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.

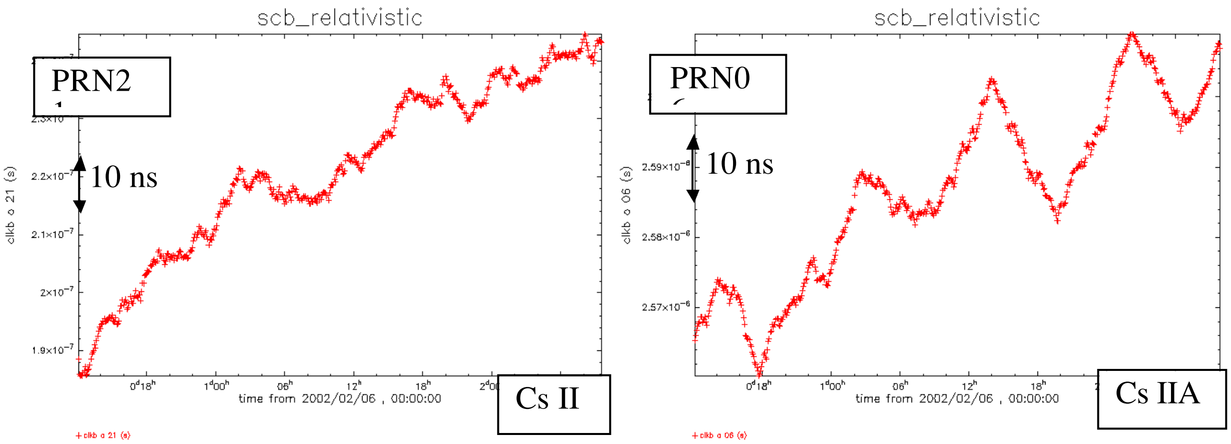

Fig. 1: Satellite clock biases estimated for 48 hrs from 12:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

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).

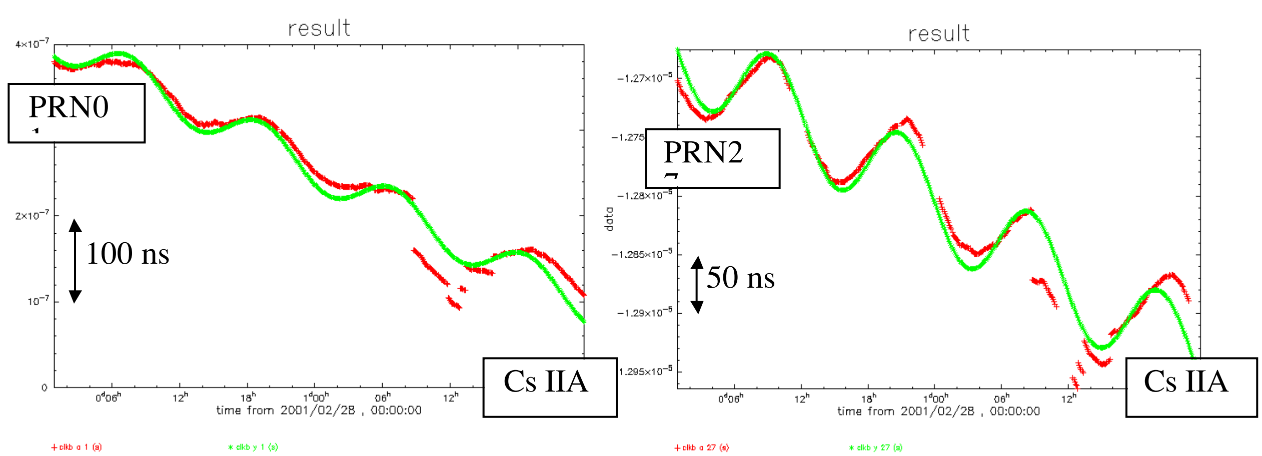

Fig. 2: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 28th,2001 (01059) (with the relativistic correction still included).

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.

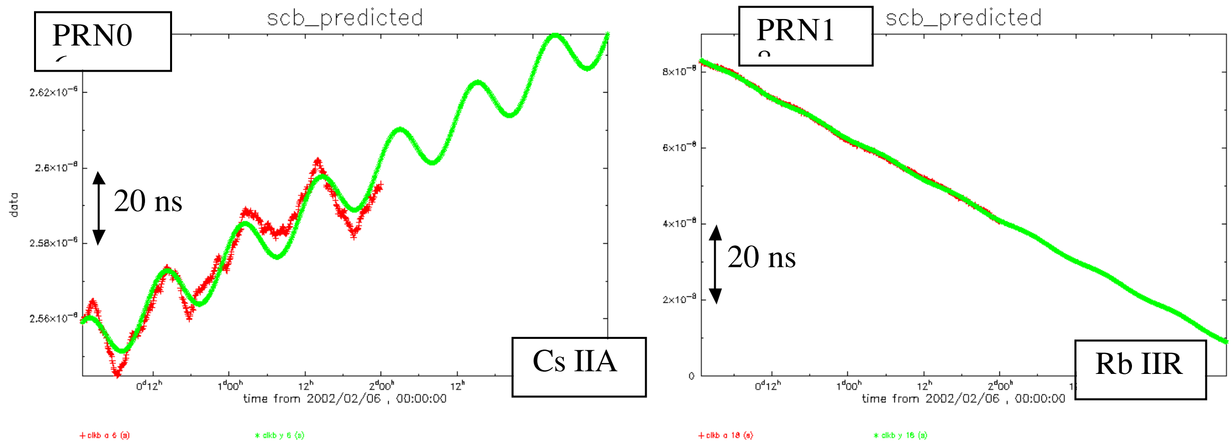

Fig. 3: Satellite clock biases estimated (red) and predicted (green) from 00:00 Feb 6th,2002 (02037) (with the relativistic correction removed).

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.

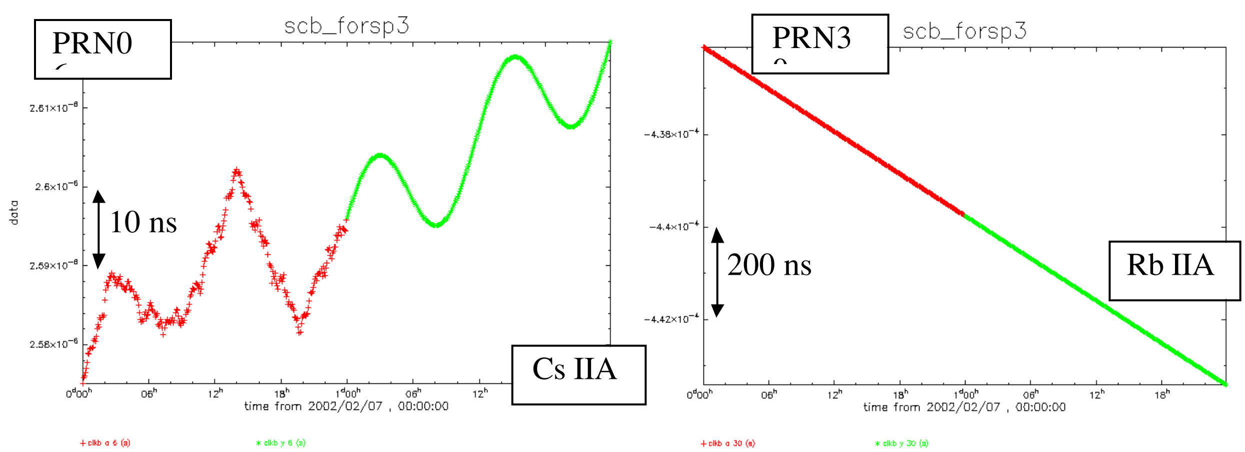

Fig. 4: Satellite clock biases estimated (red) and predicted (green) for 48 hrs from 00:00 Feb 7th, 2002 (02038) (with the relativistic correction removed).

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.

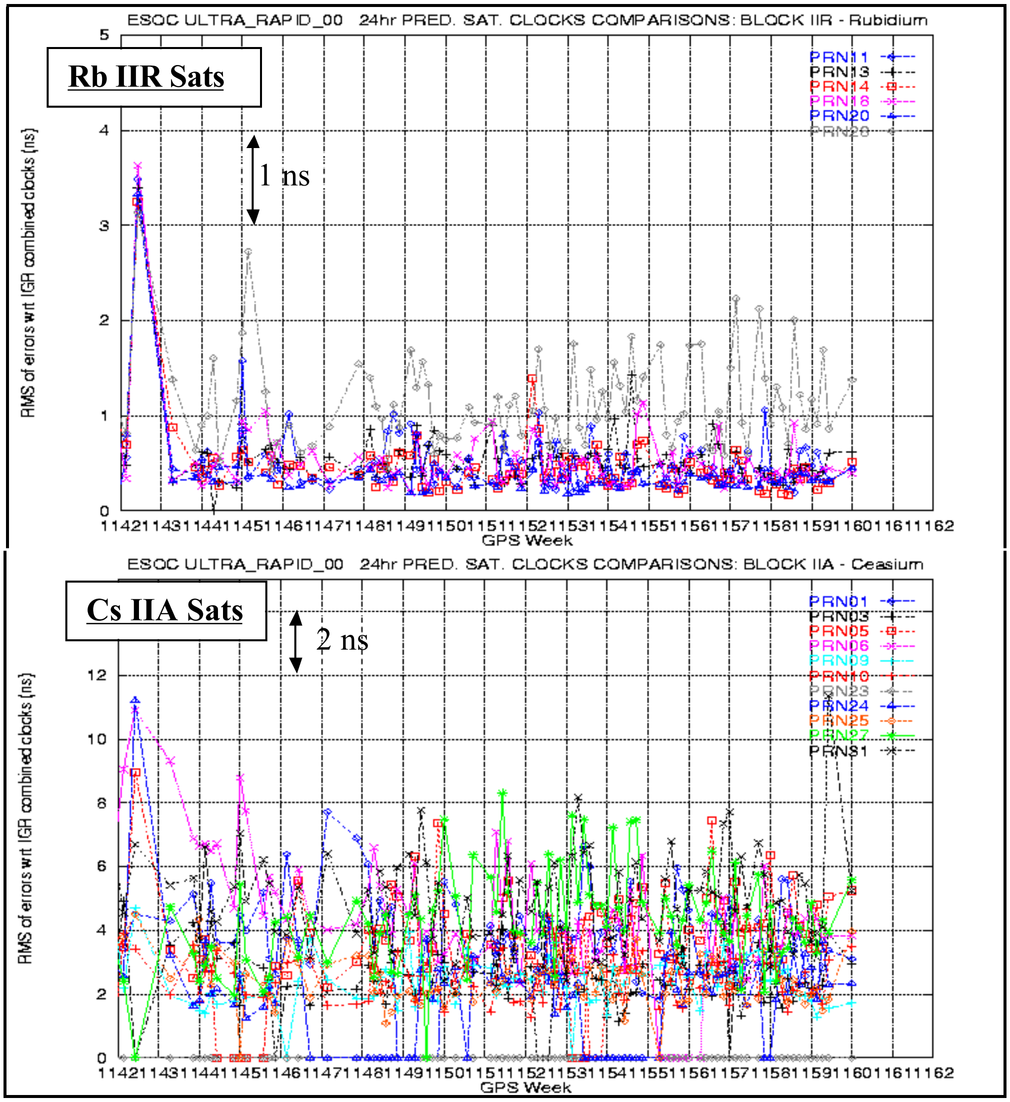

Fig. 5: Satellite by satellite comparison of predicted versus estimated clock biases from GPS week 1142 to week 1160 for two sets of GPS satellites.

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.

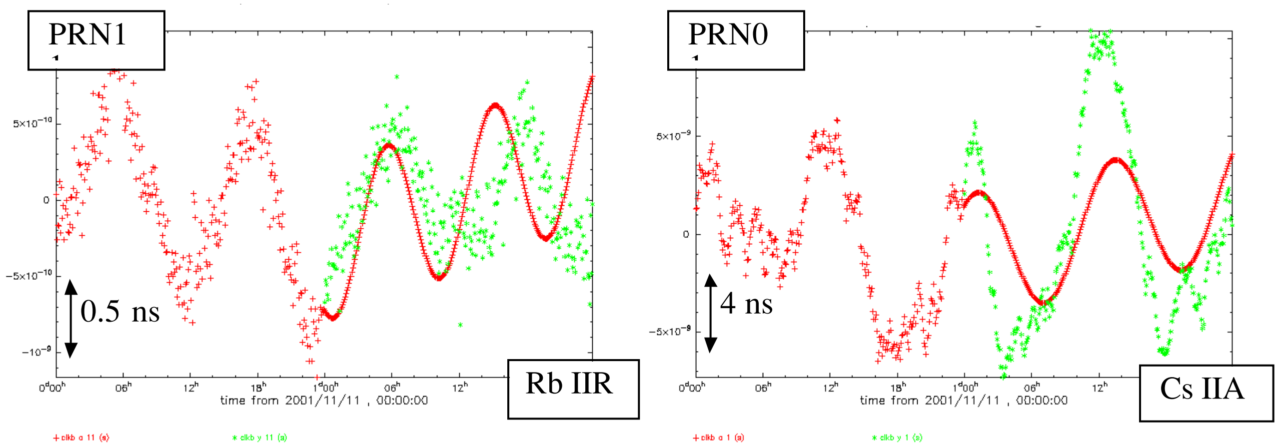

Fig. 6: Satellite clock bias values, submitted with the Ultra-Rapid (red) and estimated in the ESA Rapid process (green) for 48 hrs from 00:00 Nov. 11th 2001 (01315) (Offset and drift removed for plotting).

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).

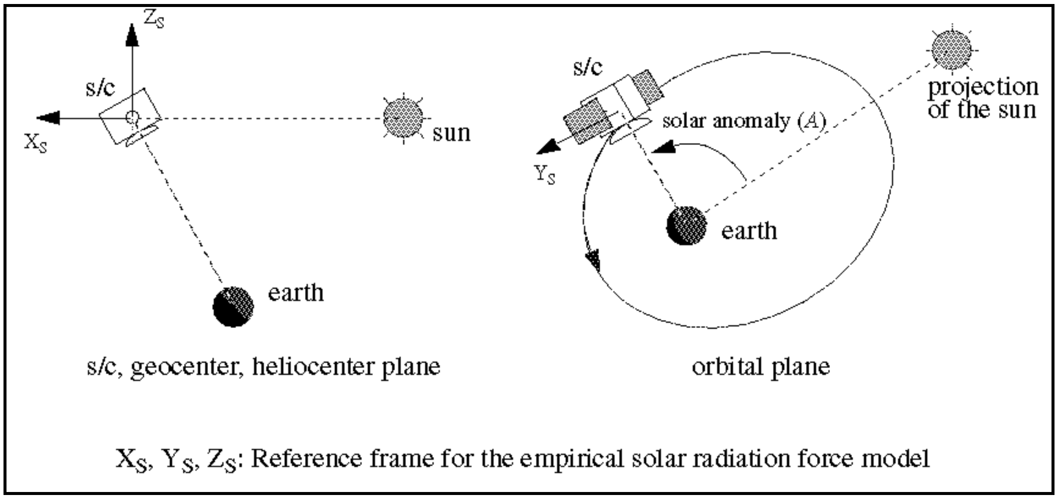

Fig. 7: GLONASS Solar Radiation Pressure Modelling.

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.

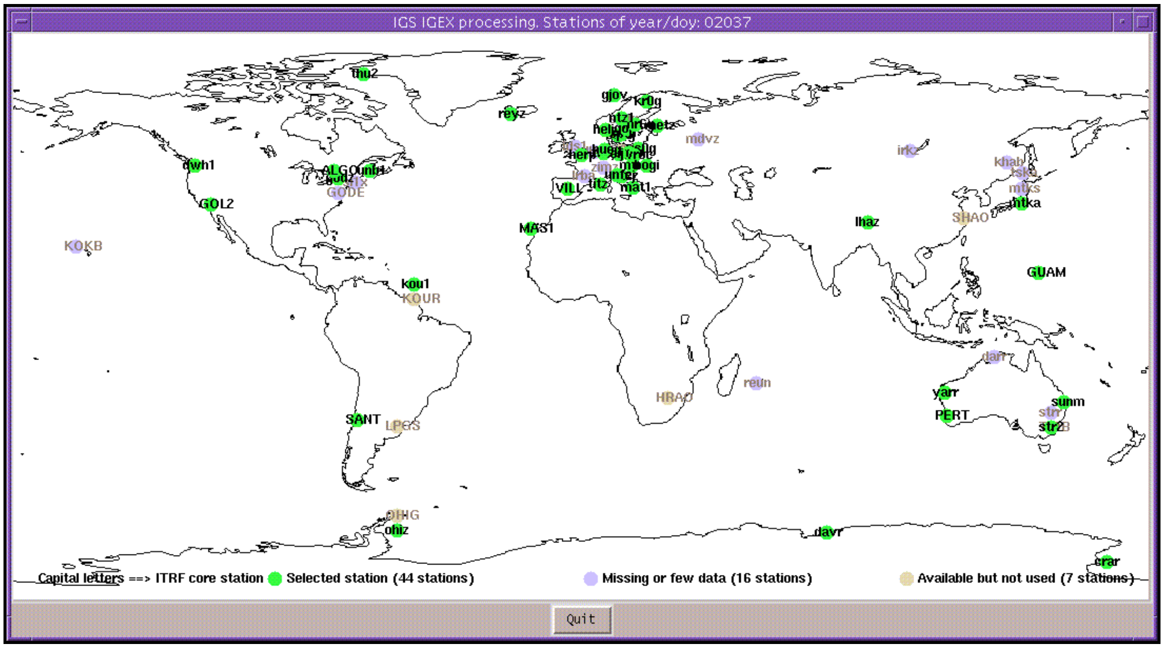

Fig. 8: GPS/GLONASS typical station selection for IGLOS processing.

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.

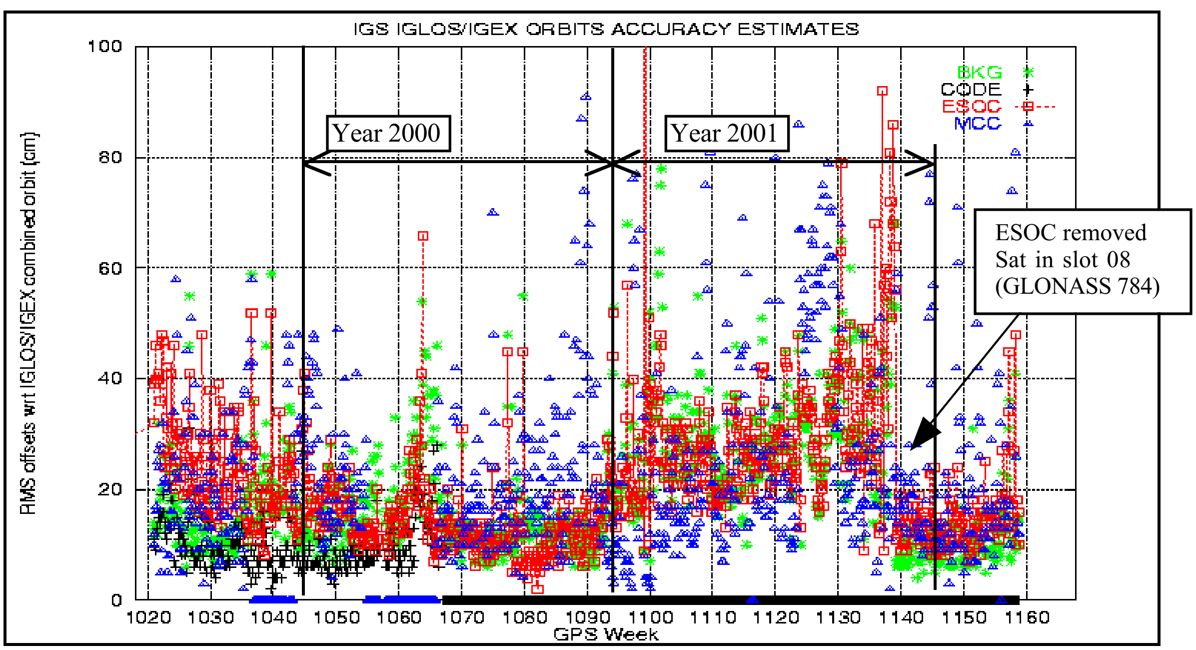

Fig. 9: IGLOS/IGEX AC orbit comparisons versus the combination.

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.

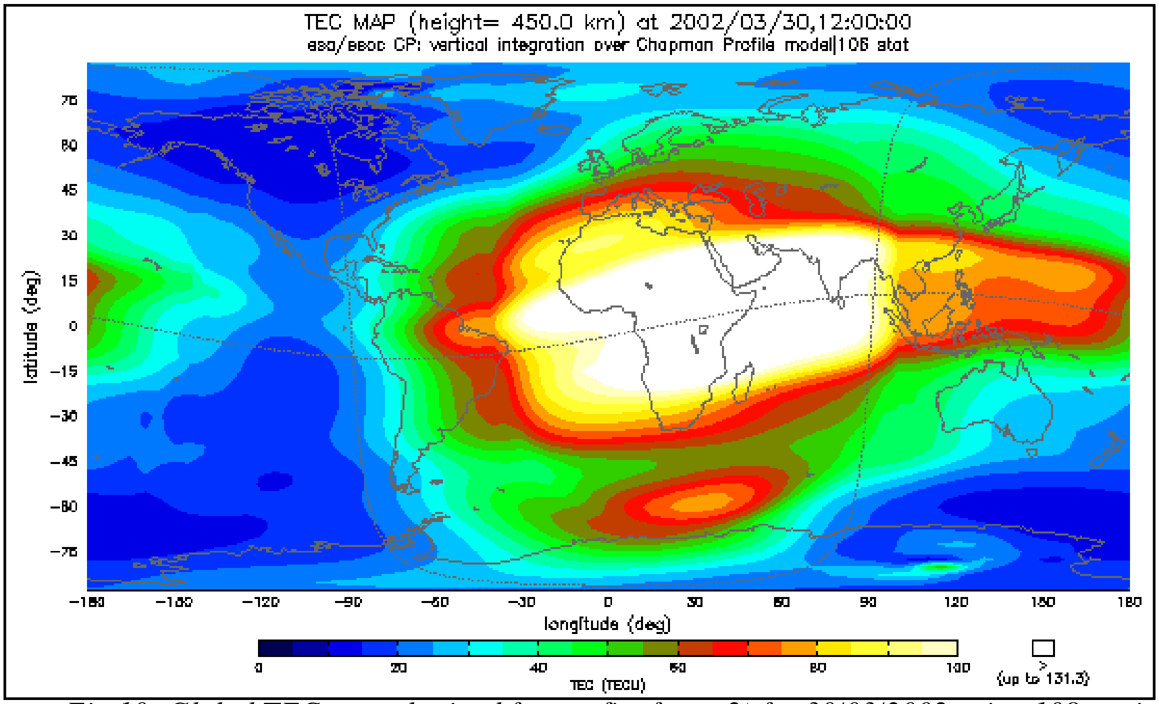

Fig 10: Global TEC map obtained from a fit of type 2) for 30/03/2002 using 108 stations.

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.

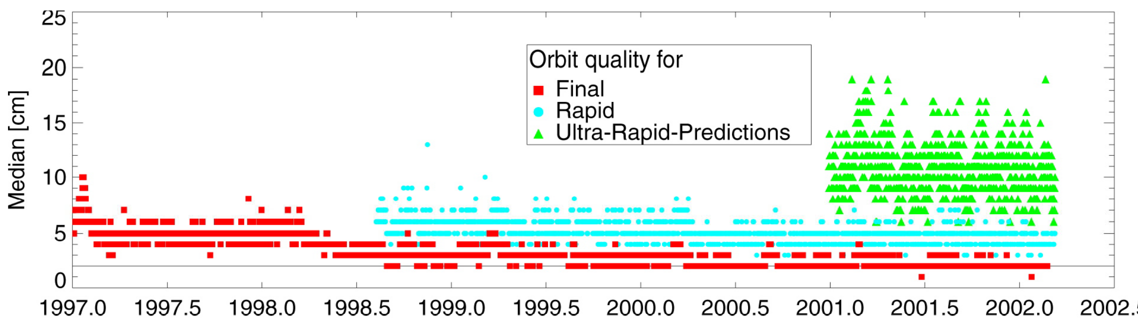

Fig. 1. Quality of the various GFZ satellite orbit products taken from the official combinations reports

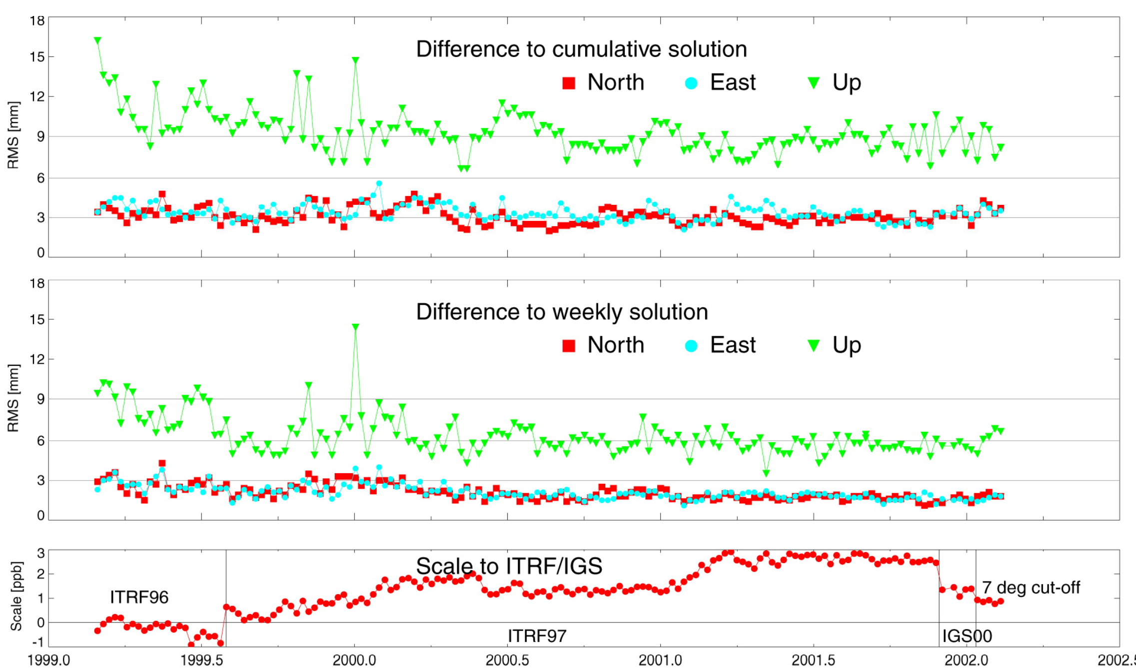

Fig. 2. Quality of GFZ station coordinate solutions extracted from the IGS SINEX combination reports

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.

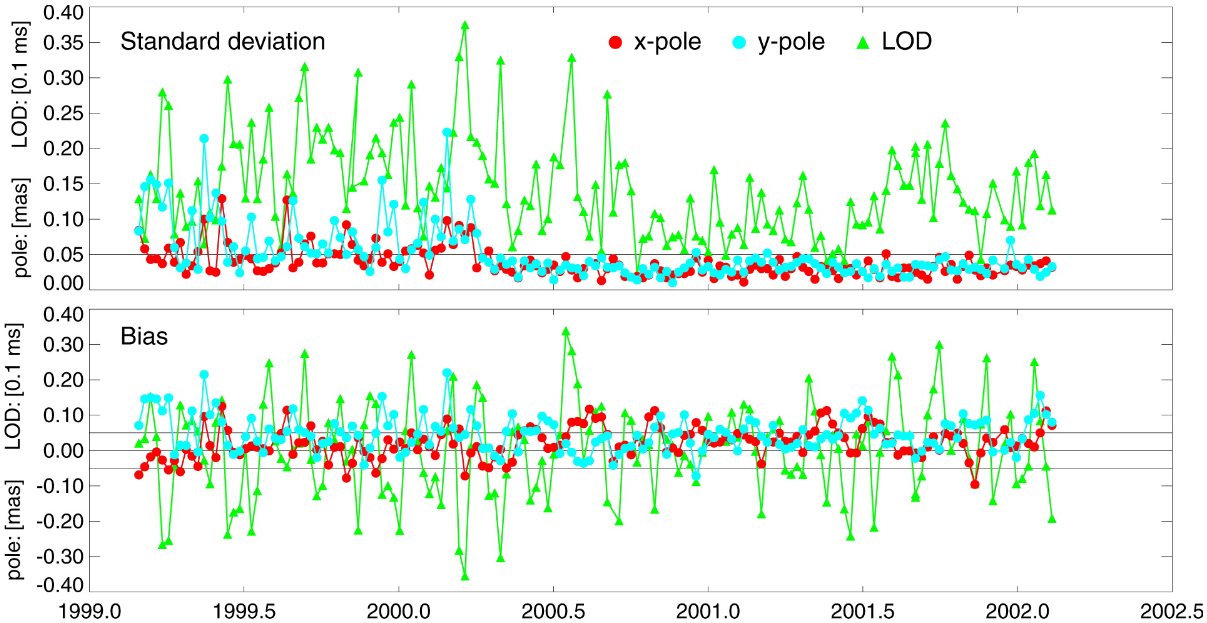

Fig. 3. Quality of ERP solution

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.

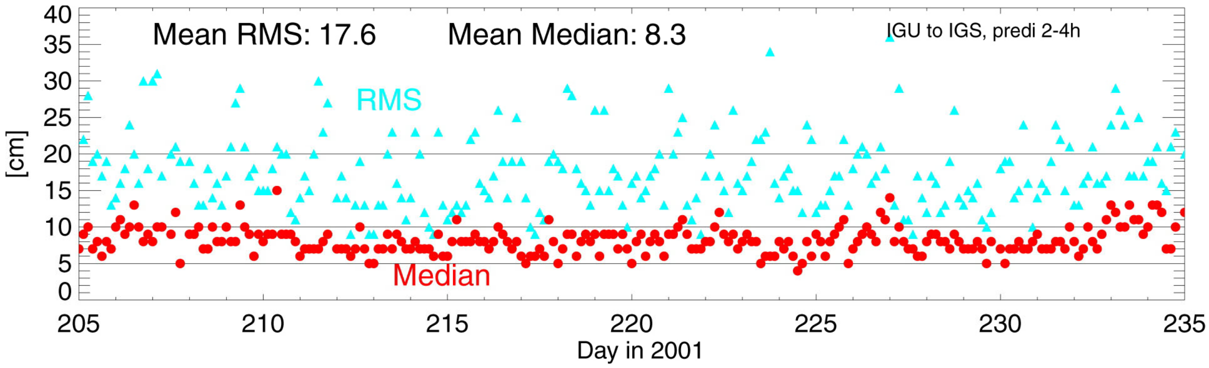

Fig. 4. Ultra Rapid prediction with 3-hour repetition interval. Prediction quality in August 2001 for intervals 2-4 hours

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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

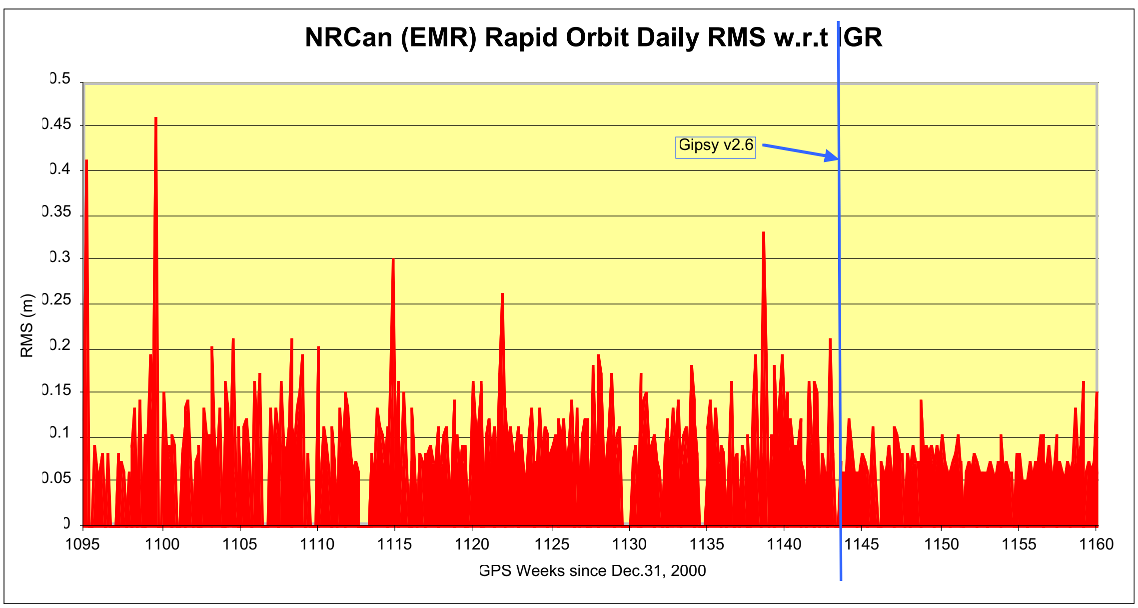

Figure 1: NRCan (EMR) Rapid orbit daily RMS w.r.t. IGR since Dec. 31, 2000

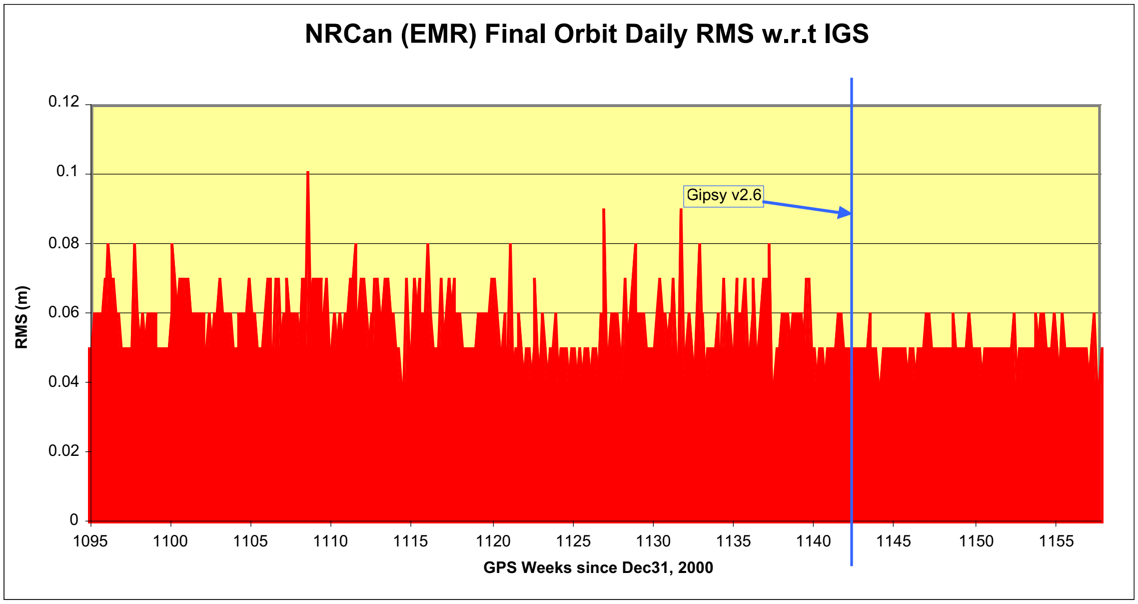

Figure 2: NRCan (EMR) Final orbit daily RMS w.r.t. IGS since Dec. 31, 2000

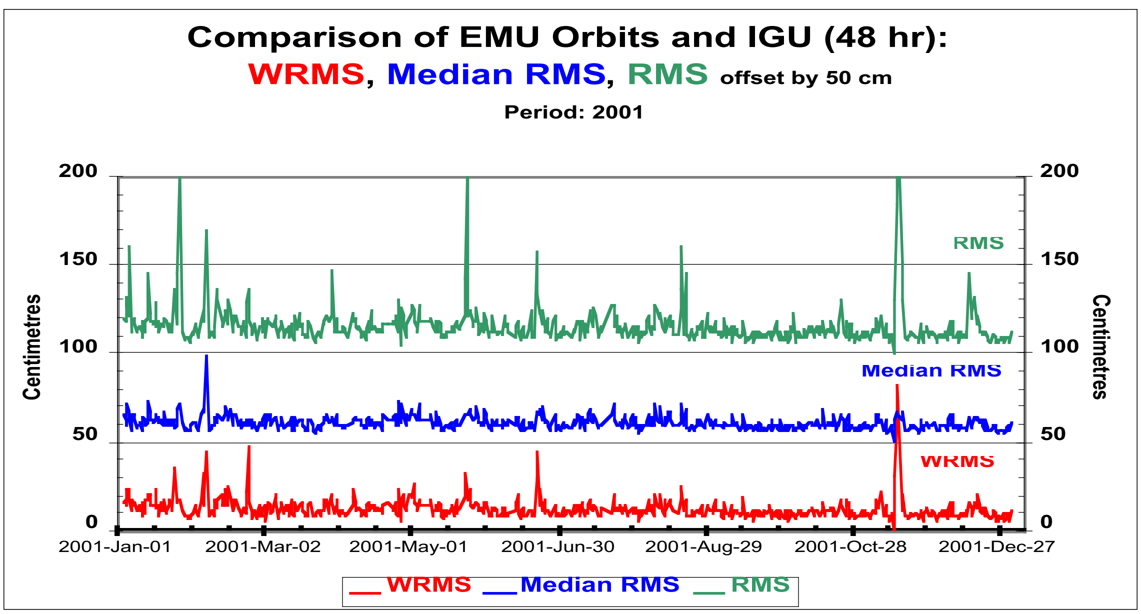

Figure 3: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): WRMS, Median RMS and RMS, each offset by 50 cm.

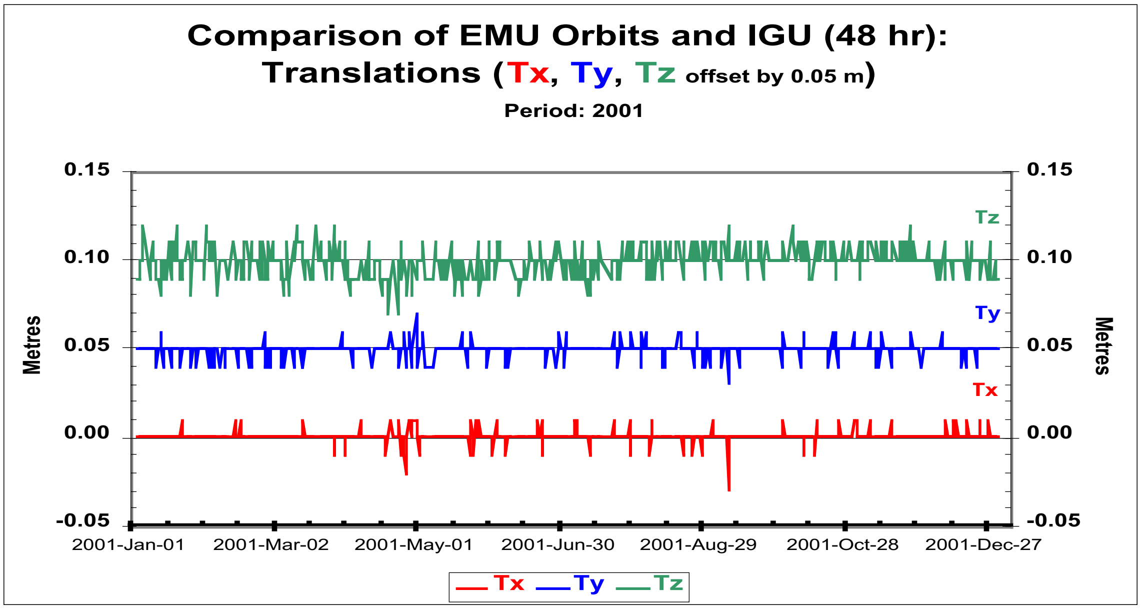

Figure 4: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): Translations Tx, Ty and Tz, each offset by 0.05 m.

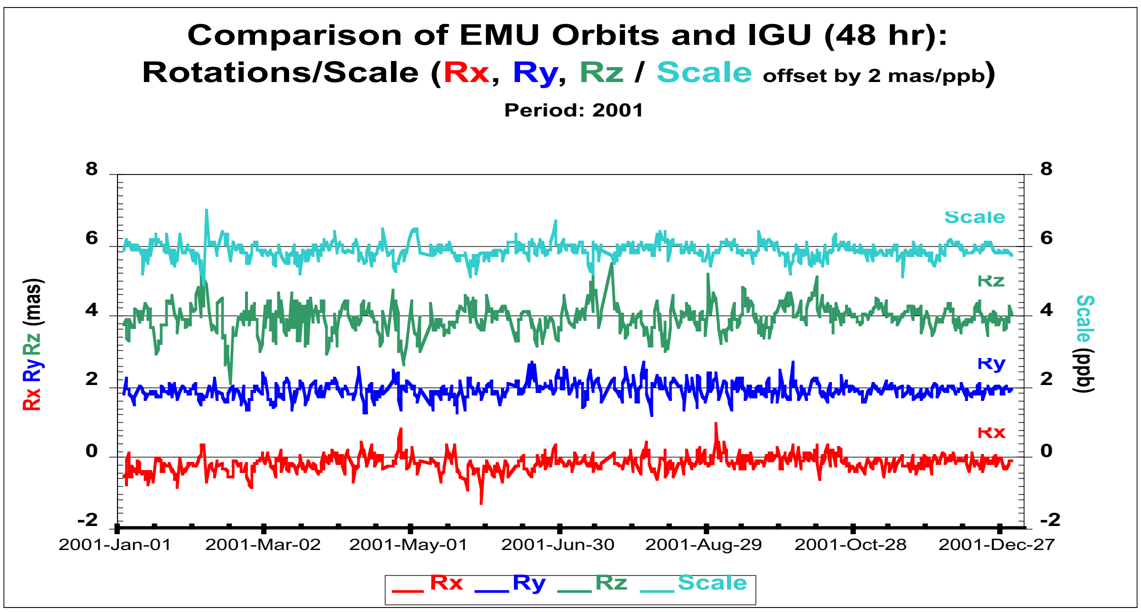

Figure 5: Comparison of EMU Orbits and IGU for 2001 (48-hour Orbit): Rotations Rx, Ry, Rz and Scale each offset by 2 mas, 2 mas, 2 mas and 2 ppb respectively.

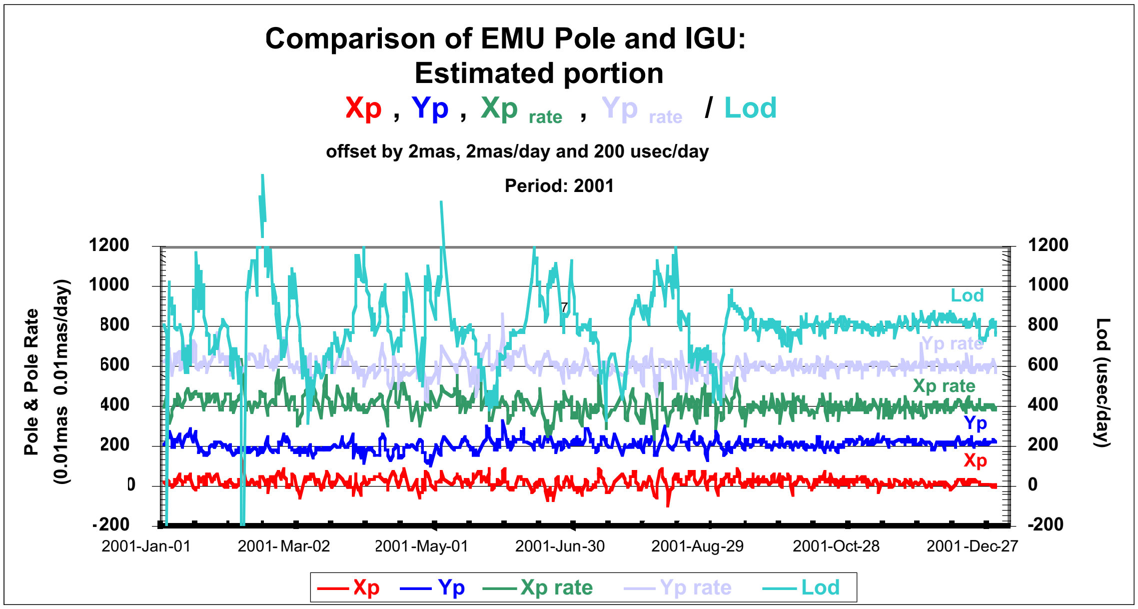

Figure 6: Comparison of EMU Estimated Pole and IGU for 2001: Xp, Yp, Xp_{rate} , Yp_{rate} and Lod, each offset by 2 mas, 2 mas, 2 mas/day, 2 mas/day and 200 usec/day respectively.

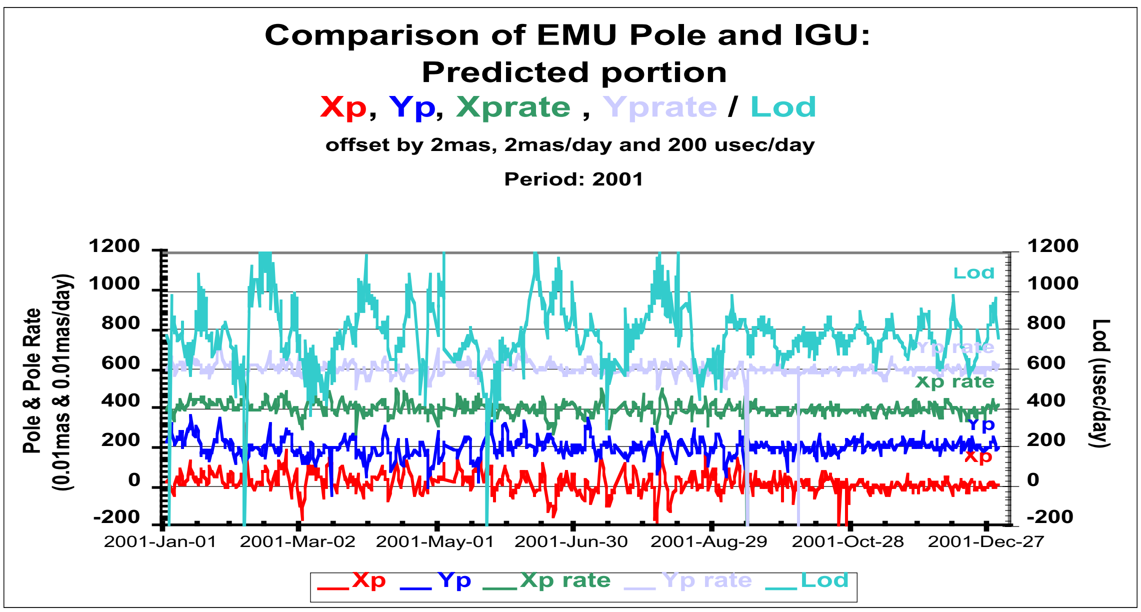

Figure 7: Comparison of EMU Predicted Pole and IGU for 2001: Xp, Yp, Xp_{rate} , Yp_{rate} and Lod, each offset by 2 mas, 2 mas, 2 mas/day, 2 mas/day and 200 usec/day respectively.

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

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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.

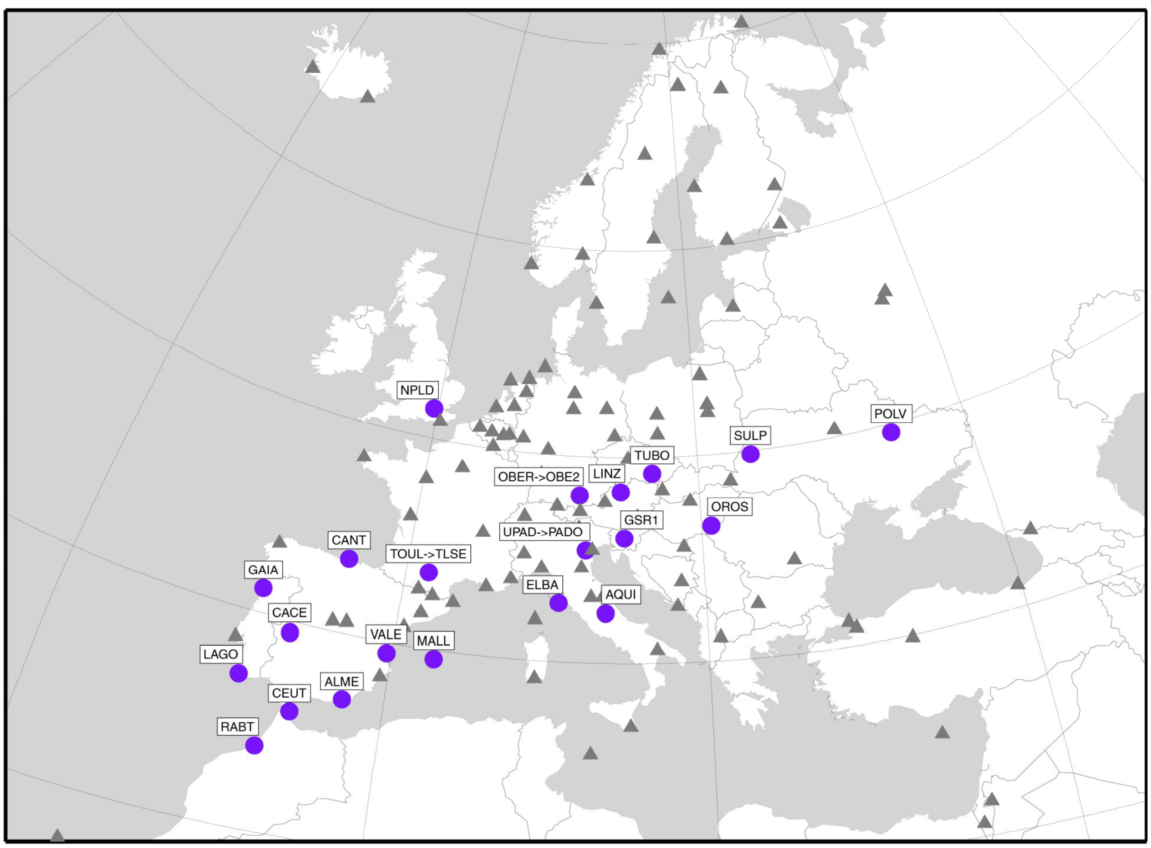

Figure 1: EPN tracking network (status Dec. 2001), stations denoted with circles joined the EPN in 2001.

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

Geoffrey Luton

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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).

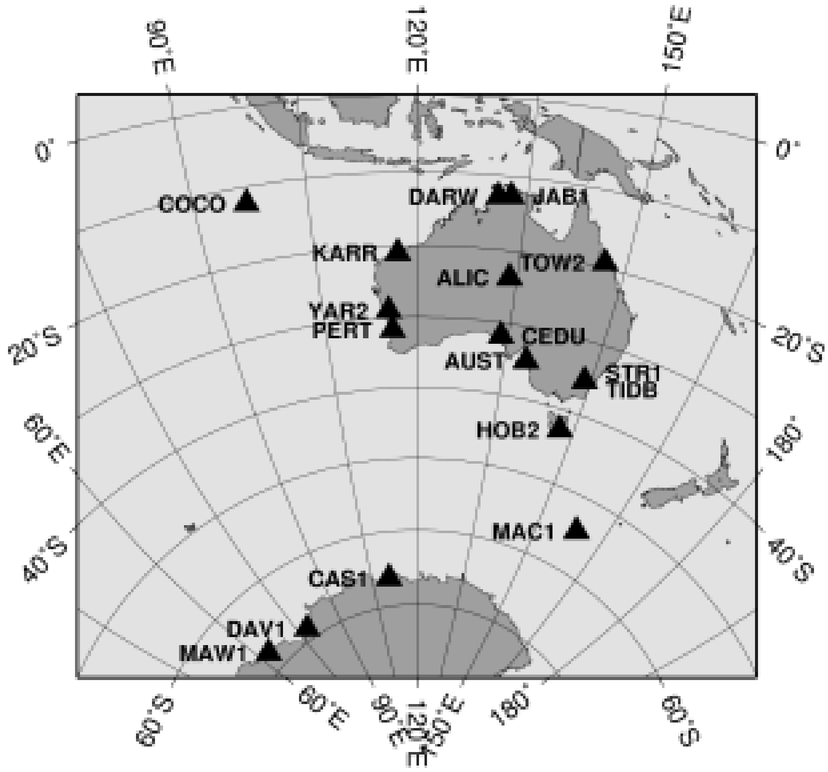

Figure 1. Geoscience Australia RNAAC station network as of 31 December 2001

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

Wolfgang Seemüller and Hermann Drewes
Deutsches Geodätisches Forschungsinstitut, München, Germany

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.

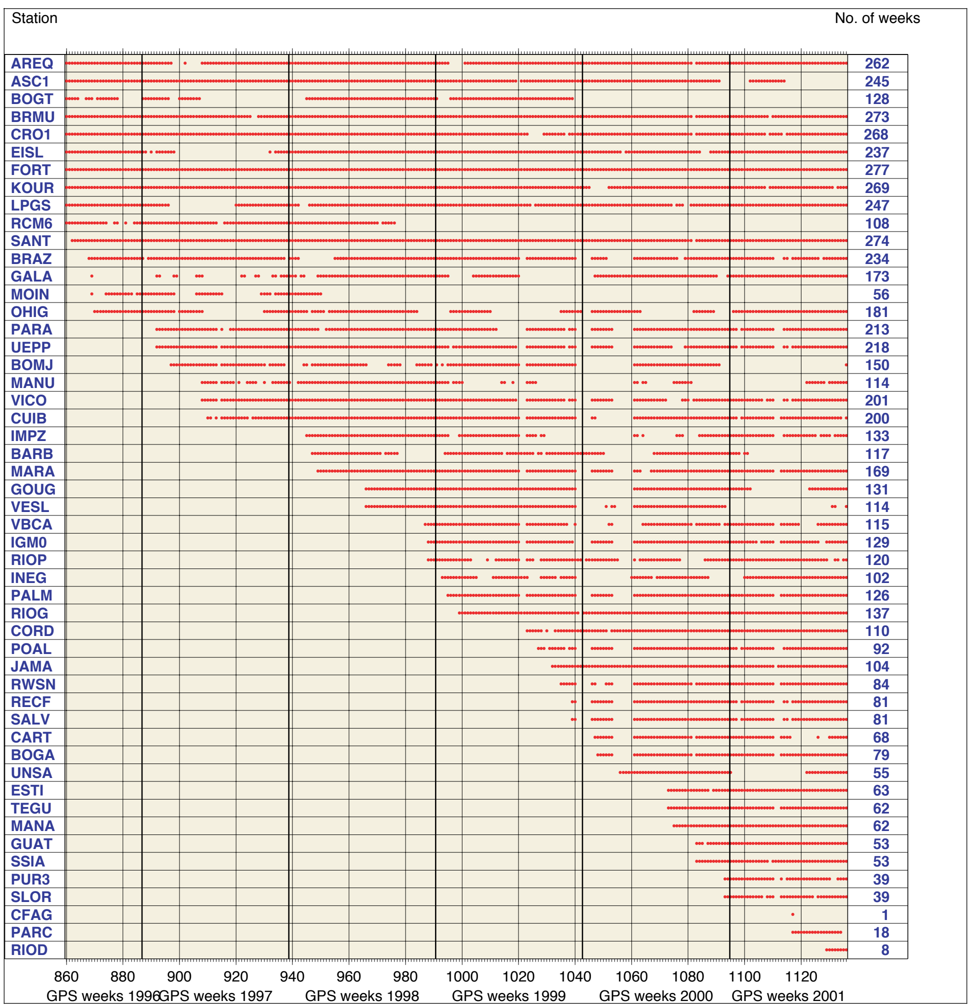

Figure 2: Weekly contribution of RNAAC SIR stations to solution DGFI01P02

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.

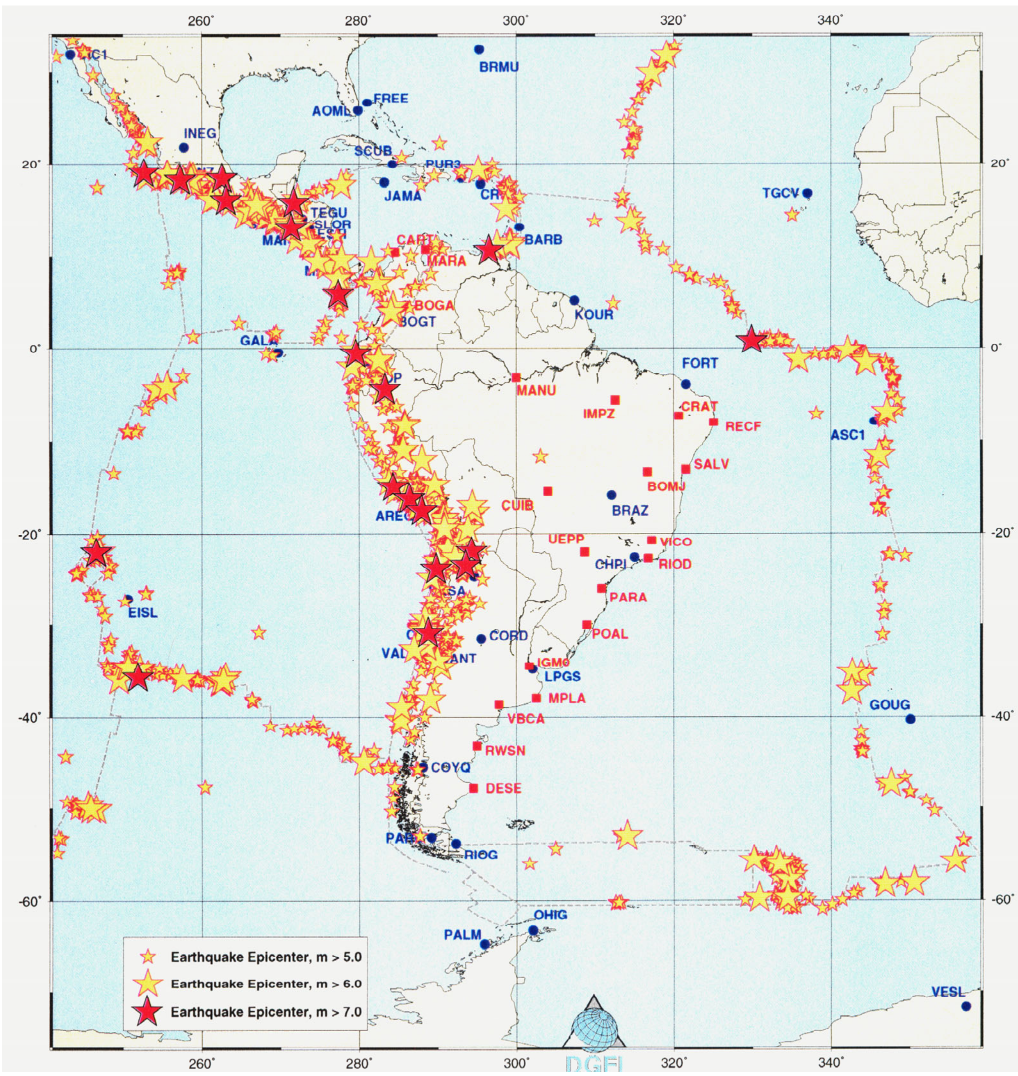

Figure 3: Earthquakes in the area of the IGS RNAAC SIR network from June 30, 1996 to end of Year 2001 (Source: USGS National Earthquake Information Center)

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).

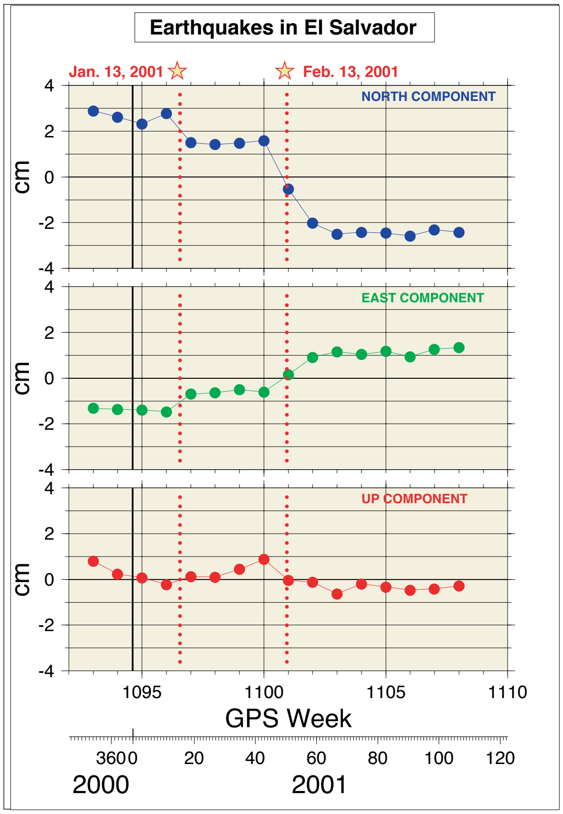

Fig. 4: Variations of station SSIA position components due to earthquakes in El Salvador (Seemüller et al., 2002).

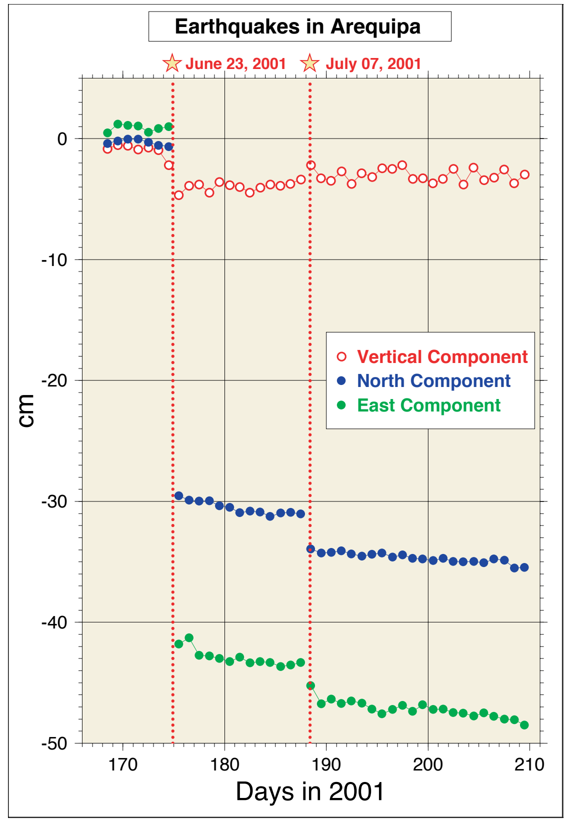

Fig. 5: Daily estimates of the AREQ position components in the reference frame realized by fiducial stations (Kaniuth et al., 2002).

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

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

IGS

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.

<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 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:

Ms. Carey E. Noll	Phone:	(301) 614-6542
Manager, CDDIS	Fax:	(301) 614-5970
Code 920.1	E-mail:	*Carey.Noll@gsfc.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 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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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

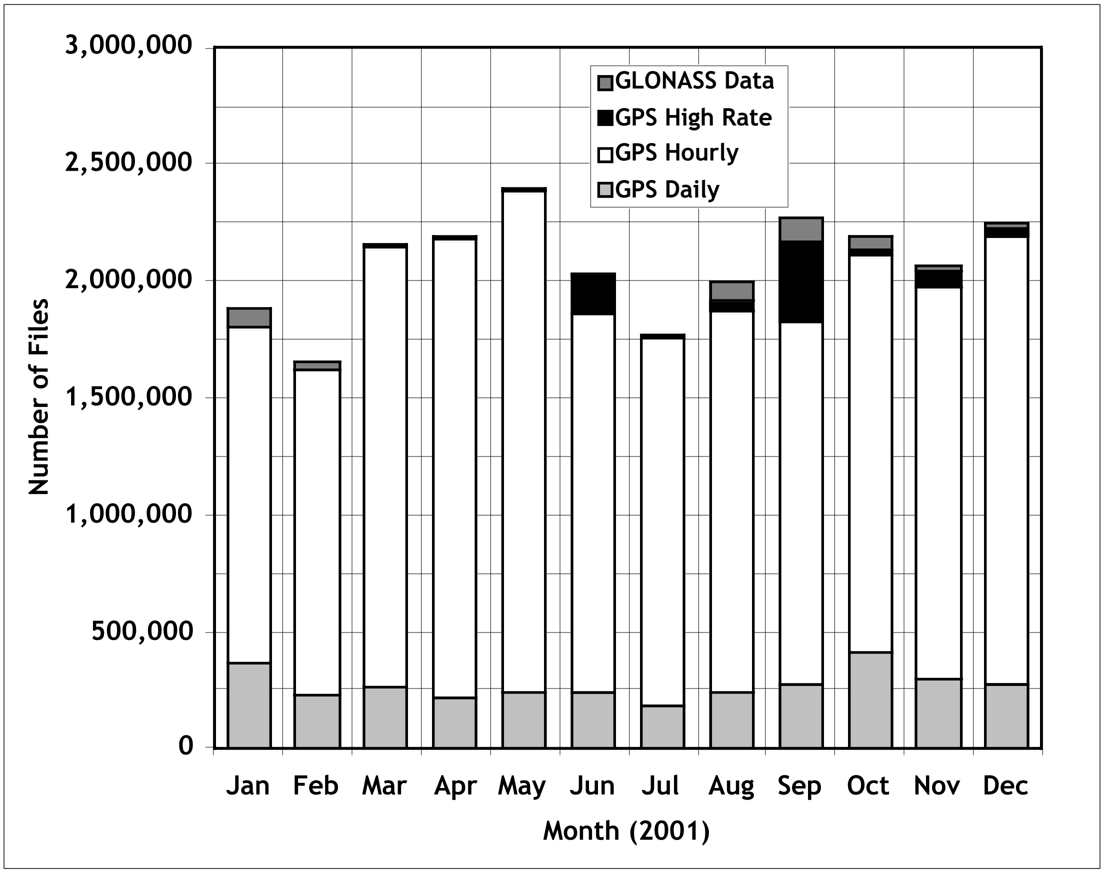

Figure 1: Number of GPS data files transferred from the CDDIS in 2001

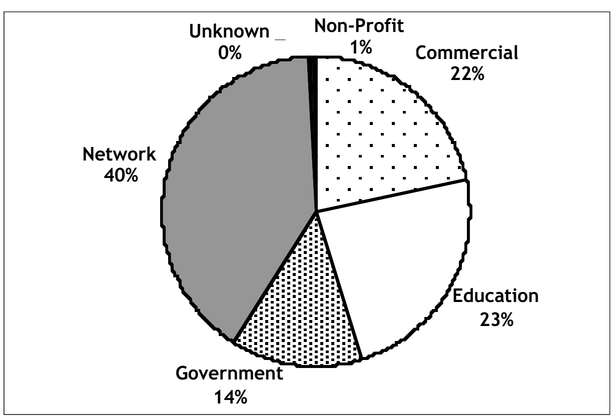

Figure 2: Distribution of IGS users of the CDDIS in 2001

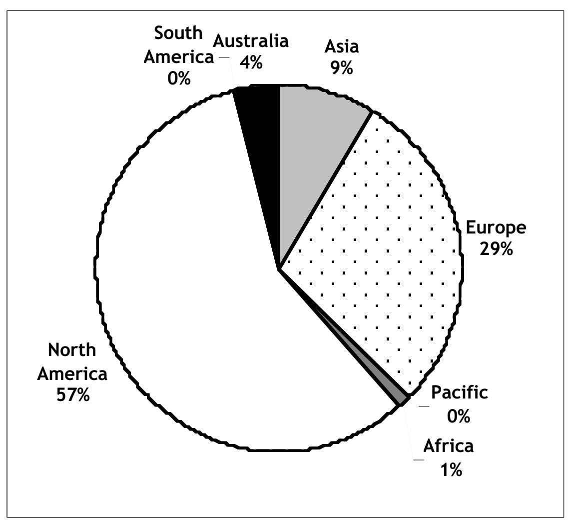

Figure 3: Geographic distribution of IGS users of the CDDIS in 2001

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.

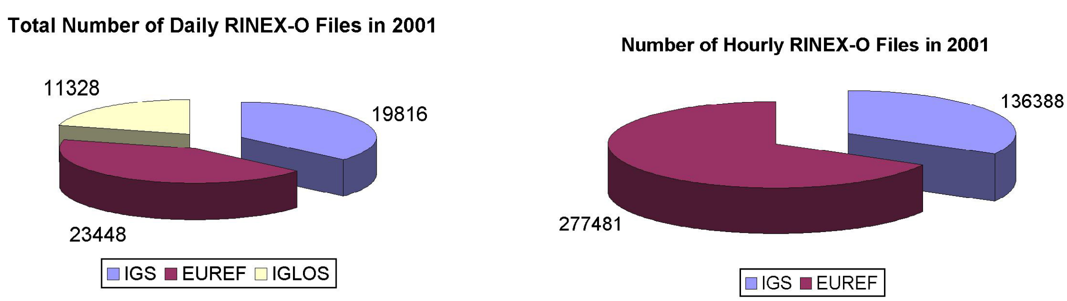

Figure 1

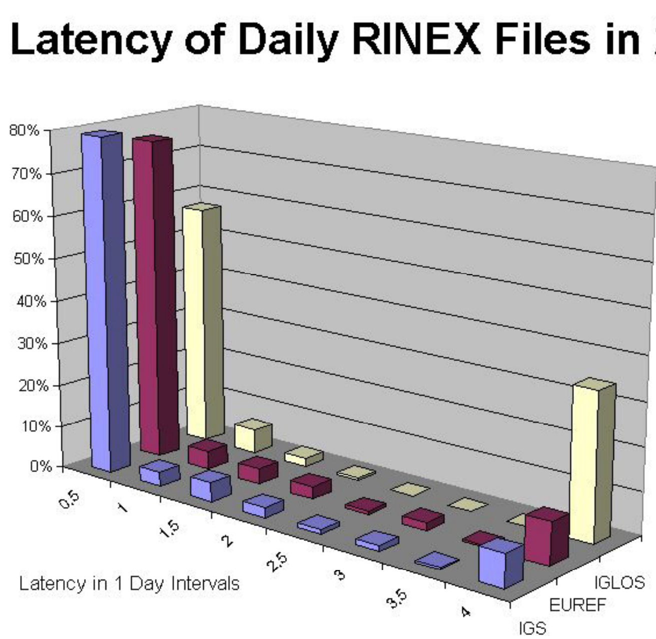

Figure 2

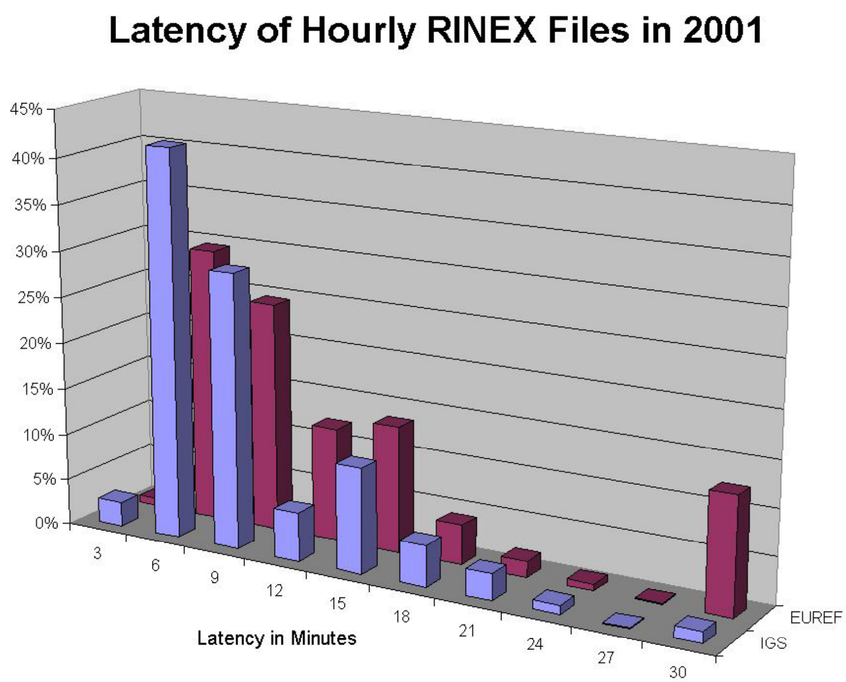
Latency of Hourly RINEX Files in 2001
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
3
6
9
12
15
18
21
24
27
30
Latency in Minutes
EUREF
IGS

Figure 3

IGS

NETWORK AND STATION REPORTS

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G L O B A L ,   R E G I O N A L ,   A N D
L O C A L   N E T W O R K S

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

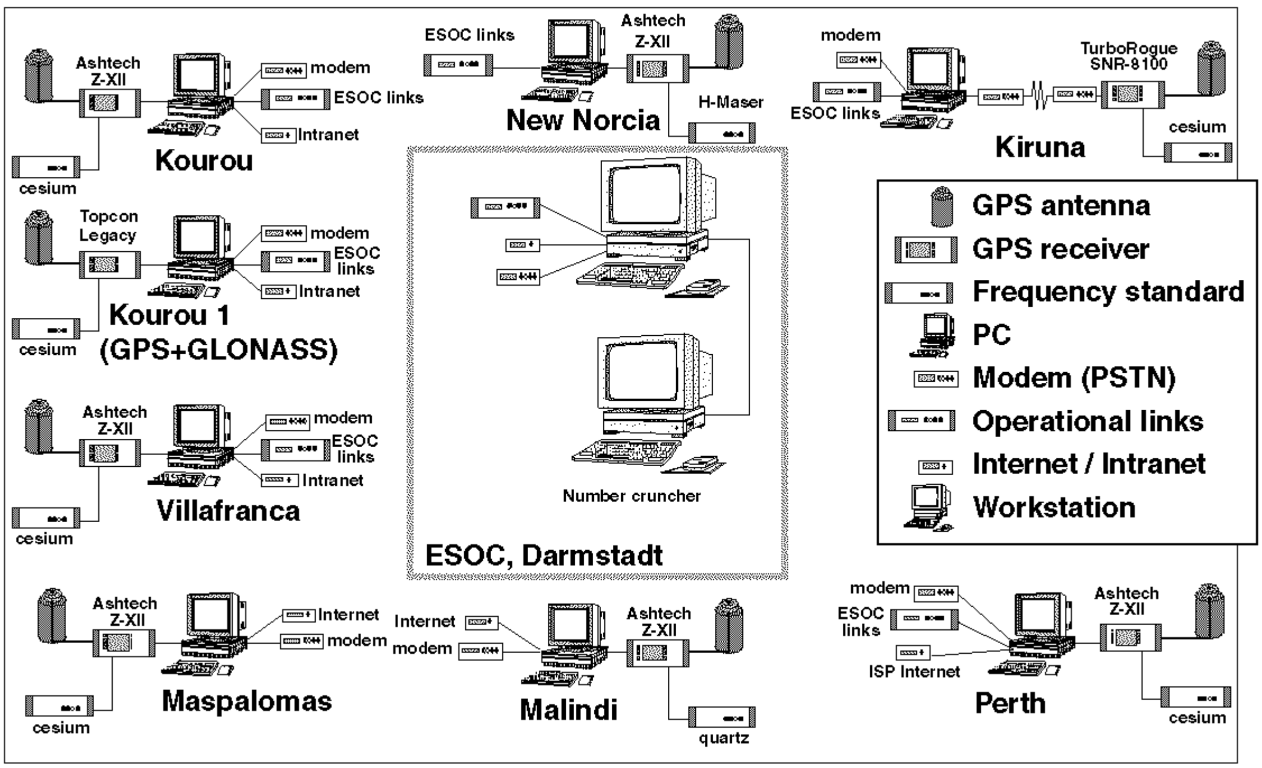

Figure 1: Configuration of the ESA stations by middle 2002.

Network Visibility

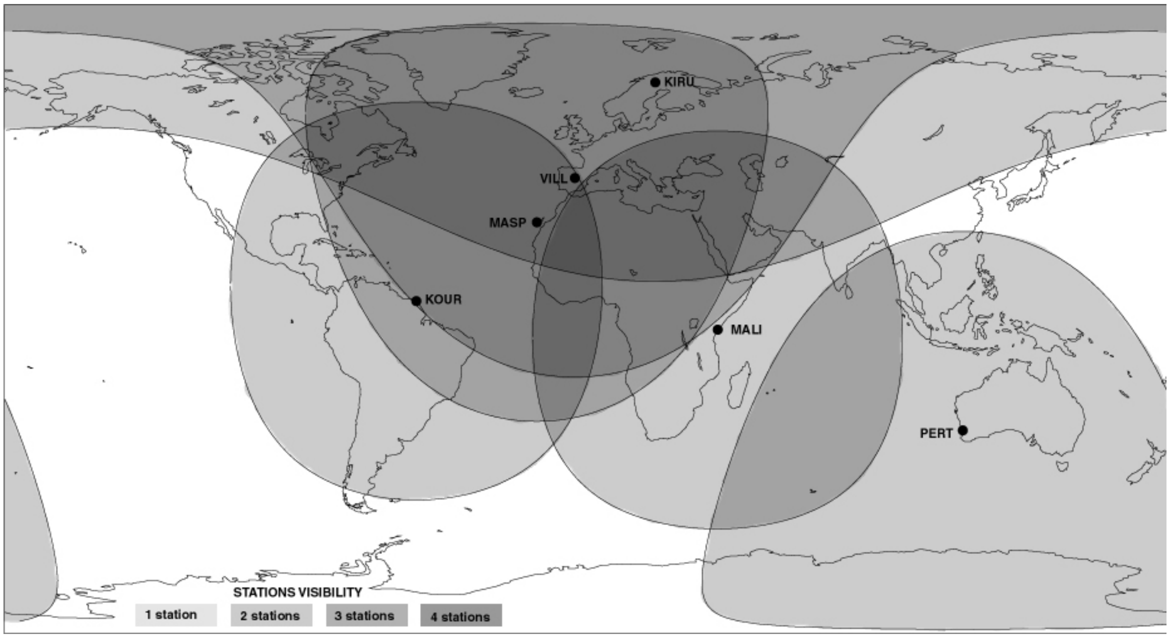

Figure 2: Visibility of the ESA network with 20 degree minimum elevation.

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.

IGS

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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Geodetic Observatory Pecny
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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.

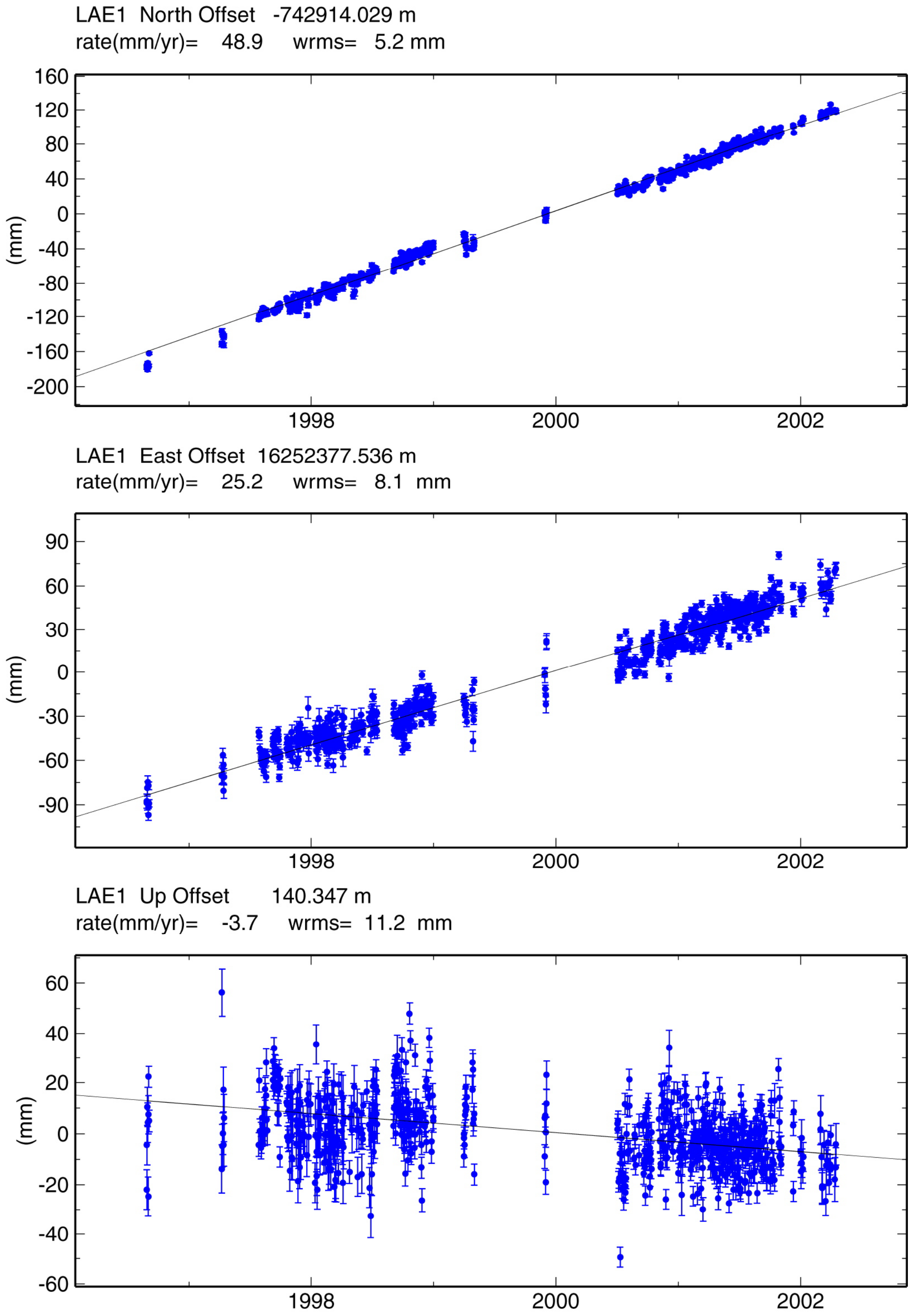

Figure 2. Time series of daily coordinate estimates. The data were processed at RSES using the GAMIT/GLOBK software.

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.

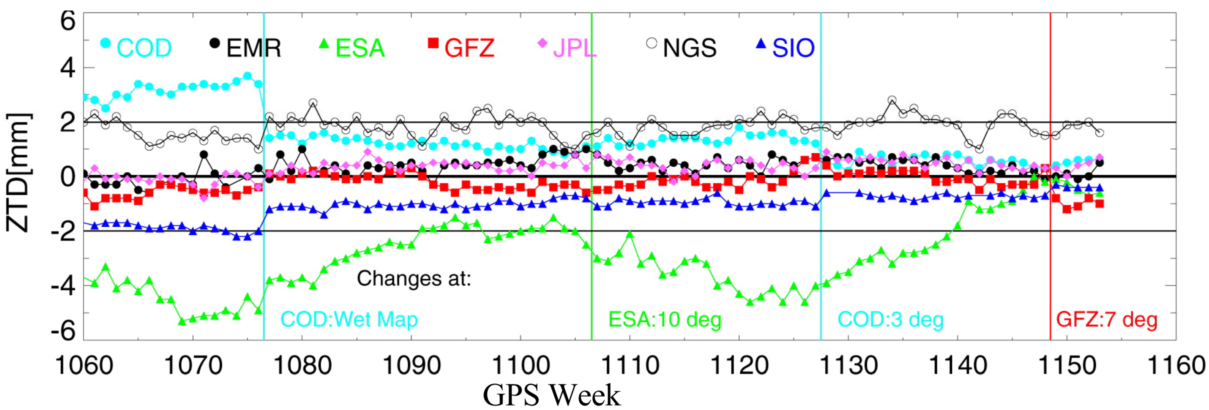

Fig. 1. Bias in the zenith neutral delay between the individual GPS estimates and the IGS Combined Product. Mean values (over all sites) per week and per Analysis Center.

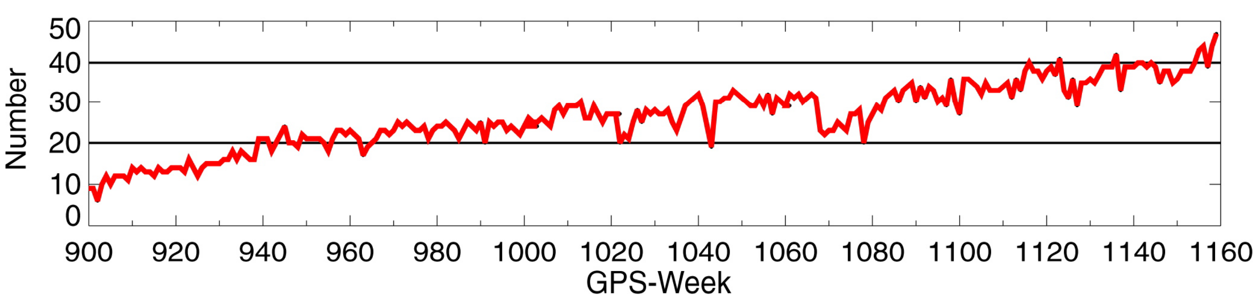

Fig. 2. Number of sites with meteorological sensors

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.

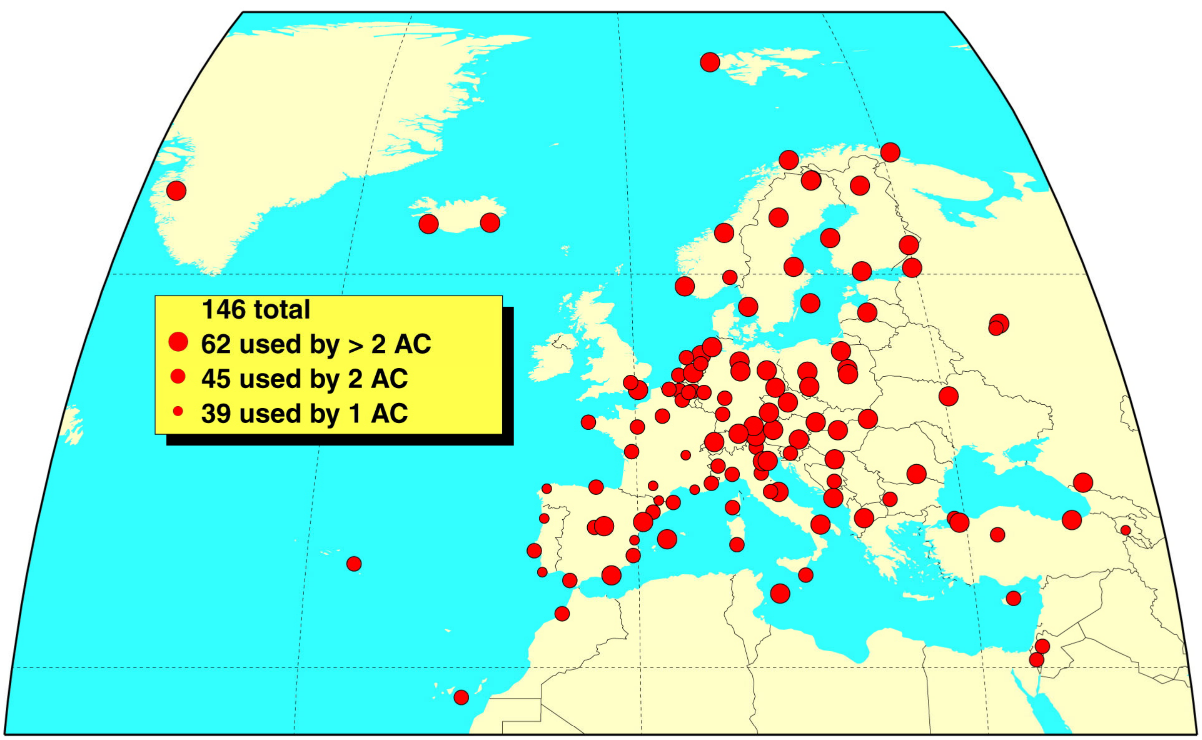

Fig. 3: EUREF network with tropospheric estimates

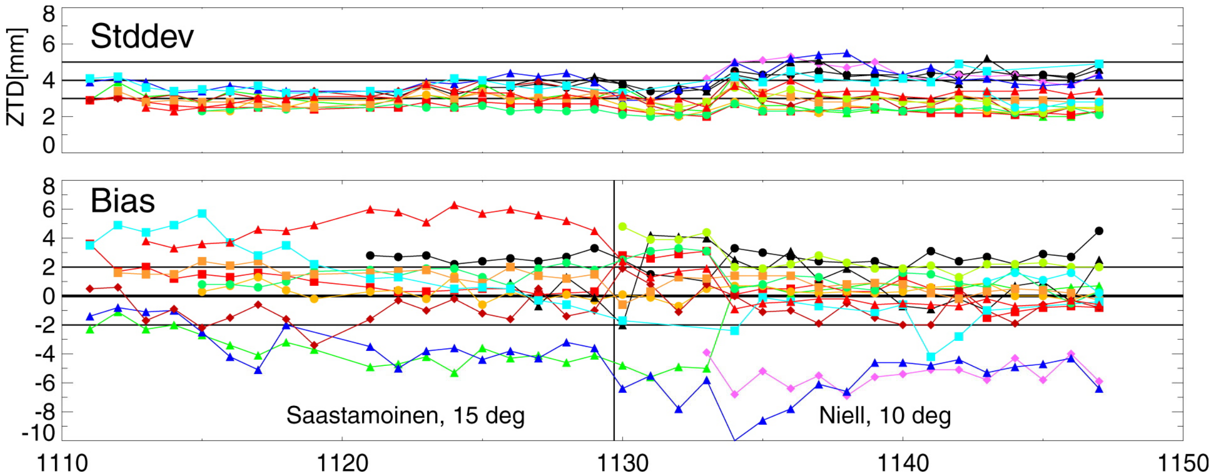

Fig. 4: Consistency within EUREF. Comparison of individual submissions to the EUREF combined product.

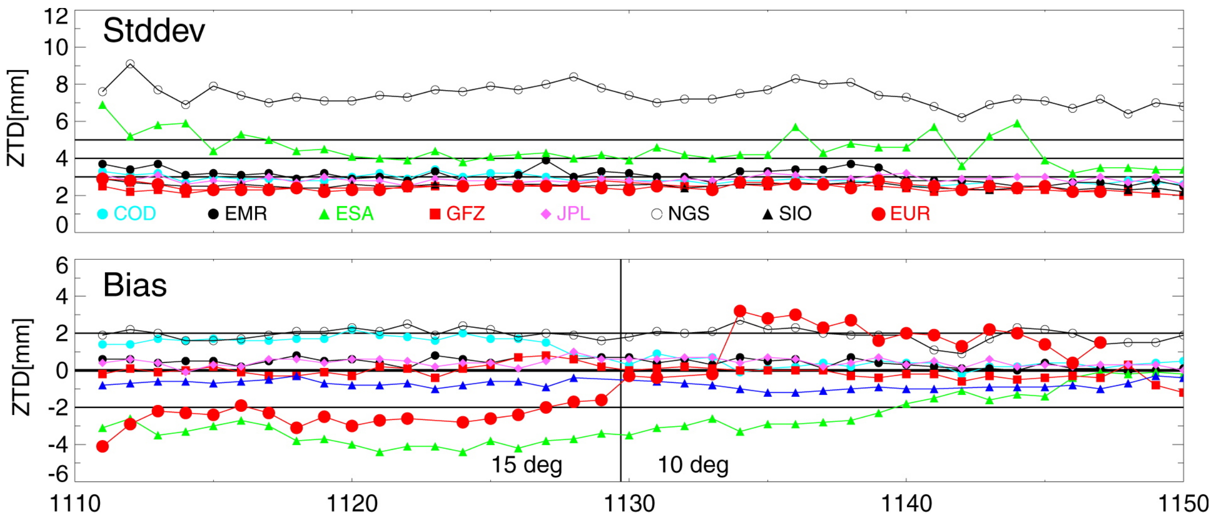

Fig. 5: Inclusion of EUREF into IGS-Combination. Comparisons to the IGS combined product.

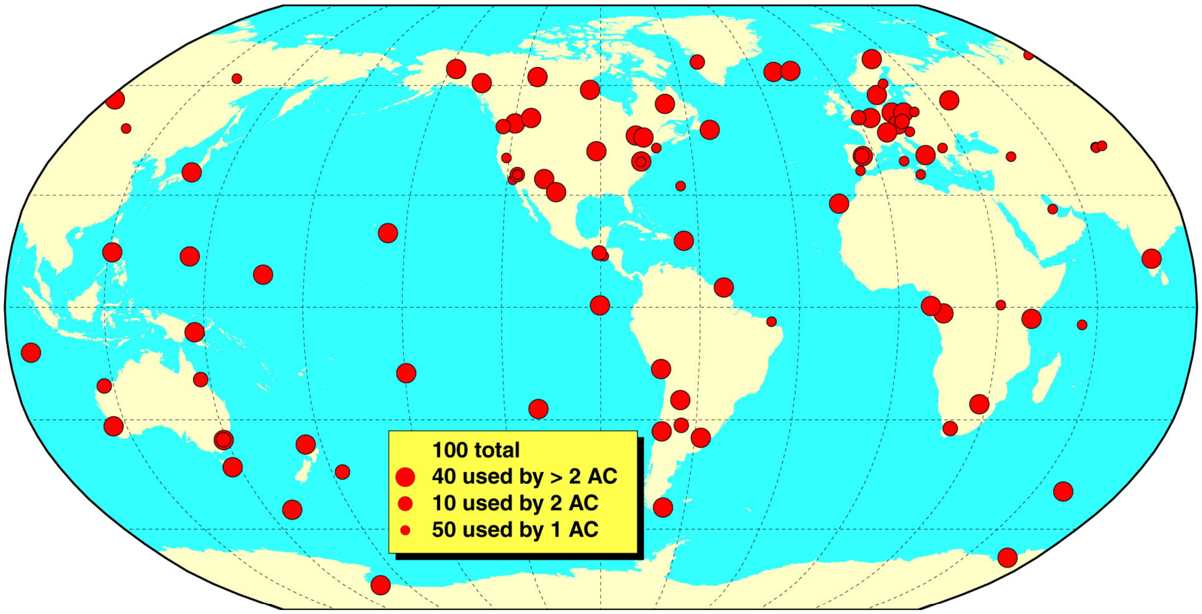

Fig. 6. IGS network with NRT tropospheric products

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

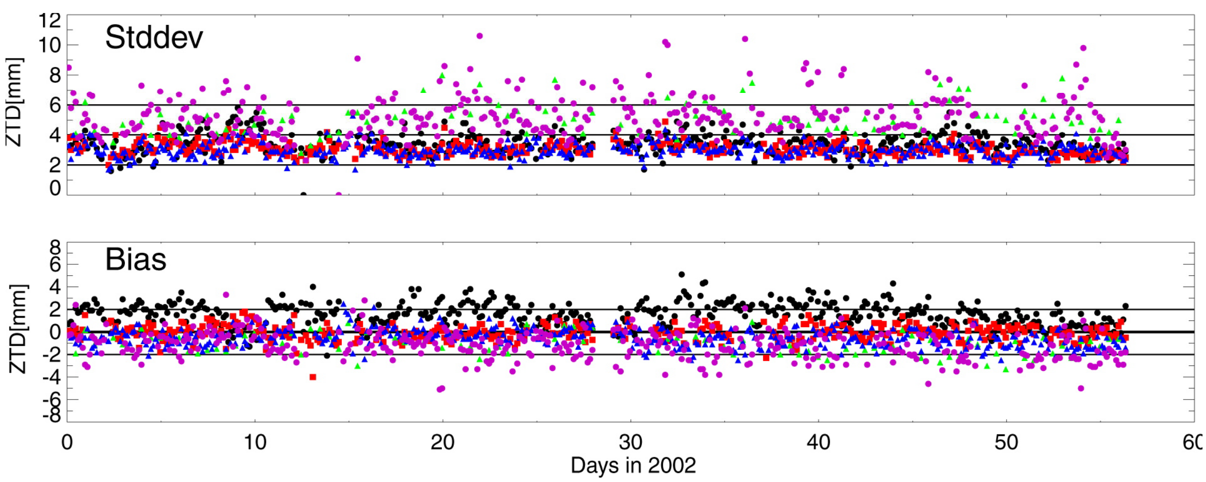

Fig. 7. Difference of NRT Analysis Center solutions to the NRT combined product. (Each symbol corresponds to one Analysis Center.)

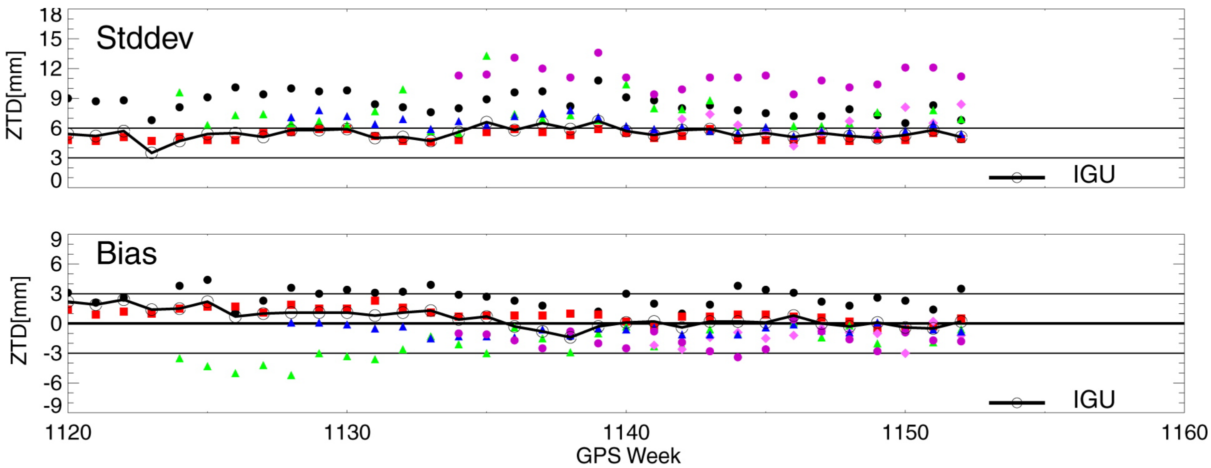

Fig. 8. Difference of NRT Analysis Center and NRT combined solution to the IGS Final weekly product. (For comparison daily NRT files are composed by last 3 hours of all NRT solutions. Each symbol corresponds to one Analysis Center.)

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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).

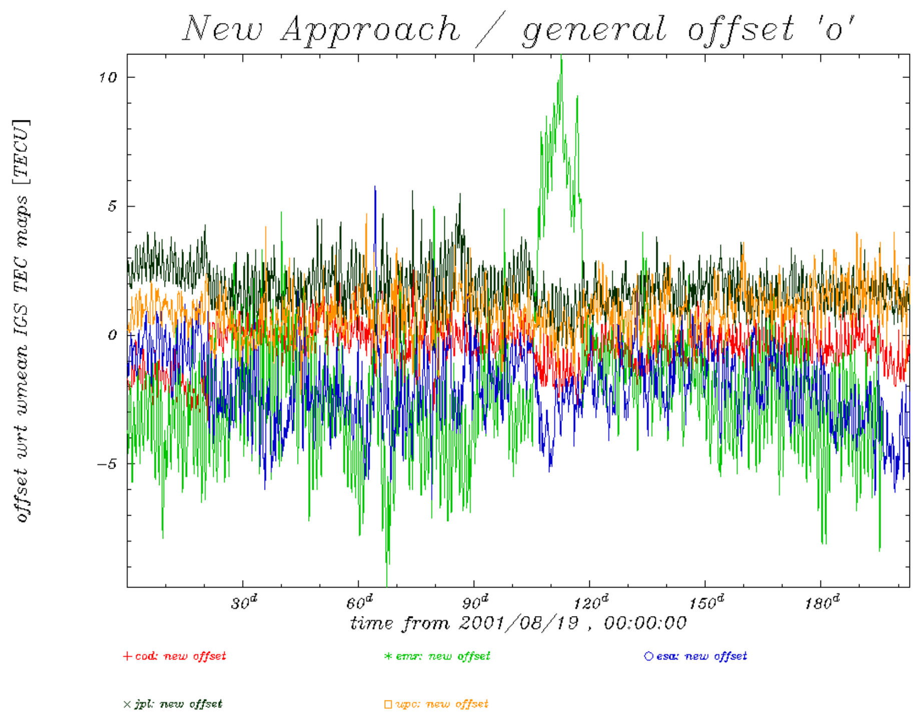

Figure 1a. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

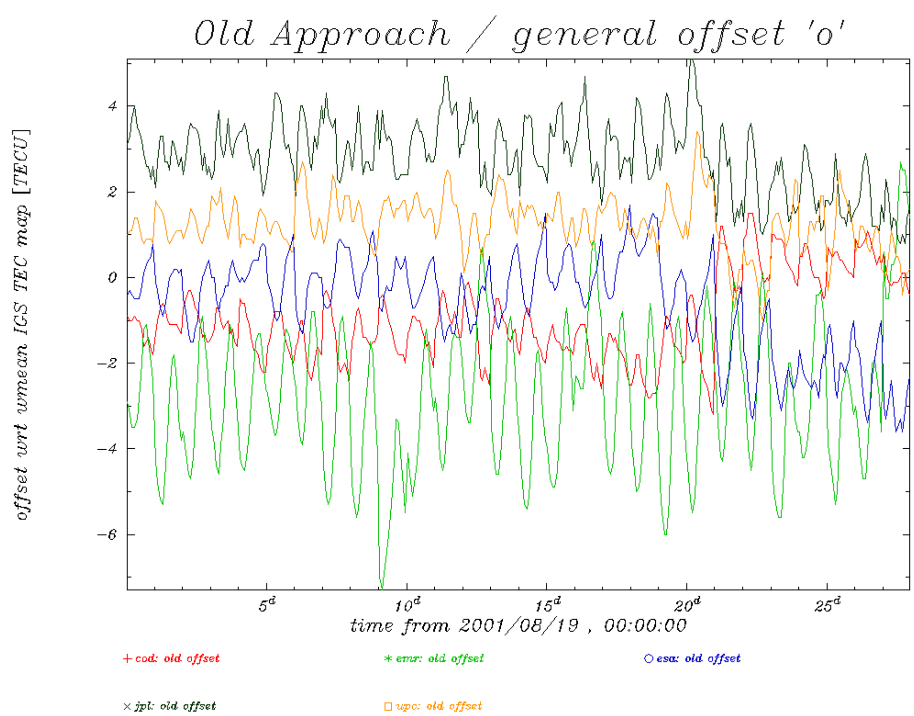

Figure 1b. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

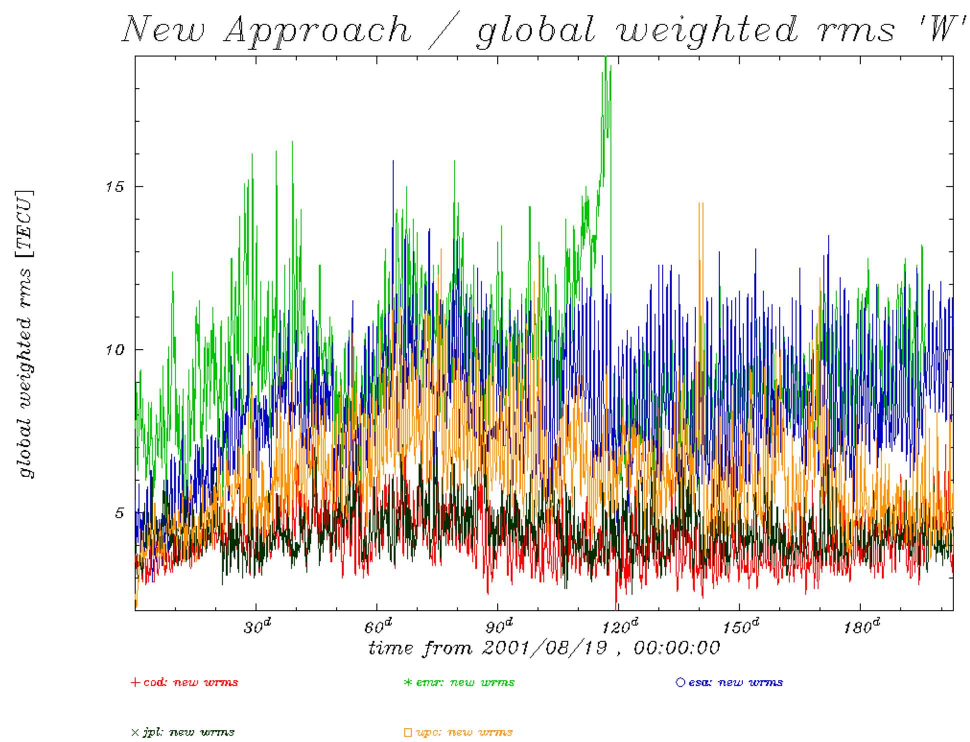

Figure 1c. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

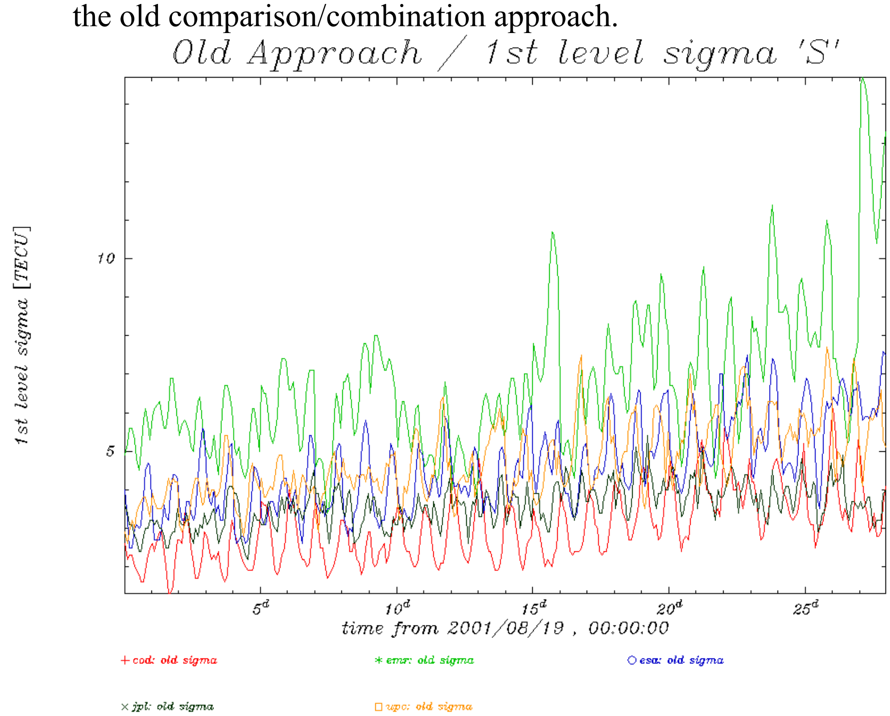

Figure 1d. IAACs global offsets and weighted rms values obtained with the new and with the old comparison/combination approach.

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.

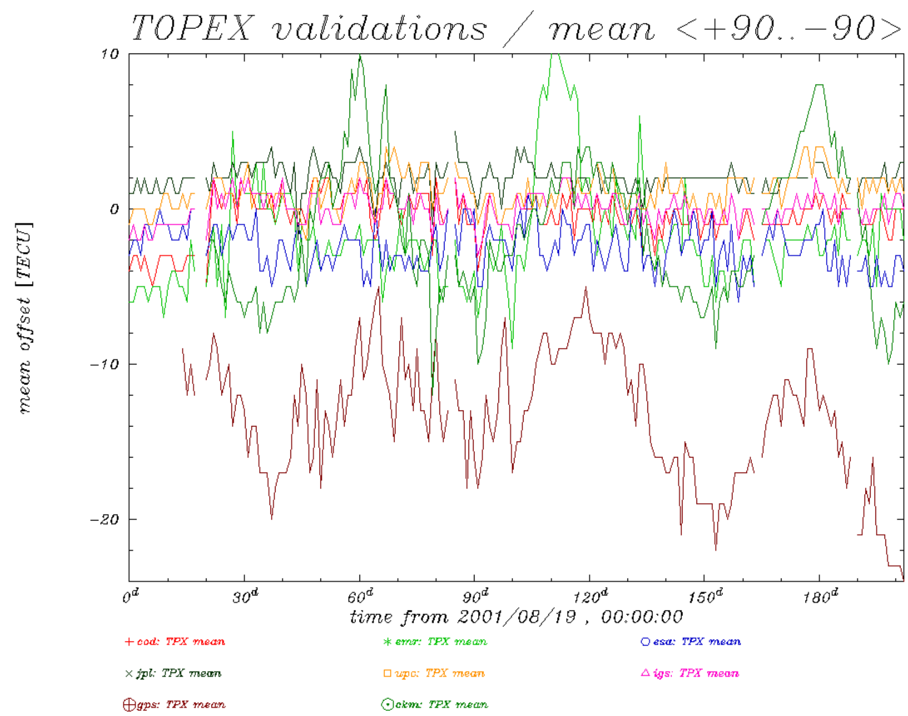

Figure 2a: The basic TOPEX validation statistics mean, rms-diff and rms.

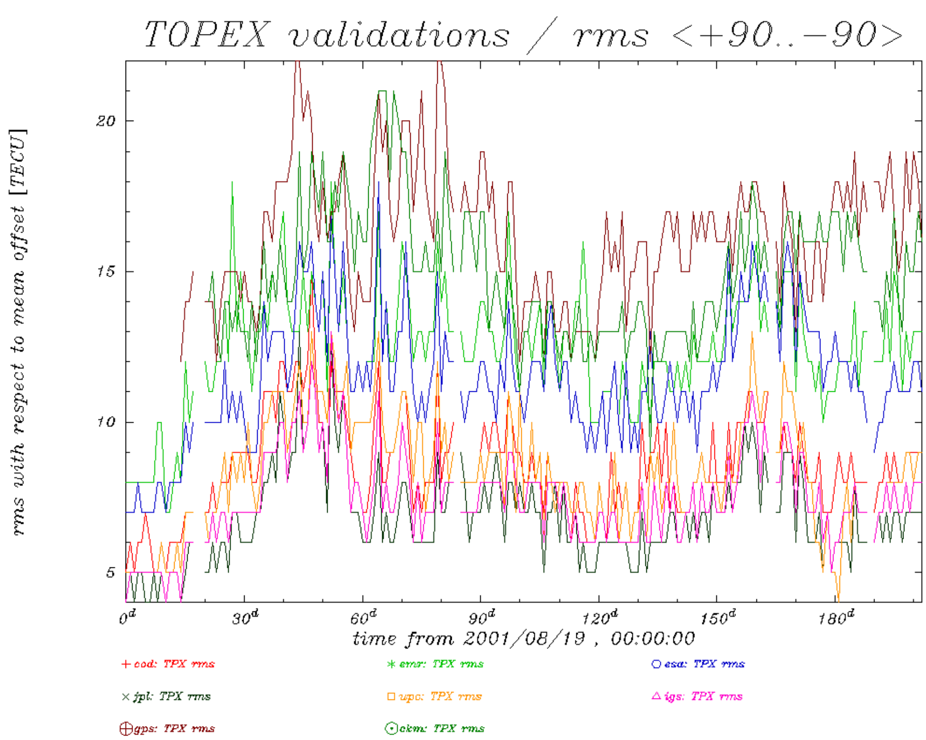

Figure 2b: The basic TOPEX validation statistics mean, rms-diff and rms.

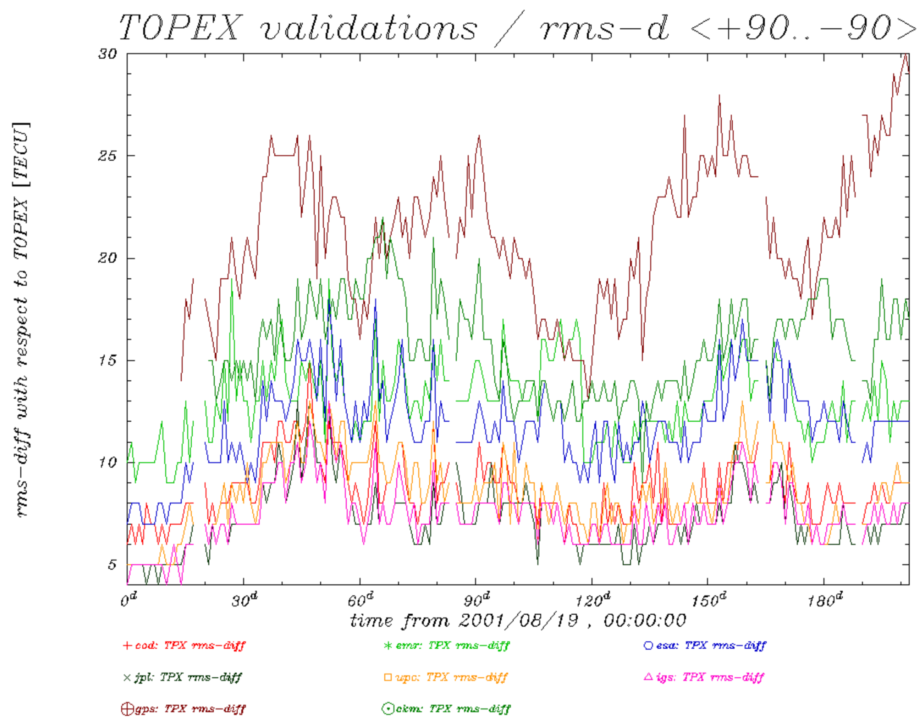

Figure 2c: The basic TOPEX validation statistics mean, rms-diff and rms.

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.

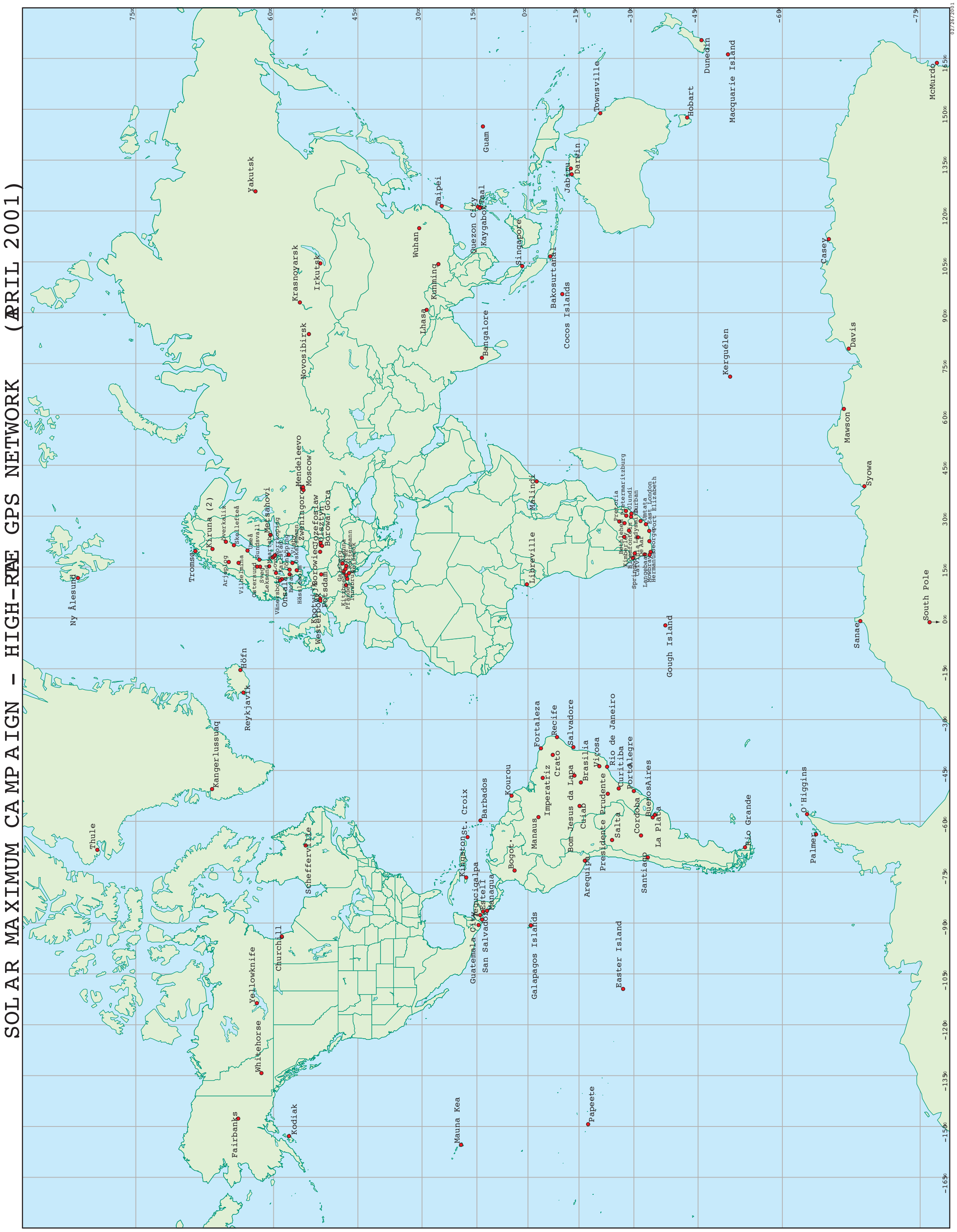

Figure 3: The HIRAC/SolarMax Campaign GPS/GLONASS Network
(courtesy C. Noll, CDDIS).

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

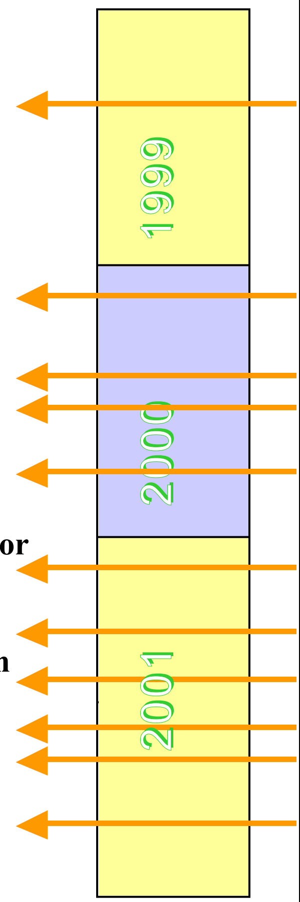
- ***January*** **Call for participation IGS Mail 2669**
- ***April*** **LEO proposals deadline - 26 proposals**
- ***July*** **Launch of CHAMP**
- ***November*** **Launch of SAC-C**

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



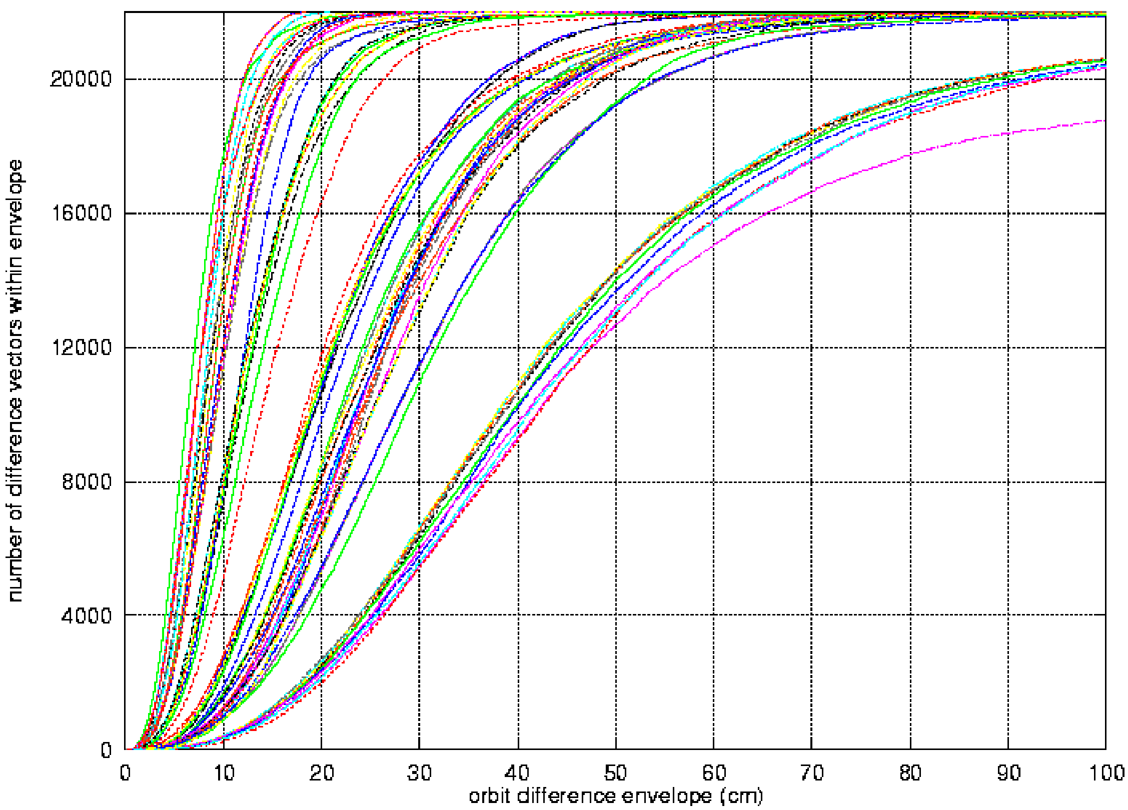


Figure 1: CHAMP orbit difference distributions for the 78 comparisons that can be formed between 13 independent solutions. The RMS over 22000 sample points varies from 8.3 cm (top curves) to 60 cm (lowest curves).

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.

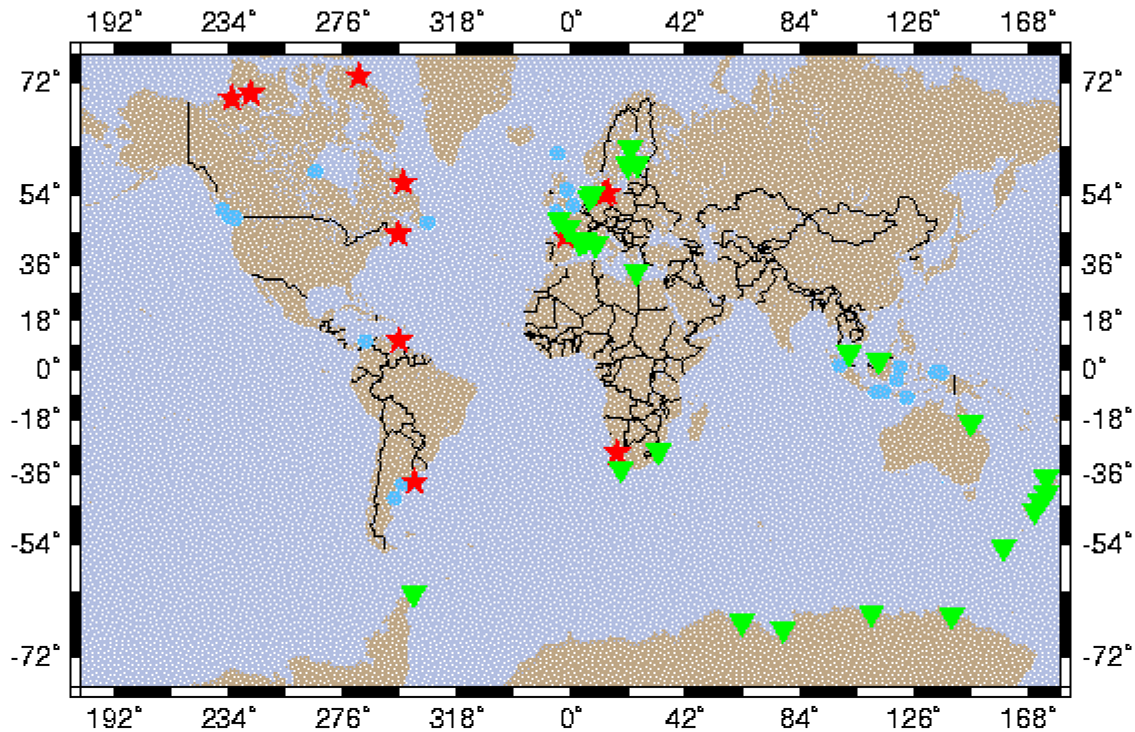

Figure 1: Overview about the current status of TOS stations (as of August 2002)
For few stations (triangles) all necessary information is available. In the near future, more stations will become available (dots). In response to the TIGA Call for Participation also new GPS stations will be installed near tide gauges (stars).