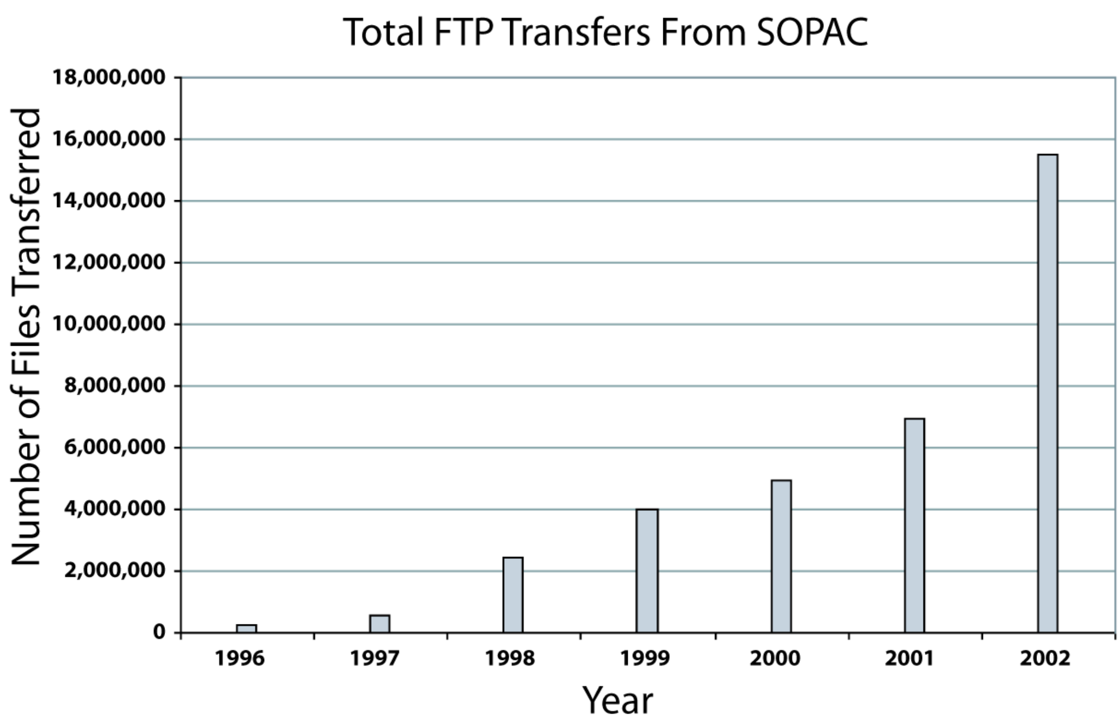


Figure 2. Number of files transferred from SOPAC via ftp://garner.ucsd.edu between 1996 and 2002.

SOPAC's user constituency in 2002 was comprised in large part of U.S. educational institutions (.edu domains) and U.S. government institutions (.gov domains). The .gov domains accounted for the highest number of transfers (Figure 5), followed closely by machines without identifiable hostnames (e.g. only IP addresses), the Swiss domain (.cz), U.S. education domain (.edu) and the German domain (.de). As far as total number of gigabytes transferred (Figure 6), U.S. education domains topped the list, followed by .gov, unidentifiable hosts, the French domain (.fr) and machines in Italy (.it).

As the number of continuous GPS sites archived by SOPAC continues to increase each year, so does the amount of space needed to serve this data and the need for more efficient archiving procedures. Maintaining its public archive has become one of the most important functions for

SOPAC over the years, as the demand for data continues to increase rapidly - in an ever-decreasing timeframe (latency). As such SOPAC has been dedicated to improving all aspects of its archive for the GPS community.

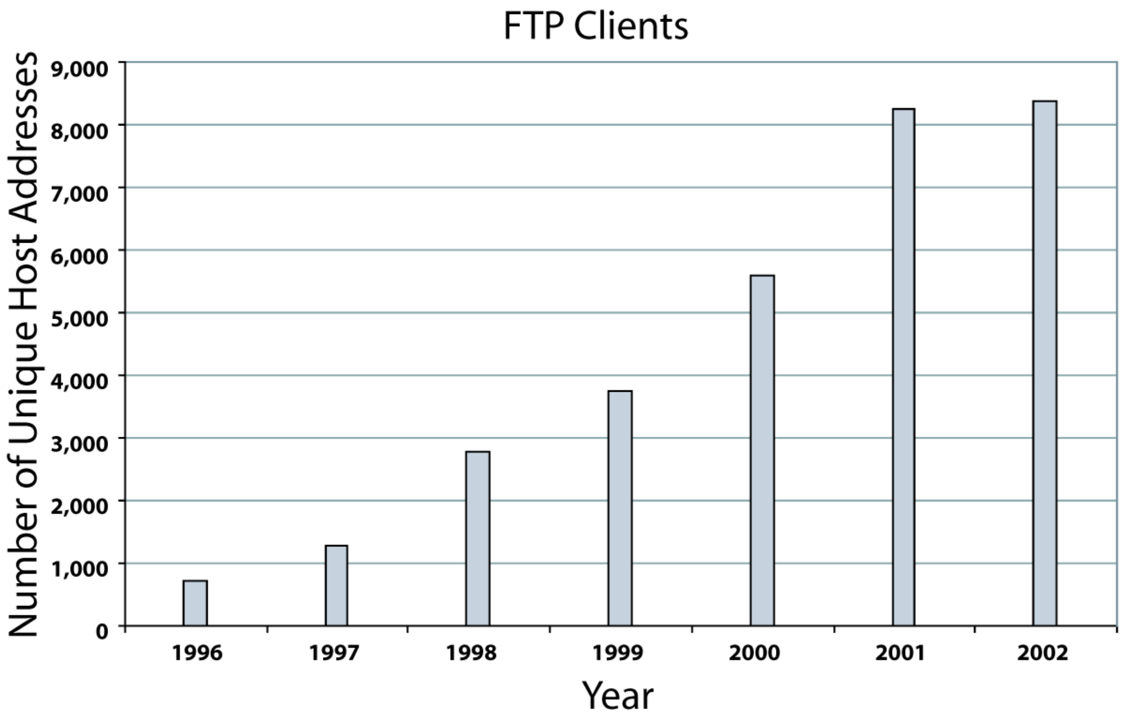


Figure 3. Number of unique clients using ftp to transfer data from SOPAC in the years 1996 through 2002. In the absence of user registration, unique hostnames are used as an indicator of the number of individuals acquiring data from SOPAC.

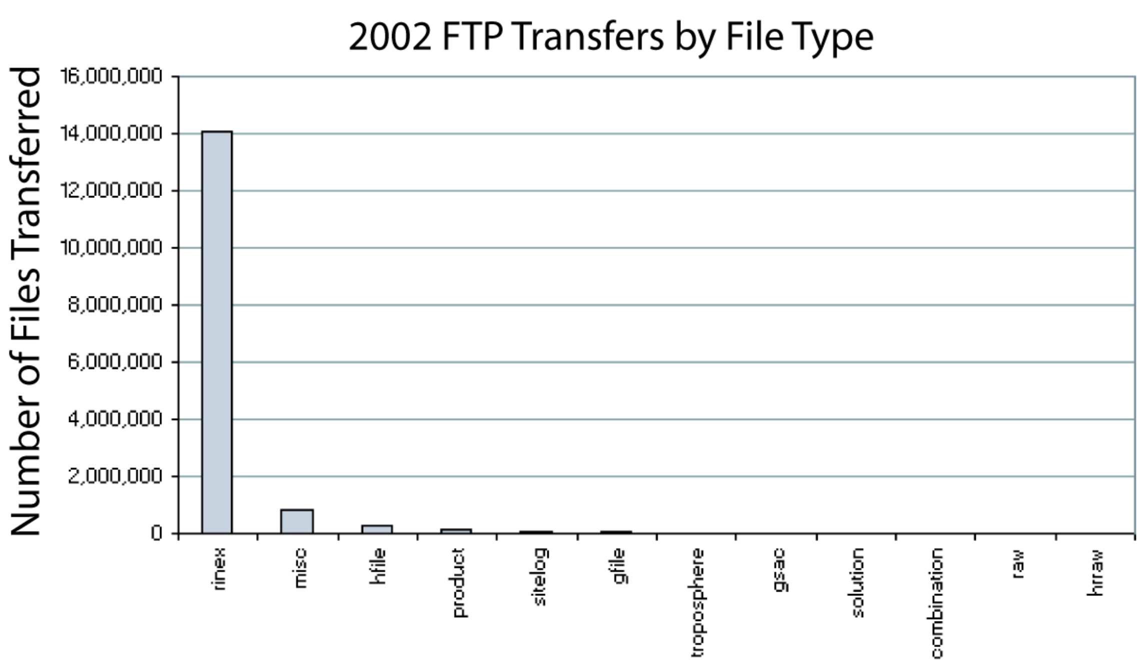


Figure 4. In 2002, as in previous years, RINEX files comprise the vast majority of files transferred by users from SOPAC's public archive.

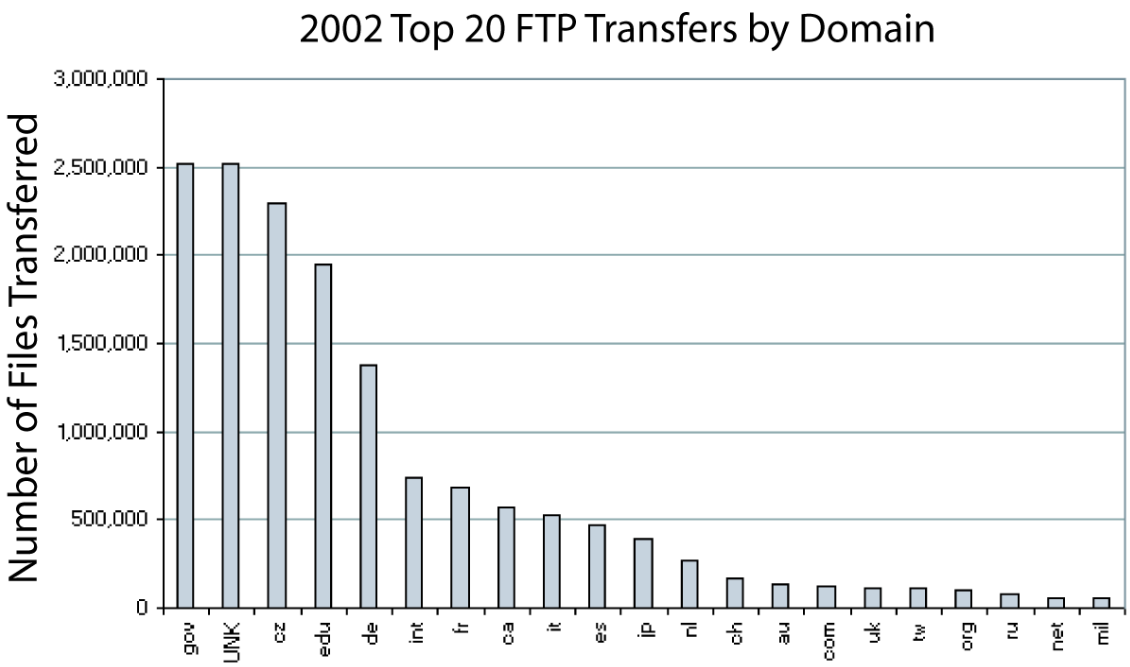


Figure 5. In 2002 .gov machines (acknowledging through DNS lookup) comprised the domain with the largest number of ftp transfers from SOPAC.

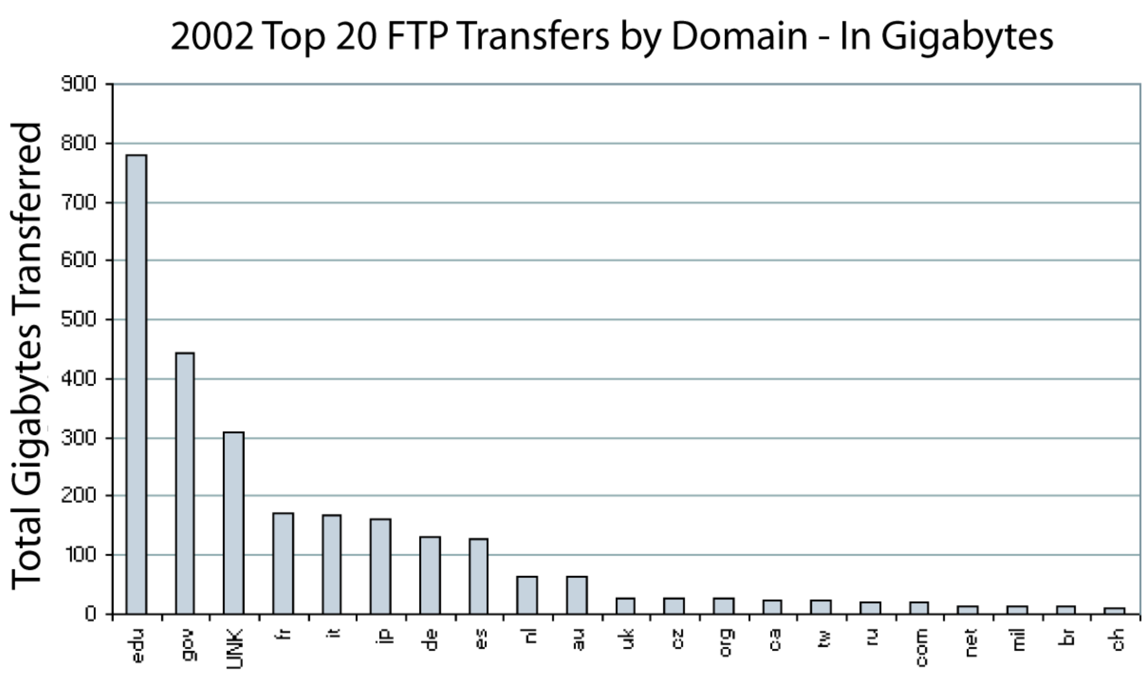


Figure 6. .U.S. educational domains (.edu) comprised, cumulatively, the most significant amount of gigabytes transferred from SOPAC via ftp.

Systems Architecture

SOPAC owns and maintains over 50 different hosts spread across three different buildings on the campus of the Scripps Institution of Oceanography. This collection of systems perform a variety of functions, ranging from basic mail servers, to a Beowolf cluster, user workstations, centralized development library servers, primary public access machines hosting ftp and/or http services, database servers and two dozen GPS data archiving and analysis machines.

SOPAC's public access systems consist of a three Dell PowerEdge servers and a Sun E220R. The Sun server (garner.ucsd.edu) hosts the primary ftp and http interface for the SOPAC public archive. The public hosts, http://sopac.ucsd.edu and http://gsac.ucsd.edu, (as of January 2003) were hosted by two different Dell PowerEdge servers. A third Dell, geopub.ucsd.edu, hosts SOPAC's primary ftp upload service. Together these four hosts play a critical role in providing public access to SOPAC.

From garner.ucsd.edu (via ftp or http) more than 3 TB of data are immediately available to the public 24 hours a day, 7 days a week. By late 2003 the amount will approach 4 TB, with another 2 TB of online copies for redundancy/backup purposes; these “secondary” copies are not linked to garner, but are immediately available in the event of host-specific outages. The data served through garner.ucsd.edu is supported through the use of the Network File Systems (NFS) protocol. Filesystems are spread across nearly a dozen hosts, and include SCSI-based RAID5, SCSI-based IDE, SCSI-based RAID1, IDE RAID0, Firewire and an AIT tape library.

For a graphical representation of SOPAC's systems architecture see the Appendix.

Archive Management

Over the years, as SOPAC's participation in various projects, particularly, but not limited to, the IGS, has expanded so has the size and complexity of its computational infrastructure and the processes required to construct it, maintain it, populate it and provide access to it. In response, SOPAC has taken steps to automate as many of these tasks as possible, while simultaneously improving other areas of major concern to SOPAC, such as information management and GPS-related scientific research. The most important aspect of this integration and automation has taken the form of a single, robust, Perl-based database application called Archive Data Manager (ADM).

Archive Data Manager (ADM)

Nearly all aspects of managing the SOPAC public archive are fully-automated – driven by a single SOPAC application called Archive Data Manager[2], which derives its configuration, job lists, archive structure (local and remote archives) and other functioning needs from a relational

[2]ADM, and its supporting collection of libraries, is a custom, system-level Perl application written and maintained at SOPAC. Over the past 3 years ADM has evolved significantly, absorbing numerous tasks once associated with one or more manual functions at SOPAC. The flexible nature of ADM, combined with its close relationship with SOPAC's production database, has allowed SOPAC staff members to direct a greater amount of their time to the analysis of GPS-related information and data files, and the modeling of GPS-related information for wider, community-based initiatives – especially those involving XML.

database schema in an Oracle 9i database server. ADM handles nearly all facets of SOPAC's public archive management and incorporates a number of automated features including 1-second latency GSAC publication of RINEX files and mirroring of RINEX content from the CDDIS and IGN global data centers.

ADM continuously probes and collects data files from more than 40 different local, regional, sub-regional and global GPS archives from around the world. Utmost attention is paid to the efficiency, intelligence and notification capabilities of ADM by SOPAC staff members, especially in relation to the topics of file collection latency, archive availability (up-time), file recollection, IGS data center mirroring, RINEX file quality-checking, GSAC integration, IGS site information log parsing, raw GPS file translation (using teqc) and near real-time RINEX archival.

As the installation of continuous GPS sites around the world continues to increase, and the frequency with which those sites record GPS observations, so does SOPAC's attention to issues related to managing the collection, archival and provision of these datasets in a professional and highly available manner. In response, SOPAC is preparing for the rapid increase in both the number of data files collected as well as the total amount of physical space required to store (and serve) these datasets.

Collection. Collection of data files by ADM occurs in parallel, across numerous SOPAC hosts. Individual processes are launched by Unix cron table entries and communicate through a common relational database server. Since 2001 (when ADM was originally written) a number of improvements have been made with regard to making SOPAC's overall archiving operations more stable, less prone to problems with a particular host, network filesystem, or remote archive and intelligent enough to recognize patterns related to particular files (e.g., quality), local hosts, or remote servers. These enhancements include load balancing, NFS traffic reduction, mirrored data files in two locations and centralized configuration maintained through database-driven user interfaces.

Storage. Storage components used by ADM are distributed across multiple servers with varying amounts of space, RAM, network bandwidth, up-time expectations, redundancy and file retrieval response times. Typically ADM stores a copy of each file it collects, in a “staging” pool (usually an inexpensive Firewire drive to be shelved when full, and cleaned to tape at a later time), in the primary archive location, and in a secondary archive location (to have two copies online at all times). Depending on the type of data file, and its association with a given project, different assignments are made to different physical storage components. Typically, older, infrequently accessed data, are stored in two separate locations (both online) on inexpensive Firewire drives. More recently, frequently accessed data files are temporarily housed on more expensive RAID disk arrays covered by on-site maintenance contracts. Yet another important storage component utilized by SOPAC, but managed by IGPP (our host department), is an 18TB AIT tape library; this system is used to store large, infrequently accessed data files such as high-rate sampling GPS raw data from realtime networks.

Administration. As far as actual staff resources are concerned, administration/oversight of ADM occurs primarily through two different means: a) via 'indicator' emails sent to SOPAC staff by

ADM, and b) configuration management by SOPAC staff through web-based applications and direct database queries.

The indicator emails highlight actual, as well as potential, problems encountered or anticipated by ADM and allow multiple staff members to remain informed of the general health of the archive. Important topics addressed by ADM in this manner include: filesystem problems (out of space, hung mount points, etc), server-related problems (archive hosts, upload ftp server, etc), file-related problems (quality-checking, small file size, availability issues, etc) and 'discoveries' (previously unknown GPS site possibly found at another archive).

Email notification by ADM works well in a reactive setting, for irregular events and otherwise unanticipated occurrences. However, the configuration of ADM (e.g., what to do, when, how) is managed primarily through SOPAC's Site Information Manager (SIM) and direct SQL interfaces with SOPAC's production database.

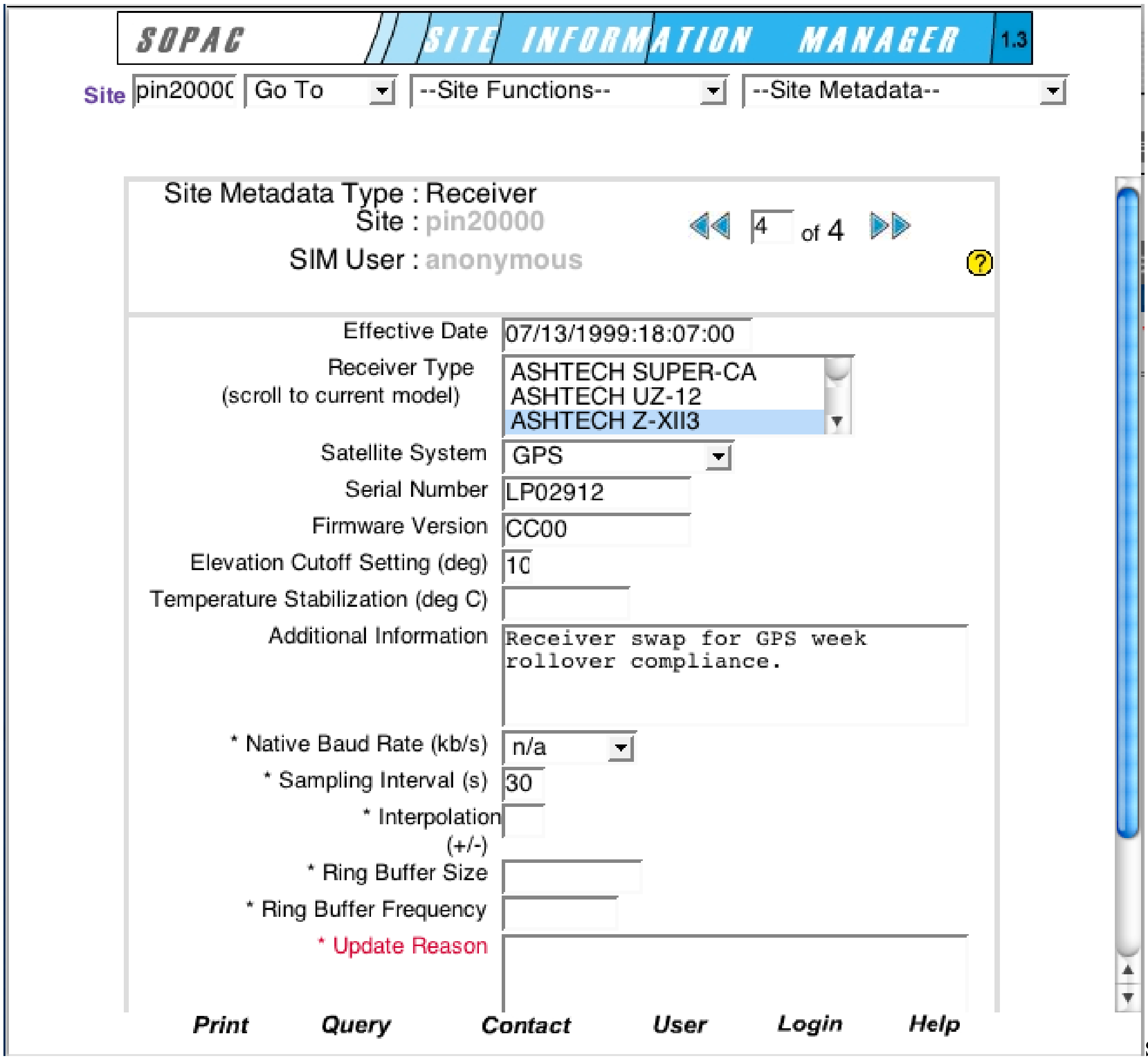
Overall, SOPAC's archive management functions remain a top priority and will continue to be a top priority into the foreseeable future. Nearly every week an improvement or addition of some kind is made to the ADM system.

Information Management

SOPAC has been dedicated to providing the GPS community with useful and timely information describing GPS data, or various components related to the use of GPS data for scientific research, education, government and commercial applications since the early 1990s. At the center of nearly all of SOPAC's information management activities is an Oracle 9i relational database. This database is used to model information critical to the functioning of SOPAC and to the assortment of GPS-related activities it performs. Interfaces to the database are many, and vary with the context and regularity with which particular information set is affected. However, one application in particular has received the most development resources over the past several years – SOPAC's Site Information Manager.

Site Information Manager (SIM)
For information associated with GPS sites (or geodetic monuments) SOPAC's primary management tool is the Site Information Manager[3] (Figure 7), a web-based application that allows users to insert, update or delete information associated with one or more GPS

[3]The SIM launches and runs in a separate browser window, accessible from http://sopac.ucsd.edu/scripts/SIMpl_launch.cgi.



sites

Figure 7. SOPAC's Site Information Manager (SIM) is a web-based database application that allows users to insert, update or delete information content associated with one or more GPS sites

they have been granted access rights to by a SOPAC staff member. The interface itself uses the same (or very similar) terminology, value domains (such as equipment model codes) and layout as an IGS Site Information Log. SIM users, among other things, can find or specify the site they wish to view/edit and then make changes (assuming they have the necessary access rights) to any information in the SOPAC database associated with the selected site, and supported in the SIM. This information then propagates directly into a variety of functions at SOPAC, many of which serve the interests of the IGS, including:

- Complete IGS site log generation from the SOPAC database on request (by a SIM user).
- Automated generation and submission of SCIGN site logs (for certain sites) to the IGS.
- Parsing/validation of IGS site logs during ADM archival processes.
- Translation of SCIGN raw GPS data files using UNAVCO's teqc utility.

- Creation of publicly-available SINEX products and GAMIT station.info configuration files for GPS analysis.

Over the past 4 years the SIM has undergone numerous updates, to conform to changes in the IGS site log format and to serve a more extensive pool of application contexts at SOPAC. This important interface has served as an invaluable asset in numerous capacities at SOPAC and continues to evolve as needed.

Automated Information Collection

Much of what ADM (described previously) does, with regard to the IGS, is to automate important tasks such as the parsing of IGS site logs. Whenever a new (or modified) site log appears at one or more ftp archives visited by ADM it is collected and parsed with respect to information present in SOPAC's production database – much of which is managed/overseen by SIM users. Any differences in content are automatically rectified with respect to the database, or shipped to a SOPAC staff member via email for confirmation. This information is then immediately available to most SOPAC applications, including GAMIT's station.info generation, ALL site information-based applications on SOPAC's websites and SOPAC's regular operational GPS analysis.

The relationship between data file collection (and subsequent provision) and ancillary metadata has received a large amount of SOPAC's development time over the years, as more and more inter-operative and collaborative functions have evolved at SOPAC. Furthermore, the benefits reaped by such development have aided SOPAC significantly in developing a more efficient and effective GPS analysis environment, for local (in-house) and public users alike.

Future Plans

In 2003 SOPAC plans to construct a Geographic Information Systems (GIS) lab to support its research and public interface activities. This lab will contain several Dell workstations (running a Windows operating system) and a central data server. All hosts will have a suite of ESRI and Leica Geosystems software installed locally, in conjunction with application development packages (Microsoft Visual Studio) and graphical development environments (Macromedia MX and Adobe). These resources will be used by SOPAC staff members and students to enhance and extend the set of online applications provided to the GPS community through SOPAC's primary websites.

Plans for 2003 and 2004 also include the development of Extensible Markup Language (XML) schemas and supporting applications for numerous GPS-related activities including the automated creation and distribution of IGS Site Information Logs, passive GPS campaign field logs and possible enhancements to GSAC information exchange mechanisms.

Contact Information

For more information about SOPAC, or any of its IGS-related functions please contact:
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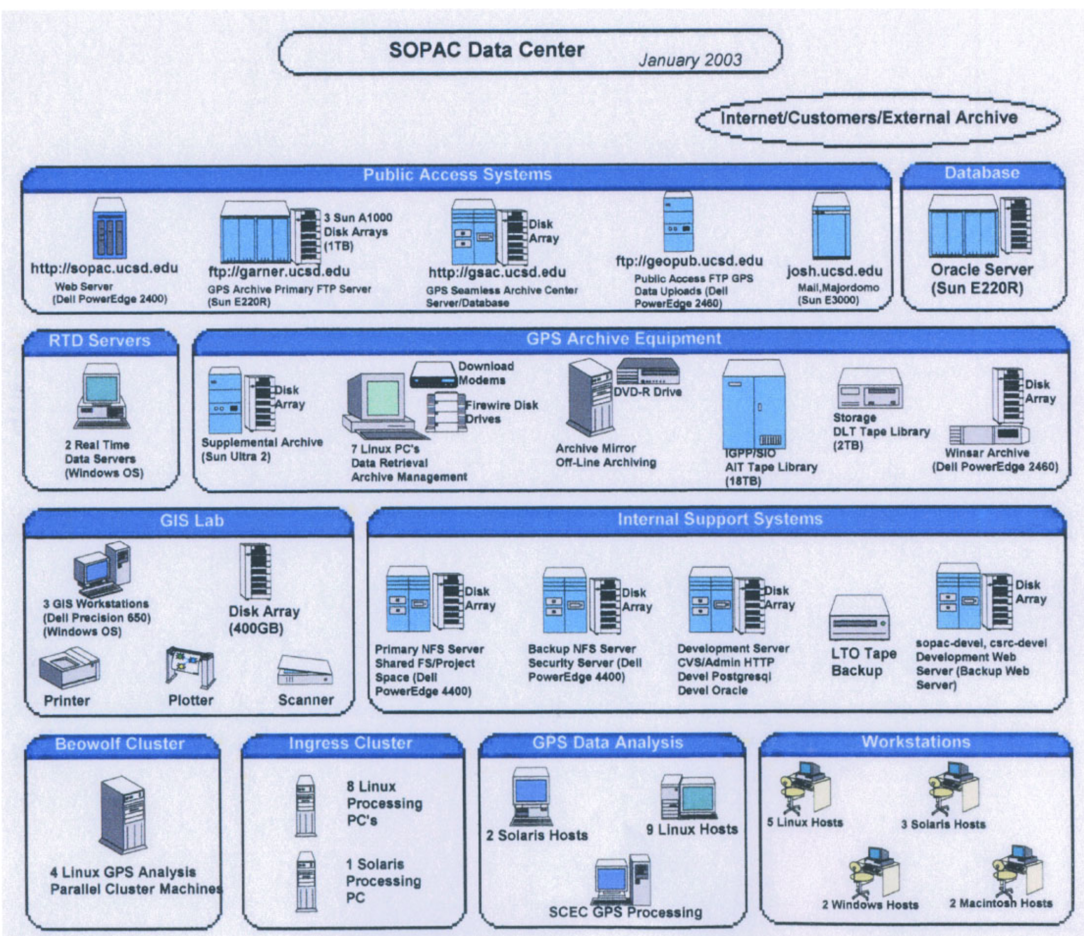
or visit SOPAC's main public website at: http://sopac.ucsd.edu.

Acknowledgments

We want to thank our IGS colleagues for sharing data, metadata, and metadata with us, and our customers for continuing to use (and stress) our archive. We acknowledge the Southern California Integrated GPS Network and its sponsors, the W.M. Keck Foundation, NASA, NSF, USGS, SCEC, for providing data used in this study. Funding also provided by NSF (through UCAR/UNAVCO), NOAA's Forecast Systems Laboratory, and NOAA's NGS (through the JIMO program to the California Spatial Reference Center).

Appendix. Systems Architecture of SOPAC's Data Center



REGIONAL/OPERATIONS CENTERS

BKG Regional IGS Data Center Report 2002

Heinz Habrich

Federal Agency for Cartography and Geodesy, Frankfurt, 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 a European institution operates these stations. The received data are uploaded to the Global Data Centers (GDCs), and are also made available to other users. BKG holds the data files from different projects in separate directories in order to handle the project related restrictions, e.g., the project specific user access. A project independent access is additionally realized through a list of all stations and links to the corresponding subdirectories. The operability of the data center is continuously adapted to meet newest requirements. In 2002 the data center was further development through the cooperation with the IGS Data Center Working Group, the preparation of the participation in GSAC, and the design of a new server concept.

Activities in 2002

In 2002 about 10 new GPS/GLONASS stations has been established in Germany by BKG and provide observations in a real-time data stream. These data streams are compiled to hourly files and copied to the data center. It increases the number of GPS/GLONASS stations in Germany significantly. The wholesaler software kid of the GPS Seamless Archive Center (GSAC) as provided by SOPAC has been installed at BKG for test purposes. A first small data holding catalogue was generated and confirms the functionality of the software installation. It is planned to run the complete wholesaler software within the new server concept (see section below). BKG is furthermore represented in the newly established IGS Data Center Working Group.

New Server Concept

BKG decided in 2002 to develop and realize a new server concept for the data center. The objective is to make the access to the data center more comfortable for the users as well as for the administrator. It should be possible to get all information by usage of the http protocol. Also the administration of the data center should easily be possible by the generation of helpful status overviews and the execution of predefined repair batches. For that purpose the LAMP (Linux operation system, Apache web server, MySQL data bank and PHP script language) server concept will be used. The new server will not change the disk file structure and thus batch programs for ftp downloads may still be used. LAMP enables to show dynamic web pages for the current content of the data base. A test server has been installed in 2002 and has demonstrated the functionality of the concept (http://igs2.ifag.de). It is planned to put the new server in operation before the end of 2003. Figure 1 shows the new designed 'check-import-like' statistic. It shows up with sensitive fields for the station code, color pad and day of year to request detailed information. Figure 2 shows the ‘station’ and ‘receiver’ menus, which are dynamically generated from the SQL data base.

Outlook

If the new server concept will be realized, BKG expects to run a very robust, flexible and comfortable data center. The participation in GSAC will be a proper global extension to the European data. It is currently not possible to correctly value the importance of real time data streams for the future. Anyhow, BKG will be prepared to introduce real time applications into the data center.

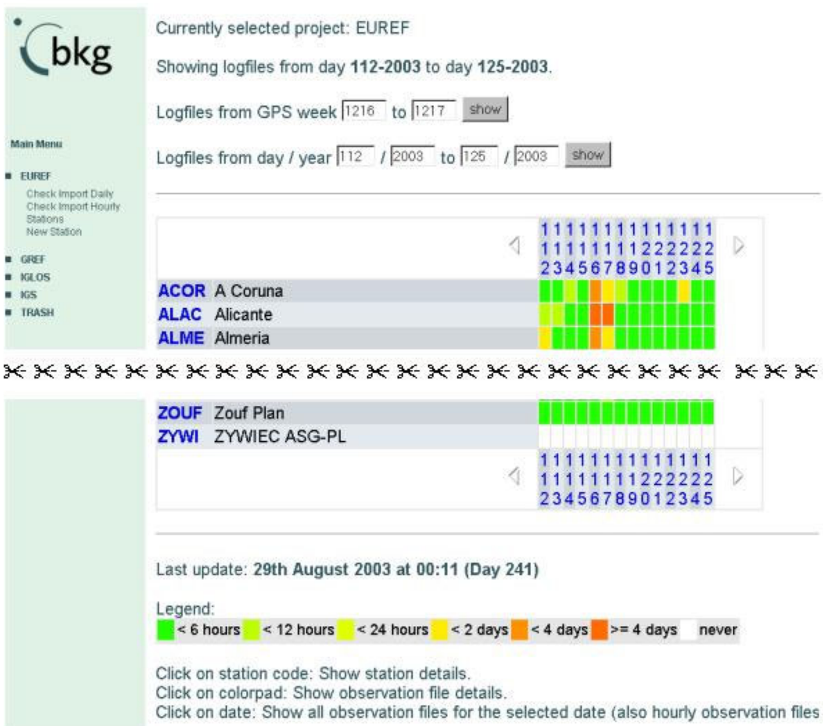


Figure 1: New ‘check-import’ statistic

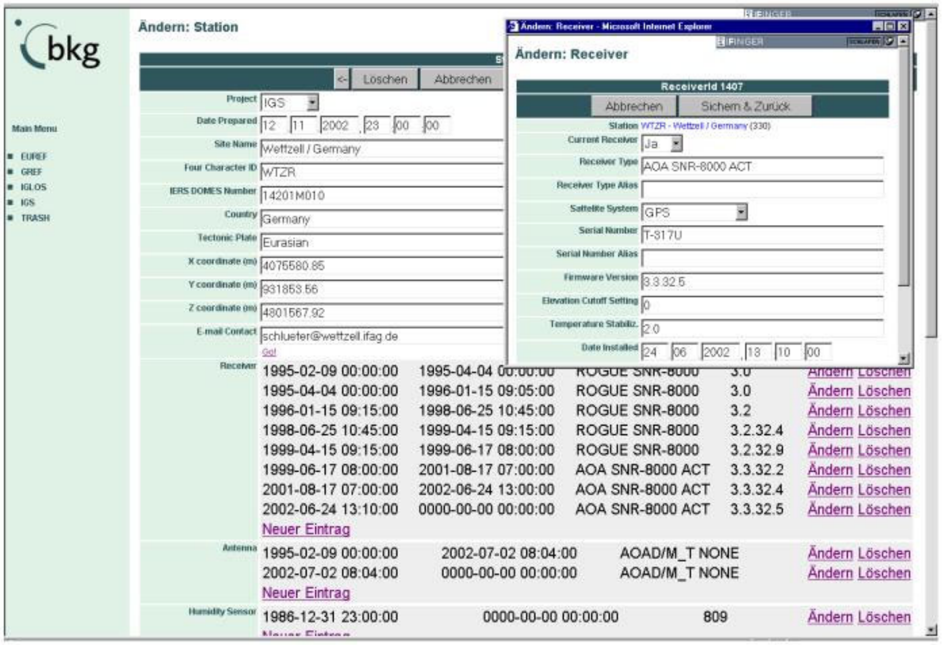


Figure 2: Selected ‘station’ and ‘receiver’ menu

HartRAO Regional Center Report 2001-2002

Ludwig Combrinck

Space Geodesy Programme
Hartebeesthoek Radio Astronomy Observatory
e-mail: ludwig@hartrao.ac.za

Introduction

HartRAO is located north of Johannesburg, South Africa, in a valley of the foothills of the Witwaters mountain range. HartRAO uses a 26 metre equatorially mounted Cassegrain radio telescope built by Blaw Knox in 1961. 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 a Satellite Laser Ranging (SLR) station MOBLAS6 (Figure 1). HartRAO is the IGS Regional Data Centre for Africa and a TIGA associate analysis centre.

Figure 1. The 26 metre radio telescope used for geodetic VLBI. Solid panels have been fitted as part of a surface upgrade, which is expected to be complete by end 2003. In the foreground is the antenna of the IGS station HRAO and to the right is the NASA SLR MOBLAS6. The collocation of these three geodetic systems makes HartRAO an important contributor to global space geodesy.

Database

Currently, data of about 40 IGS stations are archived, including the combined broadcast files and IGS precise ephemeris. The data is accessible via anonymous ftp to *geoid.hartrao.ac.za* or via the web page *http://www.hartrao.ac.za/geodesy/data.html*

Database Structure

Data is stored in the format yyyy/doy/station and usage of the web based data archive is user friendly. Access via anonymous ftp is after log on, by changing directory to *rinex/yyy/doy.* The combined broadcast (navigation) files are stored in the same directory.

IGS precise ephemeris (*.sp3) files are located in the directory *products/gpsweek,* these files commence with GPS week 0938. Rinex and combined broadcast files date to day 001, year 2000. If there is a requirement for earlier files, this can be arranged by contacting the author. We would also be willing to store data (e.g. local surveys, campaigns etc.) for local users as long as the data is available to all users.

All files are gzipped. There is a gzip utility available from the same web page. Hatanaka compression is not used at the moment, although older data will eventually be stored after having been compressed using the Hatanaka algorithm. Only 24 hour RINEX files are archived at the moment, but it is envisaged that a subset of the archive will be stored as one hour files within the near future. Typical file download traffic during 2001 was about 100 files per day. This is minute in comparison to most other data centers, but this figure continues to grow and indicates a greater use of IGS data and products on the African continent.

TIGA

TIGA related metafiles and information can be found on the web page
http://www.hartrao.ac.za/geodesy/web_TIGA/index.html

Information about the Tiga Observing Stations (TOS) as well as tide gauge specific type information is stored here. Access to data retrieval is provided to accommodate users.

A map provides a graphical interface to photos and details of several TOS installations.

Two TOS stations have been installed by HartRAO, SIMO (Simonstown) (Figure 2) and RBAY (Richardsbay).

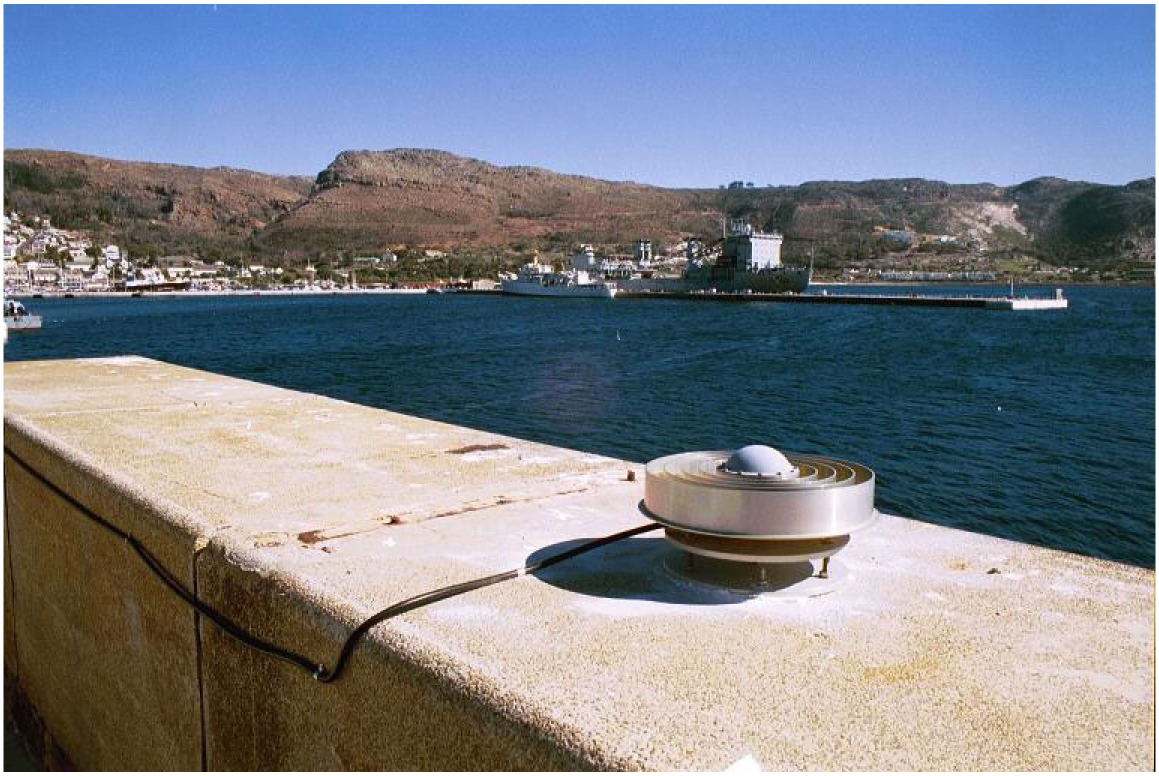


Figure 2. The GPS antenna of SIMO, an IGS TOS station located at Simonstown, South Africa.

Computer Hardware

The regional data server consists of a dual processor 450 Mhz Pentium III equipped with two twenty Gb disks and one forty Gb disk. Backups are done on 40 Gb DAT tapes. The same server is used for data processing and JPL has an account on the machine to enable access to RBAY through a multi-layered firewall. Although the server meets all present requirements as far as data archiving is concerned, it does not meet processing requirements. It is therefore necessary to obtain a more advanced computer to enable processing of data, which needs to be completed within a specific timeframe. A cluster of PCs will be acquired during 2003 to facilitate processing.

SADC GPS Network

In collaboration with GFZ Potsdam, the old regional station NAMI (an old SNR8) installed by HartRAO/JPL which is located in Windhoek (see 2000 report) was selected for an upgrade. Installation of a modern GPS station will take place during 2003. An IGS station was installed at Lusaka, Zambia (Figure 2) at the offices of the Surveyor General. The station has been providing reliable data and is used regionally (Combrinck and Nsombo, 2002) and by several IGS Analysis Centers. A paper was presented (Combrinck 2002) at the IGS workshop in Ottawa, Canada during April 2002, which described the current connectivity and networking opportunities in Africa with a view towards real-time GPS.

In South Africa, only SUTH and HRAO provide real-time streaming data. In collaboration with NRCan, it is planned to install a real-time station at MAUN (Botswana) during 2003. We are in the process to equip Malawi, Mozambique (2003), Madagascar, Botswana (2003), Namibia (2003) and Zimbabwe with IGS stations. Members of the IGS who have upgraded existing stations and have redundant equipment available should please contact the author.

A project submission has been made in collaboration with GFZ Potsdam to equip the 14 Southern African Development Community (SADC) countries with at least one IGS GPS station in the next five years. In collaboration with the TIGA IGS pilot study, several tide gauges will also be installed (collocated with GPS). A special effort will be made to install a tide gauge and GPS on Marion Island, which is located between Africa and Antarctica at about -40 degrees south.

Figure 3. The ZAMB GPS antenna monumentation located in Lusaka, Zambia. The antenna is situated on a massive concrete foundation, which extends through a large building. The foundation used to support a large water tank

Geodetic Institute

In order to bring geodesy closer to home and the African continent, the Geodesy Programme is in the process of establishing a Geodetic Institute. The purpose of this institute at 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, ILRS and IGS. It will also support the objectives of the African Reference Frame (AFREF) through the further development of the SADC GPS Network.

Research Activities

A project was launched to produce ZTD maps using GPS data and preliminary results were promising. A technique was developed using the GAMIT software to determine vertical motion due to earth tide as measured by GPS. The IGS station SUTH, located at Sutherland and collocated with a superconducting gravimeter was used to evaluate this technique. It is envisaged that a PC cluster to be purchased during 2003 will allow routine processing and further development of this technique (Neumeyer et al. 2002). Currently processing power is too limited to be practical.

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Neumeyer, J., Barthelmes, F., Combrinck, L., Dierks, O. and Fourie, P. 2002. Analysis results from the SG registration with the Dual Sphere Superconducting Gravimeter SAGOS (South Africa), published in International Center for Earth Tides' *Bulletin d' Informations Marees Terrestres (BIM), 135, 10607-10616*, and presented at the Third Workshop of the Global Geodynamics Project (GGP) on Superconducting Gravimetry.

NETWORK AND STATION REPORTS

GLOBAL, REGIONAL, AND LOCAL NETWORKS

IGS Network Coordinator Report - 2002

Angelyn Moore

IGS Central Bureau
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

Network Composition Changes

The IGS network is a set of permanent, continuously-operating, dual-frequency GPS stations operated by over 100 worldwide agencies. The dataset is pooled at IGS Data Centers for routine use by IGS Analysis Centers in creating precise IGS products, as well as free access by other analysts around the world. The IGS Central Bureau hosts the IGS Network Coordinator, who assures adherence to standards and provides information regarding the IGS network via the Central Bureau Information System website at http://igscb.jpl.nasa.gov.

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 112 stations, listed in Table 1, during 2001 and 2002.

Table 1 - Network Composition Changes During 2001-2002

```
--------------------------------------------------------------------------
Additions
--------------------------------------------------------------------------
AJAC    Ajaccio, Corsica, France
ALRT    Alert, Nunavut, Canada
ANTC    Los Angeles, Chile
BAN2    Bangalore, India
BOGI    Borowa Gora, Poland
BREW    Brewster, Washington, USA
BRST    Brest, France
CAGS    Gatineau, Quebec, Canada
CAGZ    Capoterra, Italy
CFAG    Caucete, Argentina
CHPI    Cachoeira Paulista, Brazil
CHUM    Chumysh, Kazakhstan
CONZ    Concepcion, Chile
COPO    Copiapo, Chile
COYQ    Coyhaique, Chile
DARR    Darwin, Australia
DAVR    Davis, Antarctica
DLFT    Delft, the Netherlands
DREJ    Dresden, Germany
DWH1    Woodinville, Washington, USA
FALE    Faleolo, Samoa
FFMJ    Frankfurt/Main, Germany
FREE    Freeport, the Bahamas
GMAS    Mas Palomas, Gran Canaria, Spain
GUAO    Urumqi, China
```

Table 1 - Network composition changes during 2001-2002 (continued)

Additions (cont'd)

HELJ	Helgoland Island, Germany	
HERP	Hailsham, England	
HILO	Hilo, Hawaii, USA	
HNLC	Honolulu, Hawaii, USA	
HOLM	Holman, Northwest Territories, Canada	
HUEG	Huegelheim, Germany	
HYDE	Hyderabad, India	
INVK	Inuvik, Northwest Territories, Canada	
IQQE	Iquique, Chile	
IRKJ	Irkutsk, Russia	
JOZ2	Josefoslaw, Poland	
KGN0	Koganei, Japan	
KGNI	Koganei, Japan	
KHAJ	Khabarovsk, Russia	
KOU1	Kourou, French Guyana	
KOUC	Koumac, New Caledonia	
KR0G	Kiruna, Sweden	
KSMV	Kashima, Japan	
LAE1	Lae, Papua New Guinea	
LEIJ	Leipzig, Germany	
LHAZ	Lhasa, Tibet, China	
LHUE	Lihue, Hawaii, USA	
LIND	Ellensburg, Washington, USA	
LROC	La Rochelle, France	
MALD	Male, Maldives	
MANZ	Manzanillo, Mexico	
MARS	Marseille, France	
MAT1	Matera, Italy	
MAUI	Haleakala, Hawaii, USA	
MBAR	Mbarara, Uganda	
MDVJ	Mendeleevo, Russia	
METZ	Kirkkonummi, Finland	
MIKL	Mykolaiv, Ukraine	
MIZU	Mizusawa, Japan	
MOBN	Obninsk, Russian Federation	
MORP	Morpeth, UK	
MR6G	Maartsbo, Sweden	
MSKU	Franceville, Gabon	
MTBG	Mattersburg, Austria	
MTKA	Mitaka, Japan	
NAIN	Nain, Newfoundland, Canada	
NNOR	New Norcia, Australia	
NPLD	Teddington, UK	
OBE2	Oberpfaffenhofen, Germany	Replacing OBER
OBET	Oberpfaffenhofen, Germany	
OHI2	O'Higgins, Antarctica	Replacing OHIG
OHIZ	O'Higgins, Antarctica	
OPMT	Paris, France	
OS0G	Onsala, Sweden	
OUS2	Dunedin, New Zealand	
PADO	Padova, Italy	Replacing UPAD

Table 1 - Network composition changes during 2001-2002 (continued)

Additions (cont'd)		
PARC	Puntas Arenas, Chile	
POLV	Poltava, Ukraine	
PTBB	Braunschweig, Germany	
QAQ1	Qaqortoq, Greenland	
RESO	Resolute, Nunavut, Canada	
REYZ	Reykjavik, Iceland	
SACH	Sachs Harbour, Northwest Territories, Canada	
SCUB	Santiago de Cuba, Cuba	
SIMO	Simonstown, South Africa	
STR2	Stromlo, Australia	
SULP	Lviv, Ukraine	
SUNM	Brisbane, Australia	
SUTM	Sutherland, South Africa	
SUVA	Suva, Fiji	
TCMS	Hsinchu, Taiwan, Republic of China	
TGCV	Palmeira, Republic of Cape Verde	
THU2	Thule, Greenland	
THU3	Thule, Greenland	
TITZ	Titz, Germany	
TLSE	Toulouse, France	Replacing TOUL
TNML	Hsinchu, Taiwan, Republic of China	
TWTF	Taoyuan, Taiwan, Republic of China	
ULAB	Ulaanbataar, Mongolia	
UNB1	Fredericton, New Brunswick, Canada	
USN1	Washington, D.C., USA	
VALP	Valparaiso, Chile	
VS0G	Visby, Sweden	
WROC	Wroclaw, Poland	
WTZA	Koetzting, Germany	
WTZJ	Wettzell, Germany	
WTZZ	Koetzting, Germany	
YAKT	Yakutsk, Russian Federation	
YARR	Dongara, Australia	
ZAMB	Lusaka, Zambia	
ZIMJ	Zimmerwald, Switzerland	
ZIMZ	Zimmerwald, Switzerland	

Deletions	
BARB	Bridgetown, Barbados
IGM0	Buenos Aires, Argentina
MATH	Lake Mathews, California, USA
PVEP	Palos Verdes, California, USA
TAIW	Taipei, Taiwan, Republic of China
TEGU	Tegucigalpa, Honduras

While this number may initially seem alarmingly higher than recent rates of station addition (and indeed, equal to the total number of IGS stations at the close of 1995!), it reflects the wholesale incorporation of an entire new class of sites: those which receive both GPS and GLONASS signals and participate in the International GLONASS Service Pilot Project (IGLOS-PP). The new sites also include some participating in other IGS Working Groups and Pilot Projects, such as timing activities and Tide Gauge Benchmarks. Notable coverage improvements came to the Arctic and southern Africa, as is evident from the large circles in Figure 1.

Six stations (also listed in Table 1) exited the IGS network in 2001-2002, due to decommissioning or other permanent unavailability of tracking data, bringing the total number of stations to 348 at the close of 2002.

Typical IGS stations contribute data sampled at 30 seconds on a daily basis; a growing and increasingly well-distributed subset contributes similar data hourly or more frequently, as shown in Figure 2.

Network-Related developments: IGLOS Site Integration

In 2001-2002, the IGS station operators and other IGS participants collaborated with the Network Coordinator to realize several improvements to the network element. An overhaul of the station logs which record the history of each site (crucial to the maintenance of the IGS realization of the International Terrestrial Reference Frame and the consistency of IGS products) started with a proposal of a form allowing the structured collection of information on more types of ancillary and geophysical data. After review and revision by a small yet representative group, final suggestions were collected from the IGS at large in typical IGS collaborative fashion. The changeover was handled at the Central Bureau, with significant and timely assistance from site operators when apparent discrepancies arose, over a period of days leading up to the actual switch on 11 Jun 2002. Care was taken to ensure that the IGS SINEX template (the authoritative compilation of station configuration history) was not adversely affected by the site log maneuvers.

This revised station metadata allowed stations participating in the International GLONASS Service Pilot Project (IGLOS-PP) to be fully integrated into the IGS network. Figure 3 shows an example of an IGLOS station co-located with a GPS-only IGS site. Combined GPS/GLONASS data and station configuration data now appear side by side with the GPS-only IGS stations. In addition to augmenting the IGS network and providing convenience for IGLOS-PP analysts, this serves as a significant demonstration of the IGS' capability to integrate data from other Global Navigation Satellite Systems (GNSS) into the IGS organization and information flow.

Notable New Web Features

Network maps

The IGS CBIS began to provide convenient clickable and downloadable maps of the IGS network and subnetworks, for the IGS community to use in preparing presentations, and to visualize the spatial distribution of the sets of sites.

Data quality plots

Detection of station anomalies has been a popular request in recent years. To that end, each station's web page at the Central Bureau was upgraded to include automatically-updated data quality plots representing the previous 45 days of daily RINEX data. The four quality figures (number of observations, cycle slips, and L1/L2 multipath) are obtained from teqc summary files (see http://www.unavco.ucar.edu/software/teqc/teqc.html for information on UNAVCO's teqc software) corresponding to each day of RINEX data. These are helpful in identifying sudden changes in data character which can identify a site disturbance or equipment failure.

The "spectrum" of all IGS stations' averages and standard deviations of these quality figures is also provided. This gives the viewer an idea how that particular station compares to the rest of the IGS network. See Figure 4 for an example of the L1 multipath graphs.

For IGS stations submitting hourly data, a graph of recent latency is also provided, alongside a graph depicting the recent latencies of all hourly data for comparison.

Network data table and access guide

Inquiries received at the CB made it clear that there was room for improvement in informing web visitors about the types of IGS data and how to acquire it. A table was developed to summarize the data types, including which Global Data Centers archive each kind. Links from the access column lead the visitor to all the needed information to acquire the data: file naming conventions, formats, and paths at the DCs. A portion of the table is shown in Figure 5. A similar access column was also added to the already-existing table of products. The complete tables are available at:
http://igscb.jpl.nasa.gov/components/data.html
http://igscb.jpl.nasa.gov/components/prods.html

Thanks to the Stations (and the People and Agencies That Make Them Possible)

These examples of network-wide improvements in themselves do not adequately reflect the complete picture of activity within the IGS network. All the while, the stations' operating agencies are planning new stations, arranging for equipment repair and upgrade, maintaining the integrity of station information, and improving communications and automation. It is this significant commitment to contribute to the global dataset that fundamentally makes the IGS possible.

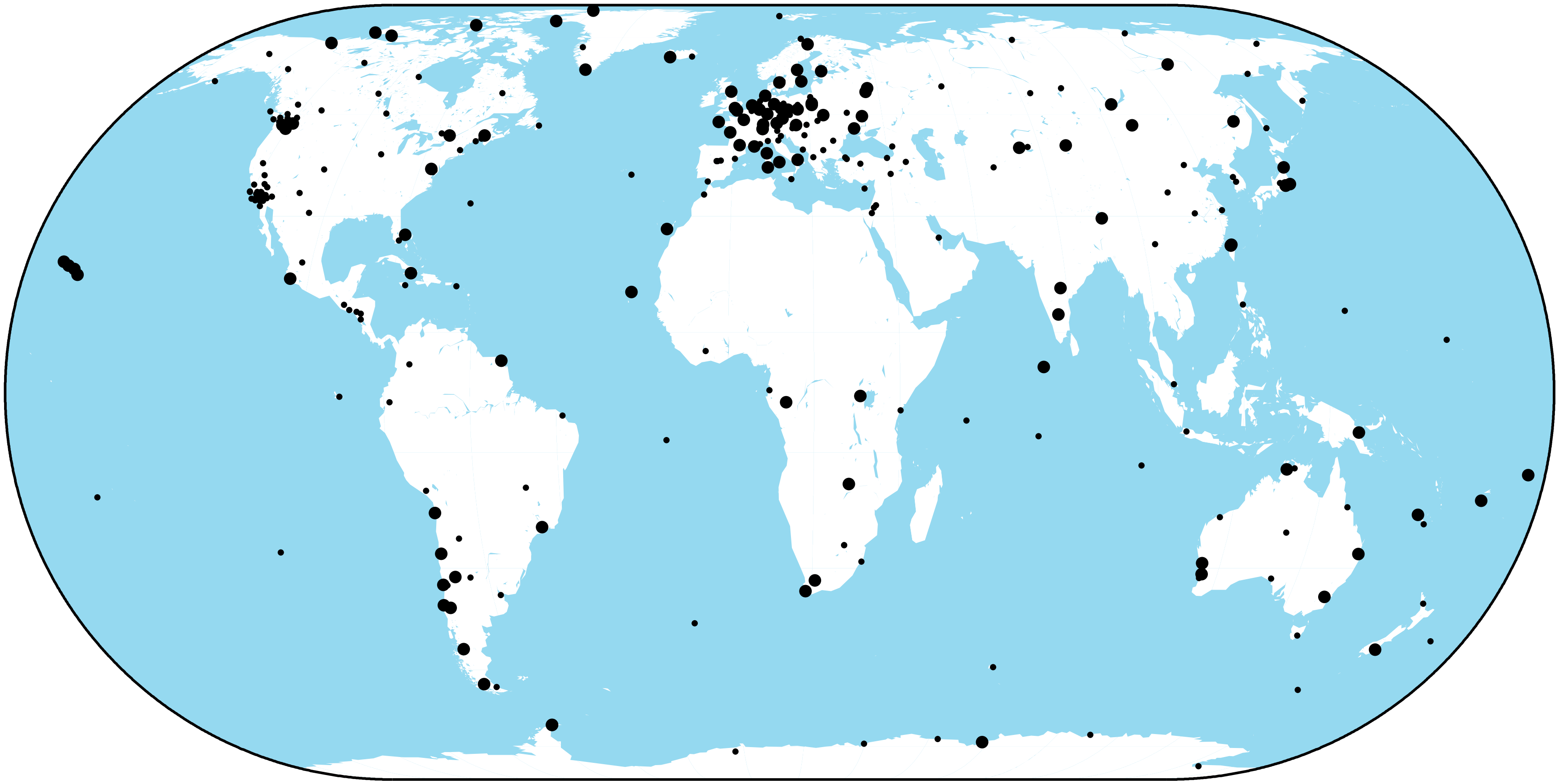

Figure 1. 112 stations (large circles) were added to the IGS network in 2001-2002, to form a total network of 242 stations (all circles).

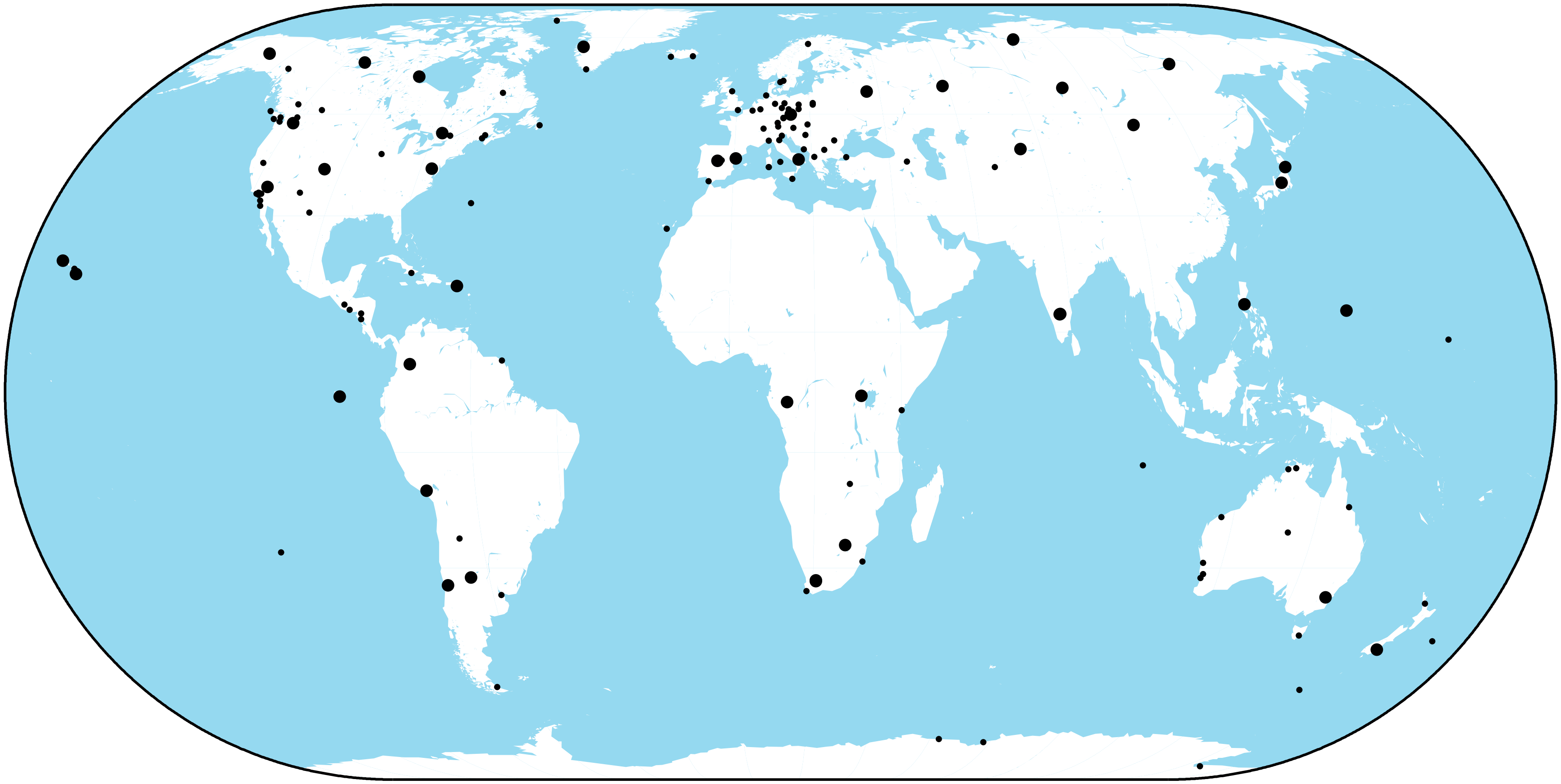

Figure 2. IGS stations contributing hourly (small circles) and sub-hourly (large circles) data during 2001-2002.

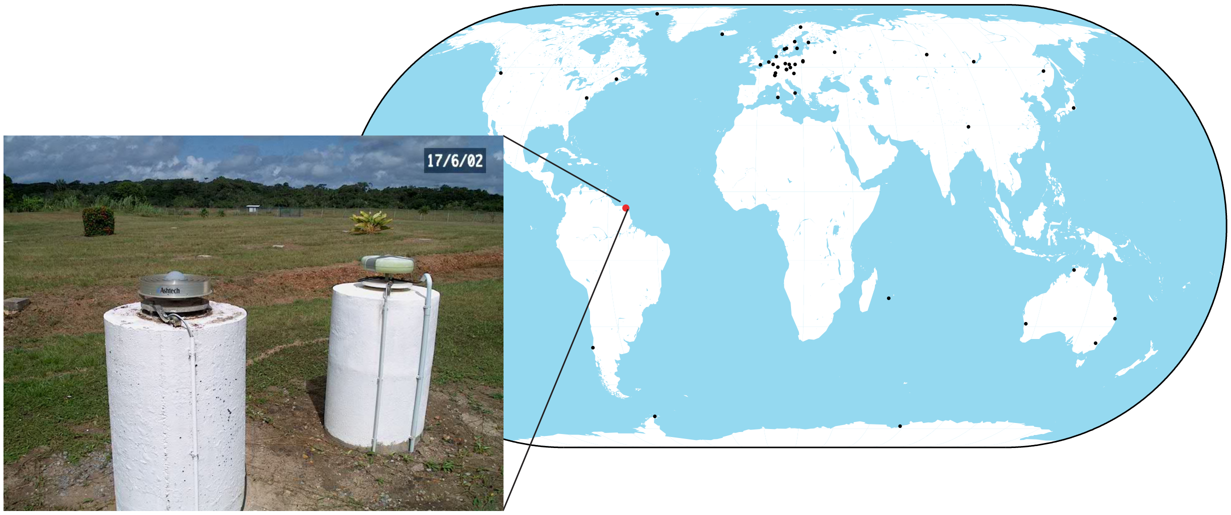

Figure 3. GPS/GLONASS tracking stations in the IGS (black circles) include the Kourou, French Guyana station, which features GPS/GLONASS tracking equipment alongside a long-standing GPS-only IGS site. Photo courtesy of ESA/ESOC.

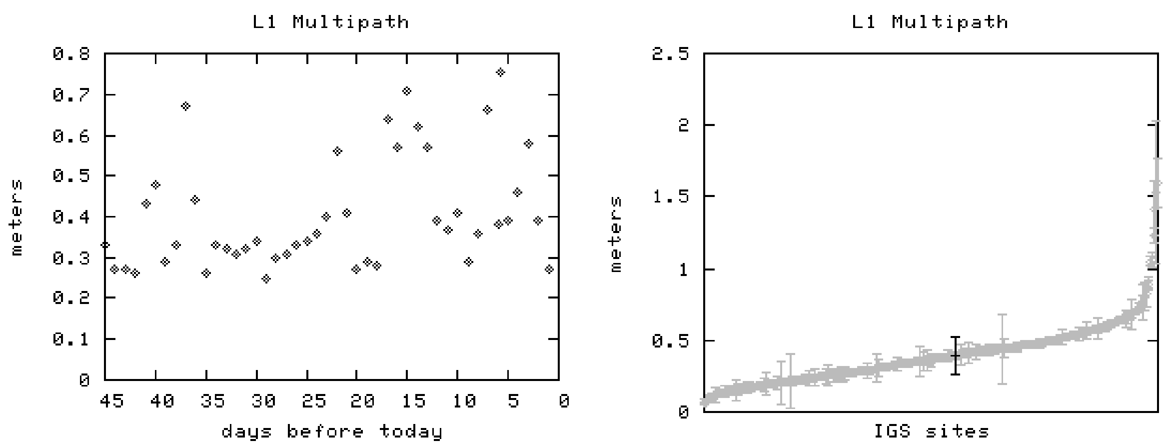

Figure 4. Graphs, updated daily at the Central Bureau website, show recent data characteristics of each sitevarying with time, and in comparison to other GPS sites.

IGS Data Table

	Latency	Updates	Sample Interval	Archive locations
Ground observations				
GPS & GLONASS	~1 day	daily	30 sec	CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	~1 hour	hourly	30 sec	CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	~15 min	15 min	1 sec(*)	CDDIS(US-MD)
	(*) Note: Selected subhourly stations have sampling intervals 1 sec < t < 10 sec)			
GPS Broadcast ephemerides	~1 day	daily		CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	~1 hour	hourly		CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	~15 min	15 min		CDDIS(US-MD)
GLONASS Broadcast ephemerides	~1 day	daily	daily	CDDIS(US-MD)
Meterological	~1 day	daily	5 min	CDDIS(US-MD) SOPAC(US-CA) IGN(FR)
	~1 hour	hourly	5 min	CDDIS(US-MD)
Low-earth orbiter observations				
GPS	~4 days	daily	10 sec	CDDIS(US-MD)

Figure 5. The data types table now available at the Central Bureau website, including access instructions for obtaining data from each Global Data Center.

NASA-Sponsored GPS Global Network Activities

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

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

Activities in 2002

Funding has been provided by NASA Earth Science Research (Code YS) Natural Hazards Program to JPL/Caltech and UNAVCO in support of these tasks.

NASA supported IGS sites established in 2002, and partner agencies:

AMC2 – Alternate Master Clock, Colorado, US Naval Observatory
BREW – Brewster, Washington, NRAO VLBA
GLPS – Puerto Ayora, Galapagos Island, Ecuador
GUAO – Urumqi, Xingjiang, China, Urumqi Astronomical Observatory
KELY – Kellyville, Greenland, The Sondrestrom Research Facility
SIMO – Simonstown, Hartebeesthoek RAO

NASA supported IGS sites upgraded with modern receivers:

CHPI – Cachioera Paulista, near Sao Paulo, Brazil, in collaboration with INPE
SEY1 – Seychelles, Seychelles National Oil Company, IRIS/IDA
EISL – Easter Island, Universidad de Chile, IRIS/IDA
QUIN – Quincy California, US Forest Service, Mt. Hough Ranger District
KOKB – Kokee Park, Hawaii
FAIR – Fairbanks, Alaska
AREQ – Areqipa, Peru
NSSP – Yerevan, Armenia, National Survey for Seismic Protection
SUTH – Sutherland, South Africa, Hartebeesthoek RAO

Site support emphasis is based on geographic coverage, multi-technique space geodesy instruments (SLR/VLBI) nearby, long-term site history, partnering opportunities, and IGS-related programs or pilot projects such as Ionosphere and Tide Gauge activities.

High-rate (1s sample rate) data continues to be available with global distribution. Initially installed in cooperation with GFZ as ground support for the CHAMP LEO mission, and in response to the IGS call for support of LEO missions in general, real-time GPS applications have provided the impetus to continue to expand the high-rate sub-network. In most cases, these sites are multi-function, providing 1s data with very low latency as well as the traditional hourly and daily 30 IGS RINEX file products.

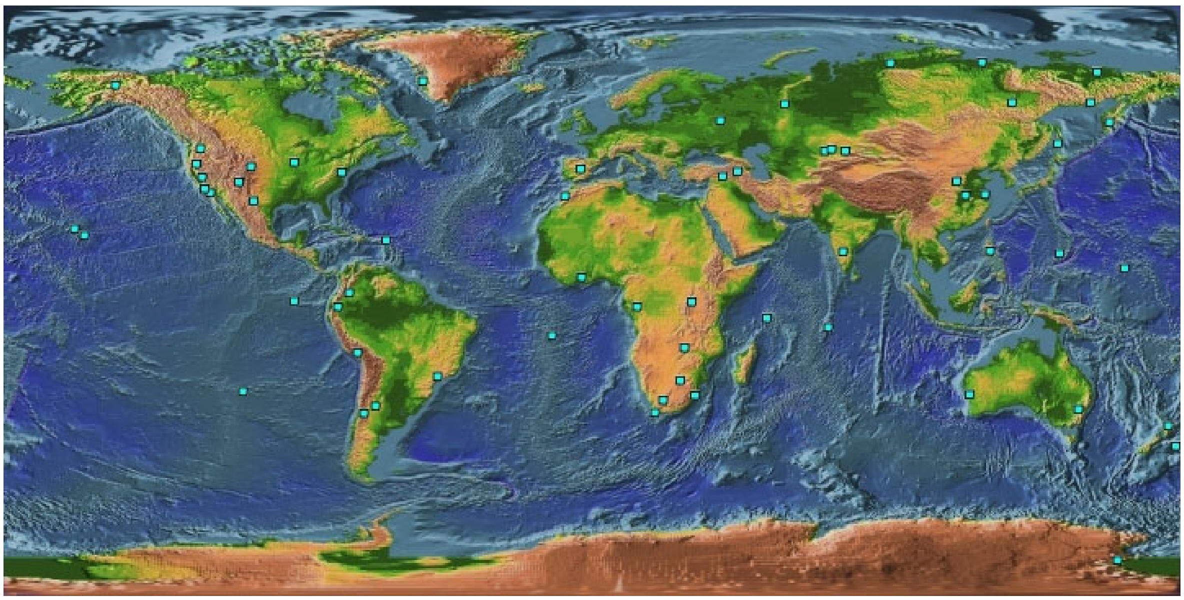

Figure 1. NASA Supported Site Distribution (non-exhaustive)

NASA Supported IGS sites (see Figure 1):

```
amc2 ASHTECH Z-XII3T
aoa1 ROGUE SNR-8000
areq ASHTECH UZ-12
artu ASHTECH Z-XII3
asc1 AOA SNR-8000
auck ASHTECH Z-XII3
bili ASHTECH Z-XII3
bogt ASHTECH Z-XII3
brew ASHTECH UZ-12
casa ROGUE SNR-8000
chat ASHTECH Z-XII3
chpi ASHTECH UZ-12
chum ROGUE SNR-8000
cic1 ROGUE SNR-8000
cord ROGUE SNR-8000
cro1 ASHTECH Z-XII3
dgar AOA SNR-8000
dyr2 ROGUE SNR-8000
eisl ASHTECH UZ-12
fair ASHTECH UZ-12
glps ASHTECH Z-XII3
gode AOA SNR-8000
gol2 ROGUE SNR-12
gold ASHTECH Z-XII3
guam ASHTECH Z-XII3
guao ASHTECH UZ-12
harv AOA SNR-8000
hrao ASHTECH Z-XII3
iisc ASHTECH Z-XII3
jplm ROGUE SNR-8100
kely ASHTECH Z-XII3
kokb ASHTECH UZ-12
kunm ROGUE SNR-8000
kwj1 AOA SNR-8100
mad2 ROGUE SNR-12
madr ASHTECH Z-XII3
mag0 ASHTECH Z-XII3
mbar ASHTECH Z-XII3
mcm4 AOA SNR-12
mdo1 ROGUE SNR-8000
mkea ASHTECH Z-XII3
mobn ASHTECH Z-XII3
msku ASHTECH Z-XII3
nlib ROGUE SNR-8000
nril ASHTECH Z-XII3
nssp ASHTECH UZ-12
petp ASHTECH Z-XII3
pie1 ROGUE SNR-8000
pimo ASHTECH Z-XII3
pol2 ASHTECH Z-XII3
quin ASHTECH UZ-12
rabt ROGUE SNR-8000
rbay ROGUE SNR-8000
riop ROGUE SNR-8000
sant ASHTECH Z-XII3
sele ROGUE SNR-8000
sey1 ASHTECH UZ-12
shao ROGUE SNR-8100
simo ROGUE SNR-8000
suth ASHTECH UZ-12
*thu1 ROGUE SNR-8100
tid2 ROGUE SNR-12
tidb ASHTECH Z-XII3
tixi ASHTECH Z-XII3
usno ASHTECH Z-XII3T
usud ASHTECH Z-XII3
wes2 ROGUE SNR-8000
wuhn ASHTECH Z-XII3
xian ROGUE SNR-8100
yakt ASHTECH Z-XII3
yar1 ROGUE SNR-8100
ykro ROGUE SNR-8000
yssk ASHTECH Z-XII3
zamb ROGUE SNR-8000
```

*thu1 deprecated to thu3 (an Ashtech UZ-12) and eventually turned off.

"Support" ranges from complete end-to-end equipment provision and operations, to simply supporting data flow (and just about everything in between).

New Zealand Continuous GPS Network

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Introduction

Years 2001 and 2002 have seen a major increase in the number of continuous GPS (CGPS) stations in New Zealand. This is due to a Land Information New Zealand (LINZ) project (PositioNZ) that has seen 12 new CGPS stations installed in the North Island by GNS. During 2003 and 2004, GNS will install a similar density of sites in the South Island, as well as few additional ones in the North Island.

In addition to the LINZ project, some 80 continuous sites will be installed over the next 5 years as part of the GeoNet project operated by GNS and funded primarily by the New Zealand Earthquake Commission (EQC). These stations will be sited to provide detailed measurements of tectonic deformation related to the Hikurangi subduction zone, and volcanic/tectonic deformation within the Central Volcanic Region.

For more information on the GeoNet project, see www.geonet.org.nz. For more information on the LINZ PositioNZ project, see www.linz.govt.nz/positionz.

Data Availability

Data from a subset of the New Zealand stations will be submitted to IGS from 2003, and all the New Zealand continuous data are publicly available from the GeoNet ftp site, ftp.geonet.org.nz/gps/rinex/. IGS-style site logs are stored at the same site in directory gps/docs/site_log/. Data from the PositioNZ sites are also available through the LINZ web site. Some of the New Zealand continuous data are already contributed to the Scripps Orbit and Permanent Array Center (SOPAC, garner.ucsd.edu), and we expect that all the data will become available at this site in the future.

The stations to be submitted to the IGS from 2003 are:

- AUCK and CHAT, as at present
- WGTN, HOKI and MQZG (which have been contributed for a number of years to the Asia-Pacific Regional Geodetic Project)
- NPLY

One additional South Island site (probably the new Otago University station – see below) will also be contributed to IGS after the South Island stations are installed.

Of these sites, NPLY is more-or-less on the Australian plate, MQZG and Otago University are more-or-less on the Pacific plate, and WGTN and HOKI are within the plate boundary deformation zone.

Present Status of Network

The New Zealand continuous GPS network at June 2003 is shown in the Figure 1, and the following sections provide notes on some of the stations.

AUCK and CHAT

AUCK and CHAT are the original New Zealand IGS stations, installed in 1995 in partnership between GNS, LINZ, JPL, and UNAVCO. These are the only New Zealand stations whose data are presently submitted to the IGS. Both stations were upgraded from Turborogue SNR-8000 receivers to Ashtech Z-12 CGRS receivers during 2001.

Sea Level Network

Since about 2000, GNS and Otago University have operated CGPS receivers at four of New Zealand's longest-running tide gauges. These are stations DUNT, LYTT, WGTT, and TAKL on the figure. Funding for this network is from the New Zealand Foundation for Research, Science and Technology (FRST). The data from these stations are contributed to the IGS TIGA pilot project, together with data from nearby high-quality stations OUSD, MQZG, WGTN and AUCK.

Southern Alps Network

The Southern Alps network (QUAR, KARA, WAKA, CNCL, NETT, HORN 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. (Note that only QUAR and MTJO are labelled on the figure.) 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 funding source is an NSF grant to Peter Molnar (with U.S. co-investigators Brad Hager and Tom Herring), with the New Zealand institutions funded initially by an Otago Research Grant and now by FRST. As well as the continuous stations, a number of "semi-continuous" stations are operated for several months per year. After 3.5 years, this network has been able to measure a vertical motion profile across the Southern Alps with vertical rate uncertainties better than 1 mm/yr (1 s) from both the continuous and semi-continuous 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. This station is located on the roof of a building, and it is planned to install a new bedrock station nearby during 2003-04. The old and new sites will then be run in parallel for a considerable time period.

Acknowledgements

Paul Denys (University of Otago) and Graeme Blick (Land Information New Zealand) have also contributed to this report.

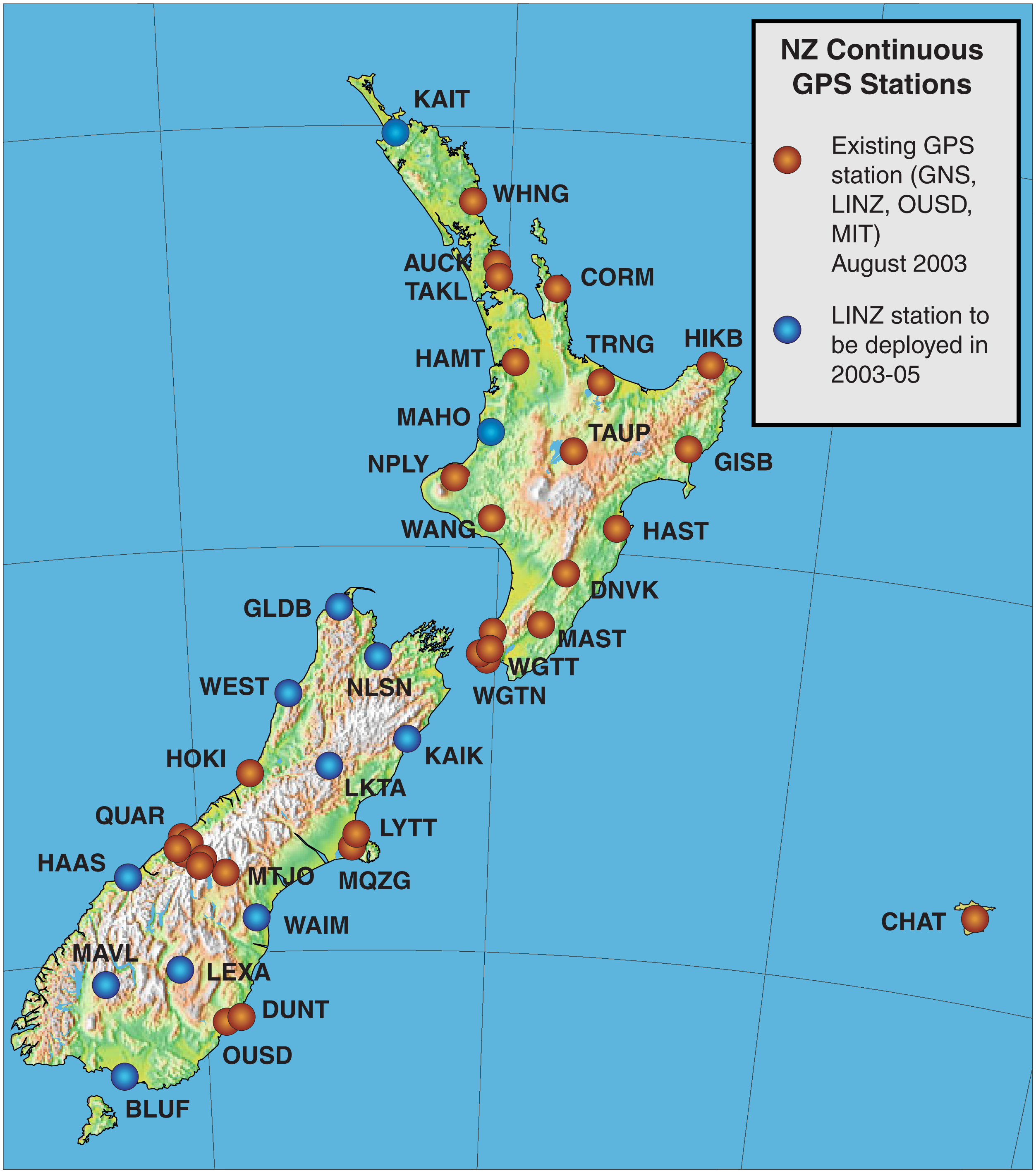

Figure 1. The New Zealand continuous GPS network at June 2003

IGS

INDIVIDUAL STATION REPORTS

The NERC Space Geodesy Facility

Robert Sherwood and Graham Appleby

The NERC Space Geodesy Facility (NSGF) at Herstmonceux, UK, continues to manage two geodetic-quality, continuously operating, GNSS receivers; an Ashtech Z12 receiver (IGS Station HERS) and an Ashtech Z18 joint GPS/GLONASS receiver (IGS Station HERT).

During the period the Ashtech Z18, originally designated station HERP, was moved some 100m from an inferior position close to the laser ranging and radar domes and re-sited at the top of a two-storey unoccupied building, close to an SLR ground calibration target.

Figures 1 and 2 show the NSGF as seen from the HERT antenna and the antenna itself. The HERS antenna is mounted on a rigid tower above the level of the laser ranging telescope.

Figure 1. HERT antenna

Figure 2. NSGF viewed from the location of HERT

The Z18 receiver and its co-located PC are linked to the Facility LAN via a fibre-optic link The system is programmed to contribute both hourly and daily 30-second RINEX GPS/GLONASS data to IGS/IGLOSS as well as to maintain a local archive of 1-second sampled data. Judging from IGS results, this system is now working extremely well, with much reduced multi-path effects and good sky coverage.

In addition, it is planned during 2003 to use the HERT system in the EUREF-IP pilot programme to stream RTK data directly into the Internet for rapid re-broadcast for general real-time navigational applications–see
http://www.epncb.oma.be/projects/euref_IP/euref_IP.html

Local Quality Control

The quality of the data obtained by these receivers is of course monitored routinely via coordinate and orbit determination solutions by the various IGS ACs and AACs. However, every effort continues to be made on site at Herstmonceux to ensure the quality of the SGF data. Following an extended period of inferior quality data from HERS, which ended at the discovery of an antenna problem during 2001, the group has developed its own automatic QC software as a tool to maximise the probability of early detection of problems. Each day from the 30-second HERS and HERT RINEX files, local ‘sky maps’ are computed that show at a glance whether or not all GPS and GLONASS satellites were tracked continuously during the previous 24 hours. The plots are available, along with some further diagnostic results, each day from the Facility website at http://nercslr.nmt.ac.uk

IGS

WORKING GROUPS/ PILOT PROJECTS/COMMITTEES

Densification of ITRF

(Please see “Reference Frame Coordinator Report” – Section 2, Analyis Center Reports)

Report of the Tropospheric Working Group for 2002

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Weekly Combined Tropospheric Product and Densification

The quality and consistency of the IGS Final weekly combined tropospheric product (Gendt, 1996) has steadily improved during its more than 6 year history. The comparisons between the individual Analysis Center (AC) solutions and the IGS official combined solution are shown in Figure 1. All but one AC agree within 3 mm standard deviation since week 1180 (August 2002), for most ACs even at the 2 mm level. This corresponds to a quality of better than 0.5 mm in the precipitable water vapor.

The bias changes at individual ACs caused by changes in their analysis strategy are even smaller, and in total they are usually in the ±2 mm band. The only exception in the bias stability seen for ESA, where a pronounced seasonal effect can be observed, the origin of that is not clear. The consistency between the ACs having the smallest standard deviations agree best. It is during the last years even at the ±1 mm level. Those good ACs have the highest weight in the combination so that the expected bias changes in the combined solution are smaller than ±1 mm.

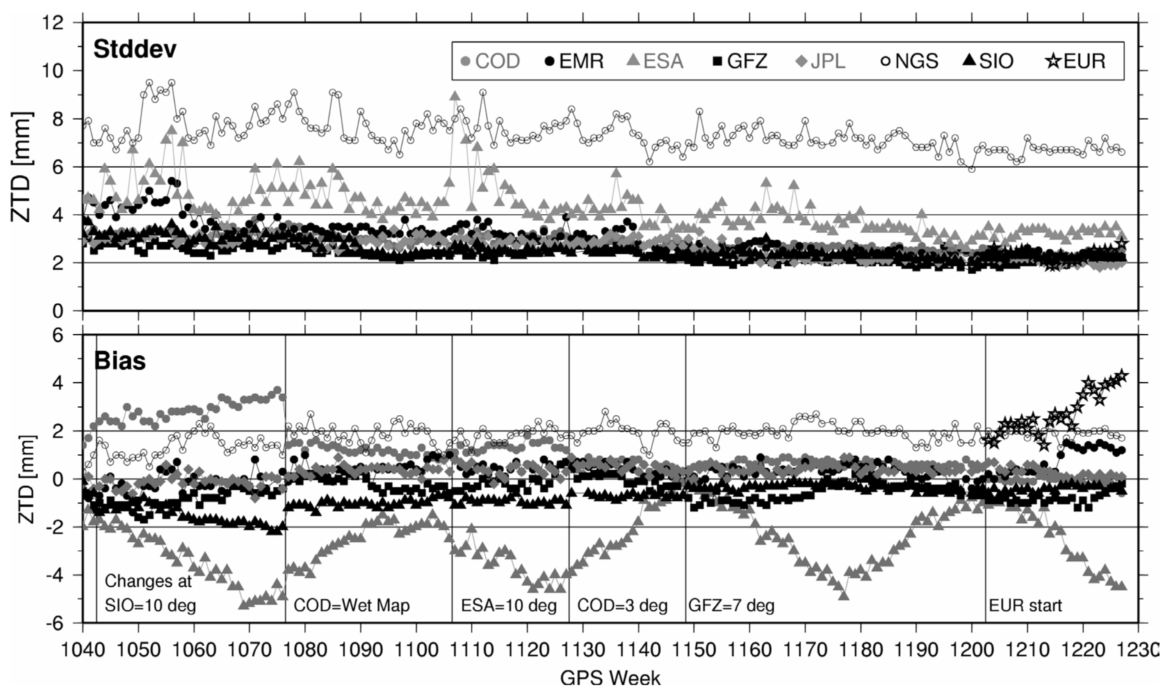

Figure 1. Standard deviation and bias in the neutral zenith total delay between the individual Analysis Center estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center.
(GPS Week 1042.6 = 2000.0)

In June 2001 the EUREF community has started a Pilot Experiment for the generation of tropospheric products. The solution is a combination of 15 individual EUREF ACs and comprises a European network of about 150 sites. After a short test phase in 2001 (Gendt 2002) an official EUREF (abbreviation: EUR) submission was included into the IGS combination starting in February 2002 (GPS week 1203). The standard deviation of the EUREF solution has the same level as seen for the best single IGS ACs. The bias seems to change with time, however, the time interval is yet too short for a final assessment. By this regional densification the number of sites included in the IGS Tropospheric Product has grown from 180 to 280.

During the last one and a half year also the number of collocated meteorological sensors have improved significantly (Figure 2). However, especially in the tropical region, where the water vapor in the atmosphere is most interesting to monitor, a need of additional sensors is obvious (Figure 3).

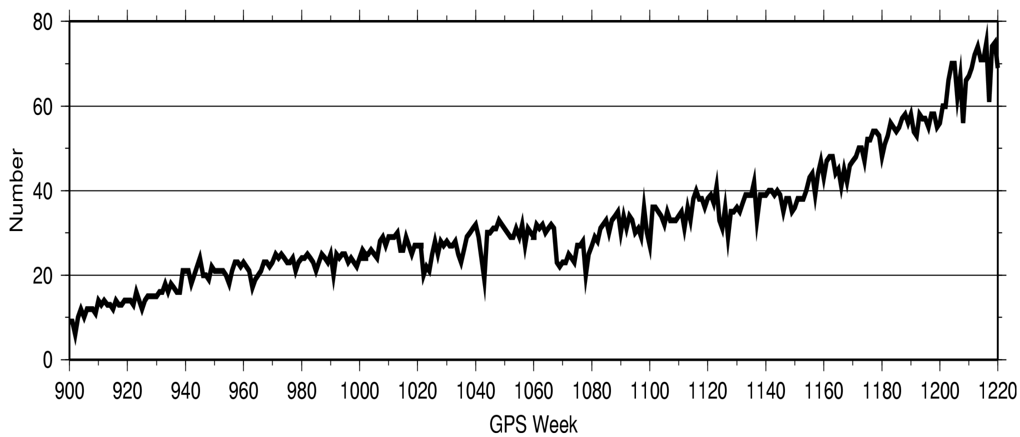

Figure 2. Number of sites with collocated meteorological sensors

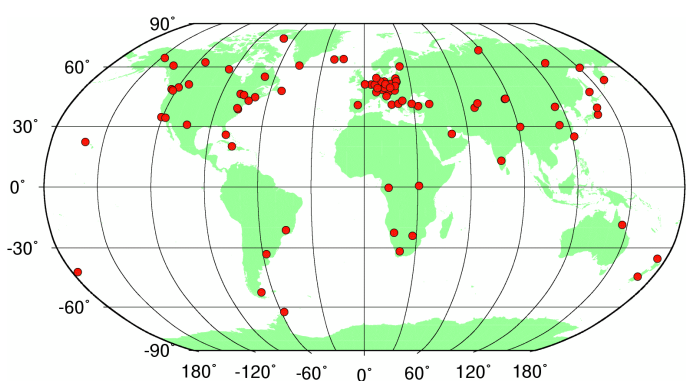

Figure 3. Network of collocated meteorological sensors

Near-Real-Time Product

After a Pilot Experiment starting in June 2001 the IGS is generating a near real-time (NRT) tropospheric product using the global hourly station network. Every three hours a product for the last 12 hours is combined by all individual submissions of up to 8 ACs. Some statistics for the contributing ACs are summarized in Table 1. The product is available with a delay of about 2.5 hours and comprises more than 140 stations (Figure 4). The consistency of the product is at the level of ±2 to 4 mm ZTD as already demonstrated in 2001 (see Gendt, 2002).

Table 1. Summary on Analysis Center contributions to NRT Trop Pilot Experiment

AC	Submission rate	No. stations	Delay[h]	Start of submission
CODE	12h	70	2:00	07/2003
EMR	3h	40	1:30	06/2001
GFZ	3h	50	1:15	06/2001
ESA	12h	40	2:00	07/2001
SIO	3h	40	2:30	08/2001
USNO	3h	35	1:30	09/2001
JPL	Real-time	60	0	11/2001
GOP*	3h	60	2:00	02/2002

* GOP- Geodetic Observatory Pecny, EUREF Analysis center

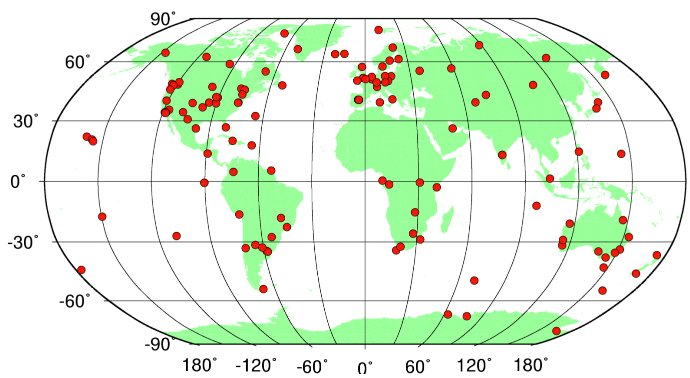

Figure 4. Network of stations with NRT tropospheric products

Summary

Progress was made since the last annual report in the densification of the Final product by inclusion of the high quality EUREF combined tropospheric product.

The NRT products were regularly generated with a high reliability (about 99% availability) since two years now.

The quality of the IGS combined products – both the Final and the NRT - corresponds to better than 1 mm in the water vapor content.

References

Gendt, G (1996): Comparison of IGS tropospheric estimates. Proceedings IGS Analysis Center Workshop, 19-21 March 1996 Silver Spring, Maryland USA, Eds. R E Neilan, P A Van Scoy, J F Zumberge, pp. 151-164

Gendt, G. (2002): Report of the Tropospheric Working Group for 2001. The IGS 2001 Technical Reports, in press.

IGS LEO Pilot Project

H. Boomkamp

Introduction

The IGS Low Earth Orbiter Pilot Project is concerned with the analysis of data from LEO satellites that are equipped with a GPS receiver. The LEO satellites employ GPS as a tracking system for their own mission objectives, while the IGS LEO Pilot Project aims at investigating possibilities to exploit this LEO GPS data for enhancing the IGS products. With the expected increase in LEO GPS satellites over the present decade, the possible ways of integrating this data in routine IGS processing must be considered with care.

Pilot Project Objectives and Implementation

During the course of 2002, the format and objectives of the IGS LEO Pilot Project have been consolidated, and were formalized in a Pilot Project charter. In parallel, the number of operational LEO GPS satellites has grown to six, although the only three satellites of which the data is now readily available are CHAMP, SAC-C and JASON. Of these three, CHAMP and JASON are receiving most attention from the scientific community although the more recent SAC-C data also appears to be in good shape. It is hoped that data from the two GRACE satellites and ICESAT will also be available in the near future.

The GPS datasets from just two or three LEO satellites would clearly have a hard time trying to influence the IGS products in any way, if their introduction would merely lead to an increase in the amount of tracking data. The IGS ground network is in fact growing much quicker than the constellation of LEO GPS satellites, and this will remain the case be for the years to come. What is of interest to IGS is therefore the analysis and exploitation of fundamental qualitative differences between LEO data and ground-based data. The principal objectives of the Pilot Project are to demonstrate whether such qualitative differences exist, and that they can be used to the benefit of the routine IGS products.

In support of this analysis, the Pilot Project charter proposes to maintain a list of fundamental differences between LEO data and ground-based data. These differences will then be investigated one by one, leading to a fairly complete view on what the LEO data may contribute to IGS. This aspect of the LEO charter is being implemented via the IGS LEO website, at http://nng.esoc.esa.de/gps/igsleo.html.

Four categories of differences are identified:

Differences in tracking geometry

The main benefit of the LEO data is expected from the rapidly changing geometry between LEO satellites and the GPS constellation, and the relative independence of the LEO satellites from models for earth rotation and reference frame. These are the areas in which LEO data has the greatest potential for improving the IGS products in some way.

Differences in signal propagation

The main benefit of LEO data would be the absence of tropospheric delays, and the significantly reduced ionosphere delays, but it is clear that these effects will always be small. The analysis of occultation data is not (yet) part of the LEO Pilot Project, but developments in this area are being followed with interest.

Differences in data flow

These differences are clearly significant, not just in terms of latency but also in terms of data distribution policies. Compared to ground-based data, LEO data will probably always have a more complicated trajectory from the receiver to the IGS analysis centers. Such issues mainly affect operational use of the data, which for the time being is not considered as a critical problem.

Differences in data processing

These differences must be carefully analyzed to ultimately make a cost/benefits assessment about the potential integration of LEO data in routine IGS processing. Processing of LEO data is still difficult; in fact, as will be discussed further below, current precision levels are not yet considered compatible with the ground based data. This additional burden on IGS analysis centers should be compensated by clear advantages.

Data Processing Precision

Before LEO data can hope to bring any improvement in an IGS product, a first requirement with regard to LEO GPS data must be to ensure data precision levels that are compatible with the precision of ground-based GPS data. Until now, this has been the main area of investigation in the IGS LEO Pilot Project.

In more concrete terms, the position of the antenna phase center of the LEO receiver is only as precise as the orbit and attitude determination of the LEO satellite. Both for CHAMP and for JASON precise orbit determination has achieved very high standards in recent times: estimated orbit errors are as low as 5 cm RMS for the best CHAMP orbits, and below 3 cm RMS for JASON. As good as this may be, the precision with which antenna phase centers of IGS ground stations are determined – as part of routine IGS processing - is assessed to be at the level of a few millimeters, which is an order of magnitude better. It is therefore optimistic to speak of compatible precision levels at this point in time.

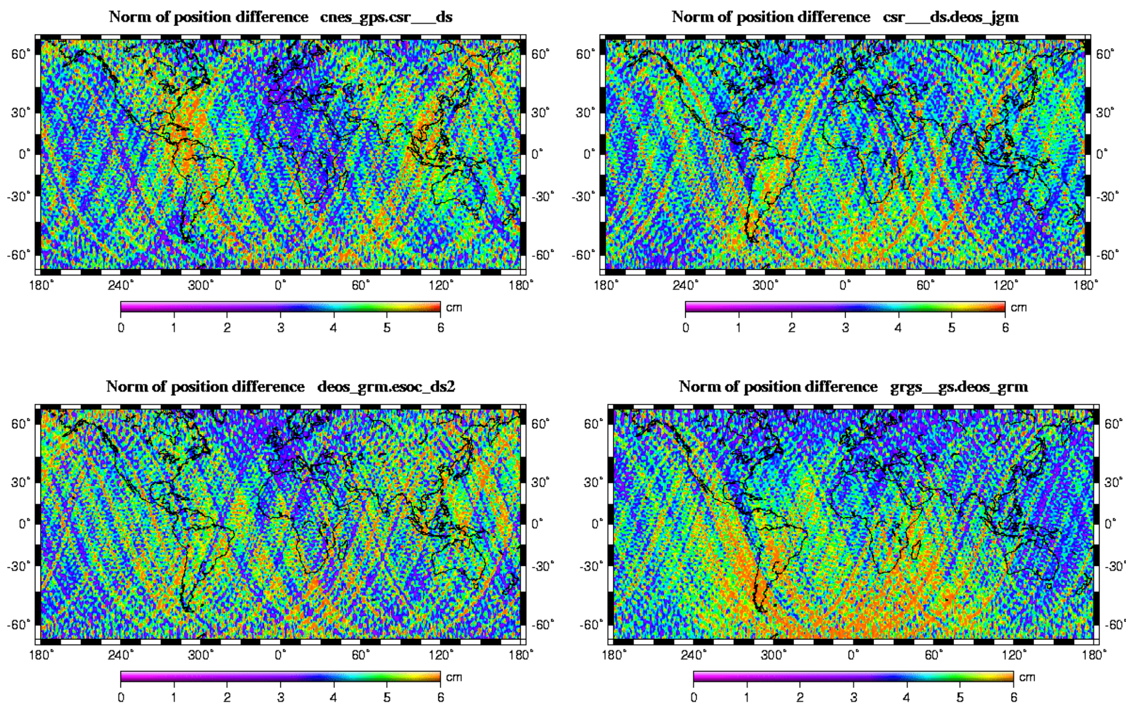

Figure 1a-d *: Examples of orbit comparisons from the JASON orbit campaign. Orbit differences between a large set of solutions form an important source of information on LEO POD quality.*

Because of its critical nature, the error mechanism that currently prevents integration of the less precise LEO data with ground-based GPS tracking data will be briefly summarized here. To reach the high precision levels of IGS products, a typical POD system for GPS - as performed routinely by the analysis centers - contains a variety of delicately balanced data editing algorithms. If a station produces tracking data that is notably of worse quality than the data from other stations, this data will either be rejected by the process, or it will be down-weighted to the point at which it no longer has any relevant influence on the output products. This second option allows for improvements e.g. of the station coordinates of the less precise station, without affecting the actual GPS orbits and clocks in a negative way. Such protection mechanisms are inevitable as long as the LEO data is referred to antenna positions that have an error level of several centimeters, and the result is that the influence of the LEO data on the output products is marginalized.

As a rule-of-thumb objective, the IGS LEO Pilot Project now aims at a LEO orbit precision level that is better than 1 cm RMS. This precision level cannot yet be confirmed for any of the available LEO satellites, but at the same time, there has been substantial progress both in LEO orbit determination itself, and in the way in which the orbit precision can be assessed with confidence. Major activities of the Pilot Project are the on-going Orbit Campaigns for CHAMP and more recently for JASON, which aim at supporting and analyzing POD improvements for these two satellites. The latest results can always be found on the IGS LEO website, referenced above. Some examples of results from these campaigns have been included as Figures 1, 2 and 3 in this Chapter.

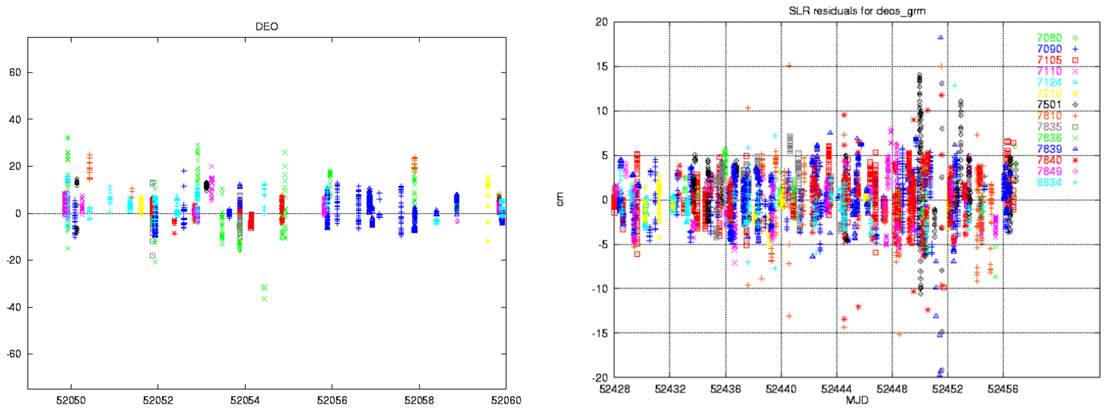

Figure 2a & b: Examples of SLR residuals from the IGS LEO orbit campaigns for CHAMP (left) and JASON (right). It is clear that the higher JASON orbit receives more SLR tracking.

High Rate Data and POD Capacity

Combined solutions of GPS and LEO satellites introduce another important technical problem, namely that of processing capacity, or POD performance. For LEO POD the tracking data rate must be much higher than for the GPS satellites, first because the LEO geometry changes more rapidly, and second because the dynamic models of the LEO contain signals of much shorter wavelengths than the dynamics of the GPS satellites. The LEO orbit model typically requires a relatively large number of estimated parameters, and therefore requires more densely spaced tracking data. This (GPS) data can only be processed if accurate clocks and phase ambiguities are available at the same high-rate, and this means that the basic GPS POD process will also have to cope with the same high data rate. As a result, various IGS centers notice that their POD systems are stretched to the limits of their capacity - or beyond - by the introduction of the LEO data.

On the one hand, these extreme demands on the POD systems have the negative consequence of slowing down the Pilot Project analysis, even prohibiting certain analysis that seems relevant. On the other hand, these new demands urge the centers to implement various improvements in their analysis systems, which can be seen as a first positive side-effect of the Pilot Project. Increased POD capacity is a matter of great interest to IGS as a whole, not just in support of LEO analysis, but also in support of other developments like (near-) real time processing or the handling of data from substantially larger ground station networks.

The two centers GFZ and JPL, who have had access to the CHAMP data since launch, produced high precision CHAMP orbits (around ~5cm RMS error) about 1.5 years later. The centers CODE and ESOC needed about the same time to implement CHAMP POD capability, illustrating the effort that is typically required to stabilize the POD systems for LEO GPS analysis. The fact that such analysis is now possible – which was not the case even two years ago - can be considered as important progress.

Table 1: Recent POD precision estimates for CHAMP

cm	1-way SLR	orbit error	sigma
DEOS	3.60	5.94	0.54
CSR	4.43	7.31	0.67
TUM	4.61	7.60	0.69
GFZ	4.81	7.93	0.72
JPL	5.31	8.75	0.80
GRGS	6.80	11.21	1.02
NCL	7.44	12.26	1.12
ASI	7.88	12.99	1.19
AIUB	13.56	22.36	2.04
CNES	13.58	22.39	2.04
ESA	16.83	27.74	2.53
UCAR	17.35	28.59	2.61
UNB	27.37	45.11	4.12

Table 2: Recent precision estimates for JASON

cm	1-way SLR	orbit RMS	sigma
csr__gds	1.700	3.656	0.606
gsfc_gs4	1.771	3.809	0.632
ncl___ds	1.844	3.966	0.658
jpl__gps	1.912	4.112	0.682
gsfc_dyn	1.973	4.243	0.704
gsfc_red	2.008	4.319	0.716
gsfc_gps	2.071	4.454	0.738
grgs__gs	2.257	4.854	0.805
esoc_ds2	2.386	5.132	0.851
esoc__ds	2.464	5.299	0.879
gsfc_rex	2.491	5.357	0.888
deos_grm	2.579	5.547	0.920
csr___ds	2.655	5.710	0.947
deos_jgm	2.669	5.740	0.952
cnes_poe	2.842	6.112	1.013
cnes_gps	2.890	6.215	1.031
asi__in2	5.138	11.050	1.832
asi__ext	9.039	19.440	3.223

Participation in Pilot Project Analysis

Initially, there were two groups of centers that expressed an interest in the LEO Pilot Project, namely centers with particular expertise in orbit determination for Low Earth Orbiters – who consider the GPS data as tracking data for the LEO itself – and centers with an interest in GPS product generation, i.e. the IGS analysis centers. The first group of centers was clearly the larger one, because outside the IGS there are very few centers that compute GPS orbits and clocks for research objectives. Nonetheless, with the consolidation of the Pilot Project charter and the concrete objectives that it formulates, it became clear that the main participation in the Pilot Project is expected to come from the second group of centers. In practice, not even all of the IGS Analysis Centers can participate in the analysis of the LEO data.

By consequence, the LEO Pilot Project may appear to have a much lower profile than was anticipated at its start, but that does not make it less relevant to IGS – on the contrary. The fact that at present only about five centers in the world are actually considered capable of analyzing LEO GPS data for the purpose of enhancing IGS products, implies that these (IGS) centers carry the full responsibility for this analysis.

Recent Focus and Future Developments

The Pilot Project wants to demonstrate potential benefits of LEO data in two stages, first at the level of individual centers – a center is expected to demonstrate that the LEO data contributes to its IGS products in a positive way – and then at the level of IGS combination solutions. Even though overall LEO orbit precision is still considered inadequate, four IGS analysis centers are now approaching a status of satisfactory LEO data processing. The first illustrations of LEO contributions to GPS data processing are expected in the very near future.

In parallel, some effort is invested in the subject of combination solutions for the LEO orbits. It is hoped that this may bring down the LEO orbit error to levels below 1 cm. Some of this analysis is being reported via the IGS LEO website, which is also recommended for any further information on the Pilot Project.

Conclusions

The Pilot Project analysis to be performed has been defined quite clearly and is made concrete via various analysis topics that are proposed on the website. The problems associated with GPS-based LEO POD are being addressed by various centers, not just the limited number of IGS analysis centers mentioned above. Processing systems are being improved and their capacity is being augmented, so that LEO GPS processing is already less of a challenge than in the early days of CHAMP data.

Progress in the Pilot Project is slow, but steady. Given the limited resources that can be dedicated to this work, and the complexity of the involved analysis, the developments in LEO GPS are satisfactory. Various general improvements in data processing are being achieved at the IGS analysis centers, merely because the demands for LEO processing require such improvements. This must be seen as a useful first contribution of the Pilot Project to the IGS.

International GLONASS Service – Pilot Project

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Abstract

The International GLONASS Service Pilot Project (IGLOS-PP) provided GLONASS observations and precise orbits from a tracking network of over 40 stations and three Analysis Centers for all of 2002. The International Laser Ranging Service (ILRS) also continued to observe three GLONASS satellites during the year. A new Russian launch of three satellites at the end of the year raised the number of available satellites to 10. After keeping the GLONASS data separate from the GPS data in the IGS for the first two years of the project, revisions were made to the IGS Site Logs, Analysis Center software and archival procedures at the Global Data Centers such that the IGLOS tracking data could be merged with the other IGS tracking data in routine operations. The accomplishment of this was a significant milestone.

GLONASS Constellation Status

On 25 December 2002, Russia launched three new GLONASS satellites into orbit plane 3 (slots 21, 22 and 23). This brought the total number of operational (healthy) satellites to 10. These satellites are the older series satellites (not GLONASS-M) and have SLR reflectors identical to the ones on the two operational satellites launched in December 2001 (132 corner cubes in panel). For most of 2002, there were 6-7 operational satellites.

Tracking Network

In coordination with the IGS GPS stations, all IGLOS stations were requested to submit new site log forms to become "official" IGS stations. These new site logs were designed to accommodate global navigation satellites in general, rather than just GPS, and to allow the full integration of dual GPS/GLONASS stations into the IGS. Only dual-frequency receivers capable of tracking at least four GLONASS satellites simultaneously were sanctioned as official IGS stations. As of December 2002, the IGLOS tracking network consisted of 46 stations, although six of these still lacked revised site logs. All the operational stations use either Ashtech or Javad Positioning

Systems receivers. The GLONASS data are now merged with the GPS data at the IGS Global Data Centers. Table 1 lists the IGLOS stations and their locations, receiver types, and sponsoring organizations.

The ILRS has provided continuous support for SLR tracking of three GLONASS satellites. In 2001, one GLONASS satellite in each of the three orbit planes was tracked (plane 1/slot 7, plane 2/slot 15, plane 3/slot 24). During 2002, the targeted satellites were changed to slots 3 and 6 of plane 1, along with slot 24 of plane 3.

Precise Orbit Computation

BKG and ESA produced precise orbits from the receiver network tracking data for all the operational GLONASS satellites. The Russian Mission Control Center (MCC) computes precise orbits based on the SLR observations alone. These individual orbits are combined in a weighted average computation by the IGLOS Analysis Center coordinator to produce the final IGLOS precise orbits. SLR orbit accuracies are probably at the 10-20 centimeter level, while the combined precise receiver-based orbit accuracies are about at the 20-centimeter level (see Figure 1). GLONASS orbit comparisons done at the Natural Environment Research Council (U.K.) have indicated that some long-term systematic biases may be present in the GLONASS receiver-based orbits compared to the SLR orbits.

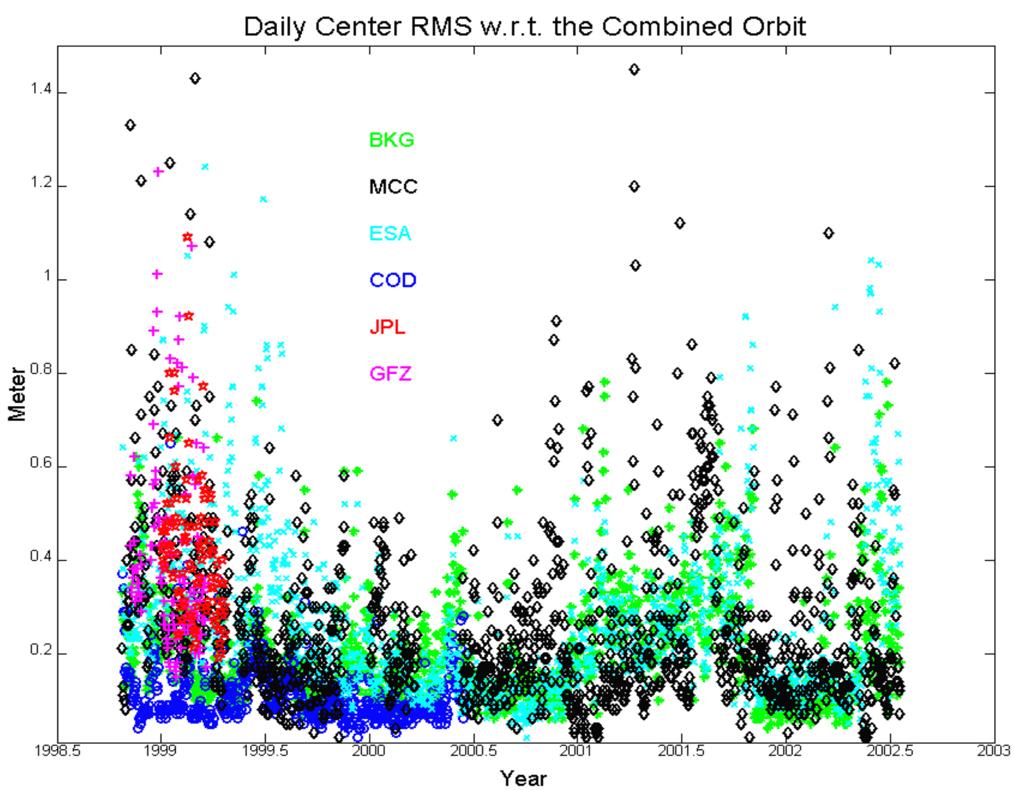

Figure 1

GLONASS Data and Product Usage

All receiver tracking data, including the satellite broadcast messages, and the precise orbit products are stored and retrievable at the IGS Global Data Center at NASA GSFC. Over an 11-month period from January to November 2002, 9,475 orbit products were downloaded from the Data Center. Two-thirds or more of these probably relate to the actual production of the precise orbits by the Analysis Centers in Austria, Germany and Russia, but at least 1,560 downloads are attributable to other users of the data products. These figures do not include downloads of the actual tracking data. It is not clear at this time what applications these products are being used for. This is definitely of interest and will be pursued in the coming year.

Summary

The number of active GLONASS satellites increased from 6 satellites in 2000 up to 10 satellites in March 2003. In the frame of IGLOS-PP precise GLONASS orbits are calculated by various Analysis Centers in regular (weekly) intervals. The accuracy of these orbits is about +/- 0.2 –0.3 m. Besides satellite clock offsets to GPS-time as well as station coordinates are provided.

Up to now the IGLOS products serve groups dealing with GNSS Time Transfer, all kinds of surveying using combined receivers (e.g. improving the situation in urban canyons with a lack of visible GPS satellites), and atmosphere monitoring for climate studies. A more rapid submissions of tracking data and a more frequent generation of products (compared to the current long latency) will certainly allow for a couple of new applications. Therefore the participants of the IGS Workshop in Ottawa 2002 passed a recommendations which asks all IGS-AC's to intensify their ability to process data from combined GPS/GLONASS tracking sites.

There is an ongoing need to continue and to increase the tracking of GLONASS satellites by ILRS. GLONASS satellites observed by two independent space techniques realize a valuable kind of collocation in space. Moreover IGLOS-PP demonstrates the extensibility of IGS to accommodate other microwave systems (GLONASS, GALILEO).

Table 1. IGLOS Pilot Project - GLONASS Receiver Tracking Stations (Dec 02)

SITE NAME	SITE ID	LOCATION	COUNTRY	LAT. (deg)	LONG. (deg)	RECEIVER TYPE	CLOCK TYPE	SPONSORING ORGANIZATION
Crary	CRAR	McMurdo Station	Antarctica	-77.85	166.67	JPS Legacy	Internal	U.S. Geological Survey (USGS)
Davis	DAVR	Davis	Antarctica	-68.58	77.97	Ashtech Z18	Internal	Geoscience Australia
O'Higgins	OHIZ	O'Higgins	Antarctica	-63.32	-57.9	Ashtech Z18	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
AU053	YARR	Dongara (Yaragadee)	Australia	-29.05	115.35	Ashtech Z18	Internal	Geoscience Australia
Brisbane	SUNM	Brisbane	Australia	-27.48	153.04	JPS Legacy		Dept. of Natural Resources, Queensland
Darwin AU014	DARR	Darwin	Australia	-12.84	131.13	JPS Legacy	Internal	Geoscience Australia
Mt. Stromlo	STR2?	Canberra	Australia	-35.32	149.01	JPS Legacy	Internal	Geoscience Australia
Mattersburg	MTBG	Mattersburg	Austria	47.73	16.40	JPS Legacy	Internal	University of Technology, Vienna
UNB, Fredericton	UNB1	Fredericton	Canada	45.57	-66.38	JPS Legacy	Internal	U. of New Brunswick
Concepcion-TIGO	CONZ	Concepcion	Chile	-36.84	-73.03	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Lhasa	LHAZ	Lhasa	China	29.66	91.10	Ashtech Z18	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Pecny (Ondrejov)	GOPE	Ondrejov	Czech Rep.	49.91	14.79	Ashtech Z18	Internal	Research Inst. of Geodesy, Topography & Cartography
Metsahovi	METZ	Kirkkonummi	Finland	60.22	24.40	JPS Eurocard	Ext. Quartz	Finnish Geodetic Institute
Dresden	DREJ	Dresden	Germany	51.01	13.43	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Frankfurt/Main	FFMJ	Frankfurt/Main	Germany	50.09	8.66	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Leipzig	LEIJ	Leipzig	Germany	51.35	12.37	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
DLR IKN Neustrelitz	NTZ1	Neustrelitz	Germany	53.33	13.07	JPS Legacy	Rubidium	German Aerospace Centre (DLR)
Helgoland Island	HELJ	Helgoland Island	Germany	54.17	7.89	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Huegelheim	HUEG	Huegelheim	Germany	47.83	7.60	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Titz (Jackerath)	TITZ	Titz	Germany	51.04	6.43	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Wettzell	WTZJ	Koetzting	Germany	49.14	12.88	JPS Legacy	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Wettzell	WTZZ	Koetzting	Germany	49.13	12.87	Ashtech Z18	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Thule Airbase	THU2	Thule Airbase	Greenland	76.54	68.82	Ashtech Z18	Rubidium	Kort & Matrikelstyrelsen (KMS)
Reykjavik	REYZ	Reykjavik	Iceland	64.14	-21.96	Ashtech Z18	Internal	Bundesamt fuer Kartographie und Geodaesie (BKG)
Cagliari	CAGZ	Capoterra	Italy	39.14	8.97	JPS Eurocard	Cesium	Universita' di Calgliari
Ferrara	UNFE	Ferrara	Italy	44.83	11.59	Ashtech Z18	Internal	Agenzia Spatiale Italiana
Matera	MAT1	Matera	Italy	40.60	16.70	Ashtech Z18	H-maser	Telespazio S.p.A.
Mitaka A	MTKA	Tokyo	Japan	35.68	139.57	Ashtech Z18	Internal	Electronic Navigation Research Inst.
Delft	DLFT	Delft	Netherlands	51.99	4.39	JPS Legacy	Internal	Delft University of Technology
Gjovik	GJOV	Gjovik	Norway	60.79	10.68	Ashtech Z18		University College of Gjovik
Borowa Gora	BOGI	Borowa Gora	Poland	52.48	21.04	JPS Eurocard	Internal	Institute of Geodesy & Cartography
Wroclaw	WROC	Wroclaw	Poland	51.11	17.06	Ashtech Z18	Rubidium	Agricultural University of Wroclaw
Irkutsk	IRKJ	Irkutsk	Russia	52.22	104.25	JPS Legacy	H-maser	Inst. of Metrology for Time & Space (IMVP GP VNIIFTRI)
Khabarovsk	KHAJ	Khabarovsk	Russia	48.52	135.03	JPS Legacy	H-maser	Inst. of Metrology for Time & Space (IMVP GP VNIIFTRI)
Mendeleevo	MDVJ	Mendeleevo	Russia	56.03	37.50	JPS Legacy	H-maser	Inst. of Metrology for Time & Space (IMVP GP VNIIFTRI)
Novosibirsk	NOVJ	Novossibirsk	Russia	55.03	82.90	JPS Legacy	H-maser	Inst. of Metrology for Time & Space (IMVP GP VNIIFTRI)

Table 1 (cont'd). IGLOS Pilot Project - GLONASS Receiver Tracking Stations (Dec 02)

SITE NAME	SITE ID	LOCATION	COUNTRY	LAT. (deg)	LONG. (deg)	RECEIVER TYPE	CLOCK TYPE	SPONSORING ORGANIZATION
SP Boras	SPT0	Boras	Sweden	57.71	12.89	JPS Legacy	Cesium	National Land Survey
Kiruna	KR0G	Kiruna	Sweden	67.88	21.06	Ashtech Z18	Internal	National Land Survey
Maartsbo	MR6G	Maartsbo	Sweden	60.60	17.26	JPS Legacy	Internal	National Land Survey
Onsala	OS0G	Onsala	Sweden	57.40	11.93	JPS Legacy	H-maser	Onsala Space Observatory, Chalmers
Visby	VS0G	Visby	Sweden	57.65	18.37	Ashtech Z18	Internal	National Land Survey
Zimmerwald GPS97	ZIMZ	Zimmerwald	Switzerland	46.88	7.47	Ashtech Z18	Internal	Swiss Fed. Office of Topography
Zimmerwald GPS87E	ZIMJ	Zimmerwald	Switzerland	46.88	7.47	JPS Legacy	Internal	University of Berne (CODE)
Herstmonceux	HERP	Hailsham	United Kingdom	50.87	0.34	Ashtech Z18	GPS/DFS	NERC Space Geodesy Facility
Greenbelt	GODZ	Greenbelt	United States	39.02	-76.83	Ashtech Z18	H-maser	NASA Goddard Space Flight Center
Woodinville	DWH1	Woodinville	United States	47.77	-122.08	JPS Legacy	Cesium	Hogarth, Douglas

TIGA - Tide Gauge Benchmark Monitoring Pilot Project

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Introduction

The TIGA Pilot Project was initiated in response to the demanding need for highly precise height coordinates and their changes with time at tide gauge benchmarks. TIGA was formally established during the 16th IGS Governing Board Meeting in Nice (April 2001).

For the first time it is not the intention of the IGS to provide results with a very low latency, but to have as many stations included as possible. The primary products of the Pilot Project are time series of coordinates for analyzing vertical motions of Tide Gauges (TG) and Tide Gauge Benchmarks (TGBM). All products will be made public to support and encourage other applications, e.g. sea level studies. In particular, the products of the service will facilitate the distinction between absolute and relative sea level changes by accounting for the vertical uplift of the station, and are, therefore, an important contribution to climate change studies. The service may further contribute to the calibration of satellite altimeters and other oceanographic activities. The pilot project will operate for a period of three years, from 2001 to 2003. After this period the IGS Governing Board will evaluate the project and decide whether or not this activity should become a regular IGS service function.

The goals of the TIGA-PP are identified as follows:

1. Establish, maintain and expand a global Continuous GPS at Tide Gauges (CGPS@TG) network
   - Select a set of GPS-equipped tide gauges with a long and reliable history practicable for both sea level change studies and satellite altimeter calibrations.
   - Apply IGS network operation standards.
   - Promote the establishment of more continuously operating GPS stations in particular in the southern hemisphere.
   - Promote the establishment of links to other sites, which may contribute to vertical motion determination, e.g., VLBI, SLR, DORIS and/or absolute gravity stations.
   - Develop recommendations for a minimum technical standard of the whole tide gauge system to be included into the Pilot Study, e.g., sensor types, the nature of the leveling program, and metadata documentation.

2. Contribute to the procedures in which IGS realizes a global reference frame in order to improve its utility for global vertical geodesy. This may involve reprocessing a significant subset of the (past and present) IGS global tracking data set.

3. Compute precise station coordinates and velocities for the CGPS@TG stations using a processing stream that runs months behind real-time in order to include the largest possible

number of stations. This effort will incorporate all previously collected GPS data at each CGPS@TG station. Later on the combined solution will have a maximum latency of one year.

4. Establish a secondary processing stream with much reduced latency in order to support operational activities that cannot tolerate large processing delays.

5. Monitor the stability of the network.

The progress of the project and other related information is maintained at the WEB site http://op.gfz-potsdam.de/tiga/.

Major Steps in 2001

An initial meeting was held during the APSG Sea Level Workshop in Hawaii (April 2001). A wide range of experts attended this meeting from the tide gauge as well the GPS community. A very intensive discussion took place aiming at the goals and deliverables of TIGA. Participants agreed on two main points. The first is that the completeness of data has a much higher priority than the latency of the processing stream. At second, only CGPS@TG's will be considered in a final solution for which all information, including the tide gauge data and the leveling data between the different benchmarks, is freely available to the scientific community.

Consequently, a Call for Participation was drafted and issued in June 2001. In total 23 Letter of Intent arrived, while finally 15 proposals were submitted. Proposals are covering all components of TIGA. These components are in particular TIGA Observing Stations (TOS), TIGA Data Center (TDC, 6 proposals), TIGA Analysis Centers (TAC, 8 proposals), and TIGA Associate Analysis Centers (TAAC, 2 proposals). By end of 2001 the review of the proposals was completed and a Letter of Acceptance was sent out.

TIGA Components

TIGA Observing stations (TOS) are primarily, but not exclusively, existing IGS, EUREF or NAREF stations. Some national agencies are providing GPS data not previously part of the IGS. Due to the higher latency of the processing also data from remote stations can be included into the routine analysis. A site information log for TOS was developed displaying necessary additionally information for each tide gauge. This log sheet supplements the standard IGS log. A plot of current TIGA Observing Stations is given in the figure attached (Figure 1). TOS forms are available at the TIGA web page.

TIGA Analysis Centers (TAC) will process data in different chains. The primary chain will have a latency of 460 days, which allows also the very remote stations, e.g. from Antarctica, to provide their data. A secondary chain will provide solutions with a very short latency to support operational aspects. In addition a few processing centers have agreed to re-compute a selected subset of the IGS and other network data (including a retro-processing of IGS station data for CGPS@TG) for an improved long-term stability of the reference frame since the inception of the IGS.

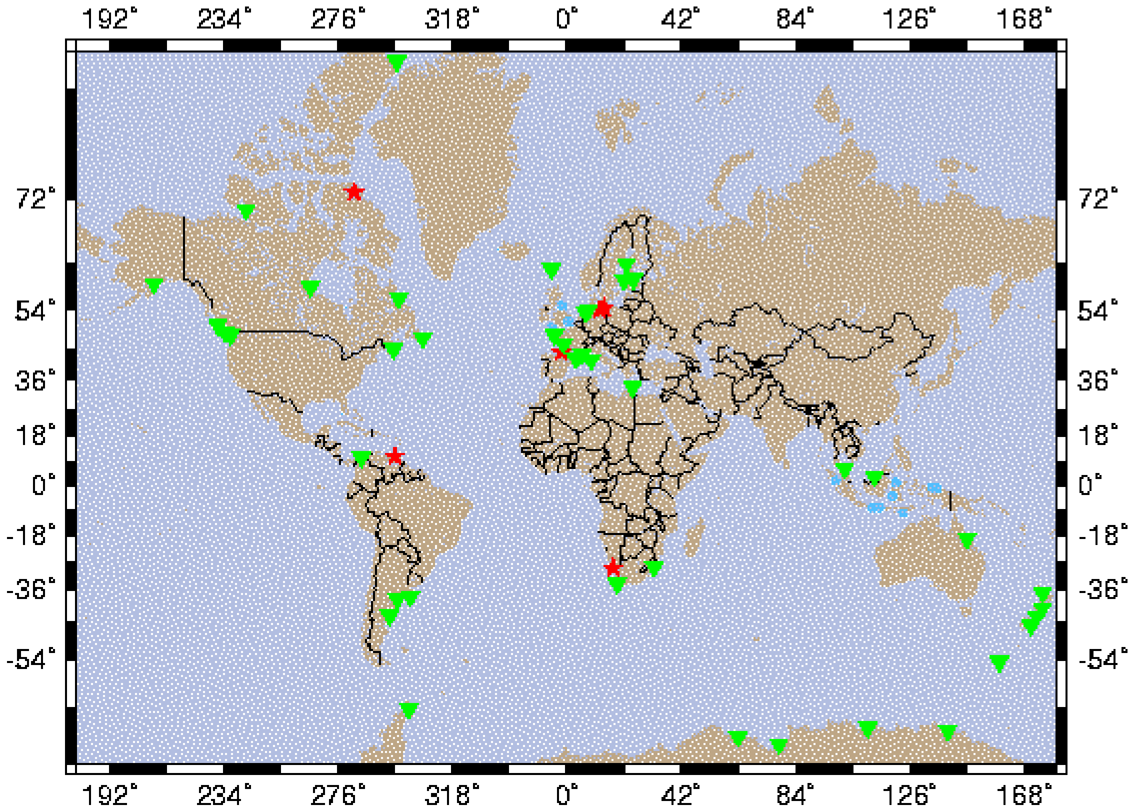

Figure 1: Overview about the current status of TOS stations (August 2003)
For few stations (triangles) all necessary information is available. In the near future, more stations will become available (dots). In response to the TIGA Call for Participation also new GPS stations will be installed near tide gauges (stars). For large areas either no CGPS@TG stations exist or the necessary information is not provided to TIGA.

TIGA Associate Analysis Centers (TAAC) will facilitate TIGA in two different ways. This ranges from the processing of a selected regional subset of CGPS@TG stations, while others will analyze the results of the TAC's in various ways, including comparisons to other space techniques or absolute gravity measurements.

As a new component, TIGA Data Center (TDC) will not only store and re-distribute GPS data, but also metadata. They will fulfill three functions:

1. Store GPS data sent by different media (FTP, computer tapes, CD-ROM, diskettes, etc.) with high and changing latency.
2. Store Metadata (e.g. leveling data, sketch maps of the TG) of any kind (e.g. computerized, handwritten, microfiches, etc.)
3. Establish links to Tide Gauge Data Centers for easy and convenient data access.

Activities in 2002

In the first half of 2002, the processing strategy for the analysis and re-analysis was discussed and some important TIGA components, like the TDC at the University La Rochelle, were established and tested. In August 2002 six TAC's started with the forward processing. It was agreed upon to allow a latency of data submission of 460 days. This primarily allows also very remote stations, like e.g. in Antarctica, to provide data in due time.

After an initial period a regular submission was established by three centers:
- EUREF
- GFZ, GeoForschungsZentrum Potsdam, Germany
- ULR, University La Rochelle/IGN, France

In addition, three more centers
- Geoscience Australia, Australia
- University of Canberra, University of Tasmania, Australian National University, Australia
- DGFI, Deutsches Geodätisches Forschungsinstitut, Germany

providesolutions with varying submission dates (Fig. 2 & 3). EUREF is providing a solution with short latency, while all other centers are processing and re-processing GPS data.

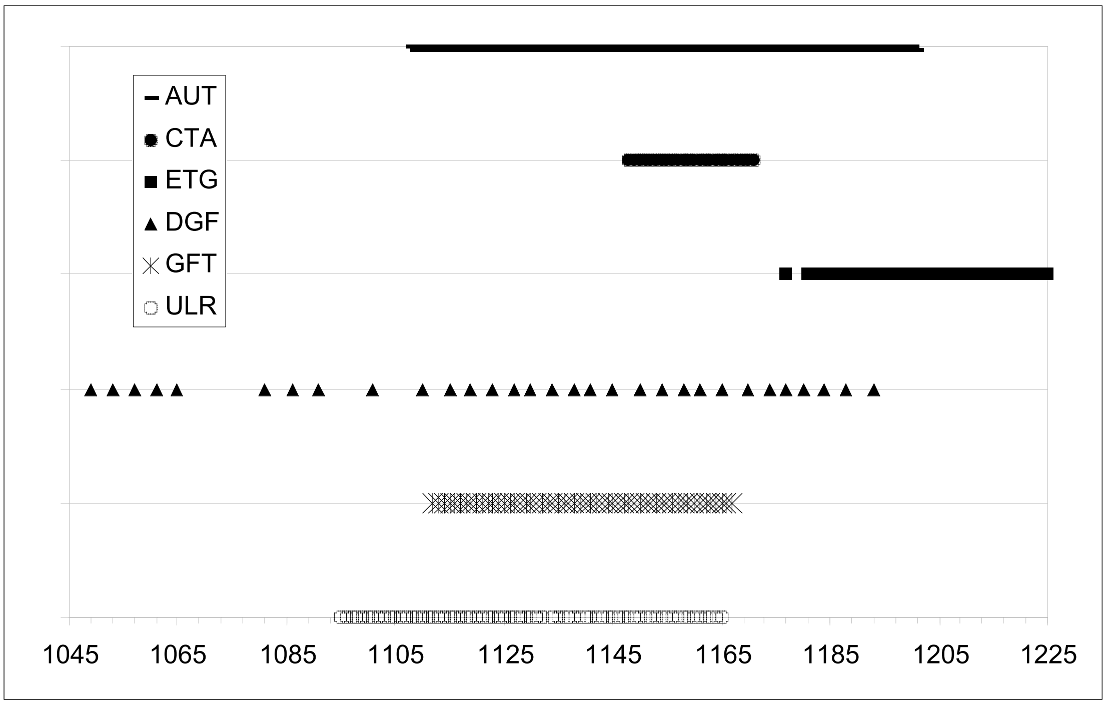

Figure 2: Weekly SINEX file availability at the TIGA FTP server.

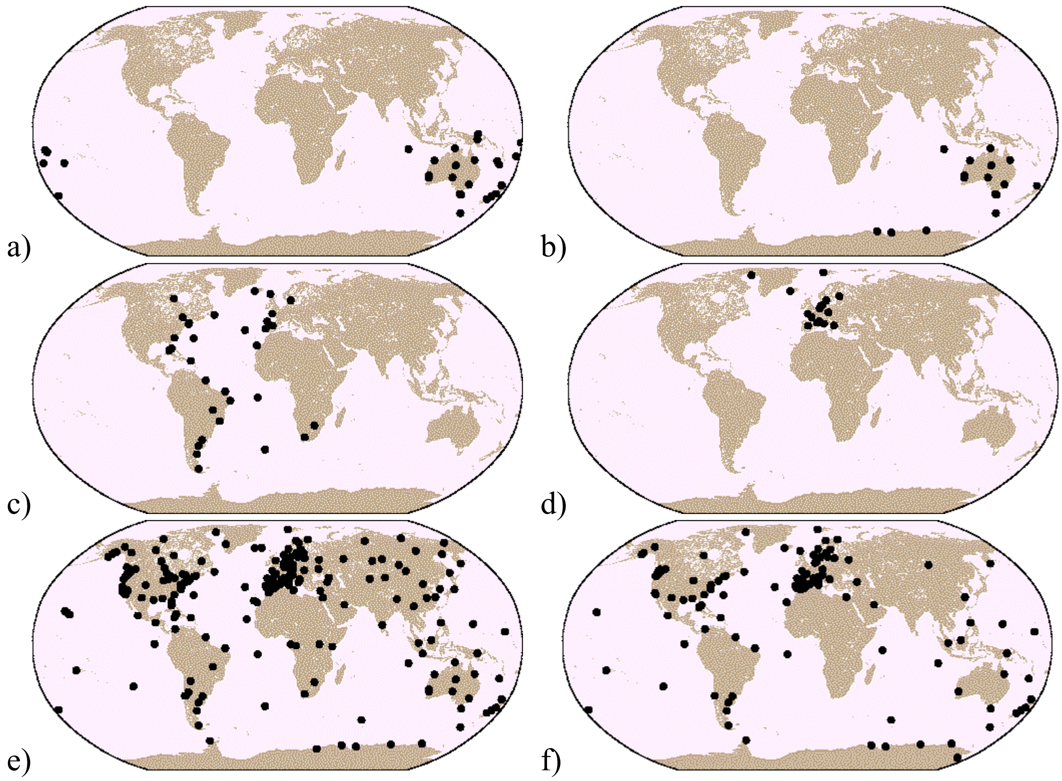

Figure 3: Station distribution for the individual SINEX solution for GPS week *1165* *for (a) Geoscience Australia, (b) University of Canberra, University of Tasmania, Australian National University, (c) Deutsches Geodätisches Forschungsinstitut, (d) EUREF (week 1181), (e) GeoForschungsZentrum Potsdam, and (f) University La Rochelle/IGN.*

Analysis of Center Solutions

Although a routine combination is not yet carried out, all individual solutions are compared by a Helmert transformation. The comparison between all solutions as well as with the IGS final solutions is used to detect inconsistencies, outliers or instabilities. However, the comparison shows an agreement in the 5 mm level for the horizontal components as well as 7 to 10mm for the vertical component. Selected Results are shown in Figure 4.

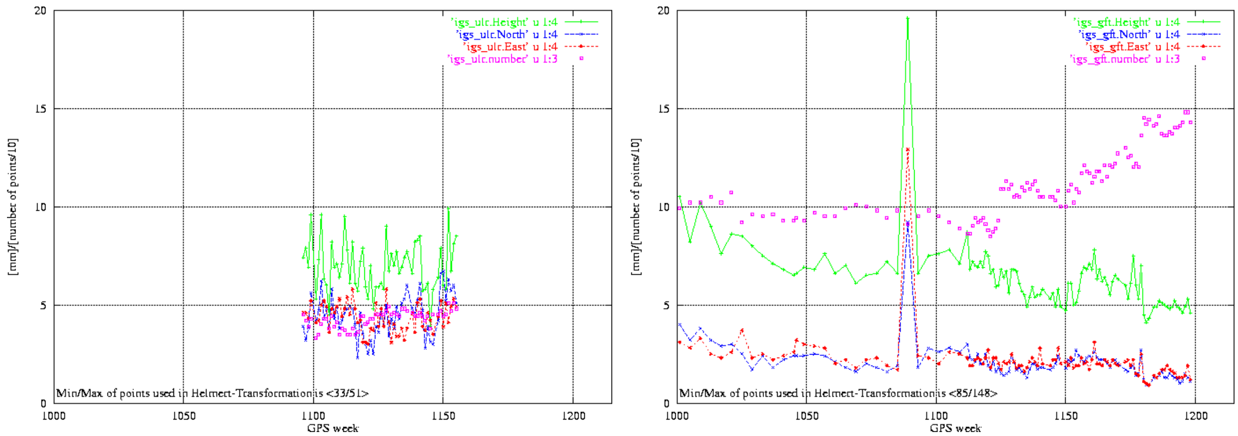

Figure 4: Comparison of individual TIGA solutions with the IGS combined solution (ULR solution (left hand side) and the GFZ solution (right hand side)). *The agreement for the ULR solution is 5 mm for the horizontal and 7 mm for the vertical component. For the GFZ solution the agreement is 3 mm for the horizontal and 10 mm around GPS week 1000 and 5 mm for the later data. This can be explained by the fact that for the later data the GFZ AC solution is part of the final IGS solution forms as well as of the GFZ TIGA solution.*

Future Tasks

By end of 2002 the processing chain was established by the TAC's. Starting with GPS week 1112 SINEX solutions are routinely provided and distributed via the TIGA FTP server. For the backward period SINEX files are provided without a strict timeline. Also by end of 2002 29 TOS stations are accepted for TIGA. However, the number is still growing. An important task for the future will be the constant effort for the establishment of more leveling ties to tide gauge benchmarks.

The main task for the future of TIGA is to establish capabilities for the analysis of the individual solutions and the combination in order to provide a final and verified TIGA product to the user community.

IGS Data Center Working Group Report

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At its 18th meeting held December 09, 2001 in San Francisco, the IGS Governing Board recommended the formation of a working group to focus on data center issues. This working group will tackle many of the problems facing the IGS data centers as well as develop new ideas to aid users both internal and external to the IGS. The direction of the IGS has changed since its start in 1992 and many new working groups, projects, data sets, and products have been created and incorporated into the service since that time. Therefore, this may be an appropriate time to revisit the requirements of data centers within the IGS.

The IGS Data Center Working Group (DCWG) will address issues relevant to effective operation of all IGS data centers, operational, regional, and global. Some of these issues include:

- effective data flow
- backup of the operational data flow
- security issues at data centers
- consistency of data holdings among data centers
- timely archive and dissemination of data as the IGS moves into a real-time mode for selected products

The charter of the IGS Data Center Working Group (DCWG) was approved at the IGS Governing Board meeting held in Ottawa in April 2002. Since that time, a web site was created (*http://cddisa.gsfc.nasa.gov/igsdc*) for the working group. This website contains the charter and list of members and has the capability to expand to include other components pertinent to the working group. In June 2002, an exploder (*igs-dcwg@igscb.jpl.nasa.gov*) was implemented at the IGS Central Bureau for the working group.

One area of interest for the DCWG is the GSAC, the GPS Seamless Archive Center initiative currently being supported by five of the six largest GPS archives within the U.S. (CDDIS, UNAVCO, SOPAC, SCEC, and NCEDC), and with intent to join expressed by NGS in the U.S., GSD in Canada, BKG (EUREF), and IGN. The GSAC working group, currently operating under UNAVCO auspices, would very much like to encourage participation in the GSAC by other GPS archives, particularly outside the U.S. DCWG members were given information about the GSAC and its documentation and were asked to run tests of the GSAC client software. In 2002, the CDDIS completed modifications to software permitting the data center to become an official GSAC wholesaler. The GSAC working group has asked the DCWG to encourage all IGS data centers to consider making the metadata from their archives accessible through the GSAC.

Plans for 2003 include the development of a data center requirements document that would be useful to any group wishing to join the IGS as a global or regional data center or an operational center. The working group will also develop procedures for identifying replacement data, methodologies for handling replacement data in all data centers, and ways to notify the user community of these data updates.

ADDITIONAL CONTRIBUTIONS

AFREF – Southern and East African Components

R. Wonnakott
Steering Committee for Southern Africa component of AFREF
Surveys and Mapping, Mowbray, South Africa

There are over 50 countries in Africa practically all of which are considered as developing nations and each with its own difficulties and challenges. With each country having its own geodetic reference system, one of these challenges as a continent lies in the inability of African countries to plan meaningful and cohesive development projects which rely heavily on a sound and uniform continental geodetic reference frame. Such a framework will be used to develop uniform mapping programmes, monitor a variety of environmental changes, provide a consistent navigational reference system and provide a common reference frame to resolve international boundary disputes.

The African Geodetic Reference Frame (AFREF) is conceived, therefore, as a unified geodetic reference frame for Africa. It will be the fundamental basis for the national three-dimensional reference networks fully consistent and homogeneous with the International Terrestrial Reference Frame (ITRF). When fully implemented, its backbone will consist of a network of continuous, permanent GPS stations such that a user anywhere in Africa would have free access to and would be, at most, 1000km from such stations. Full implementation will include a unified vertical datum and support for efforts to establish a precise African geoid, in concert with the African Geoid project activities.

In March 2001 a meeting of representatives from 8 African countries was held in Cape Town in conjunction with the Conference of Southern African Surveyors (CONSAS). In addition to these country representatives, delegates from the IGS/IAG, EUREF and NIMA attended the meeting which was intended to inform countries of the project and to gauge the level of interest that countries had in the project. The following is a summary of the main outcomes of this meeting:

- The project must be run under the IAG banner;
- The project will be best carried out on a regional basis, for example North, South, East, West and Central Africa;
- GPS is the obvious tool for the project which can be divided into a number of stages namely, the establishment of a fundamental network of permanent or semi-permanent GPS stations (1 or 2 per country) for inclusion into the IGS network, the densification of the permanent network with short campaigns using 4 or 5 GPS receivers simultaneously occupying, where possible, monuments with coordinates in the current national system and, finally, the calculation and adjustment of coordinates in the new system;
- The unification of the coordinate systems must include the vertical component and;
- One of the major points was that this project must be driven by the African national mapping agencies right from the start to be able to learn more about the new technologies. Technical and scientific expertise and assistance from non-African countries and agencies will be requested through the IAG/IGS and other sources.

In both 2001 and 2002, the AFREF project was presented to a number of IAG representatives at meetings held during the European Geophysical Society (EGS) General Assemblies held in Nice, France to sensitize the broader geodetic community and gain wider support for the project within the IAG.

In July 2002, an application for funding in support of AFREF was submitted to ICSU by IUGG on behalf of the IAG. The main thrust of the application lay around the provision of technical assistance and capacity building and the transfer of skills through workshops, seminars and short training schools. Although the application was not accepted, some sound objectives for AFREF were formulated which will be carried forward, namely:

- To define the continental reference system for Africa and establish and maintain a unified geodetic reference network as the fundamental basis for the national 3-d reference networks fully consistent and homogeneous with the global reference frame of the ITRF;
- To realize a unified vertical datum and support efforts to establish a precise African geoid, in concert with the African Geoid project activities;
- To establish continuous, permanent GPS stations such that each nation or each user has free access to, and is at most 1000km from such stations;
- To provide a sustainable development environment for technology transfer, so that these activities will enhance the national networks, and numerous applications, with readily available technology;
- To understand the necessary geodetic requirements of participating national and international agencies and;
- To assist in establishing in-country expertise for implementation, operations, processing and analyses of modern geodetic techniques, primarily GPS.

The 4TH UN / USA Regional Workshop on the Use and Application of Global Navigation Satellite Systems (GNSS) was held in Lusaka, Zambia in July 2002. Representatives from 21 African and 2 Middle Eastern countries and the IAG/IGS among other international organizations attended the workshop. The main recommendations from the workshop relating to surveying and mapping issues were:

- African Continental Reference System (AFREF)
  - that the AFREF project be endorsed by the UN/USA Workshop;
  - that GPS be the primary tool to achieve the project objectives;
  - that African nations and organizations commit to the project;
  - that international partners such as the IAG and the IGS commit their support to the project and;
  - that the AFREF project solicits the resources to procure and support the GNSS technology and network infrastructure and to promote training courses for capacity building for GNSS.
- Standards and specifications
  - that all GNSS systems must operate in an identical reference frame and coordinate system such as the ITRF (AFREF will be based on the ITRF) and;
  - that the internationally accepted standards and procedures of IAG (through ITRF and IGS), ISO/TC 211 etc be used throughout.

An organisational structure for the implementation, management and execution of the AFREF project was also proposed at the Lusaka workshop with the overall project falling within the United Nations Economic Commission for Africa (UNECA) Committee for Development Information (CODI) and that the IAG and IGS take on a technical and scientific advisory role in the project.

In December 2002, the Regional Centre for Mapping of Resources for Development (RCMRD) based in Nairobi, Kenya, convened one of the it's regular two yearly meetings in Windhoek, Namibia to discuss various matters at the Technical Committee (TC), Governing Council (GC) and Ministerial levels. Since the RCMRD brings together the heads of the NMO's of East and Southern African countries to discuss matters of mutual interest, a planning workshop for AFREF of these countries was convened prior to the RCMRD meetings. Perhaps the main outcome of this meeting was the commitment to the project shown by the participating countries to the extent that a document called "The Windhoek Declaration of an African Geodetic Reference Frame (AFREF)" was prepared and agreed upon by the represented countries. In addition, a number of potential sites for permanent GPS base stations were proposed. (See Figure 1 for map of potential GPS base stations). In May 2003 the "Windhoek Declaration" was formally adopted by CODI and AFREF became a formal project within CODI. AFREF was also formalized as a Sub-Commission within the IAG in July 2003.

There has been a lot of discussion, debate and hard work surrounding the AFREF project since 2000. Many organizations and individuals have expressed interest and strong support for the project including the IAG. A major challenge for the next four years will be to maintain and even increase the momentum and enthusiasm for the project particularly among African countries. The time has come to put all the resolutions into action and it is trusted that the IAG and the IGS will play a pivotal scientific and technical role in these actions during the next four years.

Existing and Proposed GPS Base stations for East and Southern Africa
December 2002

● Existing IGS stations
● Existing non-IGS stations
● Proposed GPS base stations as per “Windhoek Declaration”

Figure 1. Map of proposed Permanent GPS Base Stations in Southern and East Africa\

IGS

2001 TECHNICAL REPORTS

IGS

ANALYSIS CENTERS

The ESA/ESOC IGS Analysis Centre Annual Report 2001

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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 2001.

This year the ESOC AC activities have continued uninterrupted and have consolidated with the timely delivery of all the products part of the IGS and participation in several of the IGS Working Groups and Pilot Projects. There have been no major changes to the routine processing during 2001 except for the inclusion in the UltraRapid product of satellite clock bias values (estimated and predicted).

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. Information is available on the website: http://nng.esoc.esa.de/gps/gps.html

Changes and Activities in 2001

These have been the changes to IGS activities at ESOC during 2001:

- Mar 2001 *Ultra-Rapid processing*: Started clock bias submissions with the UltraRapid product (24 hr estimated + 24 hr predicted).
- Apr 2001 *Ultra-Rapid processing*: changed strategy from 2-step fit; RINEX data fit and then a longer arc Earth Fixed Position fit, to a 1-step fit; RINEX data and Earth Fixed Positions fitted together.
- May 2001 *GLONASS processing*: Raised the allowed noise level cut-off for GLONASS data to the same level as for GPS (from 30 to 50 cycles between phase and pseudorange), this allows more data to be used in the processing at the risk of some increased noisy measurements from multipath or other causes.
- May 2001 *GLONASS processing*: Started using a 9 parameter Solar Radiation Model (3 components per axis), and a 3 day RINEX data arc (from a 5 day arc).
- Jun 2001 *GPS Processing*: For satellites in eclipse excluding 14 minutes of data at the exit of the eclipse (down from 30 minutes).
- Dec 2001 *GPS Processing*: Changed terrestrial reference frame to ITRF2000, based on the IGS2000.SNX Sinex file generate by the IGS for the core stations.

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 clock biases
- Final GLONASS Orbits plus clock biases
- Rapid GPS Orbits plus clock biases
- Twice Daily Ultra-Rapid GPS Orbits plus clock biases
- 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 final ionospheric files in IONEX format
- Weekly combined IGS ionosphere IONEX files; ESOC is the IGS Ionosphere Associate Combination Center (IACC)
- 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 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 undifferenced, 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-free 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:

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http://nng.esoc.esa.de/
http://igscb.jpl.nasa.gov/igscb/center/analysis/esa.acn
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Ultra-Rapid clock predictions

During 2001 the Ultra-Rapid product delivered by ESOC to the IGS started including satellite clock bias values. The Ultra-rapid product includes both estimated and predicted orbit positions every 15 minutes. The estimated part is based on the processing of two frequency RINEX data from a multitude of stations (as explained above) the prediction part is the propagation of the orbits using the estimated part as initial conditions and using very precise dynamical models.

The clock bias estimation in ESOC is based entirely on the availability of RINEX data. No accurate modelling of an atomic clock at the level of precision required is available, as there may be for the orbit, etc, and thus the estimated clock biases are always calculated from RINEX measurements. To provide clock bias values for the entire arc of the Ultra-Rapid products (estimated + predicted parts) an external clock propagation tool has been developed.

In broad terms a function is fitted to each of the satellites' clock bias values using a least-squares adjustment process. If the results of the fit are satisfactory the function is used to propagate the clock values into the future and they are then merged with the predicted positions for submission to the IGS. The function used is,

$$y_{PRN} = A_0 + A_1 t + A_2 Sin(A_4 t + A_5)$$

this function provides reasonable propagation results for 24 hours (as required in the Ultra-Rapid product), to a few nanosecond level (but still an order of magnitude worse than the estimated clocks). Figure 1 shows the clock biases estimated for two satellites (PRN 21 and 06) as the result of one of the precise orbit determination processes run at ESOC.

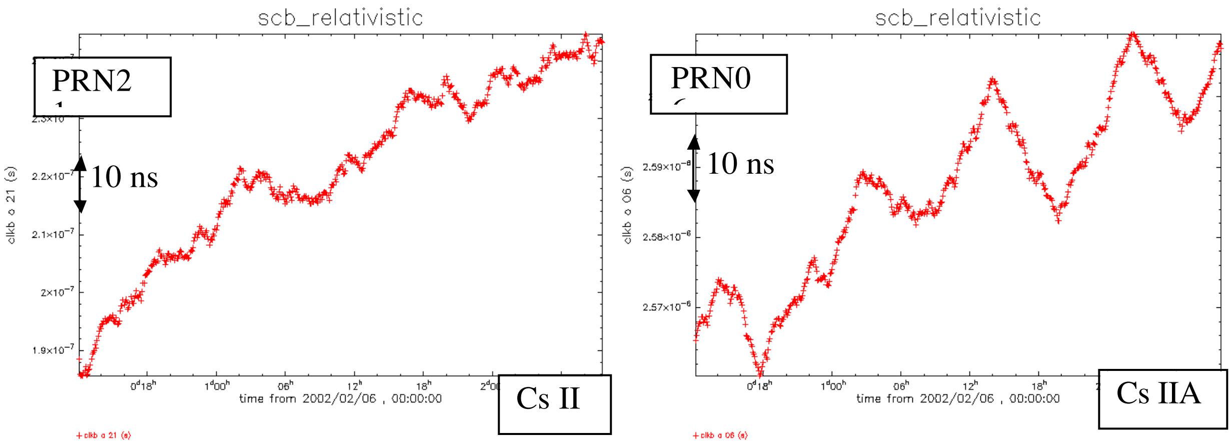

Fig. 1: Satellite clock biases estimated for 48 hrs from 12:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

The function above tries to approximate the observed values (Figure 1) by adjusting the 5 parameters. Depending on how well the function can reproduce the observed values it is either used or not to propagate values in to the future. If the function cannot fit the observed values to within 10 ns then no clock value (estimated or predicted) is included in the ESOC solution. In these cases it is assumed that the estimated values may actually not be good enough for the level of precision required for the IGS. Figure 2 shows cases in which no clocks would be sent out at all since discontinuities in the satellite clock bias values (red curves), due to RINEX station data gaps or processing problems, resulted in a poor fit (worse than 10 ns) of the prediction function (green curve).

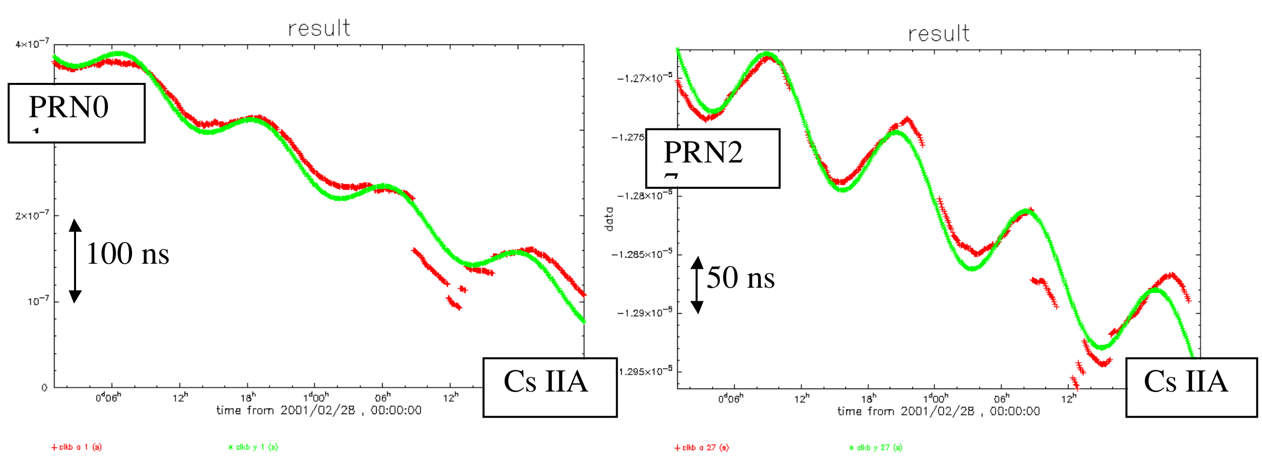

Fig. 2: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 28th,2001 (01059) (with the relativistic correction still included).

The vast majority of the time the satellite clock biases can be fitted to within 10 ns over the 48 hrs used for propagating, using the function defined above. Figure 3 shows the example of two satellites with the estimated and predicted clock bias values where the fit is OK.

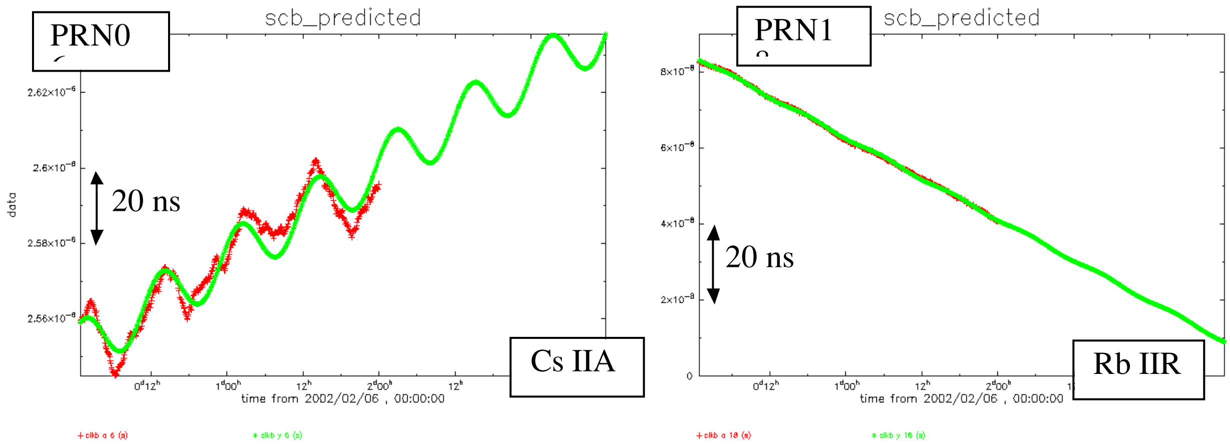

Fig. 3: Satellite clock biases estimated (red) and predicted (green) from 00:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

For inclusion in the Ultra-Rapid sp3 files delivered to the IGS the clock values are merged with the orbital positions. It is clear from Figure 3 that in just joining the estimated and predicted clock bias values a jump would be seen at the transition point from estimated to predicted clocks. This discontinuity is not desired since it breaks the continuity of the Ultra-Rapid product. These jumps are also not consistent among all of the satellite clock biases, and thus are not easy to correct after the fact. Therefore at the transition point from estimated to predicted clocks the end points are matched, as shown in Figure 4.

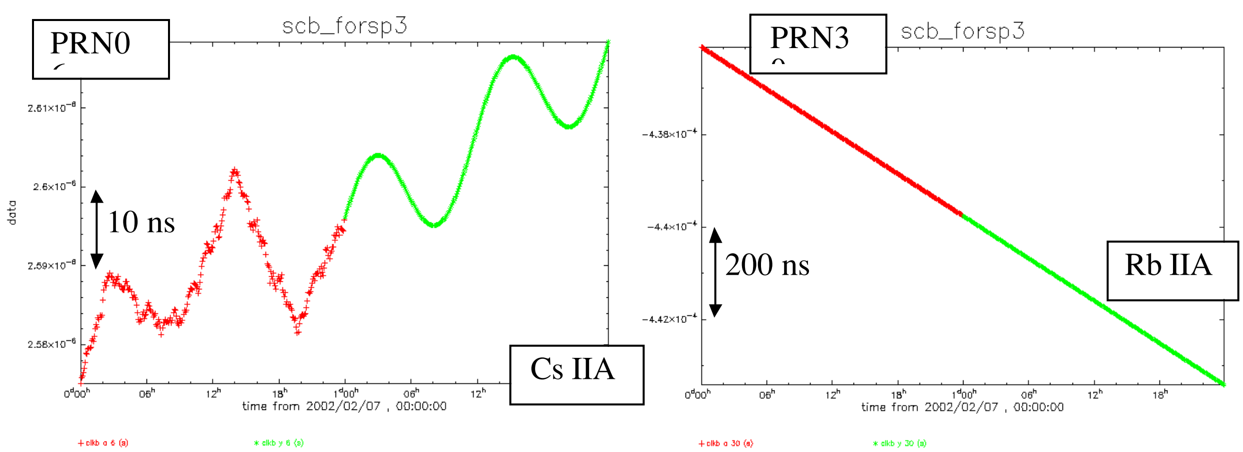

Fig. 4: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 7th, 2002 (02038) (with the relativistic correction removed).

From the Analysis Centre Coordinator (ACC) Ultra-Rapid Comparison summaries it is well known that the satellite clock bias propagations are accurate to around 5 to 7 ns (in an RMS sense over the entire constellation). Unfortunately no individual clock comparison summary is readily available except at ESOC's website:

    http://nng.esoc.esa.de/gps/igs_ana.html

where the first 12 hrs of the predicted clocks are compared with the estimated values later obtained from the Rapid product. Figure 5 presents daily comparison results of all the satellites from two of the 4 GPS Clock/Block types combinations. The results clearly show that the ability to predict clocks into the future has mainly to do with the inherent stability of the satellite's onboard oscillator. The newer Block IIR Rb clocks are the easiest to predict since they show the best behaviour in the time scales of the Ultra-Rapid product.

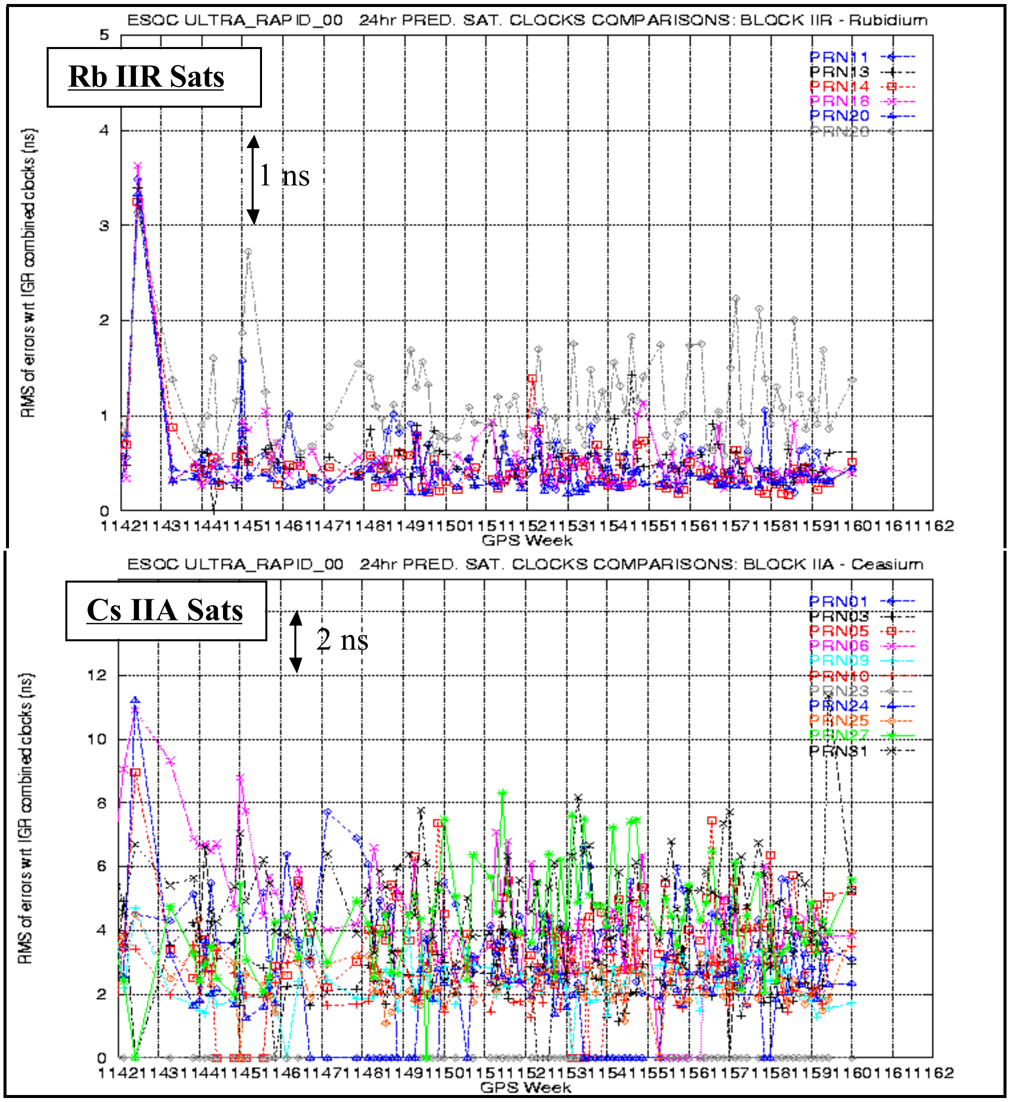

Fig. 5: Satellite by satellite comparison of predicted versus estimated clock biases from GPS week 1142 to week 1160 for two sets of GPS satellites.

Figure 5 shows the satellite by satellite comparisons of the Block IIR Rb clocks to be predictable over 12 hrs to better than a single nanosecond (except for PRN28), whereas the Block IIA Cs clocks can only be estimated to around 4 or 5 ns. Since there is no weighting currently applied by the ACC to the clock comparisons the RMS results can sometimes be very negatively affected by one bad clock prediction submission. Still on the average the clock predictions are better than the GPS navigation message by 2 or 3 ns, or around 25%.

Looking in detail at the actual clock bias values estimated and predicted, it is of interest to see Figure 6, which shows the predicted and estimated values together for two satellites. It can be concluded that given the character of the clock bias values nothing can really be gained by using more complicated fitting functions than the one above, indeed in an RMS sense estimating an offset and a drift to predict clock values is enough and that more complicated functions do not add accuracy to the clock predictions.

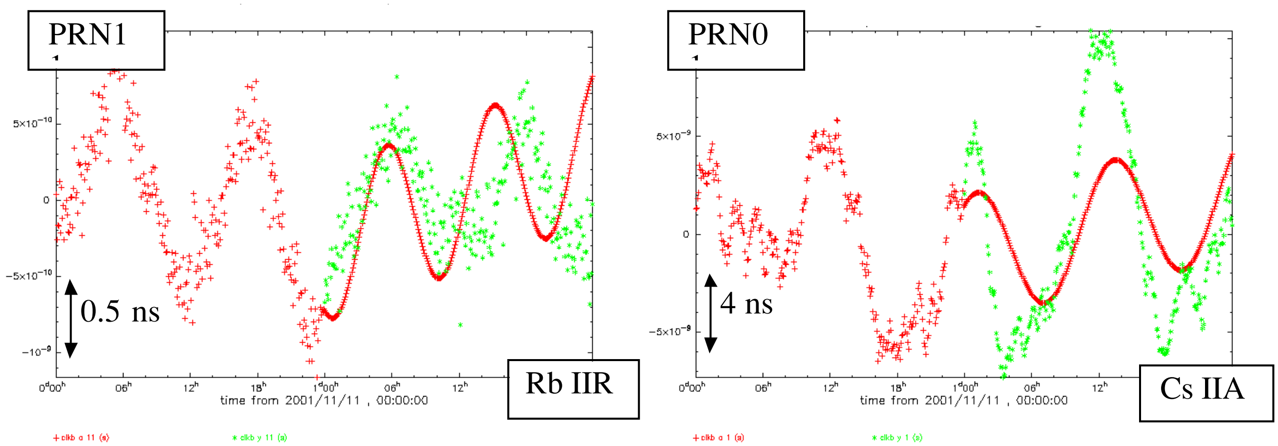

Fig. 6: Satellite clock bias values, submitted with the Ultra-Rapid (red) and estimated in the ESA Rapid process (green) for 48 hrs from 00:00 Nov. 11th 2001 (01315) (Offset and drift removed for plotting).

GLONASS Processing

GLONASS processing at ESOC has continued during 2001 under the new IGLOS Pilot Project. Some changes in the processing have been introduced and tested to try to produce more stable day-to-day solutions. ESOC's processing of GLONASS data was changed during 2001 by raising the noise cut-off permitted between the pseudorange and phase measurements from 30 cycles to 50 cycles. This in turn had the effect of increasing the amount of available data from some of the stations, which helped in the stability of the solution for those stations and in turn for the GLONASS constellation.

Another change implemented during 2001 in the GLONASS processing has been switching back to a 3-day processing arc, from a 5-day arc, which was tested from February 2000. Originally due to lack of RINEX data it was thought that increasing the daily processing arc to 5 days would allow for better parameter estimation and more stable day-to-day solutions. With the increase of RINEX data availability for GLONASS processing the data problem was improved, the processing time was also increasing considerably, so therefore the data arc was switched back to 3 days as it had been previously.

Furthermore during 2001 the processing has started estimating 4 new parameters in a 9-parameter Solar Radiation Pressure (SRP) model for the GLONASS satellites; this has been a change for testing purposes from a 5-parameter model used up to 2001 (Romero et al., 2002). The new terms which are estimated are a sine and cosine terms on the X and Y axes (Figure 7).

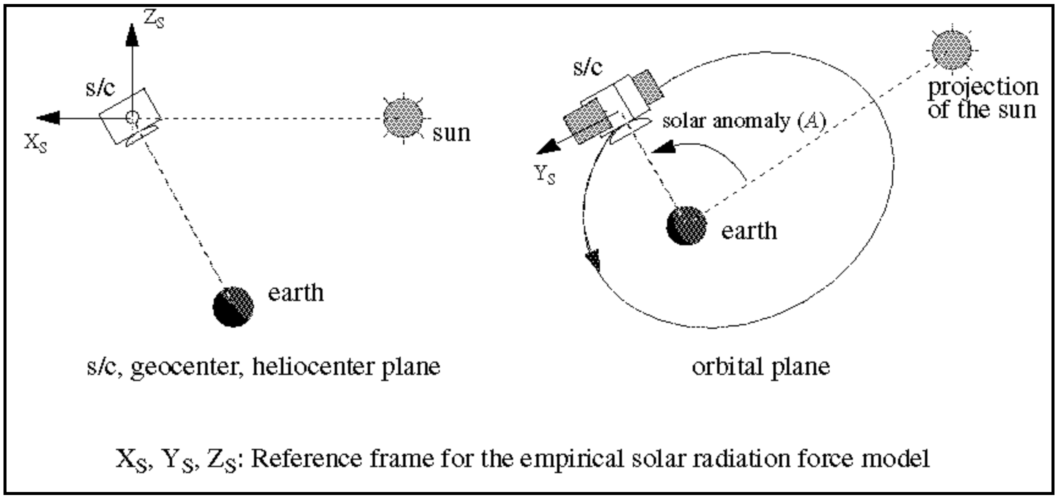

Fig. 7: GLONASS Solar Radiation Pressure Modelling.

During 2001 the GLONASS constellation of satellites has continued to decrease in numbers. Even with the launch of three new satellites in December 2001 (two of which were later introduced during 2002), the number of satellites being decommissioned meant that the total number of active dual-frequency satellites by the time of this writing was only seven, plus one which is yet to be introduced officially (number 711, slot 5) but which has been transmitting some data. 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.

The GLONASS orbit processing at ESOC currently only processes dual frequency dual system receivers, mainly Topcon and Ashtech Z18 receivers. During 2001 the increasing number of stations meant that overall the useful GPS/GLONASS stations have increased to between 30 to 35 stations. The problem continues to be poor world coverage with most stations concentrated in Europe as can be seen from Figure 8, below. In this figure the stations in capital letters are GPS-only stations which are part of the IGS ITRF core and which are kept fixed, the lower case stations are the ones with GPS/GLONASS dual frequency receivers, the stations in bold are the ones actually selected for this run.

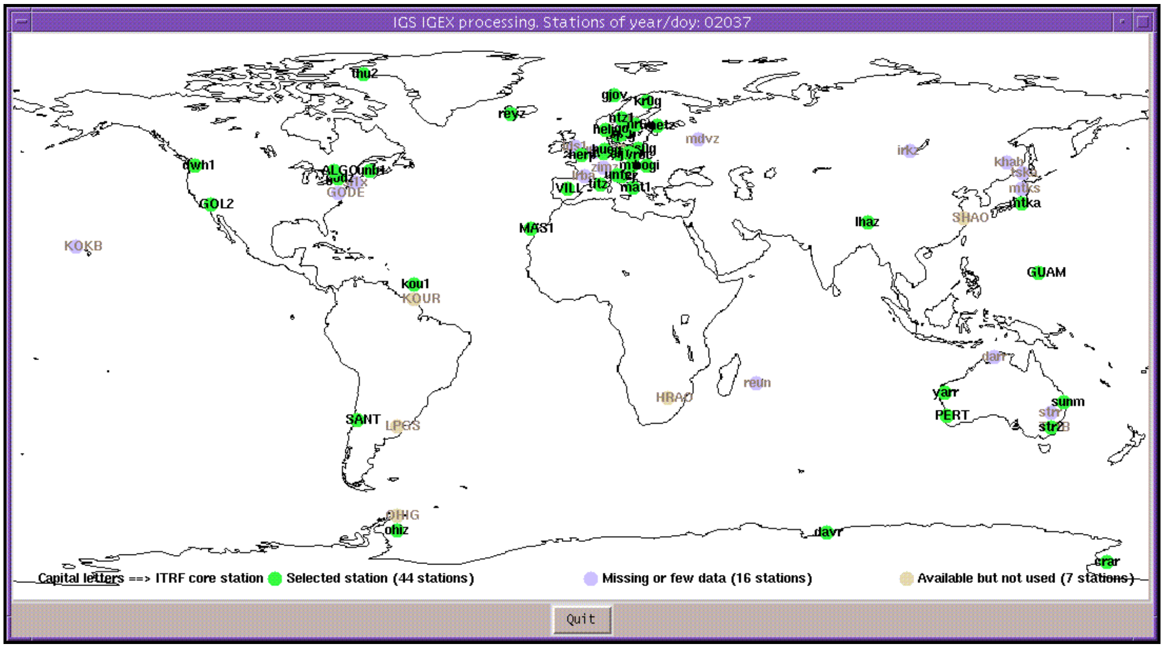

Fig. 8: GPS/GLONASS typical station selection for IGLOS processing.

Figure 9 shows the orbit comparisons between the solutions from CODE, BKG, MCC (Control Centre Moscow) and ESOC versus the GLONASS combination up to the time of writing. CODE orbit contributions ceased during 2000. The ESOC comparison to the combination has stabilised at an error level of around 20 cm. The general degradation of the comparison results observed in the plot during 2001 was most likely the result of bad solutions provided by ESOC, for GLONASS satellite 784, in slot 8. Once this solution was systematically excluded from the ESOC submission the comparison results of all the Centres improved to the expected sub-20 cm level.

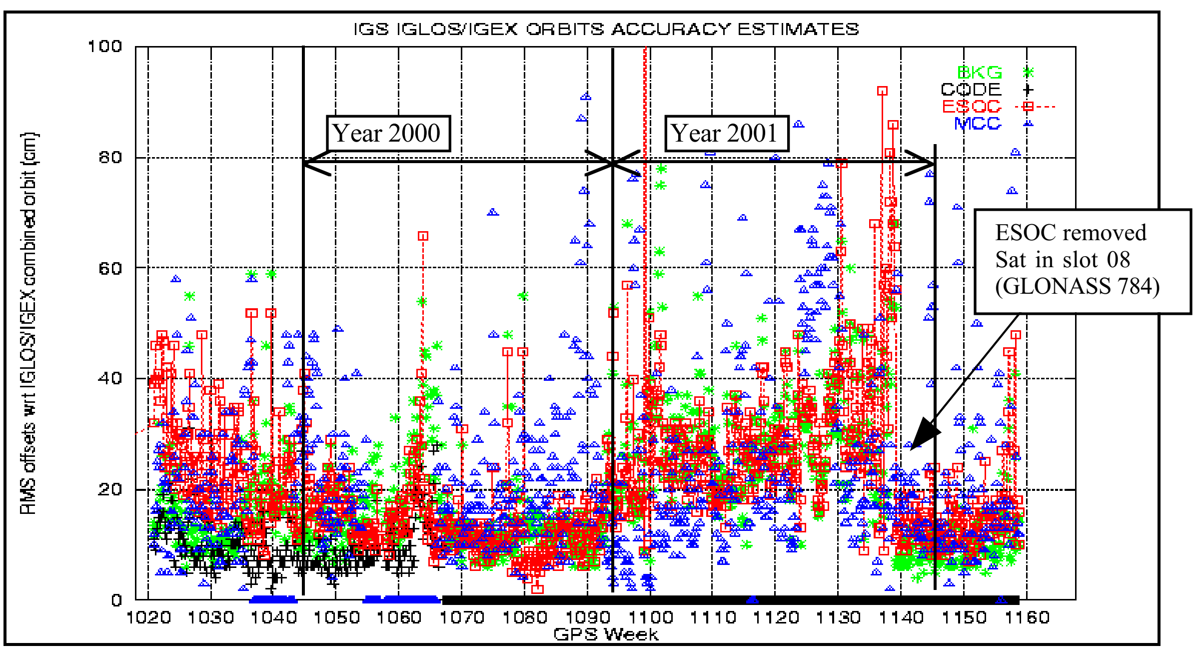

Fig. 9: IGLOS/IGEX AC orbit comparisons versus the combination.

Figure 9 and the problems with satellite 784 experienced by ESOC are indicative of the urgent need of adding Analysis Centres to the GLONASS orbit processing. With only two microwave-based orbit solutions (BKG and ESOC) for the entire set of active satellites it is impossible for the ACC to exclude bad satellites since there can be no majority voting as there is in the GPS combination process. Unfortunately the MCC solution only includes three satellites (the ones tracked by SLR) so it serves only as a limited external check for each week's combination process.

On improving the availability and world coverage of GPS/GLONASS data ESOC has purchased and installed a Topcon (formerly Javad) GPS+GLONASS receiver at our permanent station in Kourou (French Guyana), which was tested and started supplying some dual system data during 2001, both for IGS and IGLOS activities. The station has the identifier KOU1 and it is connected to the external Cesium reference clock at the station as is our other station KOUR.

Ionosphere Processing

Routine processing of ionospheric Total Electron Content (TEC) maps and satellite/receiver differential code biases (DCBs) continued during 2001.

The ionosphere processing in final mode continued with the rapid orbits. The number of ground stations used could be increased to about 180. The 24 hours time resolution with which the TEC maps are produced, could not be increased in 2001. The daily routine ionosphere processing in 2001 was 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 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 (Figure 10). This run is the official ESOC contribution to the IGS Ionosphere Working Group to be part of the combination.
3) A Chapman profile model is fitted to the TEC data, where h0 is estimated as a global constant. This run is made for test reasons and theoretical studies.
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.

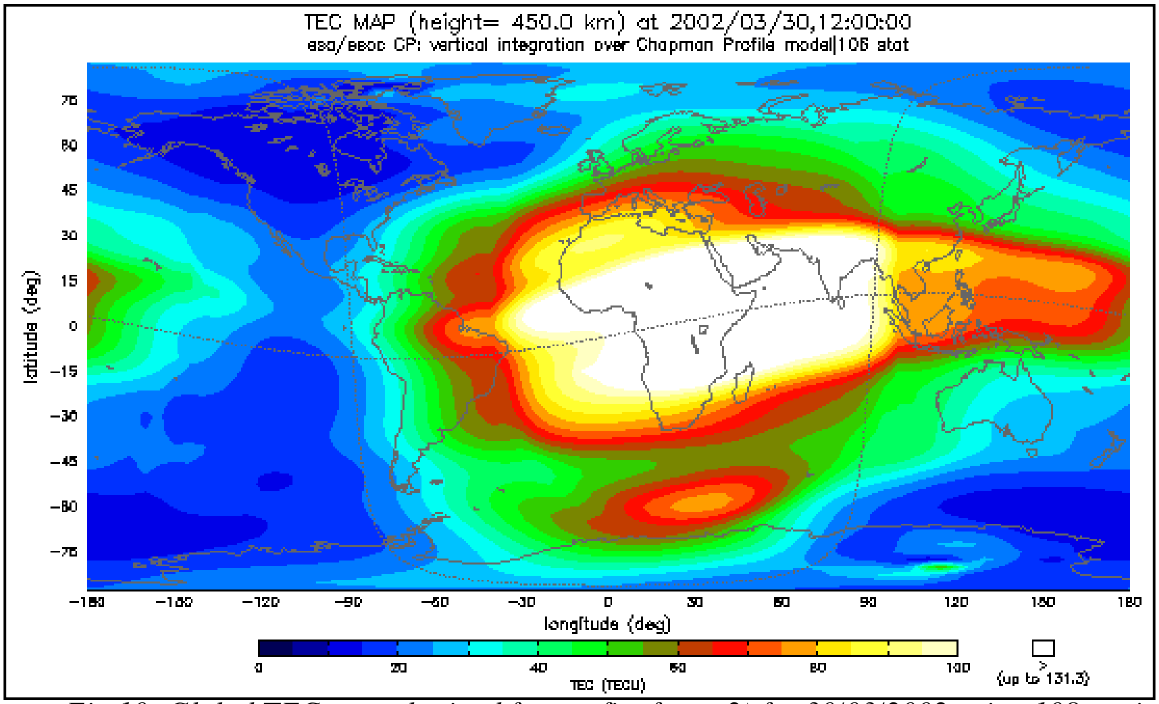

Fig 10: Global TEC map obtained from a fit of type 2) for 30/03/2002 using 108 stations.

Beyond the routine processing of our own TEC maps, ESOC has also chaired the IGS Ionosphere Working Group (Iono_WG) during 2001 (Feltens, 2002). As part of these activities, ESOC has been responsible for the weekly comparisons of Iono_WG products as IGS Ionosphere Associate Combination Centre, and generally for the coordination of the activities of this working group. (Feltens,)

LEO Activities

In the Potsdam Meeting of February 2001, ESOC offered to act as Associate Analysis Centre Coordinator for the IGS LEO Pilot project and took up this role in May (Boomkamp, 2002). The first substantial set of LEO GPS data was also released in May 2001, allowing for an increase in analysis activities at the IGS Associate Analysis Centres.

During the summer it became clear that the processing of the CHAMP data was not straightforward, and many centres seemed to come across similar practical problems. In response to a request from IGS LEO, GFZ organized a CHAMP user meeting in October, which was attended by representatives of most European groups, and was well received. A collection of practical recommendations that emerged during this meeting has been collected on some pages on the ESOC website dedicated to IGS LEO.

Shortly after the User meeting, the CHAMP Orbit Comparison Campaign was launched and coordinated by ESOC. Initial results of this campaign show that the interest in this kind of activity is substantial, and that it can support analysis activities in many different ways.

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, station network solutions and EOPs. The processes will be streamlined and the GPS-TDAF will be improved for more efficient and independent operations.

In the area of ionosphere estimation the following major improvements are under preparation:

1) The time resolution of ESA TEC maps shall be enhanced from currently 24 hours to at least 2 hours. Also the RMS maps shall be included into the daily ESA IONEX files. The required mathematical algorithms were worked out and are currently (autumn 2002) in the process of implementation into the ESA IONMON software.
2) The mathematical representation of the ionosphere as one Chapman layer, of which the maximum electron density and the height of maximum electron density are estimated as surface functions, will be replaced by a multi-layer model: The ionosphere will be represented as a superimposition of several layers, e.g. E, F_1, F_2, each of which will be modelled as a Chapman profile or by an empirical profile function. Some of these layers will depend on the solar zenith angle, while others will not. Champ electron density profiles derived from GPS occultation data will be introduced as additional observables to the TEC observations derived from dual-frequency GPS data. The mathematical algorithms for this extended ionosphere modelling have been worked out and coded. At the time of submission (autumn 2002) the new subroutines are in the tests and validation phase.

For LEO processing:

From the lessons learned with CHAMP analysis, it has become clear that the normal GPS processing software at ESOC has notable shortcomings in the processing of LEO data. Particular problems are the computation of the LEO clocks and the handling of phase data. The precision levels of ESOC POD products for LEO will not drop below the ~20 cm level until the phase data is correctly included in the processing.

To meet these challenges, ESOC will start a project in 2002 to implement GPS data processing in the NAPEOS software, a package that by its internal structure solves many problems that are currently preventing more precise LEO results. In addition, preparation of other LEO missions will take place, in particular for JASON. With its higher orbit and similarity to the TOPEX/Poseidon mission, JASON is expected to offer less practical difficulties in the processing of its GPS data than CHAMP and GRACE, so that its data must be regarded as an important basis for assessing the contributions that LEO data could bring to IGS processing.

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GFZ Analysis Center of IGS - Annual Report for 2001

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Summary

During 2001 only small changes, which are summarized in Table 1, were introduced into the analysis. The Ultra Rapid analysis was implemented on a Linux-PC. The performance was very promising, so the complete analysis of a 30-station network takes about half an hour only. By this transition the analysis got independent from the load of the mainframe central computer, which is important to meet the deadlines for the submissions.

Table 1. Changes in the analysis strategy

Week	Date	Description
1105	2001-03-11	Switch to LINUX computer for Ultra-Rapid Products
1105	2001-03-11	Ultra-Rapid product with repetition of 3 hours
1119	2001-06-20	Generation of tropospheric parameters for Ultra-Rapid products started
1143	2001-12-02	Switch from ITRF97 to IGS00 reference frame
1149	2002-01-13	Change of elevation cut-off angle from 15 to 7 degrees

Final and Rapid Products

During 2001 the quality of the orbit and clock products could be stabilized on a high level. The Final orbits have reached an accuracy of 2 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 (for orbit qualities see Fig. 1).

In the past we had several times postponed the use of low elevation data (<15 degrees), because we were afraid of any scale change in hour time series of SINEX solutions. This year we decided to do this step, because we expected more advantages than disadvantages. Beginning with 2002 (week 1149) the elevation cut-off angle was switch from 15 to 7 degrees. With this change an elevation depending weighting had to be introduced. A widely applied function is cos(z)**2 (where z is the zenith distance). This function starts to down-weight the data at medium elevation angle of 30 degrees already with a factor of 4, going down to 100 around 7 degrees. We reduced the down-weighting by choosing as weighting function:

4*cos(z)**2 if z>60 else 1.

This functions has shown during some tests a slightly better repetition in the station coordinates than cos(z)**2.
The quality of the station coordinates and Earth Rotation Parameters (ERP), which is provided with the weekly SINEX files, can be extracted from the corresponding IGS SINEX combination

reports. 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 (Fig. 2). Since spring 2000 a significant improvement in the weekly consistency can be seen. 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 exist which are similarly in all weekly analysis center submissions.

The scale has small jumps, which coincide with the transition from ITRF97 to IGS00 reference frame, and with the change of the used elevation cut-off angle from 15 to 7 degrees. The change of cut-off angle to 7 degrees gave only a small jump of 0.5 ppb. The scale change is also accompanied with a bias change of about -1 mm ZTD in the tropospheric estimates.

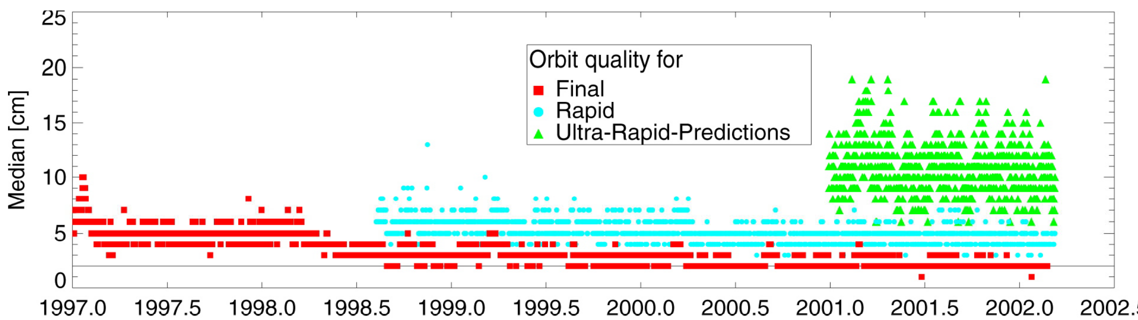

Fig. 1. Quality of the various GFZ satellite orbit products taken from the official combinations reports

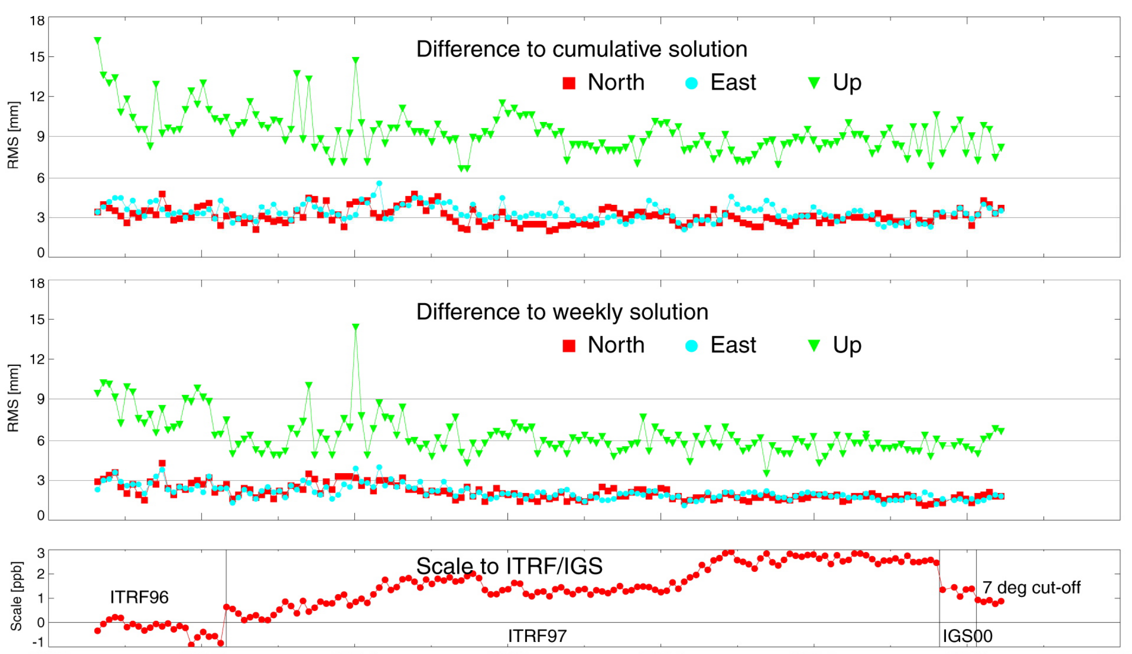

Fig. 2. Quality of GFZ station coordinate solutions extracted from the IGS SINEX combination reports

The ERP quality obtained during SINEX combination is consistent with the station coordinate quality (Fig. 3); also here an improvement in the consistency can be seen since spring 2000.

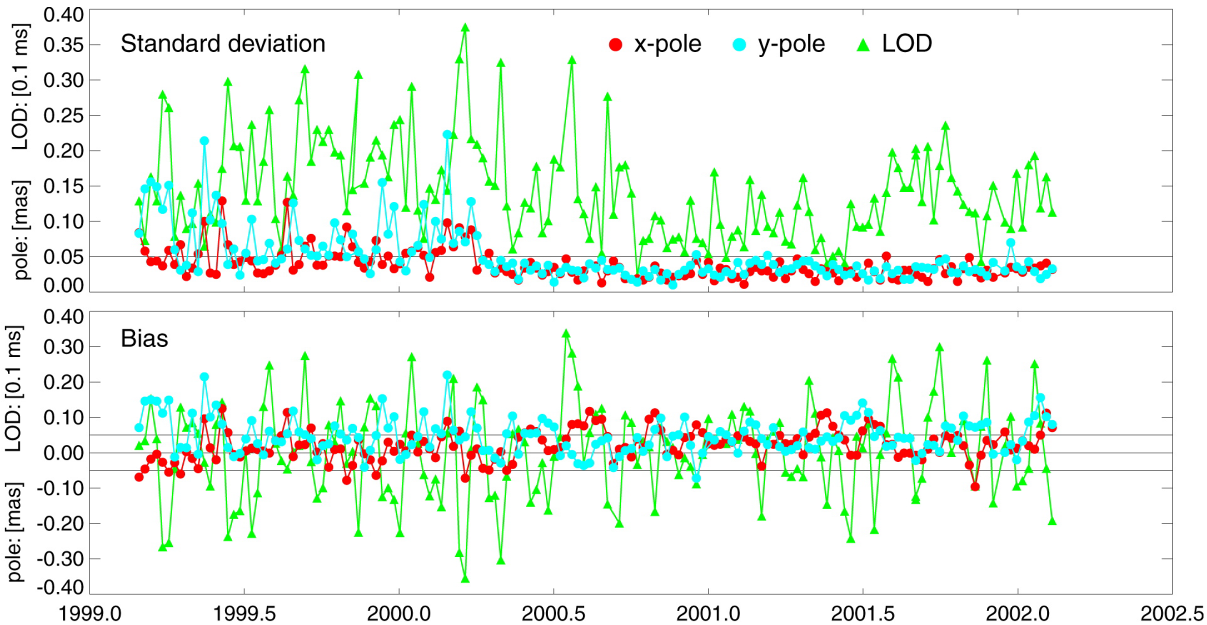

Fig. 3. Quality of ERP solution

Ultra-Rapid products

In October 1999 GFZ had started the generation of Ultra-Rapid products. The technique used was already described in Gendt et al. 2001. For the German "GPS Atmospheric Sounding Project" (GASP), which demonstrates a quasi-operational water vapor monitoring (Reigber et all. 2002), an improved quality in the predicted orbits was desirable. Therefore, the Ultra-Rapid products were started to be generated 8 times per day, instead of 2 times, continuing to use a sliding 24 h window. Having a 3-hourly repetition with a delay of about 1 hour the used predictions interval is finally shortened to 2 to 4 hours. A check of its quality yields a median of about 8 cm (rms 17 cm, cmp. Fig. 4). Presently only the products from 00 and 12 UTC are submitted for the IGS combination. The whole Ultra-Rapid analysis takes about 25 minutes on a LINUX-PC (10 minutes for preparation part and 15 minutes for the analysis).

For participation in the Pilot Experiment on generation of a global near real-time (NRT) tropospheric product (Gendt, 2002) the Ultra-Rapid analysis is used to extract the tropospheric product for ~30 stations which enter into the analysis. If further densification is necessary then a precise point positioning can easily be used for it. In GASP we have good experience with this strategy.

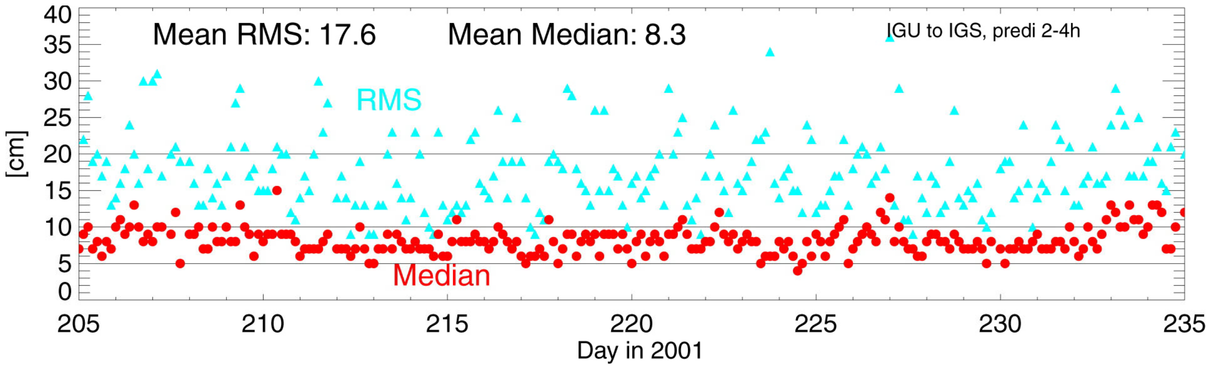

Fig. 4. Ultra Rapid prediction with 3-hour repetition interval. Prediction quality in August 2001 for intervals 2-4 hours

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Gendt, G, G Dick, W Söhne (2001): GFZ Analysis Center of IGS - Annual Report for 2000, in "IGS 2000 Technical Reports", in press

Reigber, Ch, G Gendt, G Dick, M Tomassini (2002): Near real-time water vapor monitoring for weather forecast. GPS-World, Vol. 13 No. 1,pp. 10-27,2002

Gendt, G (2002): Report of the Tropospheric Working Group for 2001. This volume.

NRCan IGS Analysis Center Report for 2001

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Summary

The year 2001 marked a period of many changes in the NRCan processing strategy used for IGS product generation. Implementing version 2.6 of the GIPSY-OASIS software to estimate our Final and Rapid products significantly reduced processing time and allowed for the estimation and submission of Rapid station and satellite clocks at 5-minute interval. Improvement in the Ultra-Rapid pole estimates reduced the noise of the EMU ERP series. Since May 2001, resolving the ambiguities in the Regional solutions improved station coordinate estimates by 1mm. Regional solutions are being submitted to NAREF (North American Reference Frame) on a regular basis since January 2001. More details on these changes and other improvements can be found in the following report.

NRCan Final and Rapid Products

During 2001, NRCan continued to estimate Rapid and Final products as described in ftp://igscb.jpl.nasa.gov/igscb/center/analysis/emr.acn. Several changes, shown in Table 1, were made to the NRCan strategy based on IGS recommendations. Efforts were devoted to upgrading computer hardware and implementing version 2.6 of JPL's GIPSY-OASIS software. These changes have significantly decreased the processing time required for both Rapid and Final product generation and have allowed us to begin using 5 minute sampling to produce Rapid satellite and station clocks at 5 minute intervals.

IGS 2000 Reference Frame

Beginning with GPS week 1143 (December 2, 2001), a-priori station coordinates and velocities were changed from IGS97 (IGS realization of ITRF 97) to IGS00 (IGS realization of ITRF 2000). IGS00, determined by the IGS Reference Frame Coordinator, is derived from a subset of 54 stations extracted from the IGS cumulative combined solution IGS01P37.snx stored in IGS01P37_RS54.SNX. In our Final solution, the coordinates of a subset of these 54 reference stations are loosely constrained (10m) while in our Rapid solution tightly constrains the coordinates to their IGS01P37_RS54.SNX sigmas. Table 2 shows the effects of the reference frame change on various NRCan Rapid products for GPS week 1157.

GIPSY-OASIS Version 2.6

Version 2.6 of JPL's GIPSY-OASIS software was in place for the estimation of NRCan Final products starting with GPS week 1139, and for the Rapid products starting with GPS week 1142. Improvements made by JPL to the GIPSY-OASIS filtering algorithm has decreased the processing time for NRCan Rapid product estimation by 2-3 hours. The reduction in processing time was largely responsible for the marked increase in the number of days that the NRCan Rapid solution was ready on time to contribute to the IGR combination. The new version of GIPSY-OASIS has also improved the consistency of the Rapid and Final solutions with respect to IGS. Figure 1 shows the NRCan Rapid orbit daily RMS with respect to the IGR combination. Figure 2 shows the NRCan Final orbit RMS with respect to the IGS combination. Currently developments are underway to further increase the consistency of NRCan Rapid and Final products in 2002.

NRCan Regional Solution

During 2001, NRCan continued to process all stations of the Canadian Active Control System (CACS) in support of the Canadian Spatial Reference System (CSRS) realization and as part of the densification of the ITRF reference frame in North America. Version 2.5 of JPL's GIPSY-OASIS is used along with other software developed in-house to produce weekly combined SINEX station coordinates files which are submitted to NAREF for combination.

Processing Strategy

In 2001, three new stations were added to the processing, namely Baker Lake (BAKE, Northwest Territories), Holman (HOLM, Northwest Territories) and Val D'Or (VALD, Quebec). Station THU1, which was one of the 6 anchor stations, was removed due to poor data quality. This brought the total to 31 stations with 5 anchor stations (ALGO, DRAO, NLIB, WES2, YELL). Our processing strategy is still based on using fixed IGS weekly combined SP3 and ERP files and one station clock, usually ALGO, as a reference.

One major change to our processing strategy was made on June 17, 2001 (GPS week 1119), when we began applying loose constraints (10m apriori) to the 5 anchor stations while continuing to apply 100m apriori sigmas to the remaining stations. This change facilitated the integration and removal of constraints in the NAREF combination. Since GPS week 1113, we have been solving, whenever possible, phase integer ambiguities. This has resulted in an improvement of about 1mm in the east and height components of the station's coordinates when compared to the IGS cumulative SINEX solution. IGS recommended P1-C1 bias values v2.0 and v2.1 were implemented in January and May 2001 respectively and the IGS reference frame was changed to IGS00 on week GPS1143. Table 3 below summarizes some of the processing options. In addition to specifics presented in Table 3, a pre-processing strategy using precise point positioning is performed on all stations forming the regional network in order to remove station-satellite pairs showing poor data quality.

NRCan Ultra Rapid Processing Strategy and Changes

During 2001, NRCan continued the development and delivery of its Ultra Rapid Products (orbits and ERP) to the IGS Analysis Coordinator. About 80 IGS stations were routinely being downloaded on an hourly basis by the end of 2001 via ftp from CDDIS (Crustal Dynamics Data Information System), SOPAC (Scripps Orbit and Permanent Array Center), BKG (Federal Agency for Cartography and Geodesy, Germany) and the National Mapping Division of Geoscience Australia (formerly AUSLIG). Although only 35-40 stations were processed in each of our 3-hour sessions, a total of 45 to 55 different stations were usually combined into 48-hour arcs (using Normal Equations) since some core stations were not always available at the time of processing. The most significant changes to our Ultra Rapid processing strategy in 2001 are listed in Table 4. The reader is referred to the IGS 2000 Technical Report [1] for more details on the processing strategy used.

Results

This section shows the comparison of NRCan Ultra Rapid orbits and ERP products (EMU) with respect to the IGS Ultra Rapid (IGU) combination. Five graphics are presented for the year 2001. Figure 3 shows the orbit RMS, Median RMS and Weighted RMS (WRMS). The biggest spike in the WRMS graphic occured in mid-November 2001 and was present for all Centers. This problem, yet unexplained, happens from time to time and to date, no means of detection have been developed. We can also observe a small but constant decrease in magnitude of all 3 RMS time series from the beginning to the end of 2001. Figures 4 and 5 show the EMU Translations, the Rotations and Scale with respect to IGU. All series, especially the Rotations, show a reduction in the noise level starting in mid-September corresponding to the time the pole estimates were improved. Finally, Figures 6 and 7 show the pole (Xp, Yp, Xp_{rate}, Yp_{rate} and LOD) comparison with respect to IGU for both the estimated and predicted portions of EMU respectively. As expected, the noise level was considerably reduced in all series after the improvement of the pole estimates.

Future Work

In the near future, we will investigate the possibility of estimating satellite clock corrections. Because of the current CPU limitations, hardware upgrades may be required to facilitate the implementation and speed up the production.

NRCan Ionospheric Product

During 2001, NRCan has continued to support the Ionosphere Pilot project as an Ionosphere Associate Analysis Centre (IAAC) and contributed daily global ionospheric maps to IGS. A new strategy for single-station estimation of station and satellite inter-frequency differential code biases (DCB) was implemented. This new approach combined with multi-day averaging has resulted in NRCan production of more stable DCB time series. This change also allowed for an increase in the number of IGS tracking stations included in our daily ionospheric grid map computation, raising the total from around 50 to 90-100. During ionospheric grid map computation, the introduction of a time dependent stochastic process for the combination of observed delays at ionospheric grid points has provided flexibility to adjust the grid point averaging period and update the ionospheric maps at variable time intervals, making the processing approach more suitable for near real-time operations. Nevertheless, the stochastic model used for spatial averaging still requires improvement for NRCan to offer ionospheric grid maps that contribute more significantly to the IGS combination. Finally, to assist in assigning proper weights to the various IAAC's contributing to the combination, NRCan continues to daily evaluate the relative precision of the IAAC grid maps and submits validation files for use in the combination process.

Table 1: Final/Rapid Processing Strategies Modifications

GPS Week	Modification
1097	Adoption of new set of <P1-C1> bias values (v2.0) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1100	Implementation of precise point positioning (fixing IGU orbits and clocks) to validate stations carrier phase and pseudorange observations for Rapid solution. This procedure was discontinued after week 1110 due to problems arising from limitations in the accuracy of ultra-rapid clock estimations.
1106	Adoption of new set of <P1-C1> bias values (v2.1) to transform cross-correlated pseudorange observations into synthesized non cross-correlated.
1121	Began applying sub-daily (12h/24h) ocean tides in the transformation from inertial to Earth-fixed coordinates (sp3) as recommended by IGS/IERS.
1139	Implementation of JPL's GIPSY-OASIS Version 2.6 software for Final solution.
1142	Estimation of Rapid clock corrections at 5 minute intervals (RINEX clock format).
1142	Implementation of JPL's GIPSY-OASIS Version 2.6 software for Rapid solution.
1143	Adoption of IGS00 (IGS realization of ITRF 2000) station coordinates and velocities.
1145	Re-aligned NRCan UT1-UTC value to VLBI derived value (Bulletin A) on day 0 and then resumed normal daily estimation procedure for UT1-UTC.

Table 2: IGS97 to IGS00 discontinuities in NRCan Rapid products forGPS week 1157

Solutions	RX (mas)	RY (mas)	RZ (mas)	Sc (ppb)	TX (cm)	TY (cm)	TZ (cm)
	-Pmy	-PMx	DUT1				
NRCan Orbits	0.020	0.034	-0.0141		-0.059	-0.003	0.848
Sigma	0.021	0.029	0.027		0.045	0.098	0.165
NRCan EOP	0.010	0.022	-0.202				
Sigma	0.021	0.028	0.054				
NRCan Stations	-0.023	-0.037	-0.173	-0.957	-0.286	-0.276	2.648
Sigma	0.019	0.019	0.039	0.113	0.050	0.065	0.101
IGS Realization	-0.024	-0.004	-0.159	-1.451	-0.450	-0.240	2.600
Sigma	0.092	0.099	0.076	0.270	0.410	0.500	0.750

Note: NRCan results were estimated processing GPS week 1157 (March 10-16, 2002) using both IGS97 and IGS00 coordinates and velocities along with their associated sigmas.
IGS results refer to epoch 02-Dec-2001 (GPS week 1143-0)

Table 3: GIPSY Regional processing strategy summary

Software used :	JPL GIPSY-OASIS v2.5
Reference frame :	ITRF as defined in the IGS orbit SP3
Orbital parameter :	IGS combined orbits held fixed
Earth rotation parameters :	X and Y pole as well as UT1-UTC from IGS combined weekly solution fixed.
Modeled observable :	Undifferenced phase and code observable at 30 seconds and 15 degree cut-off angle.
Date sampling interval :	7.5 minutes
Troposphere :	Total zenith delay and gradient modeled as random walk (~0.3cm/sqrt (h)). Niell mapping function.
Ocean loading :	Scherneck model
Station coordinates :	Network free solution carried out using 5 anchor stations with 10m sigma and 100m sigma for other stations.
Ambiguities :	Partly resolved, remaining are estimated as real values
Satellite and Station clocks :	Modeled as white noise process. One H-Maser clock fixed and used as time reference, usually ALGO.

Table 4: Modifications to NRCan Ultra Rapid processing strategy in 2001.

Date	DOY	Description of Changes
Jan. 15, 2001	015	Automated satellite de-weighting implemented using current and past processing results such as ambiguity and orbital parameters standard deviations
Jun. 19, 2001	170	First 1-hr Troposphere Zenith Delays submitted to the IGS Tropospheric Working Group Coordinator
Jul. 12, 2001	193	Station selection improved (now uses a core list and a set of replacement stations)
Sep. 15, 2001	258	Pole estimates improved (now uses one offset and 1 drift for every 48-hr arc)
Oct. 18, 2001	291	ADDNEQ2 (Bernese 4.2) used for orbit and ERP improvement/determination
Dec. 02, 2001	336	Adoption of IGS00

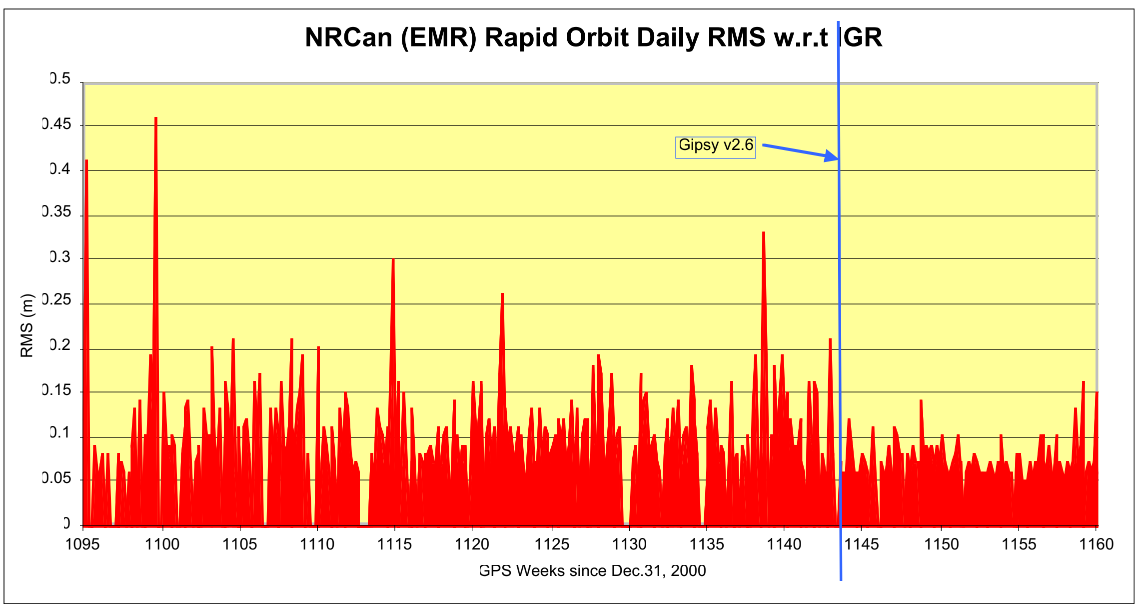

Figure 1: NRCan (EMR) Rapid orbit daily RMS w.r.t. IGR since Dec. 31, 2000

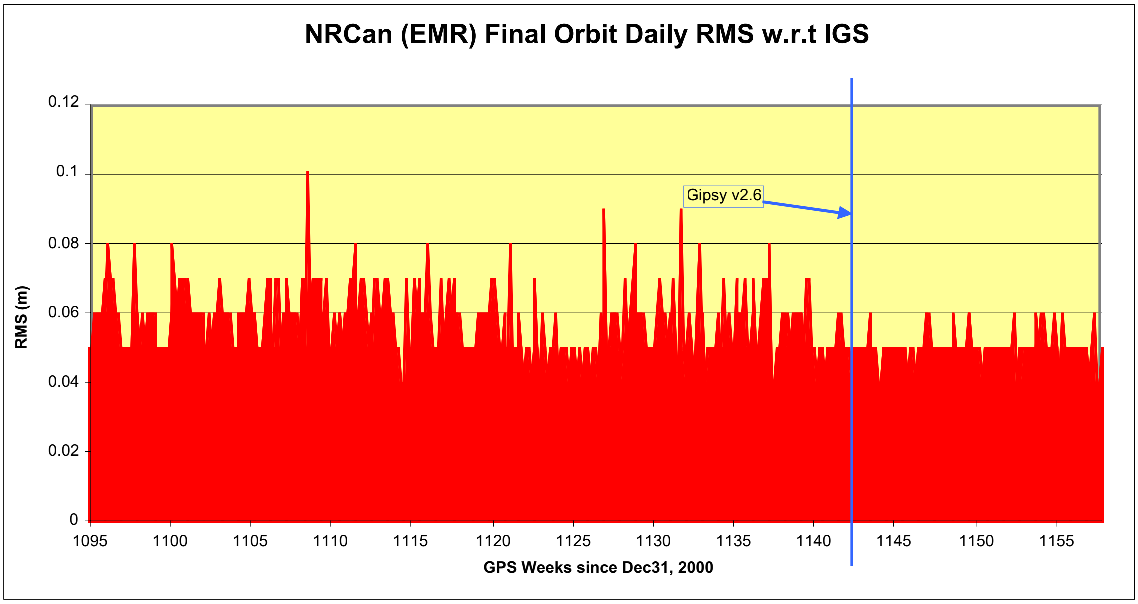

Figure 2: NRCan (EMR) Final orbit daily RMS w.r.t. IGS since Dec. 31, 2000

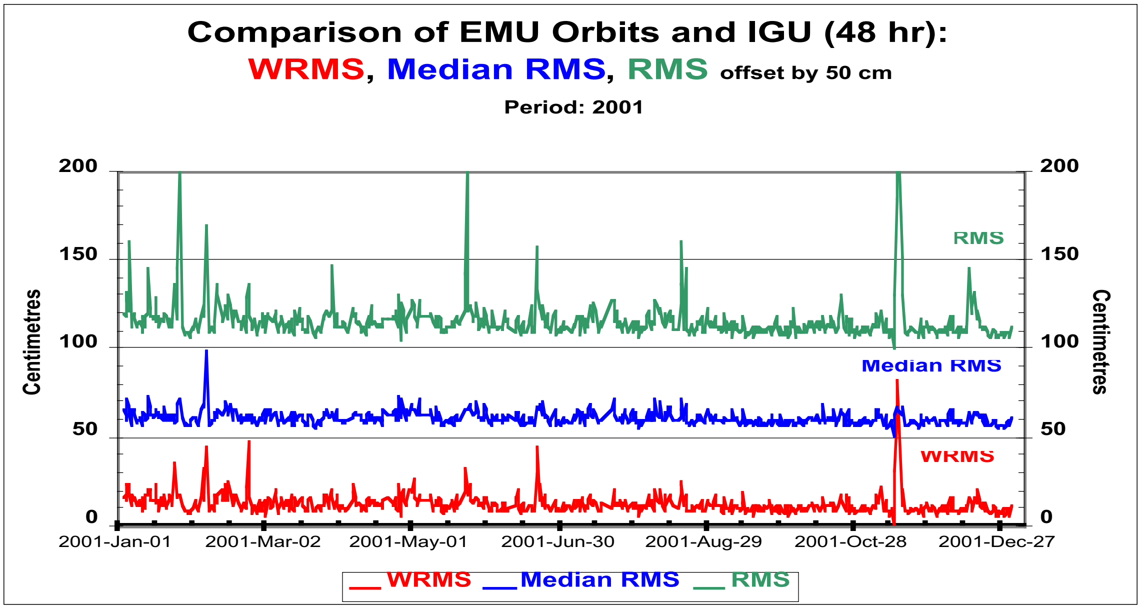

Figure 3: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): WRMS, Median RMS and RMS, each offset by 50 cm.

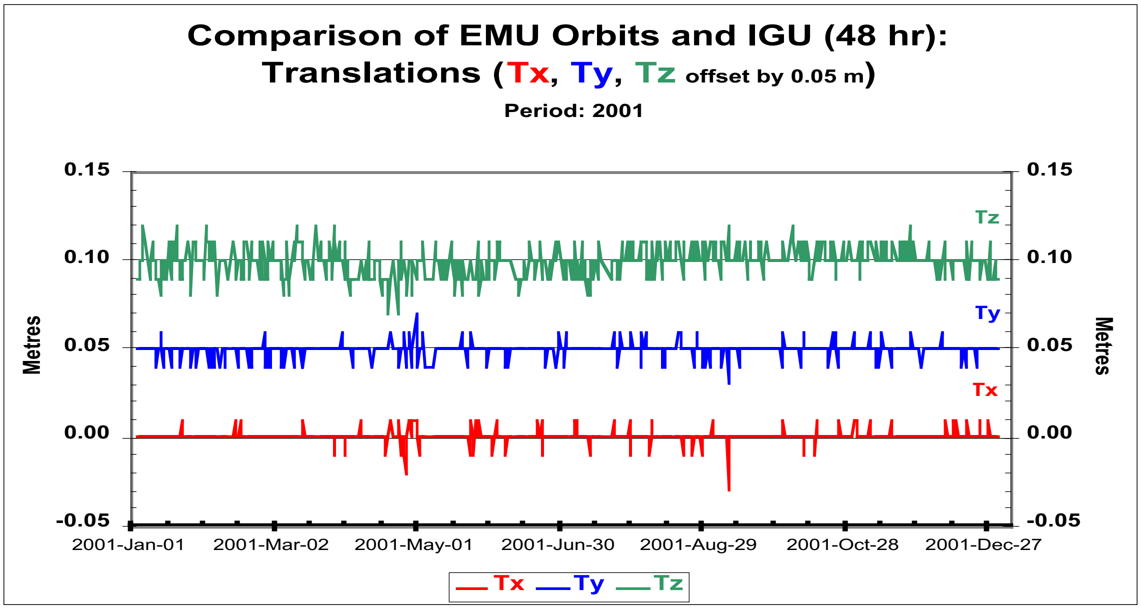

Figure 4: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): Translations Tx, Ty and Tz, each offset by 0.05 m.

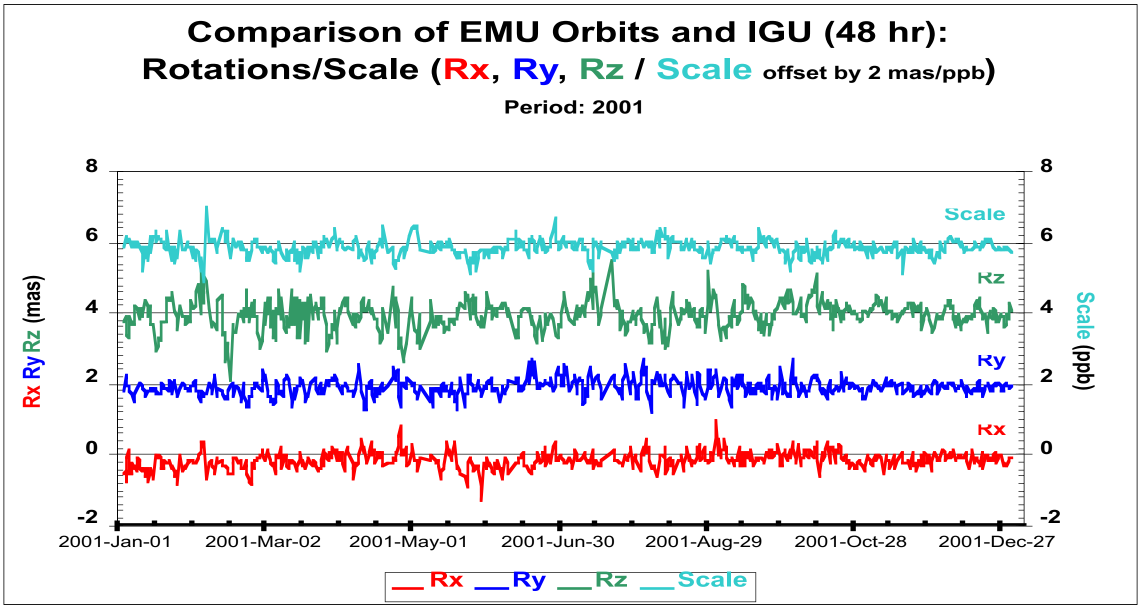

Figure 5: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): Rotations Rx, Ry, Rz and Scale each offset by 2 mas, 2 mas, 2 mas and 2 ppb respectively.

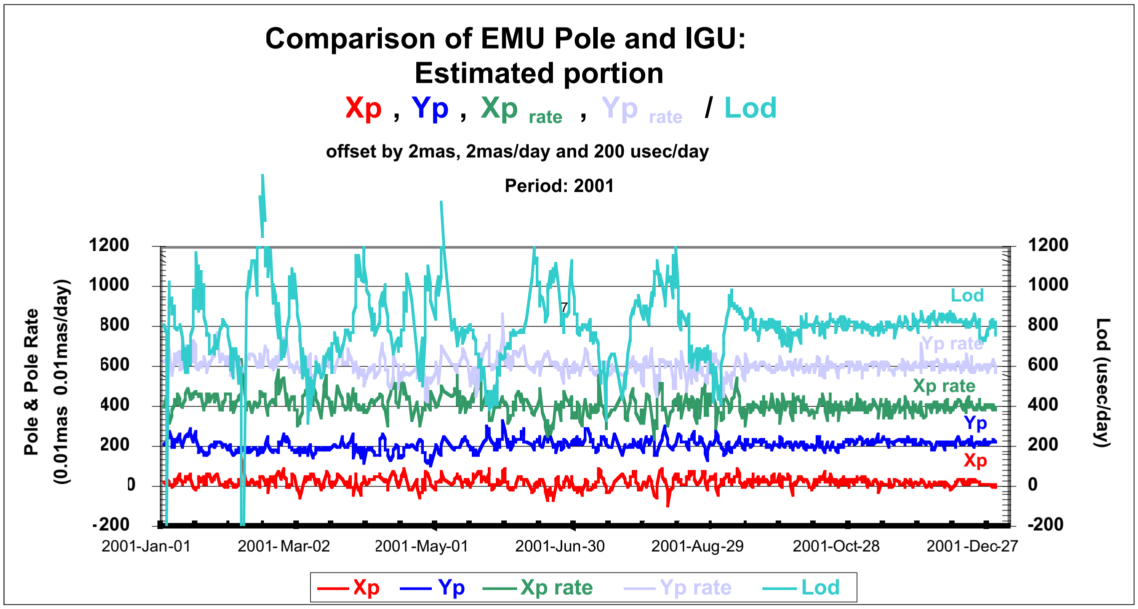

Figure 6: Comparison of EMU Estimated Pole and IGU for 2001:
Xp, Yp, Xp_{rate} , Yp_{rate} and Lod, each offset by 2 mas, 2 mas, 2 mas/day, 2 mas/day and 200 usec/day respectively.

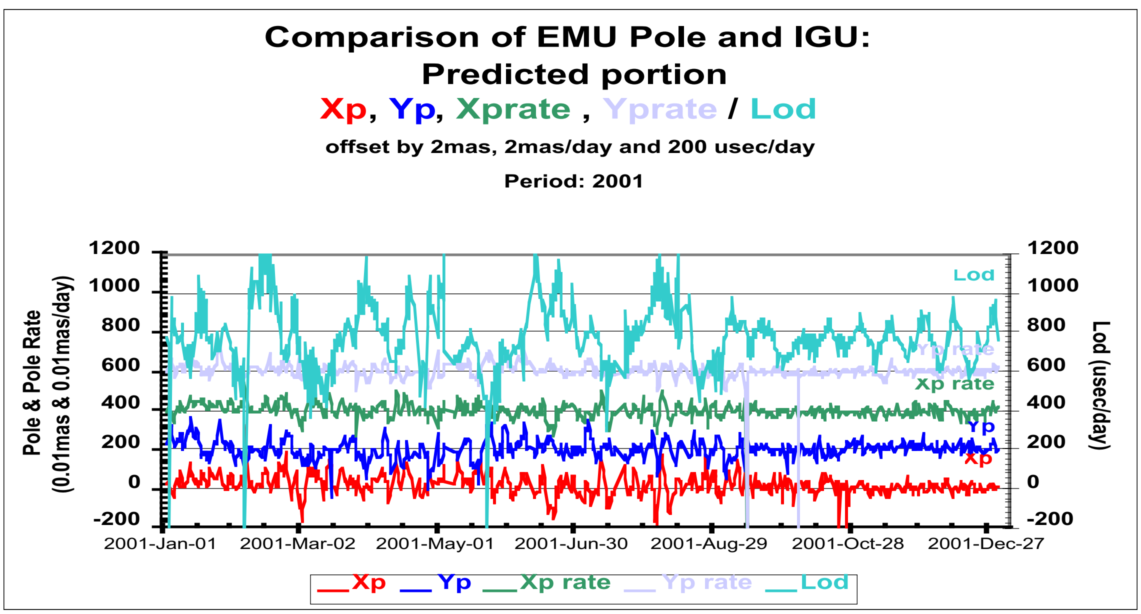

Figure 7: Comparison of EMU Predicted Pole and IGU for 2001:
Xp, Yp, Xp_{rate} , Yp_{rate} and Lod, each offset by 2 mas, 2 mas, 2 mas/day, 2 mas/day and 200 usec/day respectively.

Acknowledgement

NRCan IGS activities are carried out by the Geodetic Survey Division in support of the Canadian Spatial Reference System (CSRS). We a grateful to our GSD colleagues for their ongoing contributions to this effort and are thankful that Dr. Jan Kouba continues to be actively involved with our team by sharing his valuable expertise.

References

[1] P. Tétreault, Y. Mireault, B. Donahue , P. Héroux and C. Huot, NRCan IGS Analysis Report for 2000, in IGS 2000 Technical Report, edited by K. Gowey, R. Neilan and A. Moore, JPL/IGS Central Bureau, 11/2001, pp.111-116.

[2] B. Donahue, P. Héroux, C. Huot, D. Hutchison, J. Kouba, Y. Mireault and P. Tétreault, NRCan Analysis Center Contributions to the IGS, in IGS Network, Data and Analysis Center Workshop 2002, in print.

IGS

ASSOCIATE ANALYSIS CENTERS

REGIONAL NETWORK ASSOCIATE ANALYSIS CENTERS

Network Operations and Data Flow within the EPN

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Introduction

The EUREF Permanent Network (EPN) was initiated in 1995 by the IAG sub-commission 'EUREF', responsible for the European Reference Frame. It consists of GPS tracking stations, data centers and analysis centers organized following a similar hierarchy as the IGS and based on voluntary contributions.

The EPN has been submitting weekly network solutions to the IGS since May 1996. What makes the EPN Regional Network different from most of the other Regional Networks contributing to the IGS is that the EPN involves a larger number of different agencies (51!). The mutual friendly competition between the different agencies involved, drives the EPN to meet new challenges, e.g. the EUREF-IP activities. In addition, thanks to its close link with the IGS, the EPN grows hand in hand with the IGS; promoting the IGS standards in Europe and stimulating the European GPS community to evolve together with the IGS.

Growth of the Tracking Network

The EPN tracking network has continued to operate successfully during the year 2001, integrating 21 new stations in its network (see Figure 1):

ALME	Almeria, Spain	H	TG	
AQUI	L'Aquila, Italy	H		
CACE	Caceres, Spain	H		
CANT	Santander, Spain	H	TG	
ELBA	San Piero Campo Nell'Elba, Italy	H		
GAIA	Gaia, Portugal			
GSR1	Ljubljana, Slovenija			
LAGO	Lagos, Portugal			
LINZ	Linz, Austria	H		
MALL	Palma de Mallorca, Spain	H	TG	
NPLD	Teddington, UK			IGS
OBE2	Oberpfaffenhofen, Germany (replaces OBER)	H		
OROS	Oroshaza, Hungary	H		
PADO	Padova, Italy (replaces UPAD)	H		
PDEL	Ponta Delgada, Portugal		TG	IGS
POLV	Poltava, Ukraine			IGS
RABT	Rabat, Marocco			IGS

SULP	Lviv, Ukraine	H		IGS
TLSE	Toulouse, France (replaces TOUL)	H		IGS
TUBO	Brno, Czech Republic	H		
VALE	Valencia, Spain		TG	

With:

- H = Hourly data submission
- TG = Collocated with Tide gauge
- IGS = Included in the IGS network

Site logs are available at the EPN Central Bureau and station managers are notified promptly when inconsistencies between the RINEX headers and the site logs are detected. All EPN stations have their data available at least at one of the EPN data centers (check http://www.epncb.oma.be/datacent.html for access info) and are processed by at least three different EPN Analysis Centers. Similar to the IGS mail, changes within the EPN are notified through a mail exploder to which users can subscribe. An archive of these e-mails is available from (http://www.epncb.oma.be/eur_mail.html)

The total number of EPN stations reached 126 at the end of 2001; about 50% of them deliver hourly data.

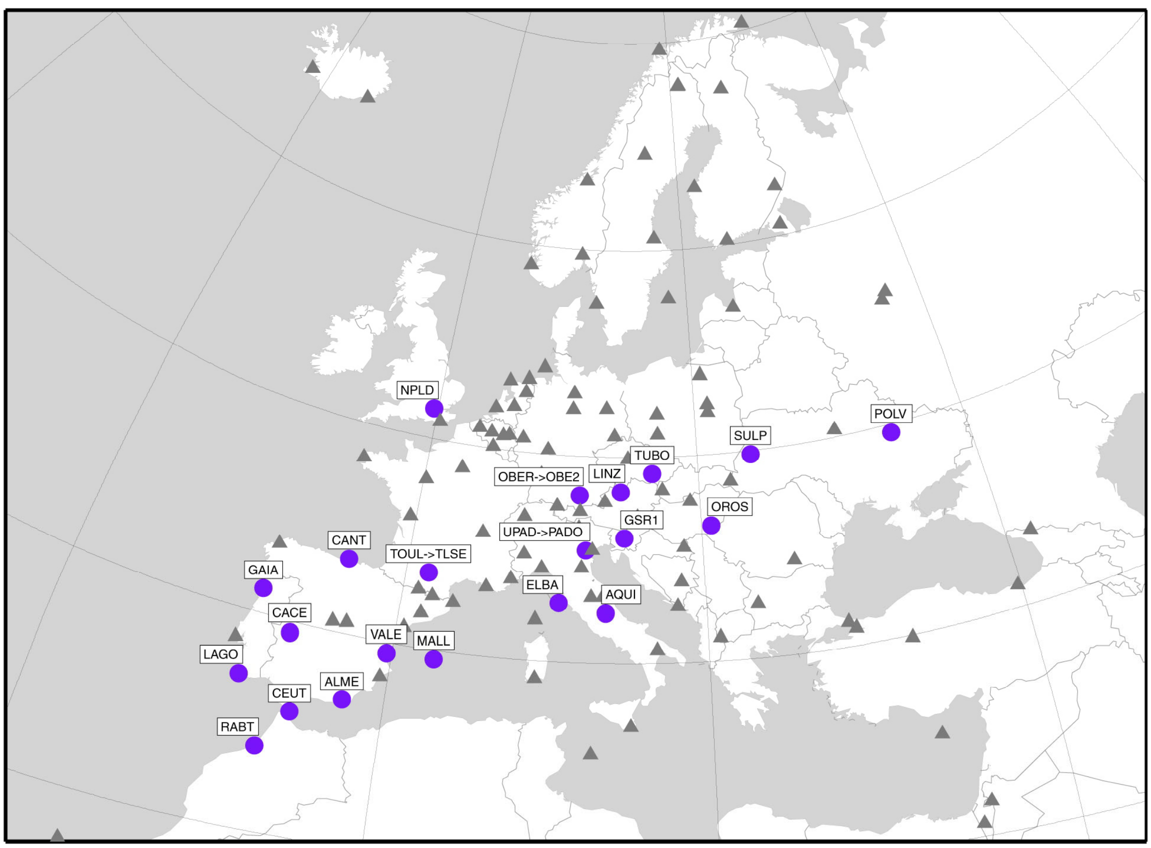

Figure 1: EPN tracking network (status Dec. 2001), stations denoted with circles joined the EPN in 2001.

Site Upgrades

Due to the size of the EPN, it is not possible to list all site configuration changes in this report. In general, we can say that the EPN has continued to modernize it GPS equipment. Information about receiver/antenna/firmware upgrades is available from the site logs and station discontinuities can be visualized from the coordinates time series available at the EPN CB web site (more in next section).

User Interface

The Central Bureau of the EPN maintains a website (http://www.epncb.oma.be/) providing relevant information about the EPN. For each of the EPN stations, this comprises:

- The site log file + station pictures
- Monthly updated tracking status using azimuth/elevation graphs
- Different types of coordinate time series
- List of the Data Centers making available its daily and hourly data + data holding files
- List of the Analysis Centers processing its data
- Link to all relevant EUREF and IGS mails.

In addition,

- Lists of the inactive stations, planned stations and temporarily excluded stations
- Downloadable tracking network maps in different formats
- Guidelines for stations and data centers
- Standard receiver and antenna names (from IGS)
- Antenna calibration values (from IGS)
- Metadata information, such as the SINEX template, extlog.sum, extlog.txt (similar to the IGS logsum.txt and loghst.txt), and updated whenever a new site log is submitted,
- All weekly EPN solutions in SINEX format are also available.

Data Flow

In general, the EPN daily data flow has improved within the last year: at the EPN Regional Data Centre (RDC) at BKG (Bundesamt für Kartographie und Geodaesie) the number of broken files is now negligible. In addition, the EPN CB checks daily the RINEX headers using the station log sheets, so that metadata inconsistencies are quickly detected and corrected.

Within the EPN, a fall-back Data Center (DC) was set up at the OLG (Observatory Lustbuehel Graz, including the Austrian Academy of Sciences and the Federal Office of Metrology and Surveying). OLG consists of two public ftp servers (olggps.oeaw.ac.at and geols01.iwf.oeaw.ac.at), both accessible by anonymous ftp, and a data centre shielded by a firewall, including storing devices.

This DC is ready to take over the activities of the BKG RDC in case of a major outage (days). Fortunately, there was no such event in 2001. In the meantime, OLG acts as a Local Data Center and in addition, mirrors the daily files of the BKG RDC. Presently, the activation of the fall-back procedure from BKG to OLG will be done manually within 15 minutes after the decision to switch from BKG to OLG, but the procedure can also run automatically.

Thanks to the increasing reliability of the hourly data transfer, a growing number of stations delivers hourly RINEX files without a daily one. The concatenation of the hourly data files is then done at the DC. The EPN stimulates this procedure for all stations with reliable hourly transfers.

If there is a need for quickening the deliverance of hourly files, the synchronization of the computer clocks should be improved; deviations of up to ten minutes can be found. The synchronization can take advantage of the fact that most station software are able to use GPS time for correcting the computer clock and consequently setting in this way very sharp the time of data submission. For the rest, a clock correction using the NTP-daemon (available for UNIX and Windows) should be used.

EUREF-IP

EUREF has decided to set up and maintain a differential GNSS infrastructure (DGNSS) on the Internet using stations of its network (EUREF Resolution #3, 2002). The objective is to disseminate RTCM corrections over the Internet in real-time for precise differential positioning and navigation purposes. The acronym for these activities is EUREF-IP (IP for Internet Protocol). EUREF-IP aims to meet the growing need for Europe-wide improved real-time determination of coordinates.

EUREF makes available server and client software (Euref-ip-rtcm, V. 1.0) to access the appropriate data stream for positioning or navigation application (see http://igs.ifag.de/euref_realtime.htm for details).

A first DGPS trial server providing RTCM corrections over the Internet has been set up at BKG, Germany. Additional stations from the EPN are expected to become involved soon. Receiving RTCM corrections from this real-time network enables the determination of coordinates referred to the European Terrestrial Reference System ETRS89. The minimum requirements for participation in today's EUREF-IP test phase are:

- Operation of a GPS/GLONASS receiver with well-known antenna position, capable of generating RTCM corrections,
- Operation of an Internet-connected PC next to the receiver, running a server program.

Today's trial software is based on a plain Serial-to-TCP conversion of streaming data on the reference-side (server) and TCP-to-Serial re-conversion on the rover-side (client). Conventions on formats for a more sophisticated dissemination of RTCM corrections over the Internet do not exist. EUREF-IP intends to make new software available under the terms of the GNU General Public License. This software will include protocol definitions to transport RTCM corrections from servers via casters to clients. It will consider specifics of reference station networks, security and firewall issues, and massive simultaneous access in support of location-based services. The software will be available free of charge by the end of 2002. Because its functionality does not interfere with RTCM standards, it will simply replace today's trial software.

Analysis and Special Projects within the EPN

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Introduction

In 2001 the 3rd Local Analysis Center (LAC) Workshop took place in Warsaw, Poland. It was settled at that workshop to change some processing options with the beginning of GPS week 1130 to improve the EPN products. The LAC's solutions are fixed to the current ITRF since the same week in order to support the EPN Troposphere Special Project, and a coordinate re-substitution is applied in the final estimation of the hourly troposphere parameters. The ITRF2000 reference frame is used in the EPN analysis since week 1143 according to the changes within the IGS.

Analysis and Combination Scheme

There are currently 15 LACs which each of them analyses a sub-network of the EPN. The LACs submit weekly SINEX files of station coordinate solutions and daily SINEX files of station troposphere parameter solutions to the EUREF Data Center at the Bundesamt fuer Kartographie und Geodaesie (BKG). There is an agreement to use common processing options by all LACs in the analysis of the EPN observations. These options will be changed to new selections or models if obviously the results will improve. Changes of the processing options have simultaneously to be introduced by all LACs to identify the corresponding changes in the results. Such changes took place in the year 2001 and are outlined in the next section.

EPN Processing Changes

All remarkable changes since the EUREF 2001 symposium concerning the analysis of the EPN observations are summarized in Table 1. A very fruitful LAC Workshop had been hold at the Warsaw University of Technology in May/June 2001. Representatives of the LACs reported about their activities and the status of the EPN Special Projects had been presented too. Details about that workshop may be found in the proceedings [Sledzinski, 2001]. It was agreed upon to commonly change some processing options in the EPN analysis with the beginning of GPS week 1130. These new options are given in the minutes of the LAC workshop which are available on the web-page of the EPN Central Bureau [Bruyninx, 2002] and summarized in Table 2. The observation elevation cut-off angle was lowered to 10° in order to better de-correlate the station height and troposphere parameters, and the elevation dependent weighting of observations was introduced to account for the increased noise of observations on low elevations. The LACs now use the Niell mapping function to more realistically map the tropospheric delay into zenith direction.

Table 1: EPN Processing History 2001/2002

16 – 19 May 2001	• EUREF 2001 Symposium, Dubrovnik, Croatia
31 May – 01 June 2001	• 3rd Local Analysis Center Workshop, Warsaw, Poland
2 Sep 2001 (week 1130)	• Introduction of new processing options, following the minutes of the 3rd LAC Workshop, Warsaw • SINEX files submitted by the LACs are fixed to the ITRFxx (contribution to Troposphere Special Project) • New analysis center IGE introduced into the combined solution
November 2001	• Proceedings of the 3rd Local Analysis Center Workshop published in the Reports on Geodesy No3 (58), 2001, Warsaw University of Technology
2 Dec 2001 (week 1143)	• Change from ITRF97 to ITRF2000 in reference frame realization • New analysis center SGO introduced into the combined solution
5 – 8 June 2002	• EUREF 2002 Symposium, Ponta Delgada, Portugal

Time Series Special Project

Within the EPN a dedicated Special Project (SP) has been established in 2000 with the specific task to monitor the EPN time series and site performance [Kenyeres et al., 2002]. In the frame of the SP, a retrospective analysis of the weekly combined EPN SINEX solutions, from 1996 to 2001, has been performed [Kenyeres, Bruyninx, Carpentier., 2002]. The analysis targeted the identification and elimination of the offsets and outliers present in the EPN coordinate time series. The general and strict rule was, that only offsets with clear indication of equipment change, according to the station log files, are treated. The analysis is continued in the future on a routine basis.

The final product of the computations is a file containing all offset and outlier information. The first version of this file is in the Bernese-specific ASCII "STACRUX" format. However, the collected information should also be stored and distributed in a more general format. For this reason, EUREF joined to the discussion started within the IGS community to select and offer a worldwide solution for the archiving of this type of station events. Based on the collected offset and outlier database, improved velocities have been estimated. The velocity improvement for the horizontal components is generally below 2 mm/year, however for the height component it may exceed the 10 mm/year.

Troposphere Special Project

The objective of the EPN Special Project "Generation of an EUREF troposphere product" is to compute a weekly combined troposphere solution for all sites included in the EUREF Permanent

Table 2: Summarized minutes of the 3rd LAC Workshop in Warsaw, May/June 2001

Guidelines	Recommendations
• Usage of IGS Orbits • Introduction of Ocean Loading Corrections • 10° elevation cut off angle and elevation dependent weighting of observations • Usage of Niell mapping function for troposphere parameters	• Estimation of hourly troposphere parameters • Save troposphere parameters in daily normal equation files, generate weekly SNX solution, re-generate TRP files with fixing on SNX coordinates • Ambiguity fixing • Include RMS of unit weight in SNX files (Bernese Software only)

Network which can be used for post-processing GPS analysis as well as for climate research [van der Marel, Weber, 2002].

The Special Project started in June 2001. While in GPS week 1110 four Local Analysis Centers had delivered daily troposphere solution files, it is since GPS week 1143 that all 15 Local Analysis Centers are participating to the Special Project. In GPS week 1130 the processing options were changed for the individual analysis at the Local Analysis Centers to improve results and to standardize the analyses. For the troposphere parameter estimation two additional changes have been introduced concerning the constraining of the weekly coordinate solution to ITRF and the fixing of the weekly coordinate solution during the final estimation of the daily troposphere parameters. These steps have yielded to a visible reduction of the weekly mean biases between the combined solution and the individual solutions which are now below 3-4 mm in Zenith Total Delay.

At present two institutions are performing the combination of the single solutions, the GeoForschungsZentrum, Potsdam (GFZ) and BKG. The differences between the two solutions are below 0.2 mm in Zenith Total Delay for the mean bias with a standard deviation of ± 0.5-0.6 mm. More about the combination procedure and detailed results are presented in [Soehne, Weber, 2002].

Outlook

As shown in this report the EPN has implemented state of the art processing options and will go on in the future to realize the highest level of accuracy. The close cooperation between IGS and EUREF provides benefit for IGS from EUREF and vice versa. The EPN products are the achievement of the continuous effort of the station operations, data centers and analysis centers among others.

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Geoscience Australia RNAAC – 2001 Annual Report

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Introduction

The RNAAC function of routinely processing all stations in the Australian Regional GPS Network (ARGN) continued during 2001. The weekly combined SINEX result files were submitted to the Crustal Dynamics Data Information System (CDDIS). The Australian Surveying and Land Information Group (AUSLIG) was merged with the Australian Geological Survey Organisation (AGSO) in September 2001 to form Geoscience Australia (GA).

Station Network

The station network processed by the Geoscience Australia RNAAC as at December 2001 is shown in Figure 1. Fourteen of the seventeen stations in this network are operated by GA. The stations AUST (formerly DST1), PERT and TIDB are owned and operated by other agencies.

Commencing GPS week 1113, data from the Tidbinbilla site was switched from TID2 to TIDB where both GPS receivers are connected to a single antenna. Commencing GPS week 1117, data from the Yaragadee site was switched from YAR1 to YAR2 where both GPS receivers are connected to a single antenna. Commencing week 1143 site DST1 was renamed AUST to conform with the name conventions in the Directory of IERS Stations.

Data Analysis and Results

The Bernese GPS Software version 4.0 was used for the GPS data processing up to and including GPS week 1142. Commencing GPS week 1143 the Bernese GPS Software version 4.2 (Hugentobler, Schaer and Fridez 2001) has been used. Daily solutions were computed using the following strategy:

- L3 double differenced phase observable.
- No resolution of integer ambiguities.
- Elevation cut-off angle of 10° (20° prior to GPS week 1143).
- Elevation dependent observation weighting (commencing GPS week 1143).
- 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 TIDB or YAR2).

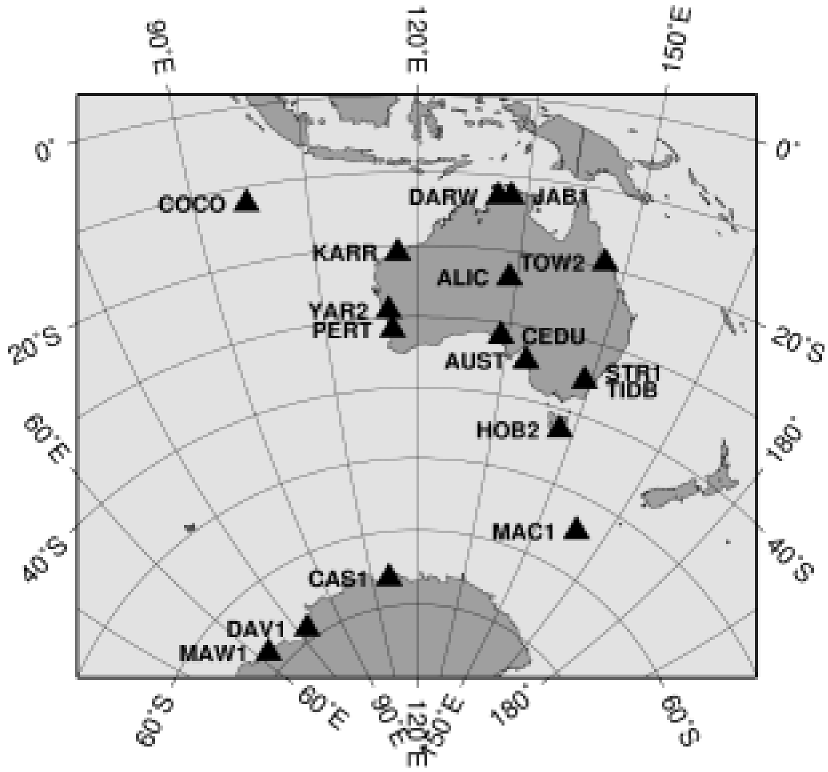

Figure 1. Geoscience Australia RNAAC station network as of 31 December 2001

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 1142 were tightly constrained to the station coordinates from the IGS97 realisation of ITRF97 at the following IGS reference stations; CAS1, DAV1, HOB2, MAC1, PERT, TID2 and YAR1. From GPS week 1143 onwards, the IGS00 realisation of ITRF2000 was used for station coordinate constraint at these seven stations, with TIDB and YAR2 substituted plus CEDU as an additional constraint station.

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

Other GPS data processing and analysis activity at GA include:

- IGS GPS Tide Gauge Benchmark Monitoring Project as a type A analysis centre.
- The South Pacific Sea Level & Climate Monitoring Project.
- Asia Pacific Regional Geodetic Project (annual observation campaigns).
- Australian South West Seismic Zone monitoring project.

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Annual Report 2001 of IGS RNAAC SIR

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Introduction

Since more than six years DGFI is acting as the IGS RNAAC SIR, and provides the weekly coordinate solutions in SINEX format of permanently observing GPS stations in South America and the surrounding area to the IGS global data centers (Seemüller and Drewes, 1997, 1998, 1999, 2000). By using the automated Bernese Processing Engine of the Bernese GPS Software (Rothacher et al., 1996, Hugentobler et al., 2001) all available data in this region are routinely processed on a weekly basis.

Station Network

Figure 1: IGS RNAAC SIR network and horizontal velocities of solution DGFI01P02 compared with ITRF2000 and NNR NUVEL-1A

The RNAAC SIR network is continously densified by new stations. In 2001, stations were installed in Caucete (CFAG) in Argentina, Manzanillo (MANZ) in Mexico, Cachoeira (CHPI) in Brazil, Punta Arenas (PARC), Coyhaique (COYQ) and Valparaiso (VALP) in Chile, and Cape Verde (TGCV). The stations CHPI, TGCV, COYQ and VALP haven't delivered data until end of 2001. A new regional GPS station Rio de Janeiro (RIOD) in Brazil was added to the net. End of 2001 the RNAAC SIR network consists of 55 stations, 38 are global and 17 are regional stations (Figure 1).

Solutions

The processing strategy was slightly modified in 2001. The elevation cutoff angle was set to 10 degrees, and since December 2001 (GPS week 1144) the version 4.2 of the Bernese GPS software is used.

In 2001 two new solutions for coordinates and velocities were generated. The second solution (Figure 1) was presented at the IAG General Meeting, August 2001, in Budapest. The contribution of the RNAAC SIR stations to this solution is given in Figure 2.

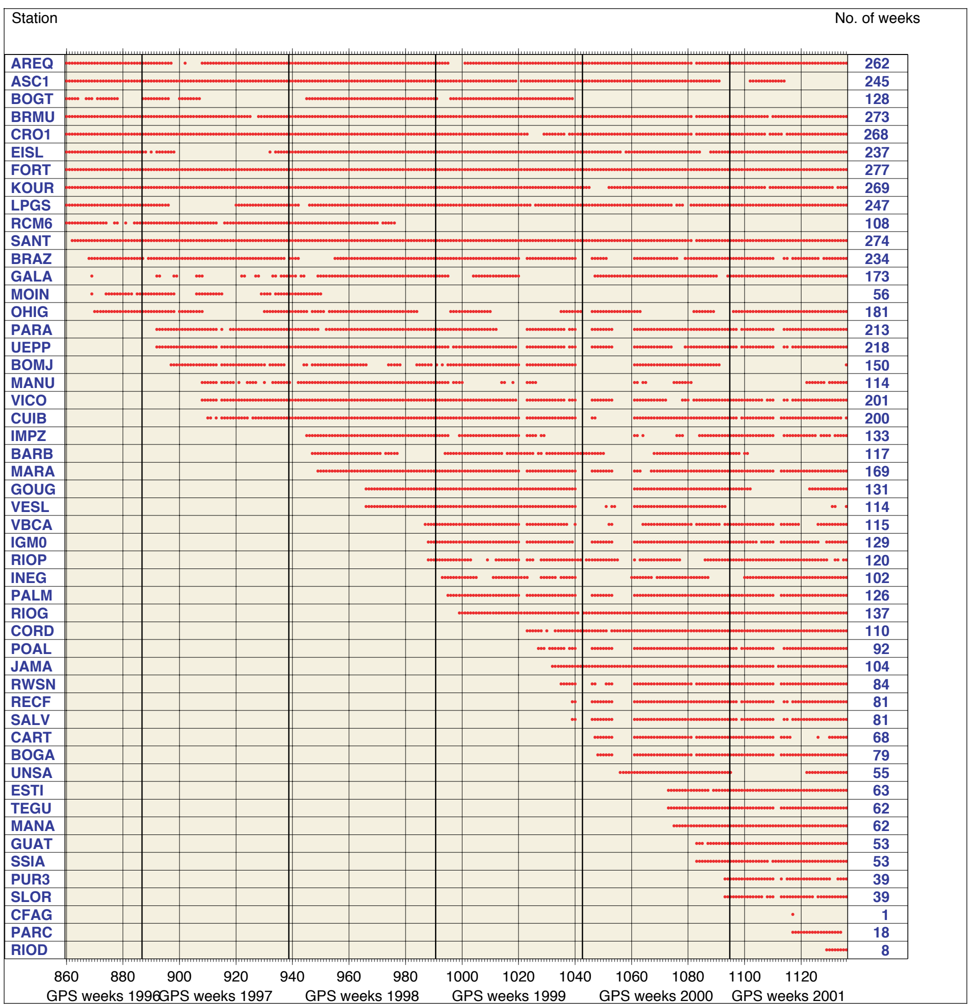

Figure 2: Weekly contribution of RNAAC SIR stations to solution DGFI01P02

DGFI01P02 is a regional solution, it covers the time period from June 30, 1996 to October 20, 2001, and provides positions and linear velocity estimates of 49 sites being in operation since at least one year. The solution is based on weekly SINEX files generated by the IGS RNAAC SIR. IGS combined orbits and earth orientation parameters were held fixed. The solution is referred to ITRF2000 by introducing positions at the reference epoch (1998, day 119) and velocities of AREQ, CRO1, FORT and SANT as fictitious observations. The weight applied to these "observations" is set such as to still allow the positions and velocities of these fiducial stations to deviate from their ITRF2000 values by some mm and 0.1 mm/year per year, respectively.

In the region of the South American reference system 1481 earthquakes occurred with a magnitude > 5, including 20 with a magnitude > 7, in the period from June 30, 1996 to end of 2001 (Figure 3). All the coordinate time series of stations close to these earthquakes were checked for eventual effects.

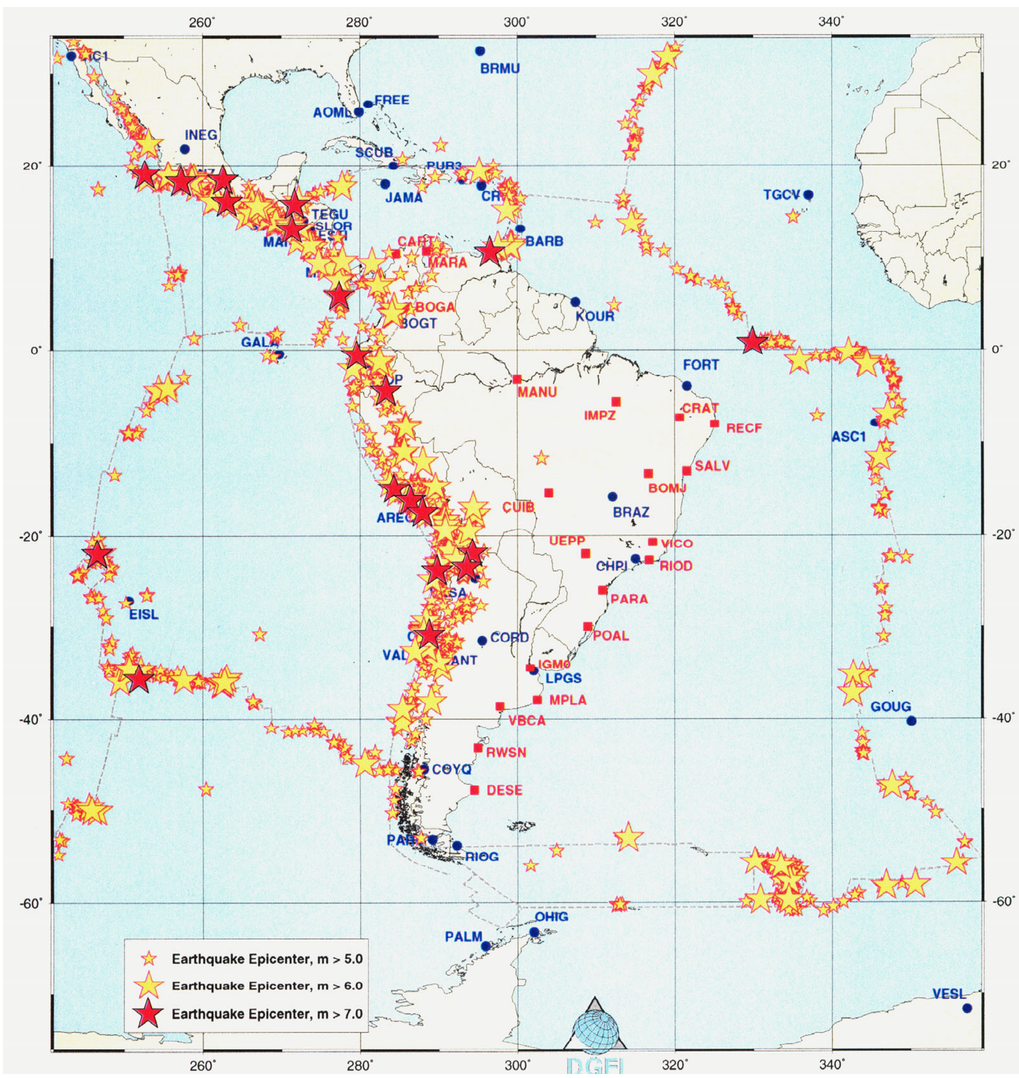

Figure 3: Earthquakes in the area of the IGS RNAAC SIR network from June 30, 1996 to end of Year 2001 (Source: USGS National Earthquake Information Center)

Four earthquakes were detected to cause significant station displacements. These are the earthquakes on January 13 and February 13, 2001 (m=7.6 and 6.5) in San Salvador (SSIA), and on June 23 and July 07, 2001 (m=8.4 and 7.6) in Arequipa (AREQ). The coseismic displacements at SSIA are 7 mm and 43 mm, respectively, for the two earthquakes, the displacements of AREQ are 520 mm and 43 mm, respectively (Figures 4 and 5). For station AREQ also postseismic displacements were detected and determined (Kaniuth et al., 2002).

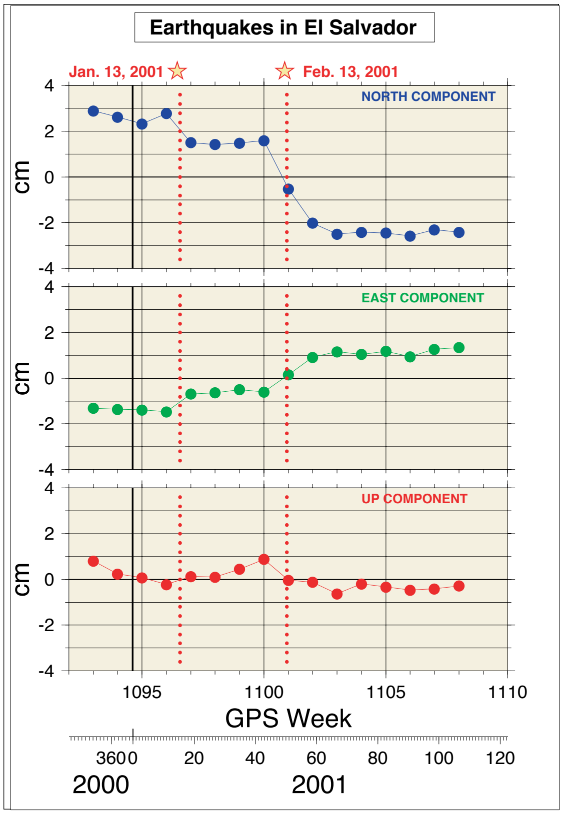

Fig. 4: Variations of station SSIA position components due to earthquakes in El Salvador (Seemüller et al., 2002).

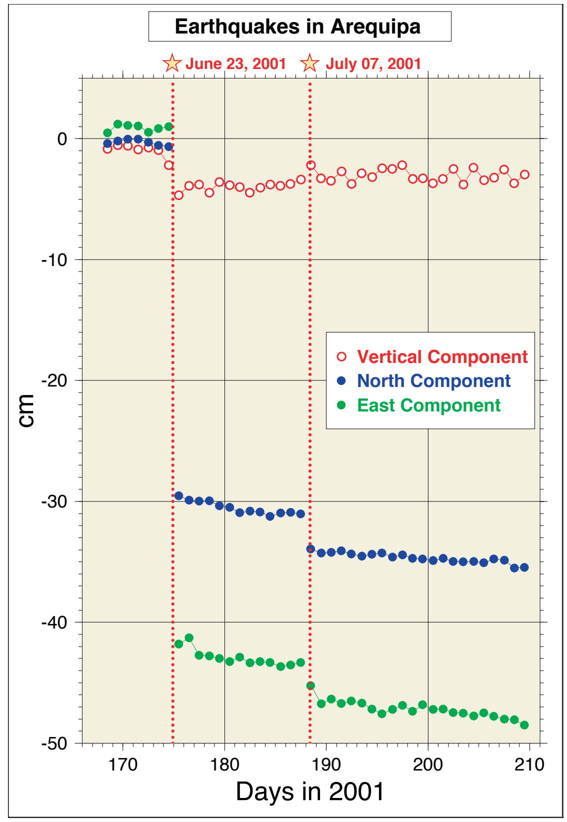

Fig. 5: Daily estimates of the AREQ position components in the reference frame realized by fiducial stations (Kaniuth et al., 2002).

Conclusion

For deriving station velocities it is necessary to pay attention to earthquakes nearby the stations, mainly in the vicinity of plate boundaries. Not to take in account the displacements of stations due to earthquakes would falsify the results of the velocity estimates. This further would have a corresponding influence on ITRF realizations and/or other global velocity determinations. The solution DGFI01P02 took care of the detected displacements in the stations SSIA and AREQ in 2001.

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IGS

DATA CENTER REPORTS

GLOBAL CENTERS

CDDIS 2001 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 2001 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 UNIX server. 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. GPS data since 1997 and IGS products since 1992 are available on-line.

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. Over twenty of these IGS data centers, shown in Table 1 make data available to the CDDIS from selected receivers on a daily (and sometimes hourly) basis. The CDDIS also accesses the archives of 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 2 lists the data sources and their respective sites that were transferred daily to the CDDIS in 2001. Over 70K station days from 232 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.2001*.

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 (in both "compact" and compressed RINEX format), 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 2001, the CDDIS archived data on a daily basis from an average of 200 stations. In 2001, 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.

At this time, the CDDIS on-line archive of daily GPS data contains data from January 1997 through the present. Prior to mid-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 majority of the data delivered to and archived in the CDDIS during 2001 was available to the user community within six hours after the observation day. Nearly sixty percent of the data from the global sites delivered to the CDDIS were available within three hours of the end of the observation day.

Hourly GPS Data Files

Since 2000, many IGS operational/regional data centers transmit hourly data files to the global data centers. 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. In 2001, approximately sixty percent of these hourly data files were available to the user community within 15 minutes of the end of the hour. GPS sites supplying hourly data to the CDDIS in 2001 are denoted by an * in Table 2; over 100 sites transmitted hourly data files to the global data centers in 2001.

The site-specific ephemeris data files for each hour are decompressed and then appended to a single file that contains the orbit information for all GPS satellites for the day up through that hour. This merged ephemeris data file, named *hourddd0.yyn.Z* (where *ddd* is the day of year and *yy* is the year), is then copied to the daily subdirectory in the hourly filesystem (*/gps/nrtdata/yyddd*). At the end of the day, this file is copied to the corresponding subdirectory under the daily filesystem (*/gps/gpsdata/yyddd/yyn*) and renamed to *brdcdd0yyn.Z*. Users can thus download this single daily file instead of all broadcast ephemeris files from the individual stations.

High-Rate GPS Data Files

In May of 2001, the CDDIS began the archive of high-rate (typically one-second) GPS data in support of the IGS Pilot Project for Low Earth Orbiting (LEO) Missions. The data are made available to the CDDIS from four sources, JPL, GFZ, ASI, and GOPE. The RINEX data are archived in files containing fifteen minutes of data using the filenaming convention *ssssdddhmi.yyt.Z* where ssss is the monument name, ddd is the day of year, *h* is the hour (a-z), *mi* is the minute (00, 15, 30, 45), yy is the year, and *t* is the file type (d, m, n). On average during 2001, the CDDIS archived high-rate data from 35 sites totaling approximately 250 Mbytes per day. Table 3 lists the high-rate sites archived at the CDDIS in 2001.

Meteorological Data

The CDDIS currently receives meteorological data from over fifty sites, as noted in Table 2. 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. 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 2001. Furthermore, a new product, the IGS ultra-rapid combination (designated IGU) were made available twice daily. 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.
The CDDIS also continued to archive combined troposphere estimates in directories by GPS week (i.e., */gps/products/wwww/trop,* where *wwww* is the GPS week number). Global ionosphere maps of total electron content (TEC) from the IONEX AACs were also archived in subdirectories by day of year (i.e., */gps/products/ionex/yyyy* where *yyyy* is the four-digit year). The CDDIS archived products generated by the individual analysis centers contributing to the IGS LEO Pilot Project (LEO-PP). Thirteen AACs have thus far submitted products for review by the LEO-PP analysis coordinator; these files are archived in subdirectories by AAC within filesystem */gps/products/leopp*.

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

During 2001, the CDDIS continued as a global data center for GLONASS data and products in support of the IGLOS-PP Call for Participation issued in 2000. The CDDIS archived GLONASS data from over fifty sites totaling nearly 12K station days of data; the data centers and sites active during 2001 are shown in Table 4. 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 in the filesystem */igex*. Through 2001, the CDDIS continued to archive both GLONASS data and products in a filesystem separate from IGS data and products.

System Usage

Figures 1 through 3 summarize the monthly usage of the CDDIS for the retrieval of GPS and GLONASS data and products for 2001. Figure 1 illustrates the amount of GPS and GLONASS data retrieved by the user community during 2001, categorized by satellite (GPS or GLONASS) and type (daily, hourly, high-rate). Nearly 25 million files were transferred in 2001, with an average of over two million files per month. Furthermore, nearly 16K GPS product files were retrieved each month from the CDDIS; less than 100 GLONASS product files were retrieved each month. Figures 2 and 3 illustrate the profile of users accessing the CDDIS IGS archive during 2001. Most accesses were through network gateways, which did not yield sufficient information about the user. Figure 3 displays the usage information by geographic region; the majority of CDDIS users are from hosts in North America.

Publications

The CDDIS staff attended several conferences during 2001 and presented papers on or conducted demos of their activities within the IGS, including:

- "2000 IGS Data Center Reports" (Carey Noll) for 2000 IGS Annual Report (submitted in 2001, to be published in 2002)
- "CDDIS 2000 Global Data Center Report" (Carey Noll) for 2000 IGS Technical Report (submitted in 2001, to be published in 2002)
- "The Crustal Dynamics Data Information System CDDIS -- NASA's Space Geodesy Data Archive at Science Data Centers Symposium, Pasadena, CA, March 2001
- CDDIS Support of the LEO Pilot Project at IGS LEO Pilot Project Planning Meeting, Potsdam, Germany, February 2001

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 four years. Additional RAID disk space may be procured in 2002, as well as a dedicated tape backup system. Purchase of a LINUX-based server will also be investigated.

Changes in the Data Archive

In late 2000, the International GLONASS Pilot Project (IGLOS-PP) steering committee recommended the incorporation of GLONASS data into the IGS data stream. Plans are to complete this transition in mid-2002.

The CDDIS proposed to serve as a data center supporting the IGS Pilot Project for Low Earth Orbiting (LEO) Missions in 2000. The CDDIS has already begun archiving high-rate data in support of the pilot project; in 2002, the CDDIS will archive space-borne GPS receiver data from selected missions (e.g., SAC-C and CHAMP).

Contact Information

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

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NASA GSFC	WWW:	*http://cddisa.gsfc.nasa.gov/cddis_welcome.html*
Greenbelt, MD 20771		*http://cddis.nasa.gov*

Acknowledgments

The author would once again like to thank members of the CDDIS staff, Dr. Maurice Dube, Ms. Ruth Kennard, and Ms. Laurie Batchelor (from Raytheon Information Technology and Scientific Services, RITSS). The successful participation of the CDDIS in many international programs can be directly attributed to their continued consistent, professional and timely support of its daily operations.

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Noll, C. E. "CDDIS Global Data Center Report" in *IGS 2000 Technical Report*. 2002.

Table 1: Data centers delivering data to the CDDIS in 2001

ASI	Italian Space Agency in Matera, Italy
AUSLIG	Australian Survey and Land Information Group in Belconnen, Australia
AWI	Alfred Wegener Institute for Polar and Marine Research in Bremerhaven, Germany
BKG	Bundesamt für Kartographie und Geodäsie in Frankfurt, Germany
CASM	Chinese Academy of Surveying and Mapping in Beijing, China
CNES	Centre National d'Etudes Spatiales in Toulouse, France
CRL	Communications Research Laboratory in Tokyo, Japan
CSIR	Council for Scientific and Industrial Research in Pretoria, South Africa
DGFI	Deutsches Geodätisches ForschungsInstitut in Munich, Germany
DLR	Deutsches Zentrum fuer Luft und Raumfahrt in Neustrelitz, Germany
DNR	Department of Natural Resources in Queensland, Australia
ENRI	Electronic Navigation Research Institute in Tokyo, Japan
ESOC	European Space Operations Centre in Darmstadt, Germany
GFZ	GeoforschungsZentrum in Potsdam, Germany
GOP	Geodetic Observatory Pecny in Ondrejov, Czech Republic
GSI	Geographical Survey Institute in Tsukuba, Japan
IMVP	Institute of Metrology for Time and Space in Mendeleevo, Russia
JPL	Jet Propulsion Laboratory in Pasadena, California
KAO	Korean Astronomy Observatory in Taejeon, Korea
NGI	National Geography Institute in Suwon
NIMA	National Imagery and Mapping Agencyin St. Louis, Missouri
NOAA/GL	NOAA's Geosciences Laboratory Operational Data Center (GODC) in Rockville, Maryland
NPL	National Physical Laboratory in Teddington, United Kingdom
NRCan	Natural Resources of Canada in Ottawa, Canada
NSTFL	National Standard Time and Frequency Laboratory in Taoyuan, Taiwan
PGC	Pacific Geoscience Centre, NRCan in Sidney, Canada
PGF	Pacific GPS Facility in Honolulu, Hawaii
RDAAC	Regional GPS Data Acquisition and Analysis Center on Northern Eurasia in Moscow, Russia
UNAVCO	University NAVSTAR Consortium in Boulder, Colorado
UNB	University of New Brunswick in Fredericton, Canada
USGS	United States Geological Survey in Reston, Virginia

Table 2: Sources of GPS data transferred to the CDDIS in 2001

Source	Sites								No. Sites
AUSLIG	ALIC	CAS1	CEDU	COCO*	DARW	DAV1*	HOB2*	JAB1	**16**
	KARR*	_LAE1_*	MAC1*	MAW1	STR1*	TID1	TOW2*	YAR2*	
AWI	GOUG	VESL							**2**
BKG	EBRE	HOFN*[m]	_NPLD_	NVSK	ORID	_POLV_	_SULP_[m]	TUBI	**11**
	UZHL	WTZT	YEBE*						
CASM	BJFS[m]								**1**
CNES	GRAS	HARB*	KERG*	NKLG*	THTI*	_TLSE_			**6**
CRL	_KGN0_[m]	_KGNI_	_KSMV_						**3**
DGFI	BRAZ								**1**
ESA	KIRU*	KOUR*	MALI*	MAS1*	PERT*	VILL*			**6**
GFZ	KIT3[m]	KSTU*	LPGS	OBER/_2_*	POTS*[m]	RIOG*	_ULAB_	UNSA*	**10**
	URUM[m]	ZWEN*[m]							
GSI	SYOG	TSKB							**2**
IGN	ANKR	BOR1*	BRUS*[m]	(EBRE)	GLSV	(GRAS)	GRAZ*[m]	(HARB)	**27**
	HERS*[m]	(HOFN*[m])	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]	_BREW_*	CASA	CHAT*[m]	CIC1*	**52**
	CORD*	CRO1*	DGAR	EISL*	FAIR*[m]	GALA*	GODE*	GOL2*	
	GOLD*	GUAM*	HARV*	HRAO*[m]	IISC*	JPLM*[m]	KELY*	KOKB*[m]	
	KRAK	KWJ1*	MAD2*	MADR*	_MBAR_*[m]	MCM4*	MDO1*[m]	MKEA*	
	_MSKU_*	NLIB*	NSSP*	PIE1*	PIMO*	POL2	QUIN*	RBAY*	
	SANT*	SELE	SEY1	SHAO	_SIMO_*	SUTH*	THU1*	TID2*	
	TIDB*	USUD*	XIAN	YAR1					
KAO	DAEJ								**1**
NGI	SUWN								**1**
NIMA	BAHR[m]								**1**
NOAA/GL	AMC2	AOML[m]	_ASPA_*	BARB	BARH*[m]	BRMU	EPRT*	ESTI*	**23**
	FORT	_FREE_	GUAT*	HNPT	JAMA	(KELY)	MANA*	SLOR*	**(24)**
	SOL1[m]	SSIA*	_TEG1_*	TEGU*	USNA	USNO[m]	WES2[m]	WUHN[m]	
NRCan	(ALBH[m])	ALGO*[m]	_CAGS_	CHUR*[m]	(CHWK)	(DRAO*)	(DUBO)	(FLIN)	**12**
	(HOLB)	_HOLM_	_INVK_	(NANO)	NRC1*[m]	NRC2*	PRDS*[m]	_RESO_	**(23)**
	SCH2*[m]	STJO*[m]	(UCLU)	(WHIT[m])	(WILL)	(WSLR)	YELL*[m]		
NSTFL	_TWTF_[m]								**1**
PGC	ALBH*[m]	CHWK	DRAO*[m]	DUBO	FLIN	HOLB	NANO	UCLU*	**11**
	WHIT*[m]	WILL	WSLR						
PGF	_CFAG_	_FALE_	_HILO_	_HNLC_	_KOUC_	_LHUE_	_MALD_	_MANZ_	**12**
	_MAUI_*	_PARC_	_SUVA_	_VALP_					
RDAAC	ARTU	BILI	MAG0[m]	_MOBN_	NRIL[m]	PETP[m]	TIXI	_YAKT_[m]	**10**
	YAKZ	YSSK[m]							
SIO	AMMN	BAKO	DRAG	INEG[m]	KODK	MONP	PIN1	PVE3	**12**
	RABT	RAMO	SIO3[m]	VNDP[m]					
UNAVCO	CHUM	KAYT	KAZA	KUNM	(NSSP)	PODG	(POL2)	RIOP	**9**
	(SELE)	SUMK	TALA	TVST					**(12)**
USGS	AMUN	PALM							**2**
Totals:	**232 daily GPS sites from 24 data centers during 2001**								
	108 hourly GPS sites during 2001[1]								

Notes: Sites in () indicate backup delivery route
Sites in _italics_ indicate sites new to the CDDIS in 2001
* Indicates site also providing hourly data to the CDDIS in 2001
[m] Indicates site providing meteorological data to the CDDIS in 2001
[1] Hourly GPS data also available from: CAGL, HFLK, MEDI, PENC, SFER, SCUB, UPAD

Table 3: Sources of GPS high-rate data transferred to the CDDIS in 2001

Source	Sites								No. Sites
ASI	MATE								**1**
GOP	GOPE								**1**
GFZ	BAN2	JOGJ	KSTU	LPGM	MIZU	NYA2	OBEM	OUS2	**13**
	POTM	SUTM	TASH	ULAB	ZWEN				
JPL	BREW	CORD	CRO1	FAIR	GALA	GODF	GOLD	GUAM	**25**
	HRAO	IISC	KELY	KOKB	MADR	MBAR	MCMZ	MKEA	
	MOBN	MSKU	NRIL	OKC2	PIMO	SANT	TIDB	USUD	
	YAKT								
Totals:	**50 high-rate sites from 4 data centers during 2001**								

Table 4: Sources of GLONASS data transferred to the CDDIS in 2001

Source	Sites								No. Sites
AUSLIG	DARR	DAVR	LINR	STR2	YARR				**5**
BKG	_BOGI_*	BORG	BRUG	DLFT	_DREJ_*	GJOV*	GOPE*	GRAB	**33**
	_HELJ_*	HERP	_HUEG_	KR0G	_LEIJ_*	LHAZ	_MAT1_	_METZ_	
	MR6G	MTBG	_OHIZ_	OS0G	REYZ	_SP0G/T0_*	THU2	TIGZ	
	_TITZ_*	_UNFE_*	VS0G	VSLD	WROC*	_WTZJ_*	WTZZ*	ZIMJ	
	ZIMZ								
CSIR	CSIR								**1**
DLR	NTZ1*								**1**
DNR	SUNM								**1**
ENRI	MTKA								**1**
GSFC	GODZ								**1**
D. Hogarth	DWH1 [m]								**1**
IGN	BIPD	REUN							**2**
IMVP	_IRKJ_	_KHAJ_	_MDVJ_	_NOVJ_					**4**
NPL	_NPLF_								**1**
UNB	_UNB1_*								**1**
USGS	CRAR								**1**
Totals:	**53 daily GPS+GLONASS sites from 15 data centers during 2001** **15 hourly GPS+GLONASS sites during 2001**								

Notes: Sites in *italics* indicate sites new to the CDDIS in 2001
[m] Indicates site providing meteorological data to the CDDIS in 2001
* Indicates site also providing hourly data to the CDDIS in 2001

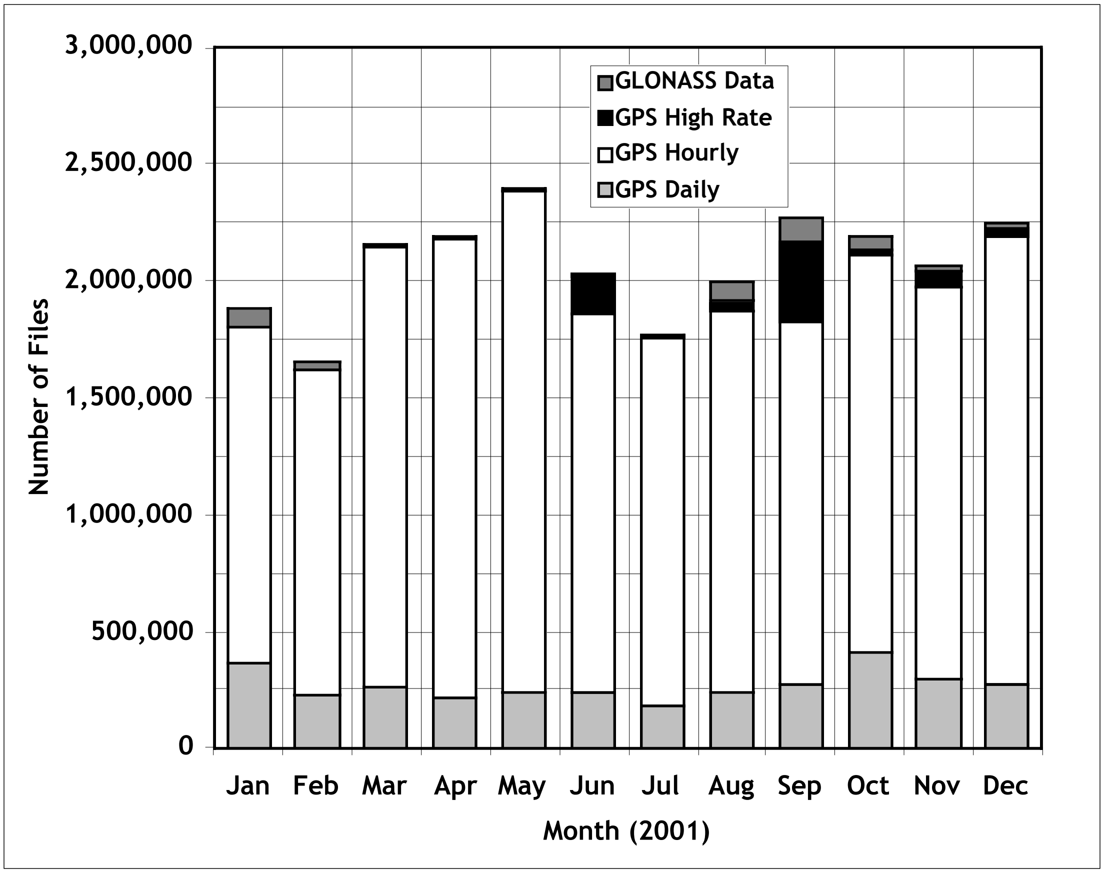

Figure 1: Number of GPS data files transferred from the CDDIS in 2001

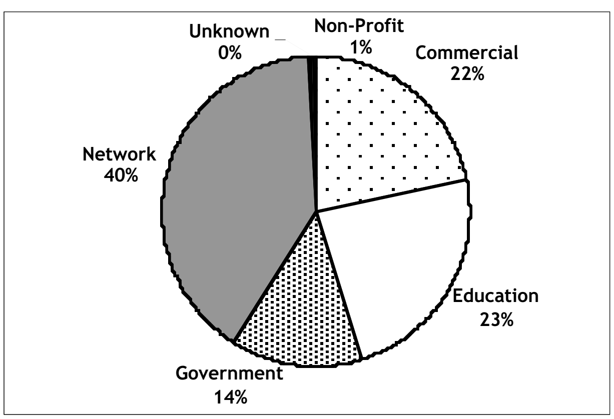

Figure 2: Distribution of IGS users of the CDDIS in 2001

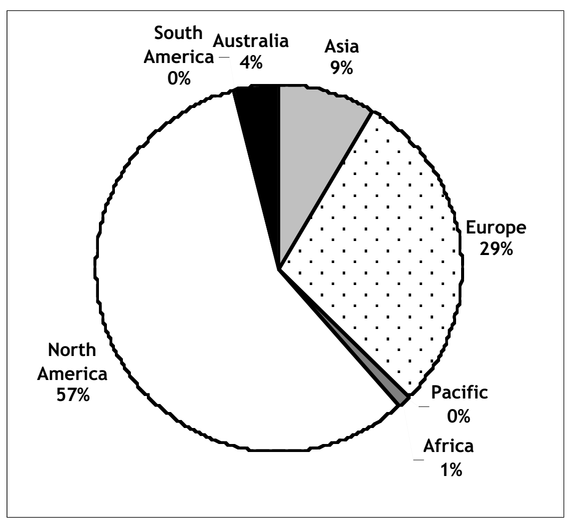

Figure 3: Geographic distribution of IGS users of the CDDIS in 2001

IGS

REGIONAL/OPERATIONS CENTERS

BKG Regional IGS Data Center Report 2001

Heinz Habrich

Federal Agency for Cartography and Geodesy, Frankfurt, 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 a European institution operates these stations. The received data are uploaded to the Global Data Centers (GDCs), 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 this information to European users. GPS observation data from the EUREF Permanent GPS Network (EPN) and mixed GPS/GLONASS observation files from the IGEX/IGLOS GLONASS Experiment are also available. A subset of the IGS, EUREF, and IGLOS stations deliver hourly observation files to BKG additionally to the daily files. BKG holds the data files from different projects in separate directories in order to handle the project related restrictions (e.g., the project specific user access). A project independent access is additionally realized through a list of all stations and links to the corresponding subdirectories.

Activities in 2001

In 2001 BKG has started to upload all hourly IGS observation files additionally to the SOPAC archive at the Scripps Institution of Oceanography for backup purpose. This was one of the first steps to establish a global redundancy of hourly observation files for near real time applications. A new RAID disk system with 2 x 250 GB capacity had been installed for the storage of the data in December. The first 250 GB are mirrored to the second ones. This makes it possible to easily change one disk in case of a disk crash. Currently the IGS data for approximately 3 years could be hold online.

File Transfers

Figure 1 shows the number of transferred RINEX observation files in the year 2001. Any other files types are not shown here because these files are the most important. Figures 2 and 3 show the latency of the observations files. About 80% of the IGS observation files had been available at the BKG within 12 hours, which is in time for daily and weekly data processing. More than 40% of the IGS hourly files had been submitted to BKG within 6 minutes. After the installation of a new firewall at BKG in the year 2000 there is currently no information about user activities available, because all external users show up with the same user name in our log-files.

Outlook

New ftp server software had been installed in 2002, which now has no write permission for the anonymous ftp user. IGS members need a user account and password to upload files to BKG. After login the users are immediately connected to the correct directory to store the files. It is planned to improve the web-based administration of the data center and the user interface. For that purpose currently a new data center structure is under development, which is based on the LAMP (Linux operation system, Apache web server, MySQL data bank and PHP script language) server concept. These new developments allow integrating new ideas that may be addressed by the newly established IGS data center working group.

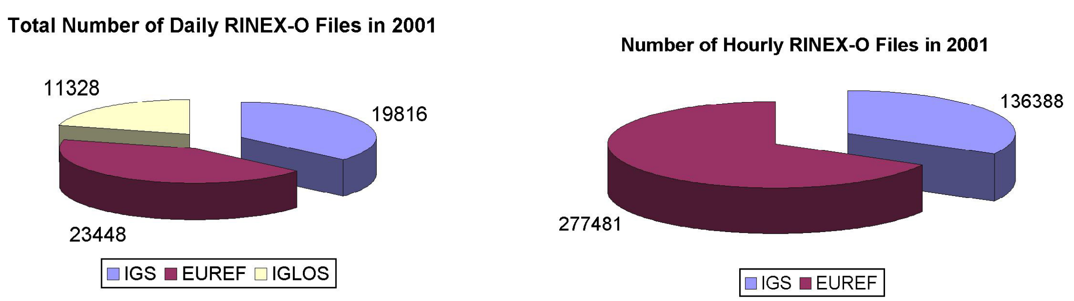

Figure 1

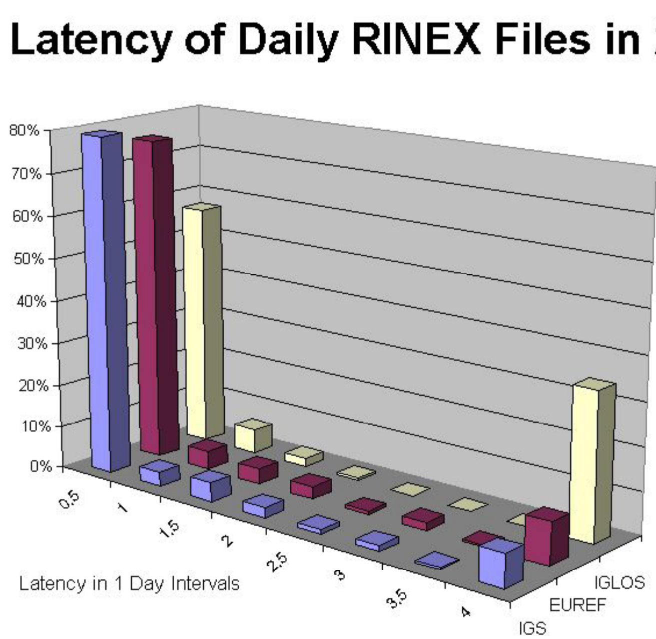

Figure 2

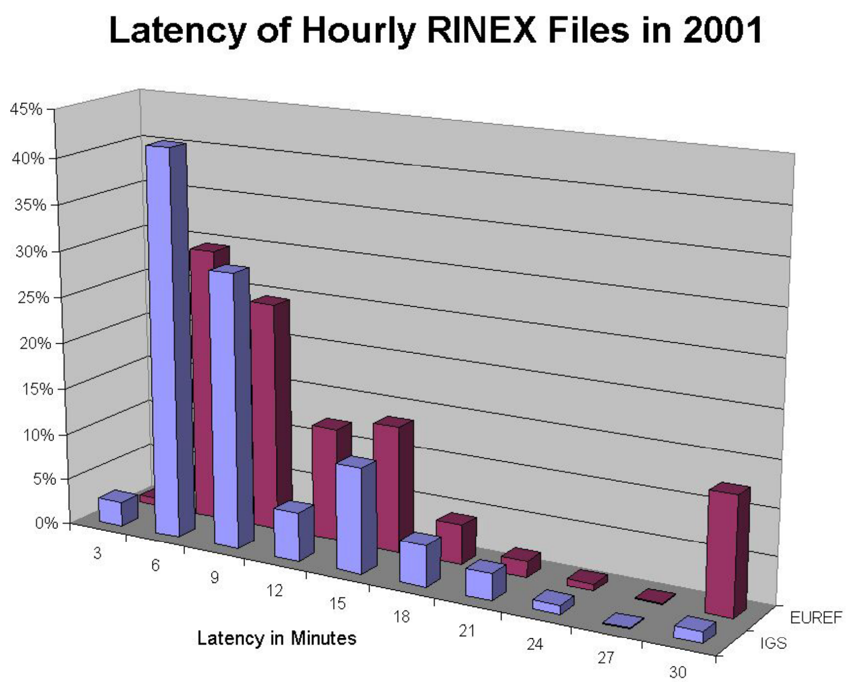
Latency of Hourly RINEX Files in 2001
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
3
6
9
12
15
18
21
24
27
30
Latency in Minutes
EUREF
IGS

Figure 3

IGS

NETWORK AND STATION REPORTS

GLOBAL, REGIONAL, AND LOCAL NETWORKS

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

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

ESA/European Space Operations Centre
Darmstadt, Germany

Overall Hardware Configuration

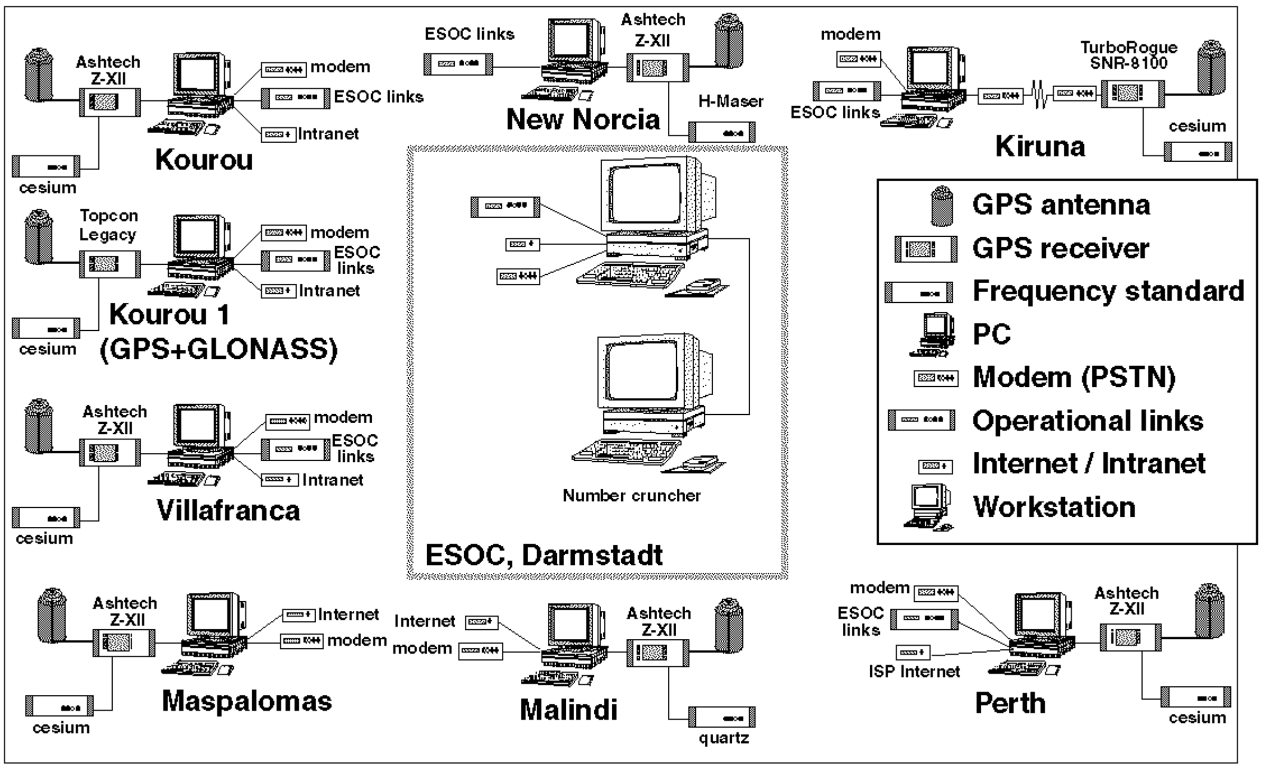

Figure 1: Configuration of the ESA stations by middle 2002.

Network Visibility

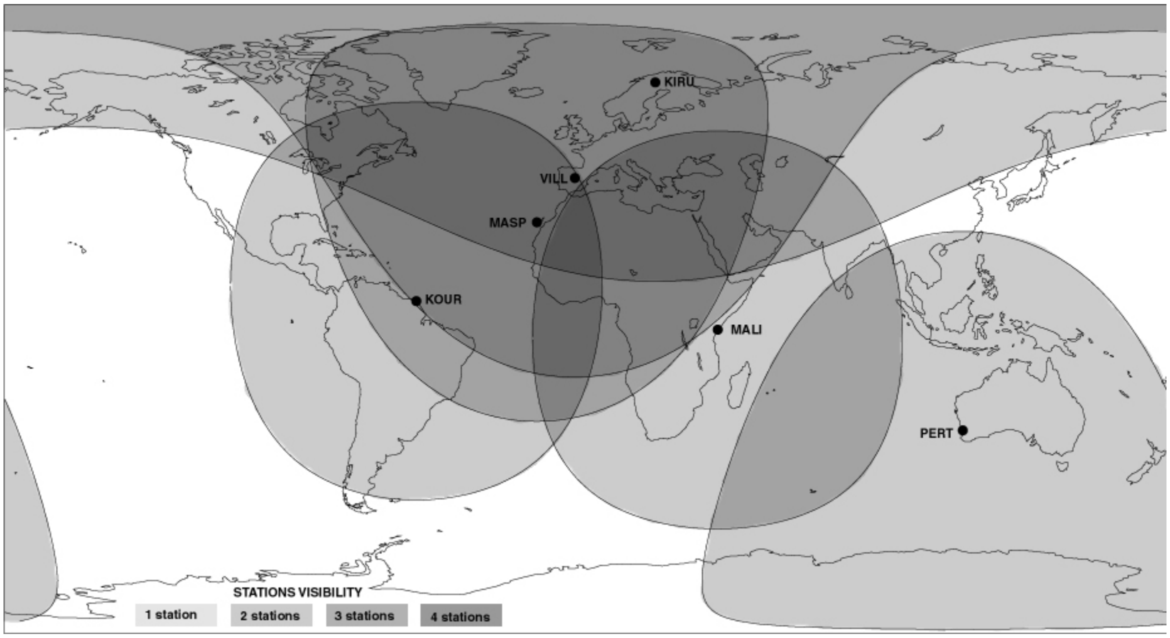

Figure 2: Visibility of the ESA network with 20 degree minimum elevation.

Receiver Performance

During the year 2001 ESOC has continued the plans to upgrade the stations with Ashtech Z-XII receivers. The following summarizes the status and upgrades that took place in 2001:

In Kiruna (KIRU) the receiver in operation was an AOA SNR-8100 ACT that was upgraded the previous year (September 2000).

In Kourou (KOUR) the Ashtech Z-XII had been upgraded in March 2000.

In Malindi (MALI) the Ashtech Z-XII was installed in April 2001 to replace the TurboRogue receiver.

Maspalomas (MAS1) was the first ACT upgrade in August 1999, but the new receiver failed some months later and had to be replaced by an Ashtech Z-XII in December 2000. During 2001 the receiver performance was nominal.

In Perth (PERT), due to the geographical location, the cross correlation receiver had an acceptable performance and the receiver was only replaced in June 2001 after the 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-XII by the beginning of 2001.

The Topcon Legacy combined GPS+GLONASS receiver was installed at Kourou (KOU1) and started the data collection by the end of 2001.

Communications

The communications to the ESA stations has been traditionally based on the permanent operational lines existing for Kiruna, Kourou, Perth and Villafranca and dial-up modems for the rest (Malindi and Maspalomas).

During 2001 the communications links have improved thanks to the development of the IP connectivity in the remote stations, either via the ESA Intranet or Internet. The IP Intranet is used in Villafranca and Kourou and the permanent Internet connectivity in Malindi and Maspalomas. Kiruna uses an asynchronous X.25 permanent line. Perth is downloaded through a modem connection to a local Internet Service Provider (ISP).

The implementation of permanent IP lines will make possible the future development of real time 1 Hz data downloads.

The 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 and download 1 Hz data. They do not present any problems in the second frequency tracking at equatorial stations caused by high ionospheric activity. The older TurboRogues were only capable of 3 seconds 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

In 2001 Maspalomas and Malindi joined the rest of stations that provide hourly data since 1999 (Kiruna, Kourou, Perth and Villafranca).

Maspalomas started in December 2000, in 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.

ESA Web Pages

Updated information and pictures of the stations can be found in the ESOC web pages:

http://nng.esoc.esa.de

References

GPS-TDAF Stations Configuration Manual. Version 1.5, May 2002.

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 the Ukrainian IGS Stations

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Science and Research Institute of Geodesy and Cartography, Kiev, Ukraine

As of the end of 2001 there are five permanent GPS stations in Ukraine (Figure 1), four of which contribute data to the IGS.

Figure 1. Ukrainian Permanent GPS Stations

Kiev/Golosiiv

Kiev/Golosiiv (4–char ID: GLSV), the first Ukrainian permanent GPS station, operates since December 16, 1997. It is located at the Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAO) in the Golosiiv Wood, the southern part of the city of

Kiev. The antenna is placed at the top of steel pillar mounted on the roof of the Observatory office.

Station Configuration

Station name:	Kiev/Golosiiv
4-char ID:	GLSV
DOMES Number:	12356M001
Receiver type:	Trimble 4000SSI
Firmware version:	TRM29659.00
Antenna height:	0.0000 m
Antenna reference point:	BPA
Clock:	Internal
Approximate coordinates (WGS–84):	
Latitude:	50.3642 N
Longitude:	30.4967 E
Height:	226.8 m
Managing Software:	ggps (bash script developed at the MAO, uses r–utilities (Trimble Navigation Ltd.), teqc, and RNX2CRX/CRX2RNX)
Data Flow:	Daily Compact RINEX observation and navigation files are sent to the Regional Data Center at the BKG (Frankfurt am Main, Germany)
Collocation:	SLR 1824 Kiev

Uzhgorod

The Uzhgorod station (4–char ID: UZHL) started the observations on February 5, 1999. This station is situated at the Space Research Laboratory of the Uzhgorod National University, city of Uzhgorod. Like GLSV it is operated by the MAO. The antenna is located at the top of steel pillar mounted on the roof of the Laboratory office.

Station Configuration

Station name:	Uzhgorod
4-char ID:	UZHL
DOMES Number:	12301M001
Receiver type:	Trimble 4000SSI
Firmware version:	7.19A (since 25–APR–2000)
Antenna type:	TRM29659.00
Antenna height:	0.0000 m
Antenna reference point:	BPA
Clock:	Internal
Approximate coordinates (WGS–84):	
Latitude:	48.6320 N
Longitude:	22.2976 E
Height:	232.0 m
Managing Software:	ggps

Data Flow: Daily Compact RINEX observation and navigation files are sent to the Regional Data Center in the BKG (Frankfurt am Main, Germany). Raw data are sent to the MAO archive.

Poltava

The new station Poltava (4–char ID) started observations April 26, 2001. It is operated by the Science and Research Institute of Geodesy and Cartography (RIGC) and situated at the Poltava Gravimetric Observatory of the National Academy of Sciences of Ukraine, city of Poltava. The choke ring antenna is installed at the top of steel pillar mounted on the roof of the main Observatory office.

Station Configuration

Station name:	Poltava
4-char ID:	POLV
DOMES Number:	12336M001
Receiver type:	TRIMBLE 4700
Firmware version:	1.30
Antenna type:	TRM29659.00
Antenna height:	0.0000 m
Antenna reference point:	BPA
Clock:	Internal
Approximate coordinates (WGS–84):	
Latitude:	49.6026 N
Longitude:	34.5429 E
Height:	178.1 m
Managing Software:	Trimble Reference Station
Data Flow:	Daily RINEX observation and navigation files are sent to the MAO, where data are translated to the Compact RINEX format and headers of the observation files are prepared following the IGS requirements. Then data are sent to the Regional Data Center in the BKG (Frankfurt am Main, Germany).

Lviv

The observations at the new station Lviv (4–char ID: SULP) were started on June 10, 2001. The station is located in the National University "Lviv Polytechnic" (NULP), city of Lviv. It is operated by the NULP in cooperation with the RIGC. The Zephyr antenna is placed on metallic construction over the fundamental astronomical monument, which was constructed and built on rock base in 1870 inside the main building of the University in such a manner to have no any contact with the building itself. In 1996–2000 SULP took part in CERGOP and CERGOP–2 campaigns as an epoch station.

Station Configuration		
Station name:	Lviv	
4-char ID:	SULP	
DOMES Number:	12366M001	
Receiver type:	TRIMBLE 4700	
Firmware version:	1.30	
	Till 13–OCT–2001	Since 13–OCT–2001
Antenna type:	TRM33429.20+GP	TRM41249.00
Antenna height:	4.7340 m	4.7295 m
Antenna reference point:	BPA	BPA
Clock:	Internal	
Approximate coordinates (WGS–84):		
Latitude:	49.8356 N	
Longitude:	24.0145 E	
Height:	370.5 m	
Managing Software:	Trimble Reference Station	
Data Flow:	Hourly and daily RINEX observation and navigation files are transferred from on-site PC (WinNT) to another PC (UNIX), where data are translated to the Compact RINEX format and headers of the observation files are prepared following the IGS requirements. Then data are sent to the EPN Local Data Center in the Space Research Institute, Department of Satellite Geodesy, Austrian Academy of Sciences (OLG, Austria)	
Collocation:	SLR 1831 Lviv	

CRAO

The fifth Ukrainian permanent GPS station CRAO, installed by Massachusetts Institute of Technology and included in the UNAVCO Mediterranean GPS Network, operates since April 27, 2000. It is located in the Simeiz Station of the Crimean Astrophysical Observatory, Simeiz, Crimea. The station is equipped with the Rogue SNR–8000 receiver (firmware version: 3.2.32.8) and the AOAD/M_T antenna with the SCIS dome. The hourly and daily RINEX observation and navigation files are available at the UNAVCO ftp server.

INDIVIDUAL STATION REPORTS

Permanent GPS Station LROC

Guy Wöppelmann

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La Rochelle is located on the French Atlantic coast in the Charente-Maritime French territorial division (001°13' W, 46°09' N). The installation of the permanent GPS station LROC comes from a successful cooperation between the university and several French governmental agencies:

- University of La Rochelle, for the coordination and funding of the GPS equipment : a dual-frequency Ashtech MicroZ receiver with a Dorne Margolin choke ring antenna.
- Institut Géographique National for the monumentation, the installation and the geodetic connections to the national leveling and geodetic networks, as well as to the tide gauge.
- Service Maritime de la Charente-Maritime, for the local infrastructure as well as the logistical support : power supply and data communication facilities.

The station is operational since November 23, 2001 (day of year 327). GPS observations are recorded in daily files at a 30s rate. It is expected to produce 1s hourly files in the future but the sampling rate will remain unchanged until an Internet connection replaces the present dial up line for data downloads. Compressed RINEX files are freely available at IGN permanent GPS network FTP server (ftp://lareg.ensg.ign.fr/pub/rgp/) or at the university of la Rochelle data center (ftp://ftp.sonel.org/pub/gps/).

The LROC station is aimed toward scientific research as well as geodetic and hydrographic applications. The GPS antenna is located on a stainless 1 meter steel mast on the roof of a concrete bunker of the second World War, less than 100 meters away from a tide gauge (see picture). The tide gauge is equipped with a modern radar sensor. It takes part in the French Oceanographic and Hydrographic Service permanent tide gauge network. The collocation with such a high quality tide gauge serves a large variety of sea-level studies, in particular related to climate change. Both tide gauge and GPS devices aim at the long term monitoring of sea-level and land-level motions. LROC is participating in the TIGA IGS pilot project.

The permanent GPS station LROC contributes to the realization of the modern French national geodetic system RGF93. It helps providing a continuous access to this geodetic system. LROC was recently accepted to contribute to EUREF permanent GPS network.

IGS Tracking Station GOPE in 2001

Jakub Kostelecky and Jaroslav Simek

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Activities at the Station GOPE Until 2001

The IGS station GOPE has been operated at the Geodetic Observatory Pecn_ since 1995. Since the beginning the daily files of 30-second data and since November 17, 1998 also hourly files have been delivered. On November 4, 1999 the original receiver Trimble 4000 SSE with Trimble 4000ST L1/L2 antenna had been replaced by the Ashtech Z18 receiver and Ashtech Choke Ring GG antenna with a snow radome and the station joined the IGEX (International GLONASS Experiment) project later continued as IGLOS-PP. Since that time the station has been providing daily and hourly files of both GPS and GLONASS 30-second data.

Participation in the LEO Project

In 2000 the station GOPE was accepted as a terrestrial tracking station for the Low-Earth Orbiter (LEO) Pilot Project. Among a number of files with different data intervals 15-minute files of 1-second data have been produced since January 2001. Since June 20, 2001 the data have been provided in compressed CompactRINEX format in agreement with the resolutions of the IGS LEO Workshop held in GFZ Potsdam in February 2001.

The primary program used on the on-site recording computer is the Geodetic Base Station Software of Magellan Corporation/Ashtech Precision Products which produces both daily and hourly files. The routine of forming 15-minute files employs an instant data record on the disk immediately after they are received on the serial port. The receiver was switched to 1-second download and a software was created to take each 15 minutes required data and to transmit them through established data flow paths to the CDDIS Global Data Center.

Improved Signal Reception

An area surrounding the observing site was cleared of trees to improve the horizon. This resulted in an improved signal reception along with a significant data gain.

Permanent GPS Station LAE1

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The GPS site LAE1 in Lae, Papua New Guinea is the first IGS station in this country and fills a geographical void in the global tracking network in the western Pacific region The successful installation and operation of the site is a result of cooperation several universities:

- The Department of Surveying and Land Studies at The Papua New Guinea University of Technology, upon whose building the antenna is mounted. Staff installed the site and are responsible for maintaining the continued operation of the GPS equipment and the internet data link.
- The Research School of Earth Sciences at The Australian National University who provide the Ashtech chokering antenna, cabling, base station software and ongoing support;
- The University of California, Santa Cruz, who provide the Ashtech Z-XII GPS receiver.

The site was first observed in 1996 in support of a national geodetic crustal motion survey. Continuous operation began at LAE1 in July 1997 (day of year 209) and has essentially continued uninterrupted to the present day. An automated, internet-connected download procedure was installed in November 2000 that allowed the data to be transferred directly from Lae to The Australian National University. The site was officially listed as an IGS site in April 2001 and both daily and hourly rinex files for this site have been provided to the IGS since this time.

LAE1 is located on the hanging wall of the Ramu-Markham Fault, the boundary between the Australian and South Bismarck Plates. These two plates are undergoing arc-continental collision at a rate of ~40 mm/yr along this part of the fault. The motion of the site has remained essentially linear since 1997, although the estimated site velocity differs from the predicted velocity of both the Australian and South Bismarck Plates. Thus, the site is located in a deforming zone. Further information about the GPS site can be found at http://rses.anu.edu.au/extarnal/unitech/lae1inst.htm .

The tide gauge in Lae harbour is 9 km from the GPS installation. A precise levelling survey was conducted in May 2002 to connect the GPS site to the tide. The height of the GPS monument reference point above the tide gauge zero was found to 58.748±0.005 m. Unfortunately the tide gauge has not been operating since 1999.

Figure 1. LAE1 antenna installation.

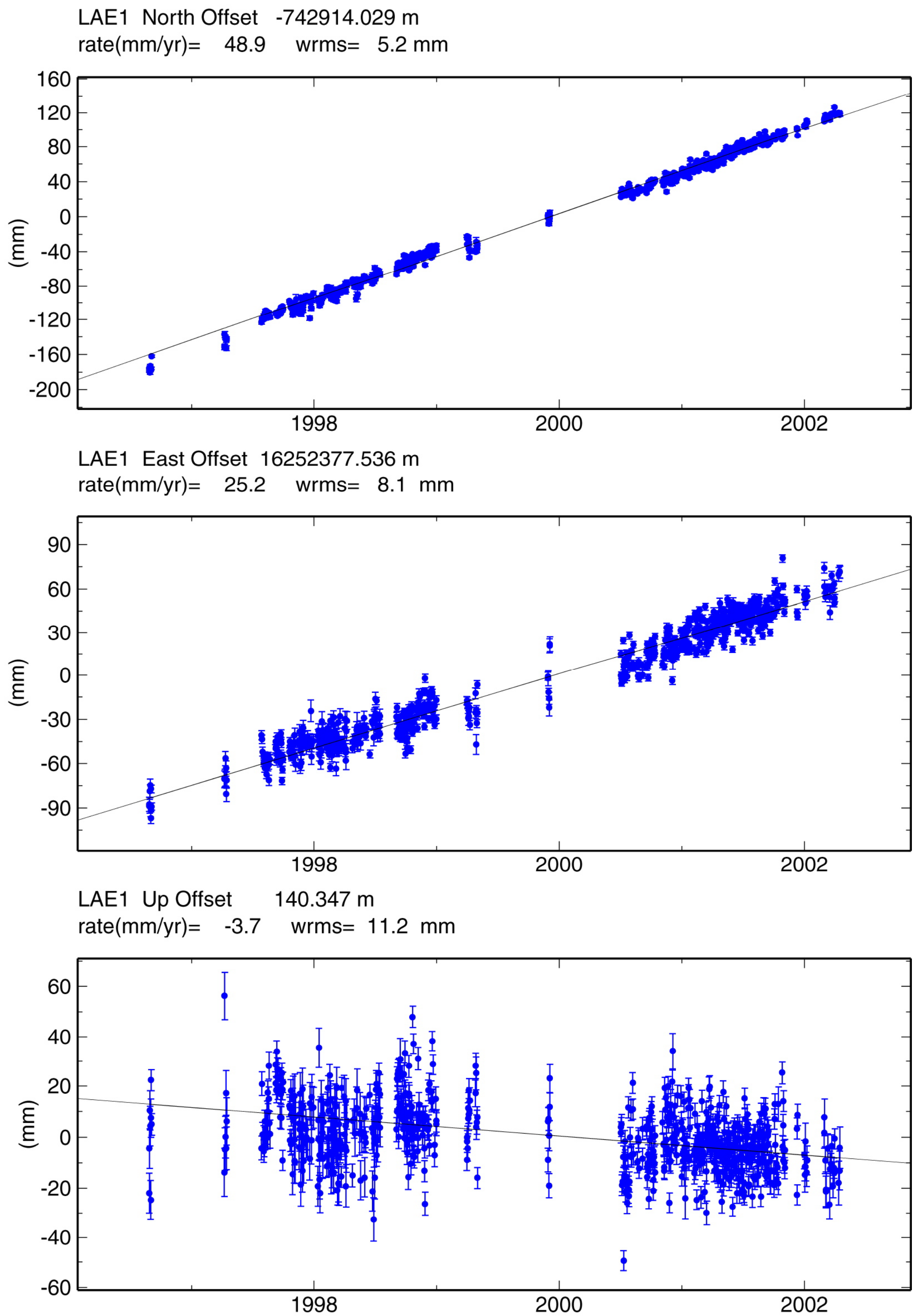

Figure 2. Time series of daily coordinate estimates. The data were processed at RSES using the GAMIT/GLOBK software.

IGS

WORKING GROUPS/ PILOT PROJECTS/COMMITTEES

IGS/BIPM Time Transfer Pilot Project

Jim R. Ray

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 Measures (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:

- Consultative Committee for Time and Frequency (CCTF) -- At its 15th meeting, held 20-21 June 2001 at the BIPM (Sèvres, France), the CCTF adopted Recommendation 2 (2001) which supports the Pilot Project and encourages full participation by the timing labs contributing to UTC.

- Deployment of GPS receivers -- The IGS network currently consists of about 300 permanent, continuously operating tracking stations globally distributed. Of these, external frequency standards are used at ~40 with H-masers, ~25 with cesium clocks, and ~15 with rubidium clocks; the remainder use internal crystal oscillators. Table 1 lists the IGS stations currently located at timing labs. Six are new: KGN0 (Koganei, Japan), MIZU (Mizusawa, Japan), OPMT (Paris, France), PTBB (Braunschweig, Germany), TWTF (Taoyuan, Taiwan), and WTZA (Wettzell, Germany).

- Common-view files from RINEX data -- Pascale Defraigne (ORB) has developed a procedure to use RINEX data from geodetic GPS receivers to form CGGTTS-format common-view observation files, the current standard for international time comparisons. This method aims to permit common-view time links using calibrated geodetic receivers to be introduced into BIPM's UTC computation.

- GPS data analysis -- The IGS implemented a new method developed by Jan Kouba (NRCanada) and Tim Springer (AIUB) to combine satellite and receiver clock estimates from the Analysis Centers (up to six). The clock values are sampled at 5-minute intervals and exchanged using the clock RINEX format, starting with GPS week 1086 (29 October 2000). Figure 1 shows the locations of the stations included in the IGS clock products.

- New IGS time scale -- A new internally realized time scale was developed by Ken Senior (USNO) to improve the stability of the IGS clock products, which are otherwise limited at about 1 day and longer by the large instability of GPS time. The consistency of the original IGS clock and orbit products is fully preserved in the new re-referenced clocks, which were released on 15 August 2001. Official adoption of the new time scale by the IGS is expected in the near future.

- Clock "densification" -- It was agreed that Analysis Centers may augment their IGS submissions by using the precise point positioning method to determine clocks for receivers not used in their orbit solutions. In this way it is expected that all stations equipped with external frequency standards, especially all timing labs, can be included in the IGS clock products.

- Assessment of accuracy & precision -- Jim Ray and Ken Senior have studied the realigned IGS clock products for 30 receivers and found that the time transfer performances vary greatly, depending on a variety of local station factors. In the best cases, the timing transfer accuracy is consistent with the formal errors, but the quality can sometimes be an order of magnitude worse.

- GPS clock predictions -- Three Analysis Centers (USNO, GFZ, and ESA) provide predictions of the GPS satellite clocks. These were combined and added to the IGS Ultra-rapid products, together with the orbit predictions, starting in 2000. The twice-daily clock predictions are only about 25% better than the broadcast clocks due to the stochastic nature of the satellite clock variations. However, more frequent Ultra-rapid updates can significantly improve the clock prediction performance for real-time users.

- Instrumental delays -- Gérard Petit (BIPM) and others have developed and demonstrated techniques to calibrate the instrumental biases of the Ashtech Z-XII3T receiver, in both absolute and relative modes. In 2001 the BIPM began a campaign to circulate an absolutely calibrated Ashtech receiver to differentially measure the biases of similar receivers deployed at timing labs.

- Comparison studies -- Efforts continue to compare geodetic timing\ results with simultaneous, independent measurements using the common-view and two-way satellite techniques.

- Future -- It is expected that the Pilot Project will transition to permanent operational status within the IGS by the end of 2002. A longer period will be required to evaluate the usefulness of the IGS clock products in the work of the BIPM.

Table 1. IGS Stations Located at BIPM Timing Laboratories (March 2002)

IGS Site	Time Lab	GPS Receiver	Frequency Standard	City
AMC2	AMC *	AOA SNR-12 ACT	H-maser	Colorado Springs, CO, USA
BOR1	AOS	AOA TurboRogue	cesium	Borowiec, Poland
BRUS	ORB	Ashtech Z-XII3T	H-maser	Brussels, Belgium
KGN0	CRL *	Ashtech Z-XII3	cesium	Koganei, Japan
MDVO	IMVP	Trimble 4000SSE	H-maser	Mendeleevo, Russia
MIZU	NAO	AOA Benchmark	cesium	Mizusawa, Japan
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
OBE2	DLR	AOA SNR-8000 ACT	rubidium	Oberpfaffenhofen, Germany
OPMT	OP	Ashtech Z-XII3T	H-maser	Paris, France
PENC	SGO	Trimble 4000SSE	rubidium	Penc, Hungary
PTBB	PTB *	AOA TurboRogue	H-maser	Braunschweig, Germany
SFER	ROA *	Trimble 4000SSI	cesium	San Fernando, Spain
SPT0	SP	JPS Legacy	cesium	Boras, Sweden
TLSE	CNES	AOA TurboRogue	cesium	Toulouse, France
TWTF	TL *	Ashtech Z-XII3T	cesium	Taoyuan, Taiwan
USNO	USNO*	AOA SNR-12 ACT	H-maser	Washington, DC, USA
WTZA	IFAG	Ashtech Z-XII3T	H-maser	Wettzell, Germany
WTZR	IFAG	AOA SNR-8000 ACT	H-maser	Wettzell, Germany

* participates in two-way satellite time transfer operations

Figure 1. Geographical distribution of IGS stations included in the IGS combined clock products (March 2002). The larger, colored symbols denote stations equipped with external frequency standards: H-masers (red), cesiums (yellow), rubidiums (blue). The smaller black dots indicate stations using internal crystals. IGS stations colocated at timing labs are shown as stars.

Report of the Tropospheric Working Group for 2001

Gerd Gendt

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Weekly Combined Tropospheric Product and Densification

Starting in 1997 the IGS Final weekly combined tropospheric product (Gendt, 1996) is now available for more than 5 years. Its internal consistency, obtained by comparing the individual submissions to the combined result, has a standard deviation of 2 to 3 mm in the zenith total delay (ZTD) for most Analysis Centers (AC), where the best ACs are approaching the 2 mm level (see Gendt, 2001). The biases between the individual submissions had stabilized during the past two years, being now in the band of ±2 mm (Fig. 1). Recent changes in the analysis strategy by a few ACs gave only small jumps in the bias.

The used parameterization is also converging. All but one AC are using now the Niell mapping function. Various elevation cut-off angles are applied (15 degrees by EMR, JPL, NGS; 10 by ESA, SIO; 7 by GFZ; 3 by CODE) with a clear tendency for lower angles.

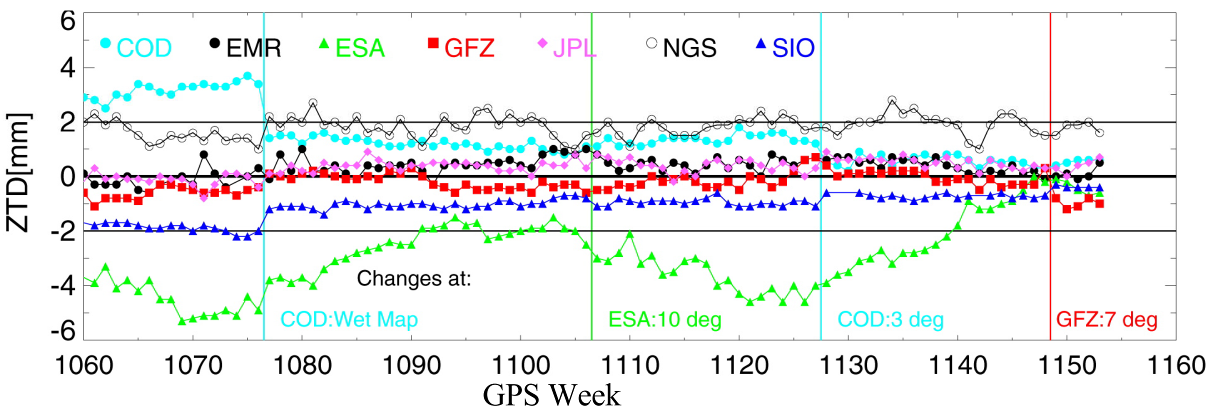

Fig. 1. Bias in the zenith neutral delay between the individual GPS estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center.

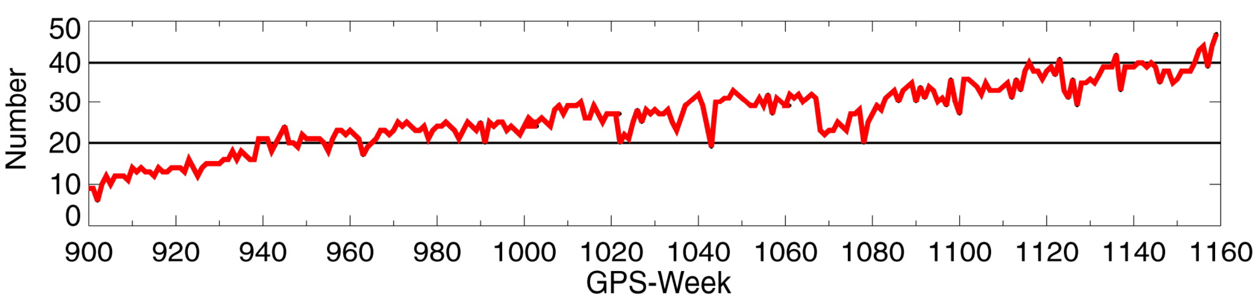

Fig. 2. Number of sites with meteorological sensors

The number of collocated meteorological sensors is improving steadily (Fig. 2), however, compared to the total of nearly 200 stations there is an obvious need for additional met packages, especially in the lower latitudes.

Test of Densification. In June 2001 the EUREF community had started a Pilot Experiment for the generation of tropospheric products. The network comprises about 150 sites (Fig. 3). Sub-networks analyzed by 15 individual EUREF ACs are combined by GFZ and BKG (since June and July, respectively) to an EUREF Tropospheric Product. The quality, checked by comparing the submissions to the combined product, is between 2.5 and 4.5 mm in the standard deviation and –6 to 3 mm in the bias. A unification of the analysis parameters (Niell mapping function, 10 degree cut-off) brought a better agreement in the bias (see Fig. 4).

The inclusion of EUREF into the IGS combination was tested during 2001. The quality of the EUREF combined product corresponds to that of the best IGS ACs (< 3mm ZTD; Fig. 5). Its bias had a jump connected with the change in the analysis strategy and is now at level of 2 mm ZTD. While the IGS weekly combined solution comprises now usually 160 sites, its number will grow to 235 adding the EUREF combination.

Summary. The quality of the IGS combined product corresponds to better than 1 mm in the water vapor content and is hence sufficient for meteorological studies. The densification with the EUREF network will be officially started as soon as EUREF finishes their pilot phase. Hopefully, other regional networks (e.g. SIRGAS, AUSLIG) can be added in future too.

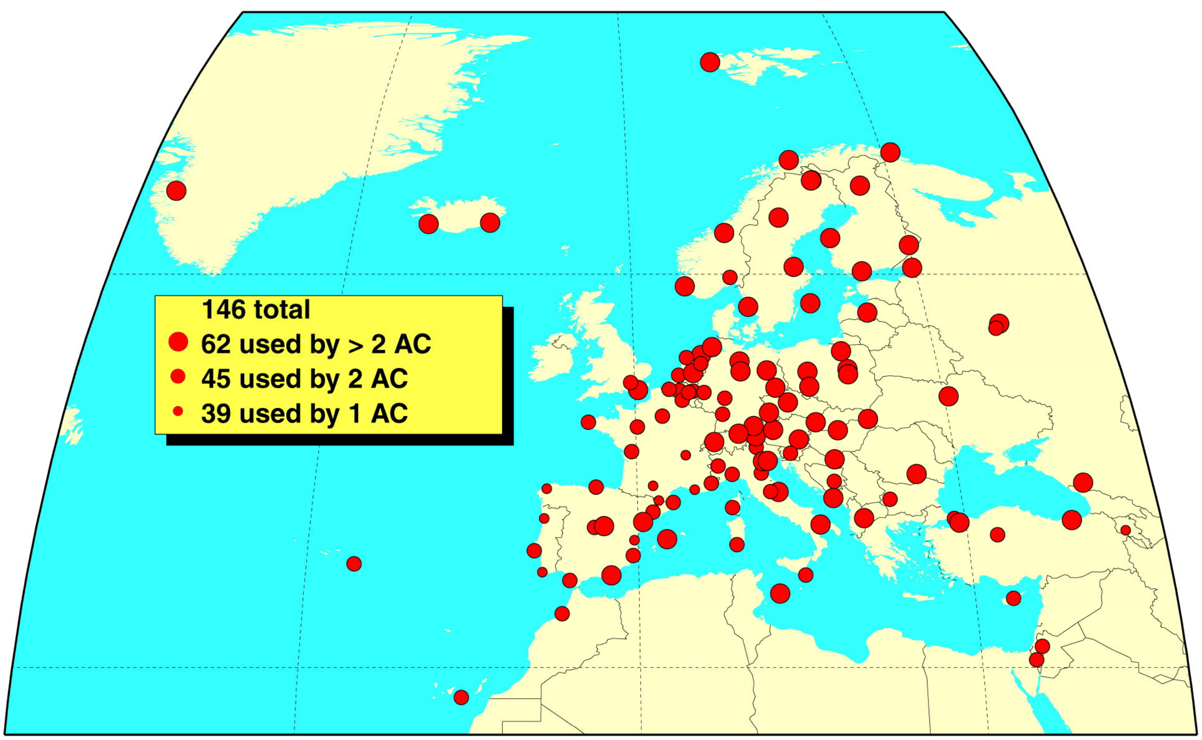

Fig. 3: EUREF network with tropospheric estimates

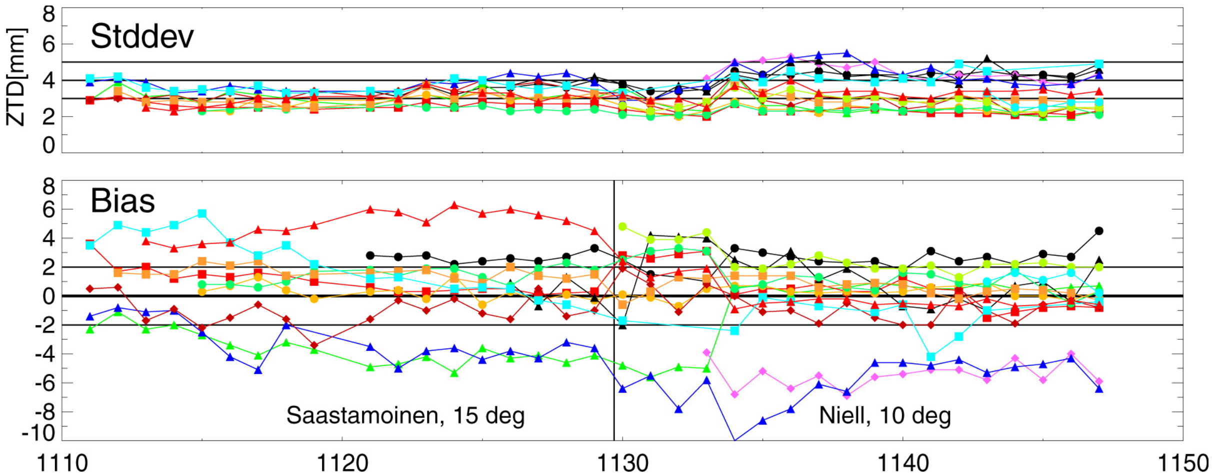

Fig. 4: Consistency within EUREF. Comparison of individual submissions to the EUREF combined product.

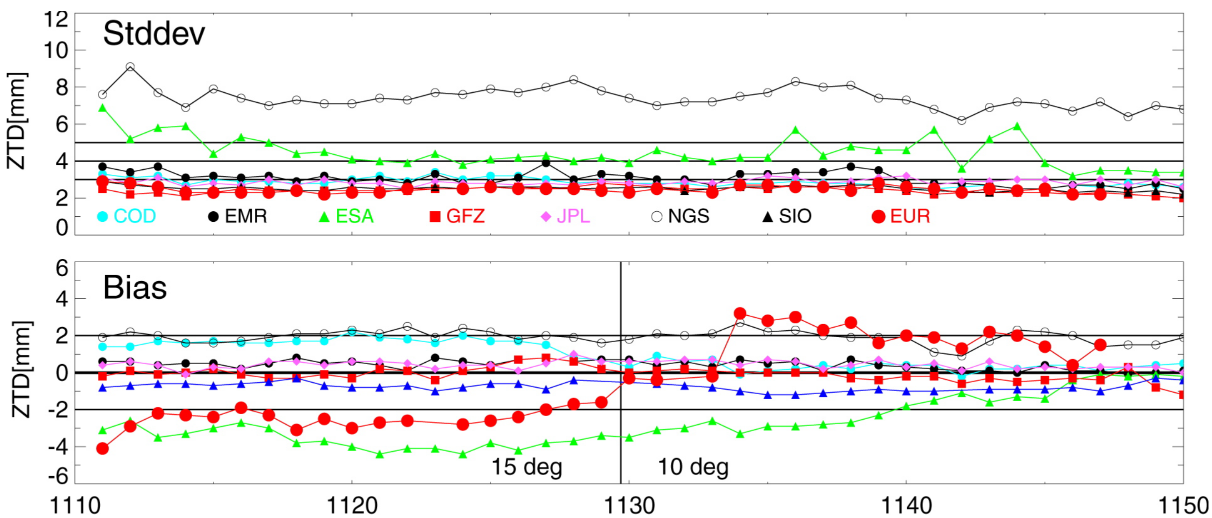

Fig. 5: Inclusion of EUREF into IGS-Combination. Comparisons to the IGS combined product.

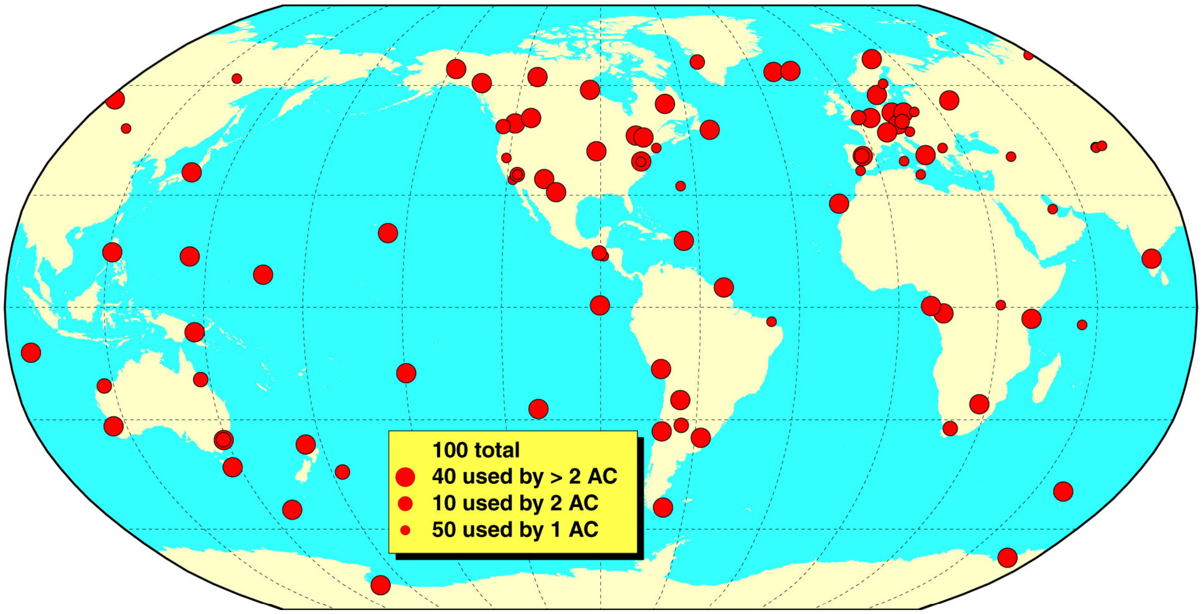

Fig. 6. IGS network with NRT tropospheric products

Towards a Near-Real-Time Product

At its 15th Governing Board Meeting in December 2000 IGS has decided to generate an hourly tropospheric product with short latency. With a Pilot Experiment, which started in June 2001, the quality of such a near real-time (NRT) product should be assessed. Initially a repetition of three hours was chosen to reduce the burden for the contributing ACs. The ACs submit a product with at least hourly resolution including the last 12 hours (or more), and the combined product is formed every three hours for the latest 12 hours. In Table 1 information on all contributions is summarized. It should be emphasized that JPL already computes real-time products.

The combination is performed as soon as all contributions are available or if after 3 hours (not to exclude late ACs) at least 2 ACs had submitted. In case of problems with ftp or hardware the combinations of old products is performed automatically as soon as possible, so that a complete set of products is available for statistics. The new product is generated with a very high reliability since more than half a year now. The network comprises about 100 stations (Fig. 6). For more than 50, which are analyzed by at least two ACs, the consistency can be checked. The differences of the NRT ACs submissions to the NRT combined product show standard deviations of 3 to 5 mm ZTD and biases in the band of ±4 mm (Fig. 7). To get an 'absolute' quality measure for the NRT products, individual and combined ones, daily files are composed from the last three hours of each NRT solution. These daily files are then compared to the IGS weekly products. For the individual ACs standard deviations from 4 to 9 mm ZTD and biases of ±3 mm can be seen, whereas the combined product has a standard deviation of 5 to 6 mm and only a small bias, which went down to 1 mm during the last months (Fig. 8).

Summary. The experiment demonstrated that a reliable NRT product in a global scale could be generated. The value of such a product lies in a quality control of regional applications (here 5-20 sites per region should be the goal). If the product should be assimilated into numerical weather prediction models then the delay has to be shortened to less than 2 hours and the update cycle has to be coordinated with the time of the model runs (possibly IGS has to go to an hourly update cycle). Both requirements could principally be fulfilled. An enlargement in the number of stations could easily be realized using the available satellites clocks for a precise point positioning for all hourly stations.

Table 1. Summary on Analysis Center contributions to NRT Trop Pilot Experiment

AC	Submission rate	No. stations	Delay[h]	Start of submission
EMR	3h	40	1:40	06/2001
GFZ	3h	35	1:15	06/2001
ESA	12h	30	2:30	07/2001
SIO	3h	36	1:50	08/2001
USNO	3h	30	2:00	09/2001
JPL	Real-time	34	0	11/2001
GOP*	3h	60	2:30	02/2002

* GOP- Geodetic Observatory Pecny, EUREF Analysis center

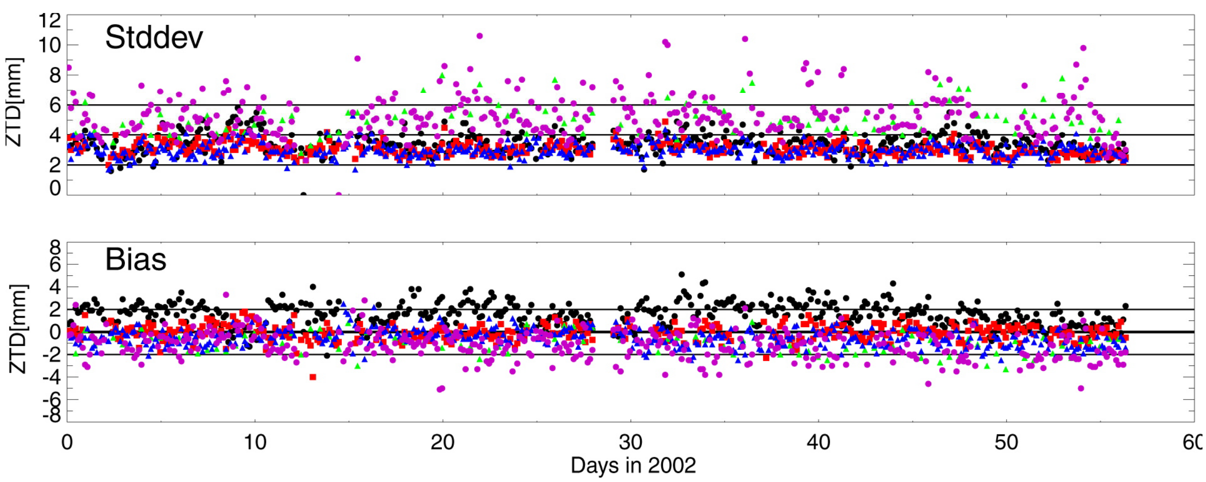

Fig. 7. Difference of NRT Analysis Center solutions to the NRT combined product. (Each symbol corresponds to one Analysis Center.)

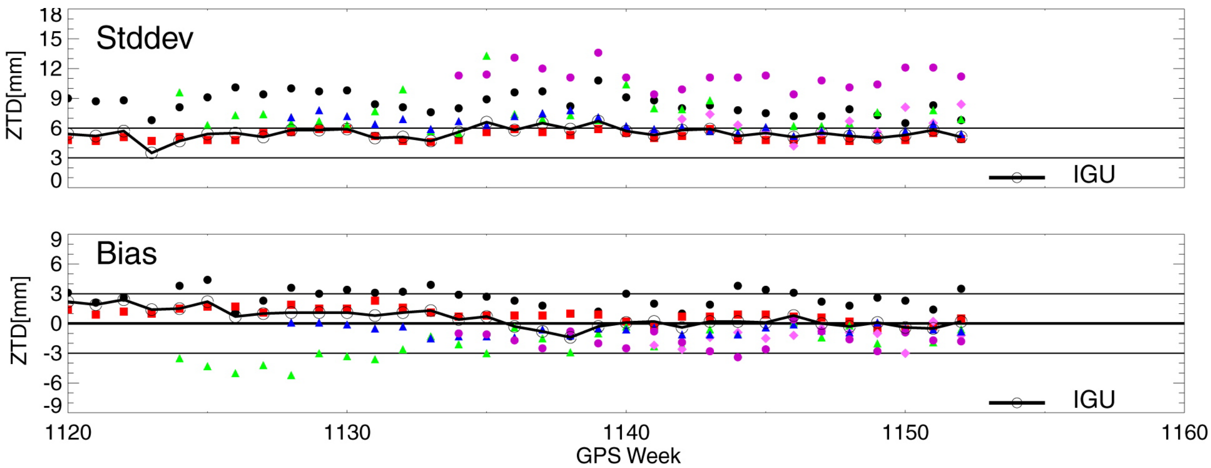

Fig. 8. Difference of NRT Analysis Center and NRT combined solution to the IGS Final weekly product. (For comparison daily NRT files are composed by last 3 hours of all NRT solutions. Each symbol corresponds to one Analysis Center.)

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2001 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 Total Electron Content (TEC) maps plus differential code biases (DCBs) with a delay of some days. In the year 2001, to which this Technical Report is dedicated to, the delivery of DCBs was restricted only to those of the GPS satellites. At the time when this Technical Report was written in August 2002, the routine delivery of station DCBs was implemented too.

In the medium- and long-term, the working group intends to develop more sophisticated algorithms for deducing mappings of ionospheric parameters from GPS measurements and to realize near-real-time availability of IGS ionosphere products. 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:

+ CODE ..... Center for Orbit Determination in Europe,
  Astronomical Institute, University of Berne, Switzerland.
+ ESOC ..... European Space Operations Centre of ESA, Darmstadt, Germany.
+ JPL ...... Jet Propulsion Laboratory, Pasadena, California, U.S.A.
+ NRCan .... Natural Resources Canada, Ottawa, Ontario, Canada.
+ 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 2001.

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 ground station receivers DCBs were included in July 2002).

Weekly Comparisons

On Wednesday of each week the TEC maps from the different IAACs are compared for all days of the week before. These comparisons are done at the IGS Ionosphere Associate Combination Center (IACC) at 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, ftp anonymous@nng.esoc.esa.de .

The IAACs use very different approaches to establish their TEC maps, resulting in very different temporal and spatial resolutions, and the RMS maps provided in the IAACs IONEX files represent only the internal accuracy of the respective approach. These circumstances reflected strongly in the comparison results, and it became clear quite soon, that the old comparison scheme (Feltens 2000a, Appendix B and Feltens 2000c, Appendix B) had to be improved. The Iono_WG thus decided to upgrade the comparison/combination algorithm with a geographic-dependent weighting, whereby the individual IAACs-weights are derived from external validations with self-consistency tests (Feltens 2000a, Appendix A and Feltens 2000c, Appendix A). The weekly comparisons are done with this new approach since August 2001. The external validations needed for this method are made routinely by the Ionosphere Associate Validation Centers (IAVCs) UPC and NRCan prior to the weekly comparisons at the IACC at ESOC. The transition from the old approach to the new one with the weights derived from external validations was done with an overlap time of four weeks from 19 August 2001 until 15 September 2001, i.e. during that time the comparisons were run with both methods. Figures 1a, 1b, 1c, and 1d show the different IAACs the global offsets and the weighted rms values with respect to the weighted mean IGS TEC map, obtained with the new and with the old method (the plots of the old method end on 15 September). The plotted values were taken from the Table 1 of the daily short summary "igsg{ddd}0.{yy}s" (the values are denoted in Table 1 as "o" "S" in the old summary and as "o" "W" in the new summary).

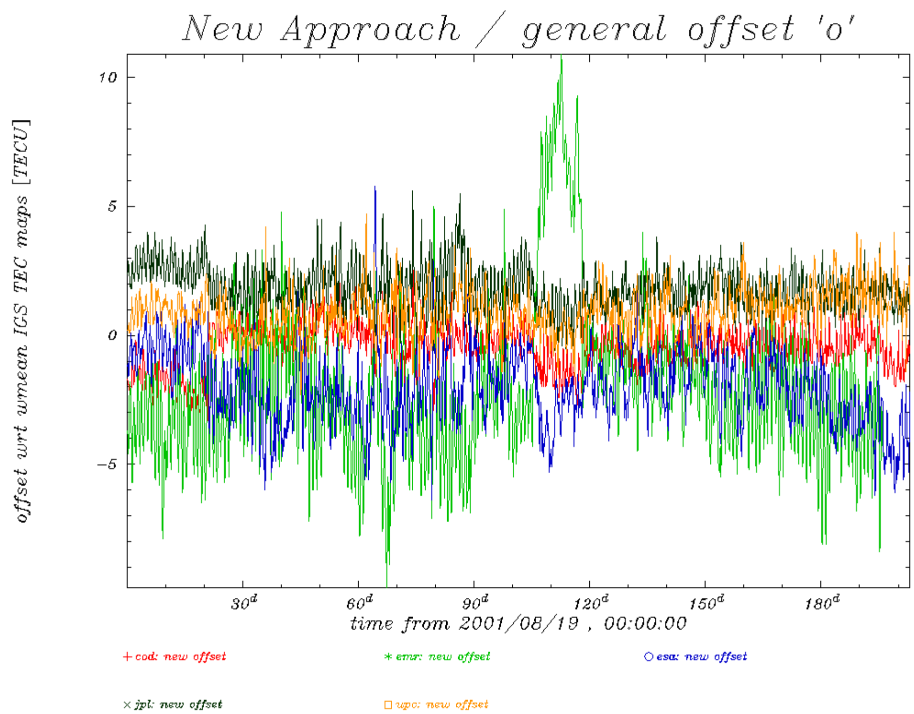

Figure 1a. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

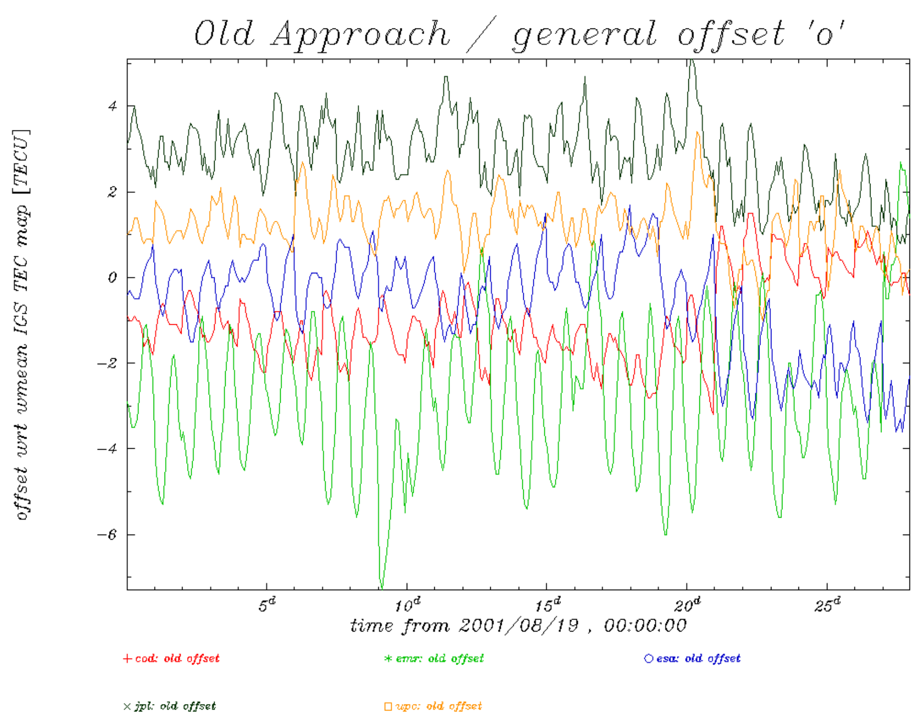

Figure 1b. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

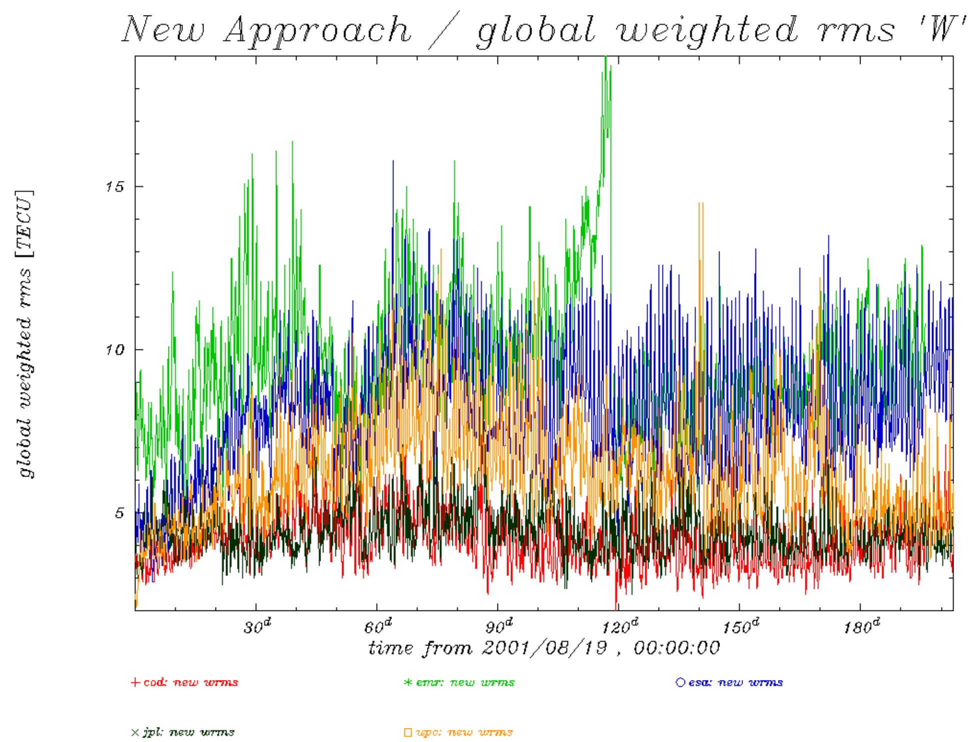

Figure 1c. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

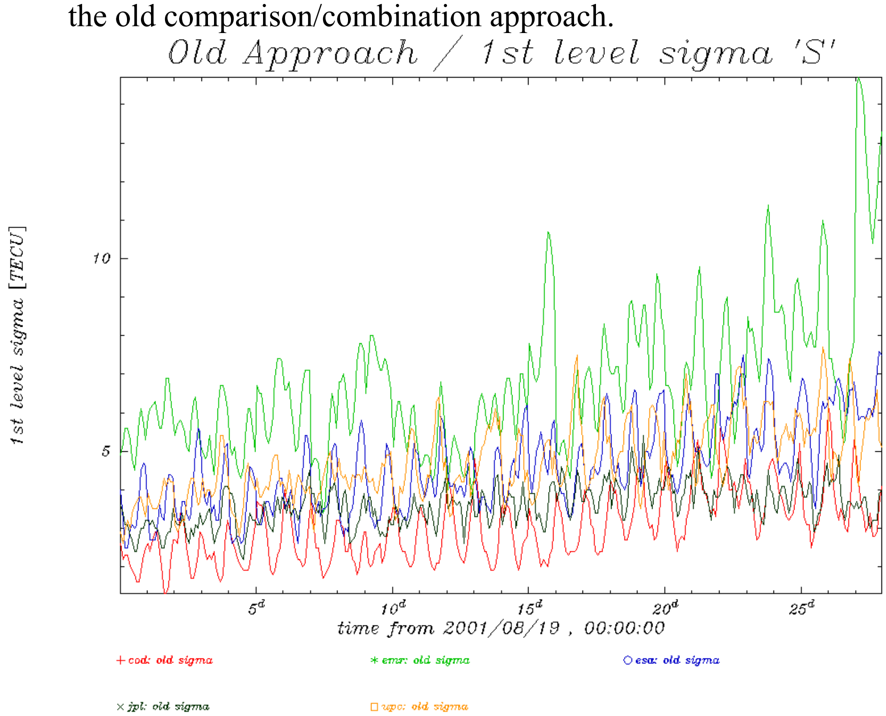

Figure 1d. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

The curves in Figures 1a, 1b, 1c, and 1d seem to indicate that the new comparison/combination approach favours the higher quality TEC maps more than the old approach did.

On the northern hemisphere the deviations of the different IAAC TEC maps from the IGS "mean" are under normal conditions 5 TECU or less. On the southern hemisphere and especially at the equator 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, and the densification of the IGS ground sites net is ongoing.

Inherent in the application of the geographic-dependent weights, i.e. in assigning constant weight values to discrete geographic "areas", is a "chessboard-like" pattern of the weights when drawing them into a global map, and this pattern is then propagated into the combined RMS maps and sometimes also into the combined TEC maps (at the time when this Technical Report was written this problem had been solved by using global weights derived from the geographic-dependent ones from June 2002 on).

The day-by-day variations of the different IAAC GPS satellite DCBs series provided by most of the IAACs are quite constant, oscillating between 0.2 and 0.4 nanoseconds around their mean values.

TOPEX Validations

Since July 2001 JPL provides VTEC data derived from TOPEX altimeter observables to the working group to enable validations. At the IACC at ESOC a dedicated computer program has been set up to do that task; its runs are attached to the weekly comparisons.

Due to its orbital geometry TOPEX scans every day only a limited band of the ionosphere. Additionally, the TOPEX data may be biased by +2-5 TECU. These two aspects must be kept in mind when interpreting the validations with TOPEX VTEC data.

Principally these TOPEX validations work as follows: JPL provides per day a so-called TOPEX file containing VTEC values derived from TOPEX altimeter data in dependency of time, latitude and longitude. VTEC values are then interpolated in the different IAACs IONEX files for the same times/latitudes/longitudes, of which the corresponding TOPEX VTEC values are then subtracted. The VTEC-differences thus obtained are used to establish different kind of statistics, like mean daily offsets & related rms values for each IAAC. The TOPEX validation results are made available at ESOC's FTP account at the same place where also the comparison products can be found: ftp anonymous@nng.esoc.esa.de. They are always stored within the comparisons directory for a certain day in the subdirectory ~/TOPEX. For details see the TOPEX validation short - and long summary files located in these ~/TOPEX subdirectories.

Figures 2a, 2b, and 2c condense the basic statistics that were obtained from the TOPEX validations since 19 August 2001. The numbers plotted here were taken from the daily TOPEX validation long summaries "tpxobs.long.sum" and are denoted there as (see also Feltens, 2002a, Section 3.2, Figure 5):

mean	mean IAAC VTEC offset with respect to the TOPEX VTEC values, i.e. the mean value over n differences, d = tecval(IAAC) - TOPEXtec,
rms-diff	RMS of differences,
rms	RMS of residuals with respect to the mean.

In the meantime the following two statistics parameters were included too (Feltens, 2002a and Feltens 2002c):

sf/rms	estimate of the scale factor of the rms-values obtained from the TOPEX validation in relation to the corresponding IAAC rms values, should be close to one for IAAC = IGS, i.e. for the combined TEC maps,
wrms	a "mean" rms that might be an indicator for a TEC map's quality.

The TOPEX validations are done globally for all latitudes ("+90..-90") and separately also for medium and high northern latitudes ("+90..+30"), equatorial latitudes ("+30..-30") and medium and high southern latitudes ("-30..-90"). The daily TOPEX validation short summary "tpxobs.short.sum" contains only the global values. Beyond the IAACs TEC and the IGS TEC, also TEC computed with the GPS broadcast model ("gps") and TEC computed with CODE's Klobuchar-Style Ionosphere Model ("ckm") enter into the daily TOPEX validations. The latter two are provided by CODE. When inspecting the results from the different latitude bands one recognizes immediately that the best agreement of the distinct ionosphere models with the TOPEX data is achieved at medium and high northern latitudes, while the worst agreement is in the equatorial region. The agreement in the southern medium and high latitudes is more worse than in the northern ones, but as far as not as worse as in the equatorial latitude band.

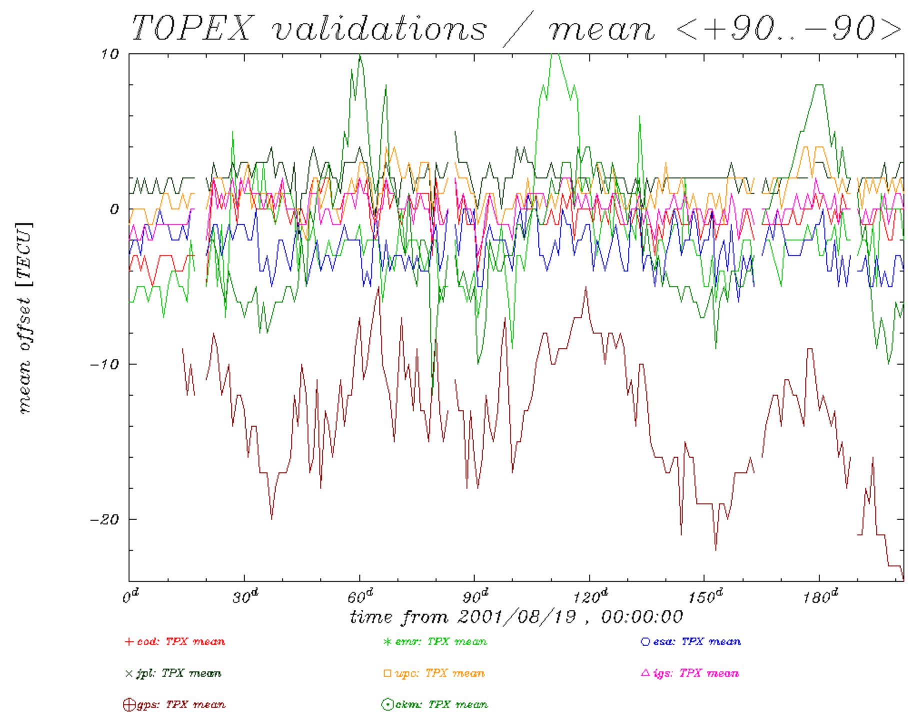

Figure 2a: The basic TOPEX validation statistics mean, rms-diff and rms.

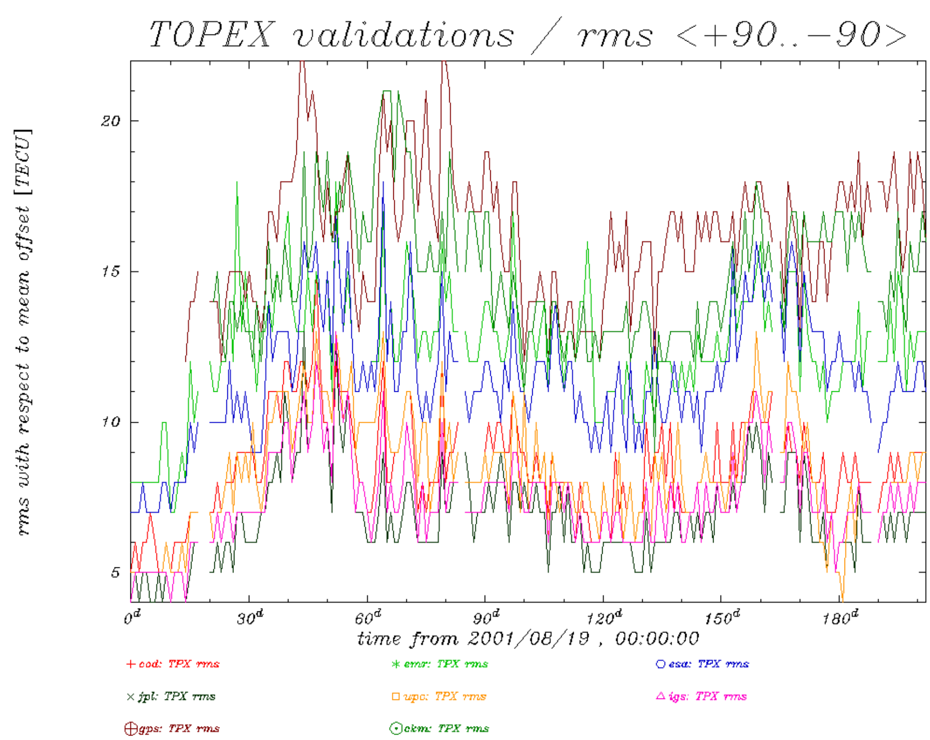

Figure 2b: The basic TOPEX validation statistics mean, rms-diff and rms.

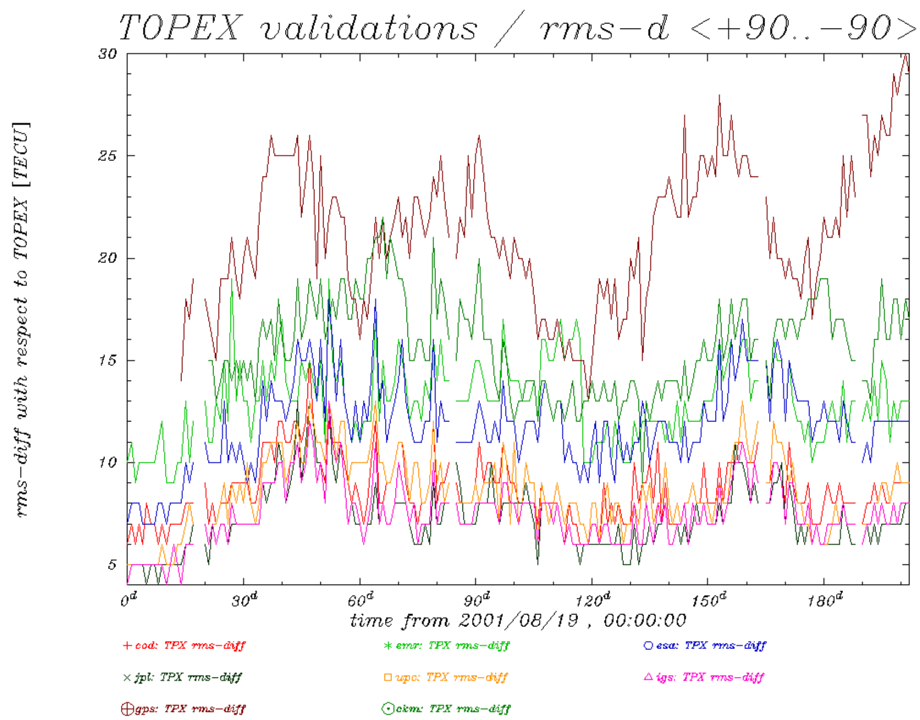

Figure 2c: The basic TOPEX validation statistics mean, rms-diff and rms.

The other thing that can be seen from Figures 2a, 2b, and 2c is that the IAACs TEC and the IGS TEC values, which are derived from GPS dual-frequency data, are considerably closer to the TOPEX TEC than the Klobuchar and especially the GPS broadcast model - and what is essential for the delivery of a combined IGS Ionosphere Product: The routine validations with TOPEX since July 2001 show an agreement of the "combined" IGS TEC maps with the TOPEX data on the same order as the best IAACs TEC maps.

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. In the year 2001 the HIRAC/SolarMax campaign did run from 23 - 29 April: About 100 IGS sites, being located at the northern and southern polar regions and in the low latitudes including the crest regions at both sides of the geomagnetic equator, recorded over 7 days dual-frequency GPS data with 1- and 3-second sampling rates. This IGS/Iono_WG activity was coordinated with other ionospheric observation programs or measurement campaigns using ionosondes, EISCAT, high resolution magnetometers, etc. to obtain a comprehensive view of the geomagnetic and ionospheric state. The high rate GPS and GLONASS data are archived at the CDDIS and are open to research groups to study the ionosphere's behavior under solar maximum conditions (Feltens et al., 2001). The data are available at the CDDIS at ftp://cddisa.gsfc.nasa.gov/gps/01solarmax .

Figure 3 shows a global map with all IGS sites involved.

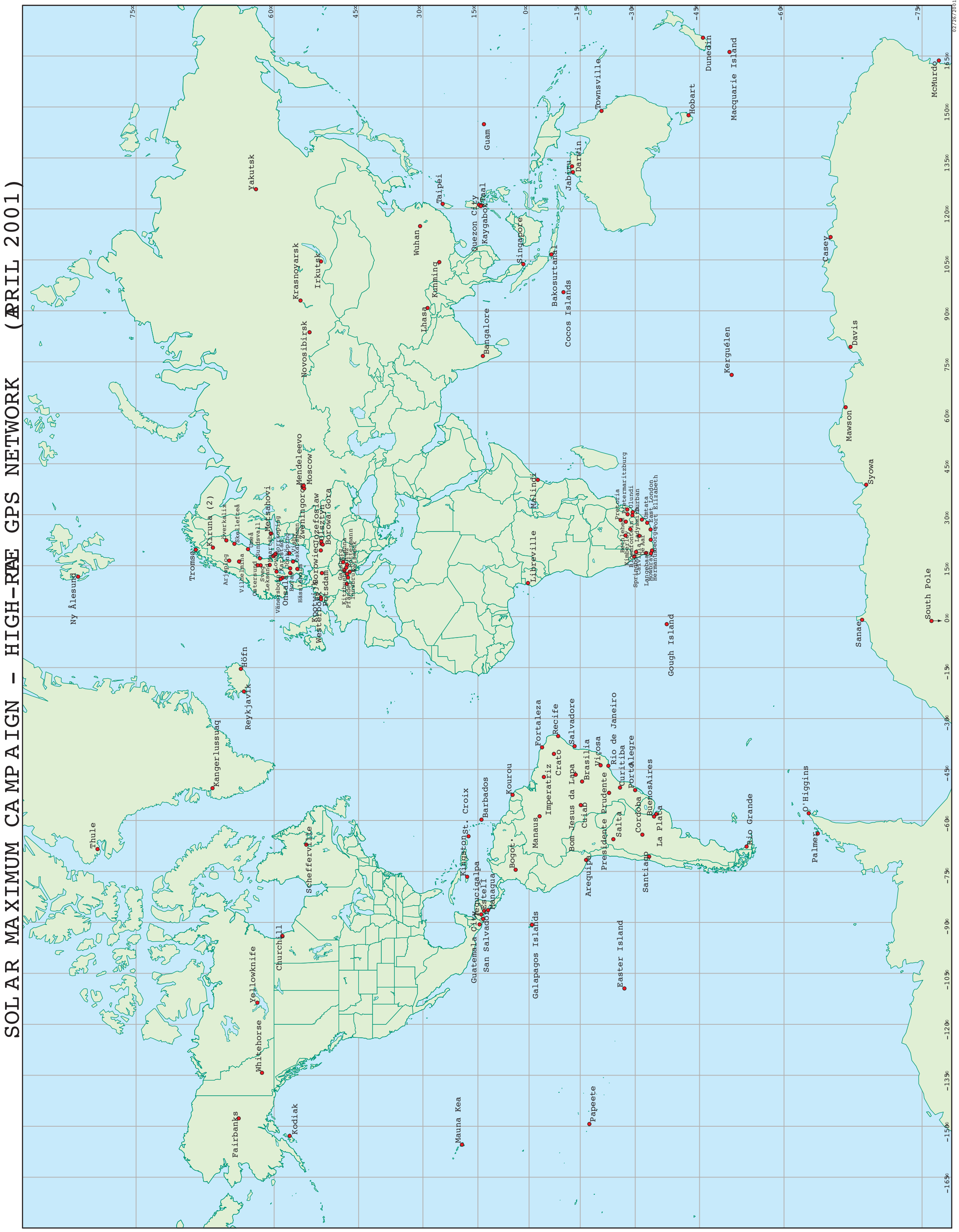

Figure 3: The HIRAC/SolarMax Campaign GPS/GLONASS Network (courtesy C. Noll, CDDIS).

Future Tasks

At the IGS/IAACs Ionosphere Workshop at ESOC in Darmstadt, Germany, January 17-18, 2002 (Feltens, 2002b), and at the IGS Analysis Center Workshop at NRCan in Ottawa, Canada, April 8-11, 2002 (Feltens, 2002c), proposals and decisions were made on how to progress to bring the Iono_WG soon into a position to start, after the implementation last required upgrades in the comparison/combination program, with the routine delivery of a combined IGS ionosphere product. Some of these upgrades, like the global weights derived from the local weights and the inclusion of station DCBs, were done in the meantime (August 2001), others, like the change to even hour numbers, i.e. 0h, 2h, 4h, 6h, ... , 24h, for the combined IGS TEC maps and the improvement of the comparison/combination program output are currently under work. It is planned to complete these upgrades by the end of September 2002, so that the Iono_WG can then start with the routine delivery of an official combined IGS Ionosphere Product.

Beyond that major target, it is intended to implement, in addition to the TOPEX validations, also routine validations with ENVISAT and JASON satellite altimeter data during 2002.

The reduction of IGS ionosphere products delivery times up to a realization of a near-real-time service will then be another very important task and also the enhancement of the time resolution of ionosphere TEC maps to less than two hours. Corresponding pilot projects are planned.

Another aspect would the inclusion of other than GPS data, like Champ profiles, and considerations concerning the establishment of 3-d ionosphere models.

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IGS LEO Pilot Project

H. Boomkamp, J. R. Dow

In comparison to ground-based tracking systems like SLR or DORIS, on-board GPS offers the important advantage of continuous tracking coverage of a low Earth orbit, without needing a complex network of tracking stations. To the LEO missions this means that GPS has become an attractive, straightforward tracking system, which is why there will be five operational low Earth orbiting satellites with a GPS receiver on board. To the IGS the LEO can form an orbiting tracking station for the GPS constellation itself that may provide information that is not available from Earth-based stations. The primary goal of the IGS LEO Pilot Project is to explore the ways in which LEO GPS data may enhance the IGS products.

The year 2001 marked the release of the first substantial LEO datasets, first from CHAMP and later from the SAC-C mission. Some initial problems with SAC-C lead to a situation where most centers concentrated on the CHAMP data. The orbital height of CHAMP varies from about 450 km just after launch to below 300 km at the end of its operational life (~2006 or later). At this low altitude a satellite is very sensitive to orbit perturbations due to high-degree gravity field harmonics - which illustrates the main mission objective - and due to atmospheric effects. Accordingly, the IGS Associate Analysis Centers that started working on the CHAMP data soon found out that precise orbit determination for such low satellites is much more difficult than it is for the GPS satellites.

Although it is not obvious what precision level is required before the LEO data can have some positive impact on the IGS products, the initial POD precision for CHAMP was around 25 cm RMS or worse, which is an order of magnitude larger than the typical precision with which Earth-based IGS station coordinates are known. It was generally considered premature to start analyzing data in IGS context from a single LEO at a precision level that must be considered incompatible with that of the IGS products. By consequence the principal interest became to improve POD quality at the centers that were working on the CHAMP data. To this purpose the CHAMP Orbit Comparison Campaign was initiated in September 2001, in which ultimately 13 different Centers participated (see Table 1). The status of the CHAMP campaign – which will continue as long as centers keep sending new contributions - can be found on the IGS LEO PP website at http://www.nng.esoc.esa.de/gps/igsleo.html.

To further assist the AACs in their efforts of processing the CHAMP data, GFZ agreed to organize a CHAMP user meeting in October 2001, which was attended by representatives of many of the participating centers, and was well received. Towards the end of the year 2001 several of the centers approached POD precision levels of around 5 cm RMS. This showed that there should no longer be fundamental difficulties in GPS-based POD for low satellites. It also became clear that several AACs had to implement substantial changes in their software before reaching the same precision levels. These initial technical difficulties have so far limited the extent to which LEO GPS data could be analyzed for IGS purposes, but rapid progress can be noticed among the centers that participate in the LEO Pilot Project.

Table 1: Associated Analysis Centres participating in the CHAMP Orbit Campaign 2001

ASI	Agenzia Spaziale Italiana, Matera, Italy
AIUB	Astronomical Institute, University of Bern, Switzerland
CNES	Centre National d'Etudes Spatiales, Toulouse, France
CSR	Centre for Space Research, University of Texas, USA
DEOS	Delft institute for Earth Oriented Space Research, The Netherlands
ESOC	European Space Operation Centre, Darmstadt, Germany
GFZ	GeoForschungs Zentrum, Potsdam, Germany
GRGS	Groupe de Recherche de Geodesie Spatiale, Toulouse, France
JPL	Jet Propulsion Laboratory, Pasadena, USA
NCL	Newcastle University, UK
TUM	Technical University of Munich, Germany
UCAR	University Corporation for Atmospheric Research, USA
UNB	University of New Brunswick, Canada

Table 2: Highlights of IGS LEO Pilot Project

1999

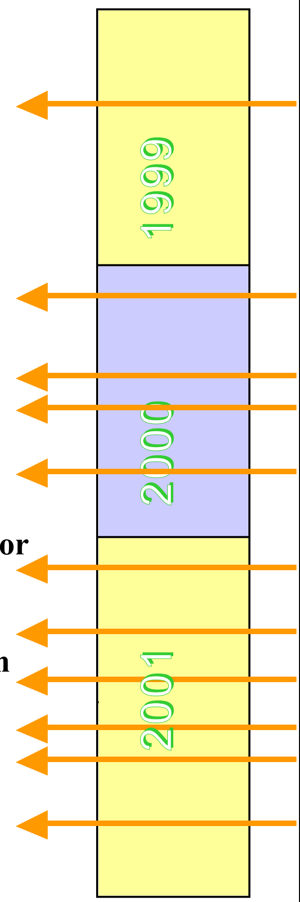
- ***March*** **Potsdam workshop recommendations for starting PP**

2000

- ***January*** **Call for participation IGS Mail 2669**
- ***April*** **LEO proposals deadline - 26 proposals**
- ***July*** **Launch of CHAMP**
- ***November*** **Launch of SAC-C**

2001

- ***February*** **LEO Working Group Meeting, Potsdam**
- ***May*** **Release of CHAMP data - ESOC AAC Coordinator**
- ***Summer*** **Implementation of CHAMP processing at AAC**
- ***September*** **Call for participation in CHAMP Orbit Campaign**
  Release of SAC-C data
- ***October*** **CHAMP user meeting Potsdam**
- ***December*** **First results of CHAMP campaign**
  Launch of JASON



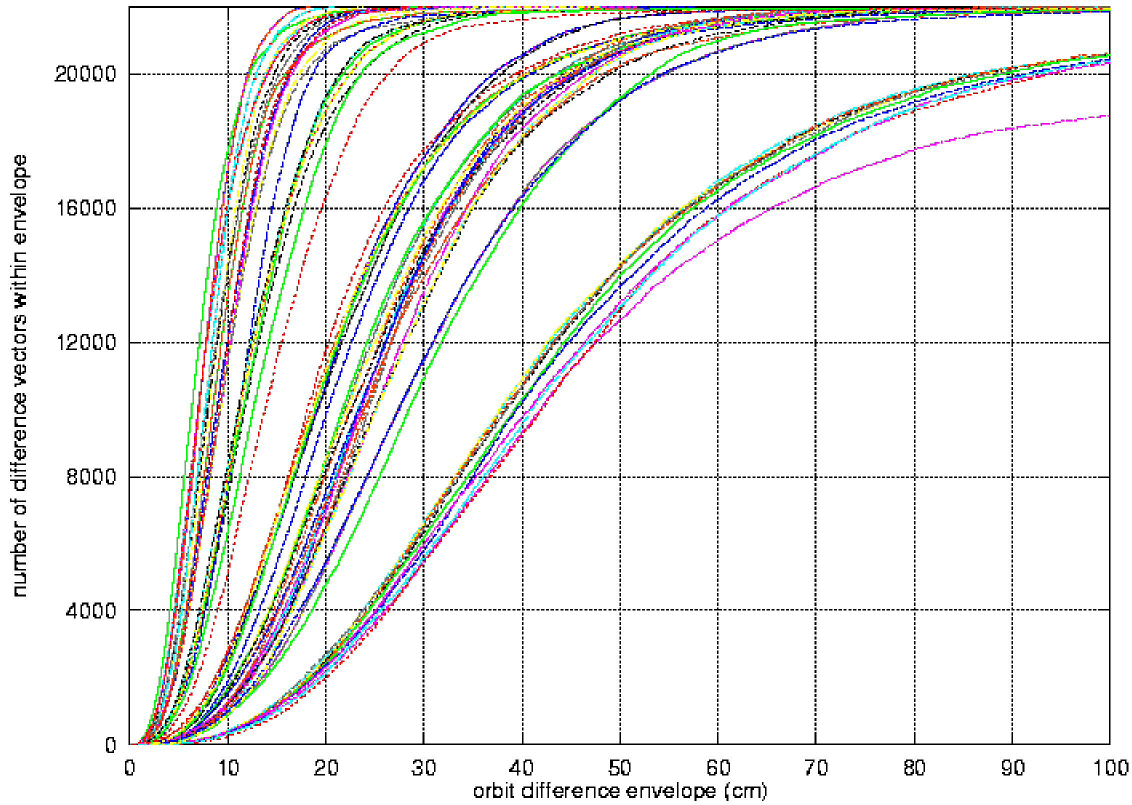


Figure 1: CHAMP orbit difference distributions for the 78 comparisons that can be formed between 13 independent solutions. The RMS over 22000 sample points varies from 8.3 cm (top curves) to 60 cm (lowest curves).

A different issue has been some lack of clarity about the organization of the IGS LEO Pilot Project. The IGS LEO Working Group has existed since 1999, but by May 2001, when ESOC took on the role of IGS LEO Associated Analysis Center coordinator, there had been no concrete activities within the Pilot Project (mainly because of the lack of LEO data). When the LEO data arrived and the technical difficulties were being solved, it became apparent that the maturity of LEO data processing differed widely among the participating Associate Analysis Centers. In general three categories of AACs can be identified:

- Centers that have been involved with the CHAMP or SAC-C mission from the start, and have had access to the data and satellite information since its launch: GFZ, JPL, GRGS.
- Centers that were not directly involved with the CHAMP mission but that had adequate expertise in LEO POD combined with state of the art processing systems: e.g. CSR, DEOS, TUM.
- Centers that have experience with GPS orbits and clocks, but little or no experience with LEO satellites. By the time that the data was released, these centers discovered that they need substantial changes to their processing systems to reach state of the art precision levels for CHAMP data processing.

Independent of this, a difference in emphasis can be noticed between typical LEO groups, which mainly consider the GPS data as a means for generating precise LEO products, and typical IGS (associate) analysis centers that prefer to look at the LEO data as if implementing a new IGS station.

Diversity in processing methods and diversity in emphasis among participating centers are traditionally the strengths of the IGS, but the risk of incoherency must of course be avoided. An important goal for the immediate future is therefore to focus the LEO Pilot Project on its principal objectives, and to define a clear set of long-term and short-term objectives.

A single LEO platform like CHAMP or SAC-C is valuable to implement data processing flows, but will probably not bring a notable enhancement of the routine IGS products. The launches of JASON-1 in December 2001 and the twin GRACE satellites in March 2002 ensure that there will soon be flight receiver data from five operational LEO satellites. Their number is only expected to grow in the future, and it is not unrealistic to predict that a constellation of twenty GPS LEO platforms will be reached within the second decade of this century. An entire new approach to IGS product generation may be on the horizon, but before this can be confirmed or discarded a substantial effort must be invested in LEO data analysis. The bulk of these analysis activities will take place in the two or three years to come, so that the IGS LEO Pilot Project can look forward to very interesting times.

TIGA - Tide Gauge Benchmark Monitoring Pilot Project

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Introduction

The TIGA Pilot Project was initiated in response to the demanding need for highly precise height coordinates and their changes with time at tide gauge benchmarks. TIGA was formally established during the 16th IGS Governing Board Meeting in Nice (April 2001).

For the first time it is not the intention of the IGS to provide results with a very low latency, but to have as many stations included as possible. The primary product of the service is time series of coordinates for analyzing vertical motions of Tide Gauges (TG) and Tide Gauge Benchmarks (TGBM). All products will be made public to support and encourage other applications, e.g. sea level studies. In particular, the products of the service will facilitate the distinction between absolute and relative sea level changes by accounting for the vertical uplift of the station, and are, therefore, an important contribution to climate change studies. The service may further contribute to the calibration of satellite altimeters and other oceanographic activities. The pilot project will operate for a period of three years, from 2001 to 2004. After this period the IGS Governing Board will evaluate the project and decide whether or not this activity should become a regular IGS service function.

The goals of the TIGA-PP are identified as follows:

1. Establish, maintain and expand a global Continuous GPS at Tide Gauges (CGPS@TG) network
   - Select a set of GPS-equipped tide gauges with a long and reliable history practicable for both sea level change studies and satellite altimeter calibrations.
   - Apply IGS network operation standards.
   - Promote the establishment of more continuously operating GPS stations in particular in the southern hemisphere.
   - Promote the establishment of links to other sites, which may contribute to vertical motion determination, e.g., VLBI, SLR, DORIS and/or absolute gravity stations.
   - Develop recommendations for a minimum technical standard of the whole tide gauge system to be included into the Pilot Study, e.g., sensor types, the nature of the leveling program, and metadata documentation.

2. Contribute to the procedures in which IGS realizes a global reference frame in order to improve its utility for global vertical geodesy. This may involve reprocessing a significant subset of the (past and present) IGS global tracking data set.

3. Compute precise station coordinates and velocities for the CGPS@TG stations using a processing stream that runs months behind real-time in order to include the largest possible number of stations. This effort will incorporate all previously collected GPS data at each CGPS@TG station. Later on the combined solution will have a maximum latency of one year.

4. Establish a secondary processing stream with much reduced latency in order to support operational activities that cannot tolerate large processing delays.

5. Monitor the stability of the network.

The progress of the project and other related information is maintained at the WEB site http://op.gfz-potsdam.de/tiga/. The full Call for Participation can be found at http://op.gfz-potsdam.de/tiga/DOWNLOAD/TIGA_CfP.pdf.

Major Steps

An initial meeting was held during the APSG Sea Level Workshop in Hawaii (April 2001). A wide range of experts attended this meeting from the tide gauge as well the GPS community. A very intensive discussion took place aiming at the goals and deliverables of TIGA. Participants agreed on two main points. The first is that the completeness of data has a much higher priority than the latency of the processing stream. A second, only CGPS@TG's will be considered in a final solution for which all information, including the leveling data, is freely available to the scientific community.

Consequently, a Call for Participation was drafted and issued in June 2001. In total 23 Letter of Intent arrived, while finally 15 proposals were submitted. Proposals are covering all components of TIGA. These components are in particular TIGA Observing Stations (TOS), TIGA Data Center (TDC, 6 proposals), TIGA Analysis Centers (TAC, 8 proposals), and TIGA Associate Analysis Centers (TAAC, 2 proposals).

By the end of 2001 the review of the proposals was completed and a Letter of Acceptance was sent out.

TIGA Components

TIGA Observing stations are primarily, but not exclusively, existing IGS and EUREF stations. Some agencies are providing now also their GPS data not previously part of the IGS. Due to the higher latency of the processing also data from remote stations can be included into the routine analysis. A site information log for TOS was developed displaying necessary additionally information for each tide gauge. This log sheet supplements the standard IGS log. A plot of current TIGA Observing Stations is given in the figure attached. TOS forms are available at the TIGA web page.

TIGA Analysis Centers will process data in different chains. The primary chain will have a latency of 460 days, which allows also the very remote stations, e.g. from Antarctica, to provide their data. A secondary chain will provide solutions with a very short latency to support operational aspects. In addition a few processing centers have agreed to re-compute a selected subset of the IGS and other network data (including a retro-processing of IGS station data for CGPS@TG) for an improved long-term stability of the reference frame since the inception of the IGS.

TIGA Associate Analysis Centers will facilitate TIGA in two different ways. This ranges from the processing of a selected regional subset of CGPS@TG stations, while others will analyze the results of the TAC's in various ways, including comparisons to other space techniques or absolute gravity measurements.

As a new component, TIGA Data Center will not only store and re-distribute GPS data, but also metadata. They will fulfill three functions:

1. Store GPS data sent by different media (FTP, computer tapes, CD-ROM, diskettes, etc.) with high and changing latency.
2. Store Metadata (e.g. leveling data, sketch maps of the TG) of any kind (e.g. computerized, handwritten, microfiches, etc.)
3. Establish links to Tide Gauge Data Centers for easy and convenient data access.

Future Tasks

By 2002 a regular service will be established for the continuous processing of CGPS@TG data. Starting with a high latency processing chain, the reprocessing of older data will be initiated too.

Also by 2002 more TOS stations will become available to complement the existing network. A main and important task will be also the constant effort for the establishment of more leveling ties to tide gauge benchmarks.

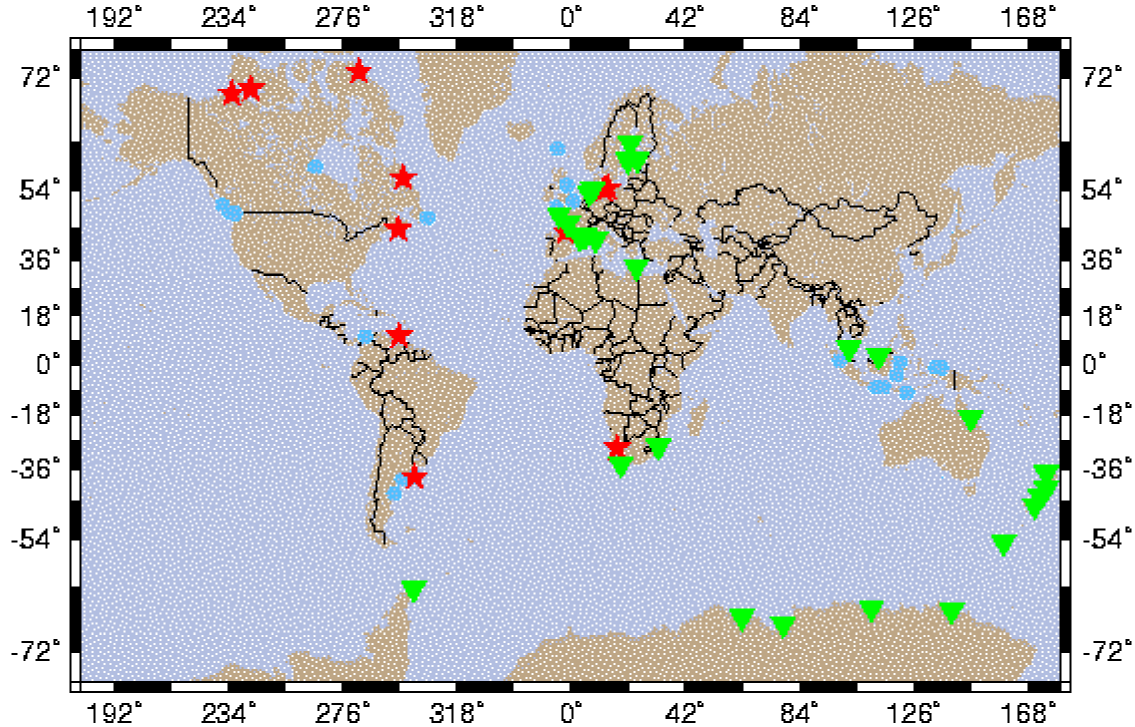

Figure 1: Overview about the current status of TOS stations (as of August 2002)
For few stations (triangles) all necessary information is available. In the near future, more stations will become available (dots). In response to the TIGA Call for Participation also new GPS stations will be installed near tide gauges (stars).