IGS

ANALYSIS CENTERS

CODE IGS Analysis Center Technical Report 2000

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Introduction

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

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

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

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

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

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

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

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

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

Table 1: CODE products made available through anonymous ftp.

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

Table 2: CODE products made available through anonymous ftp.

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

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

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

Changes in the Routine Processing

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

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

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

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

Contribution to ITRF2000

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

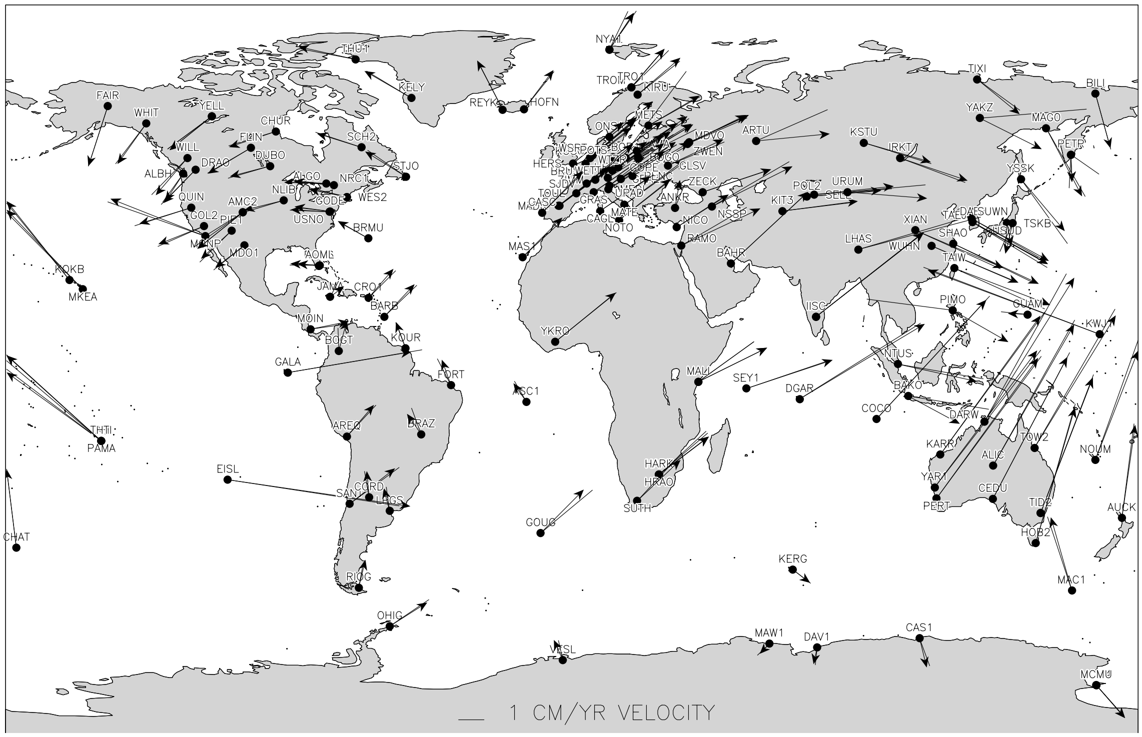

Figure 1: Velocity vectors estimates from a constrained solution (arrows) and from ITRF97 (lines).

Estimation of Satellite and Receiver Clock Parameters

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

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

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

Determination of Differential Code Bias Values

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

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

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

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

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

Klobuchar-Style Ionosphere Parameters

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

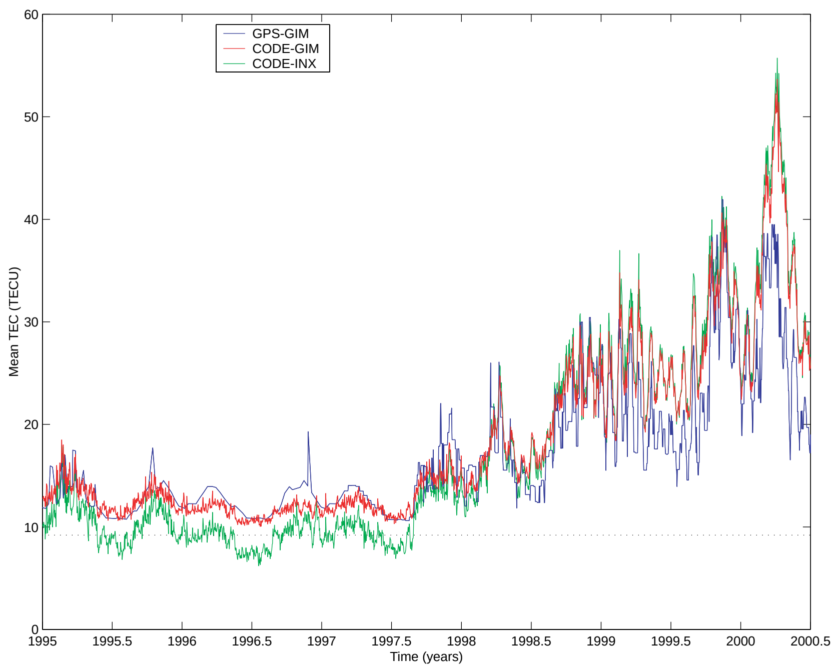

Figure 2: Mean TEC of the ionosphere derived from GPS broadcast model coefficients, CODE generated model coefficients, and CODE IONEX reference, compared from 1995.0 to 2000.5, gathered from [Schaer, 2001].

Sensitivity of GPS and GLONASS Orbits to Geopotential Resonance Terms

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

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

Kinematic and Dynamic Orbit Determination for Low Earth Satellites

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

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

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

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

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

Summary and Outlook

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

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

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

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The ESA/ESOC IGS Analysis Centre Annual Report 2000

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Introduction

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

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

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

Changes and activities in 2000

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

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

Routine Activities

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

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

Processing Method

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

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

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

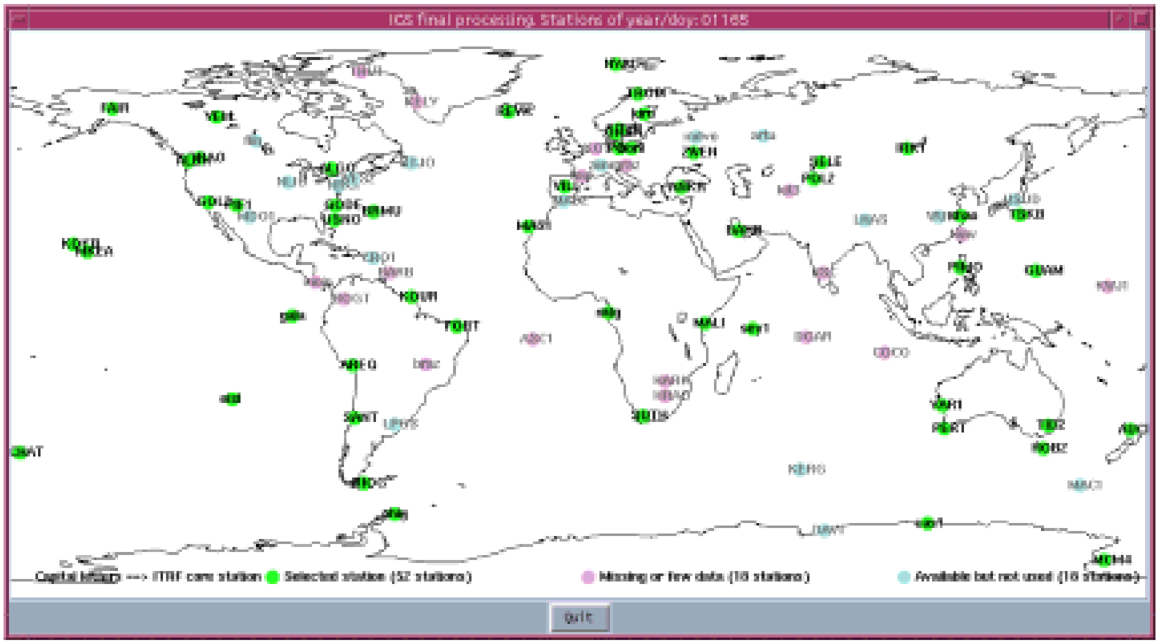

Figure 1: GPS stations typically selected for Final processing.

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

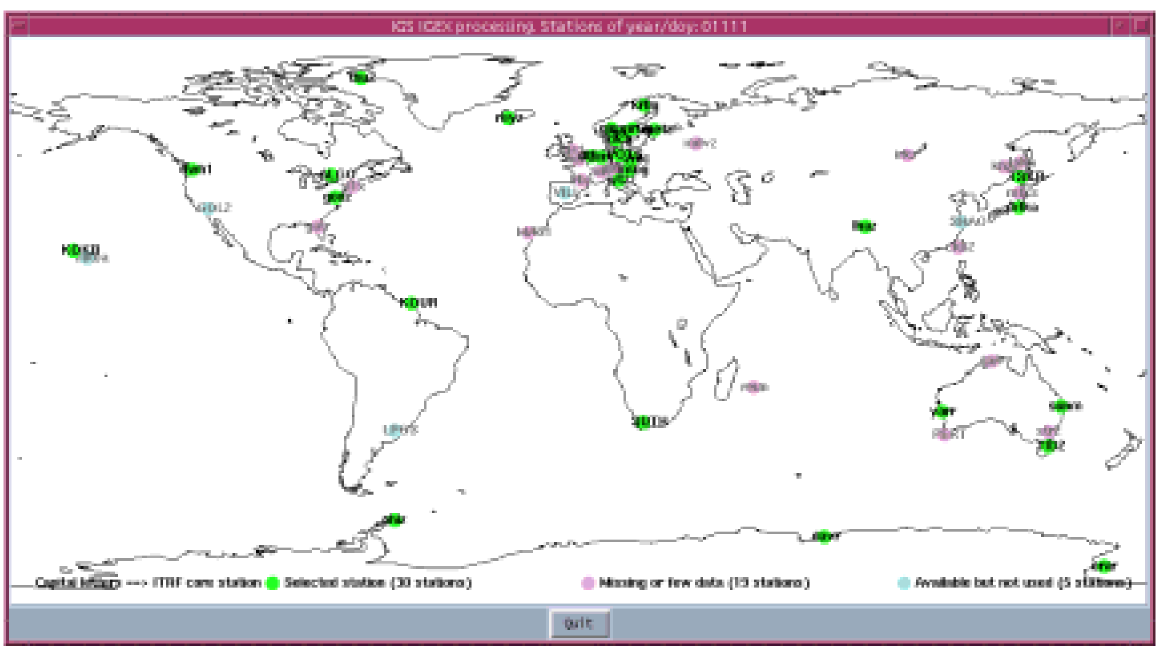

Figure 2: GPS/GLONASS stations typically selected for IGEX processing.

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

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

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

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

Ultra-Rapid implementation

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

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

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

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

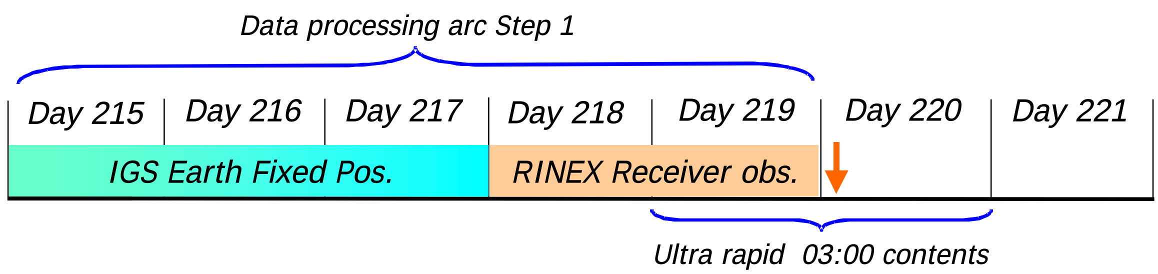

Figure 3. ESA Ultra rapid solution first step, data types and processing arc.

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

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

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

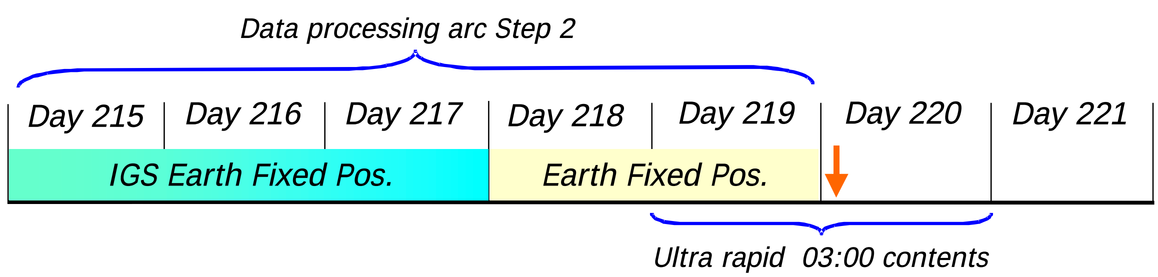

Figure 4: ESA Ultra rapid solution second step, data types and processing arc.

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

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

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

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

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

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

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

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

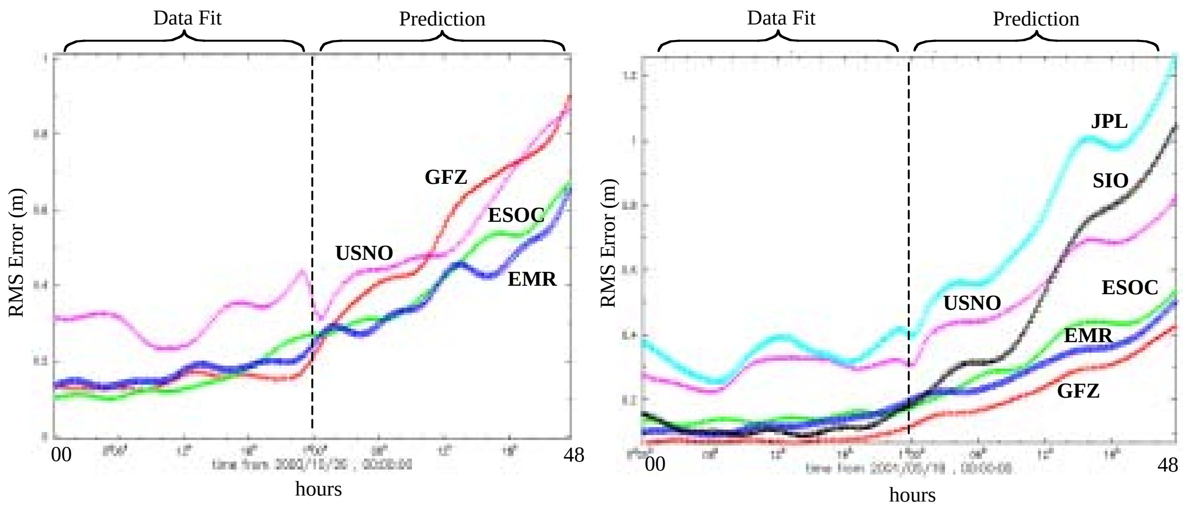

Figure 5: Epoch by epoch unweighted RMS error versus IGU for October 26th,2000 (00300) on the left and May 19th, 2001 (01139) on the right.

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

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

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

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

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

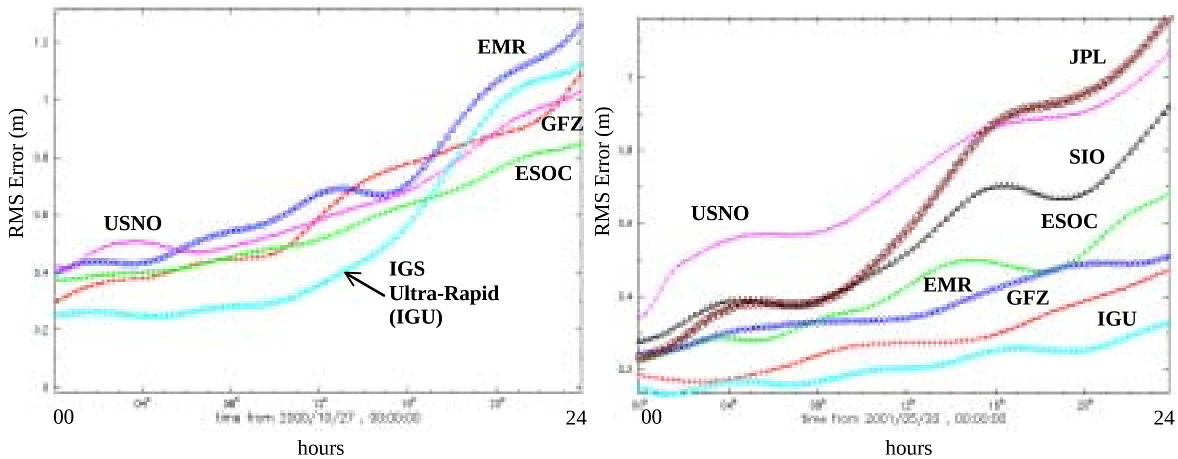

Figure 6: Epoch by epoch unweighted RMS error of predicted part of Ultra-Rapid AC submissions and the IGU versus the IGR for October 26th,2000 (00300) on the left and May 19th, 2001 (01139) on the right.

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

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

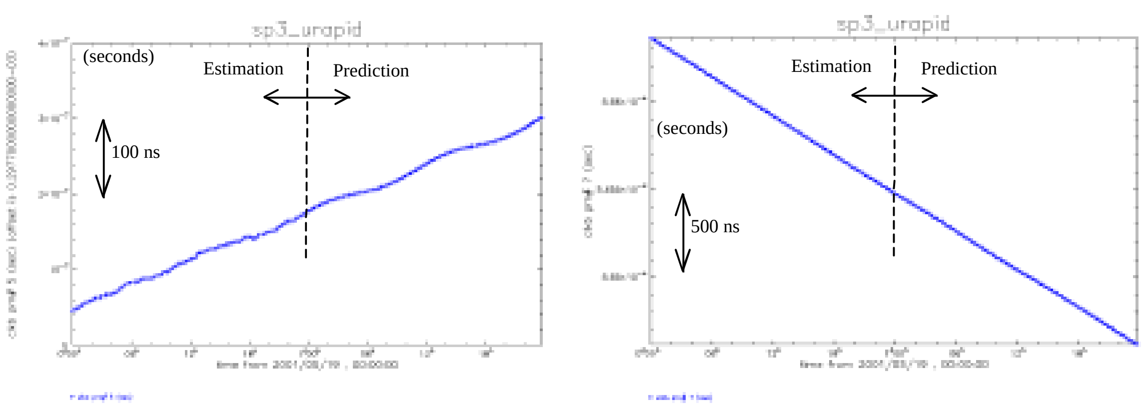

Figure 7: PRN 05 (left) and PRN07 (right) Satellite clock bias estimated and predicted for May 19th,2001 (01139).

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

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

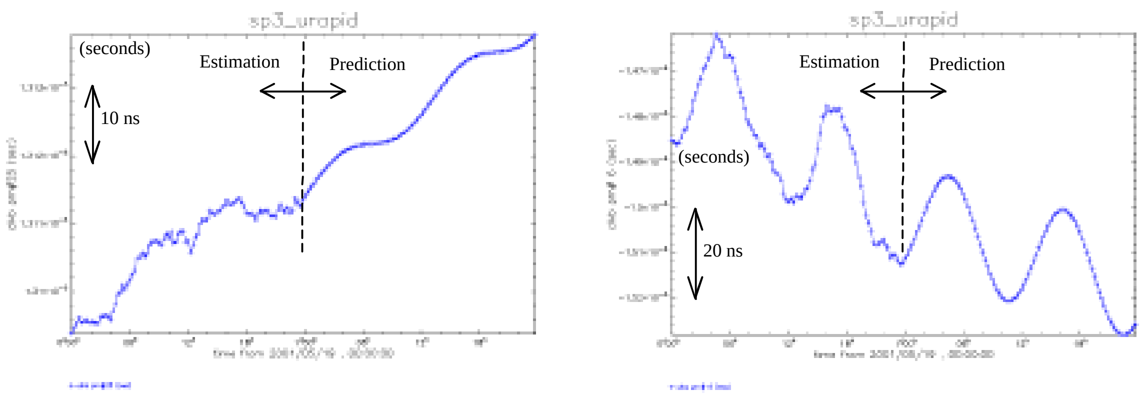

Figure 8: PRN 25 (left) and PRN06 (right) Satellite clock bias estimated and predicted for May 19th,2001 (01139).

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

GLONASS Processing

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

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

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

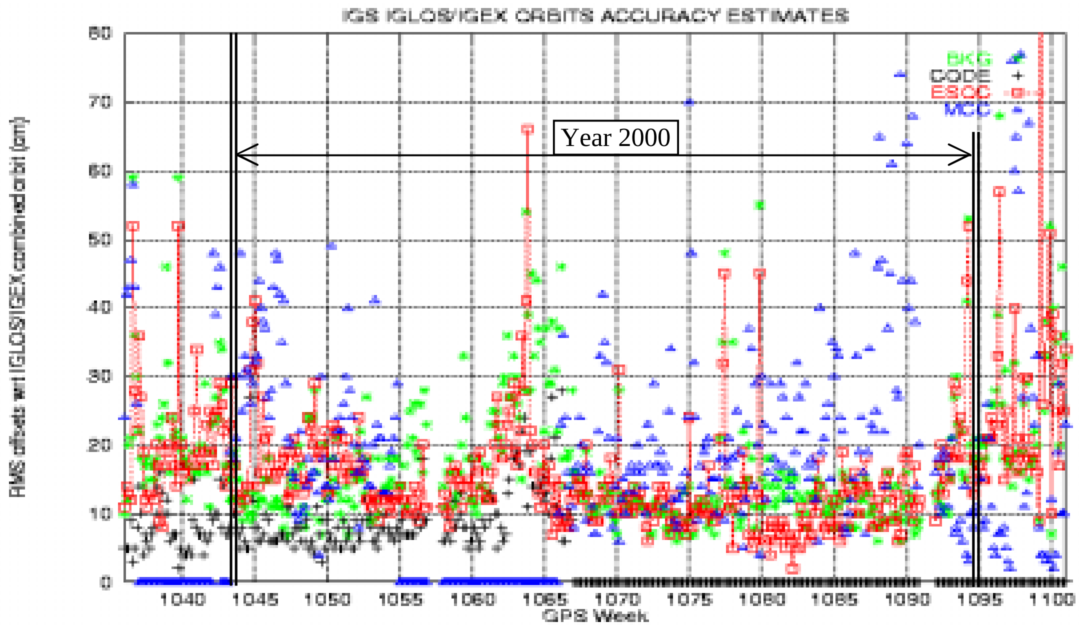

Figure 9: IGLOS/IGEX AC orbit comparisons versus the combination.

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

Ionosphere Processing

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

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

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

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

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

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

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

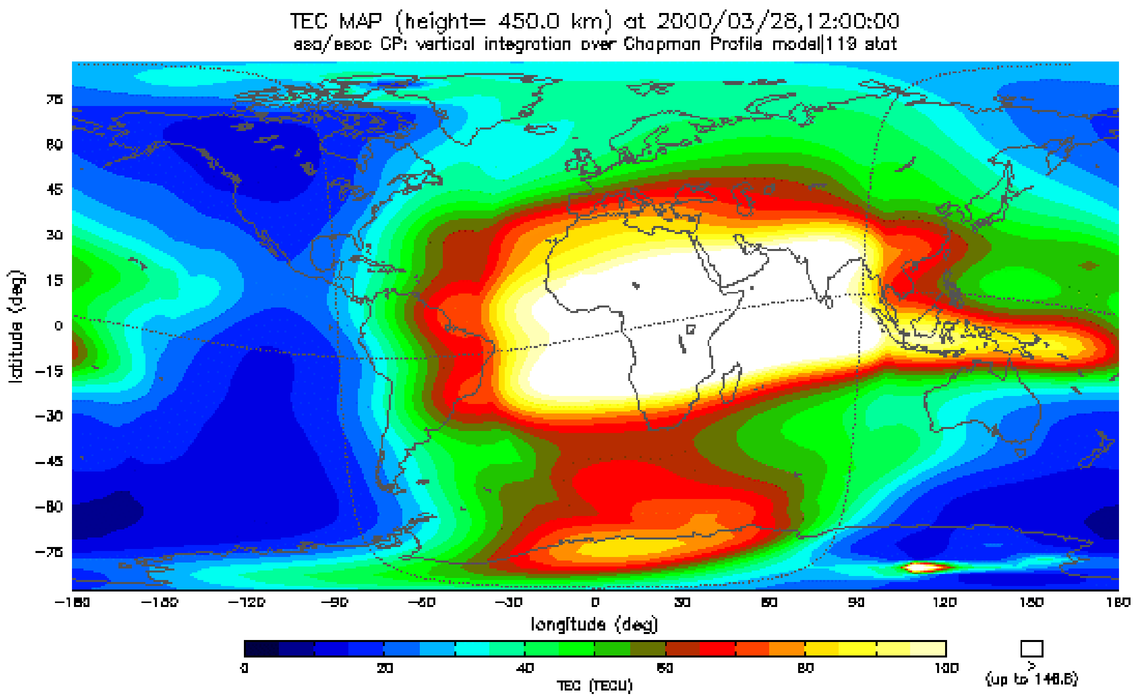

Figure 10: Global TEC map obtained from a fit of type 2) for 28 March 2000, a day during a period in the current solar maximum, when the TEC level was very high.

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

Future Activities

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

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

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GFZ Analysis Center of IGS - Annual Report for 2000

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Summary

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

Classical IGS/IGR products

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

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

Table 1. Changes in the analysis strategy

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

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

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

Ultra-Rapid Products

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

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

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

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

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

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

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

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

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

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

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

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

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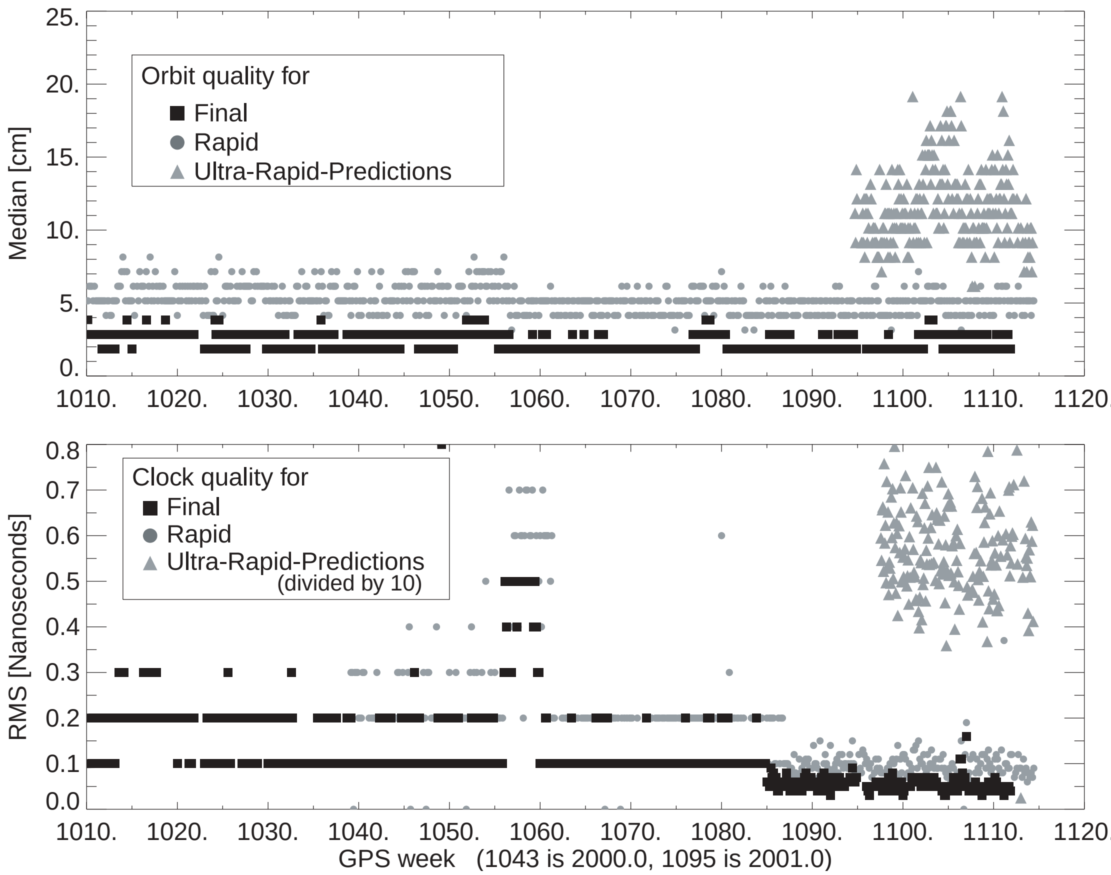

Figure 1. Quality of the various GFZ satellite orbit and clock products taken from the official combinations reports (Rem.: Clock resolution until GPS week 1085 was only 0.1 ns)

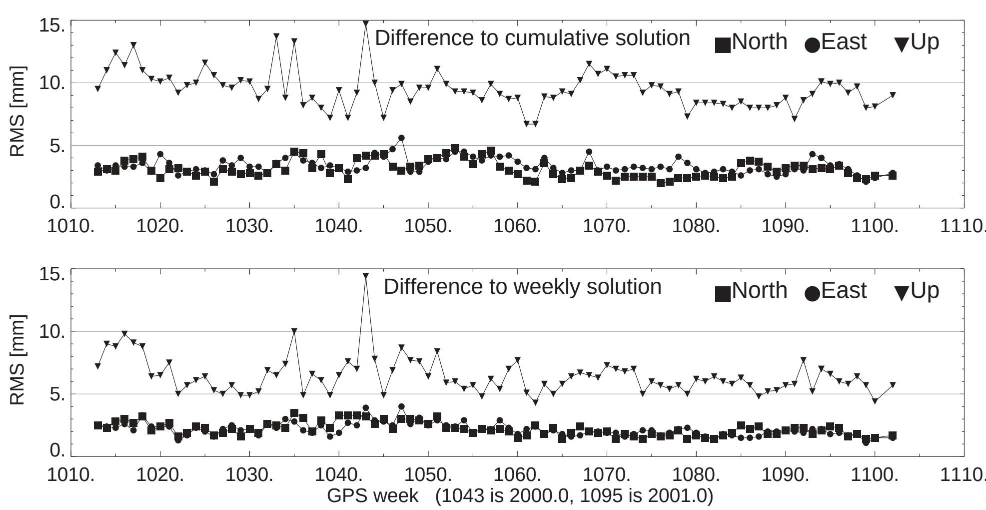

Figure 2. Quality of GFZ station coordinate solutions extracted from the IGS SINEX combination reports

JPL IGS Analysis Center Report, 2000

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Summary

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

Evolution in 2000

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

Table 1: 2000 Analysis Evolution

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

Product Summary

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

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

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

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

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

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

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

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

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

Example File	Contents

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

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

Table 4: Addresses of Relevant Web Pages

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

Strategy Update: P1-C1 Bias Corrections

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

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

Strategy Update: Use Of IGS97

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

Clock Solution Update

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

New Products

Ultra-Rapid:

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

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

Real-Time 15-minute

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

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

Results And Performance

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

Table 5: Latency and Accuracy of JPL IGS AC Products

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

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

Figure 1 chronicles the progression of the final orbit solution quality since 1995. As in the past, our metric for orbit quality is the day-to-day consistency of the solutions, i.e. the degree to which estimates from adjacent days agree near the midnight boundaries. Contributing factors to improvement are the continuing expansion of the global network and quality of receivers used, the use of global phase ambiguity resolution (implemented in April 1996), the estimation of tropospheric gradients (implemented in August 1997, and the application of P1-C1 bias corrections (implemented in April 2000).

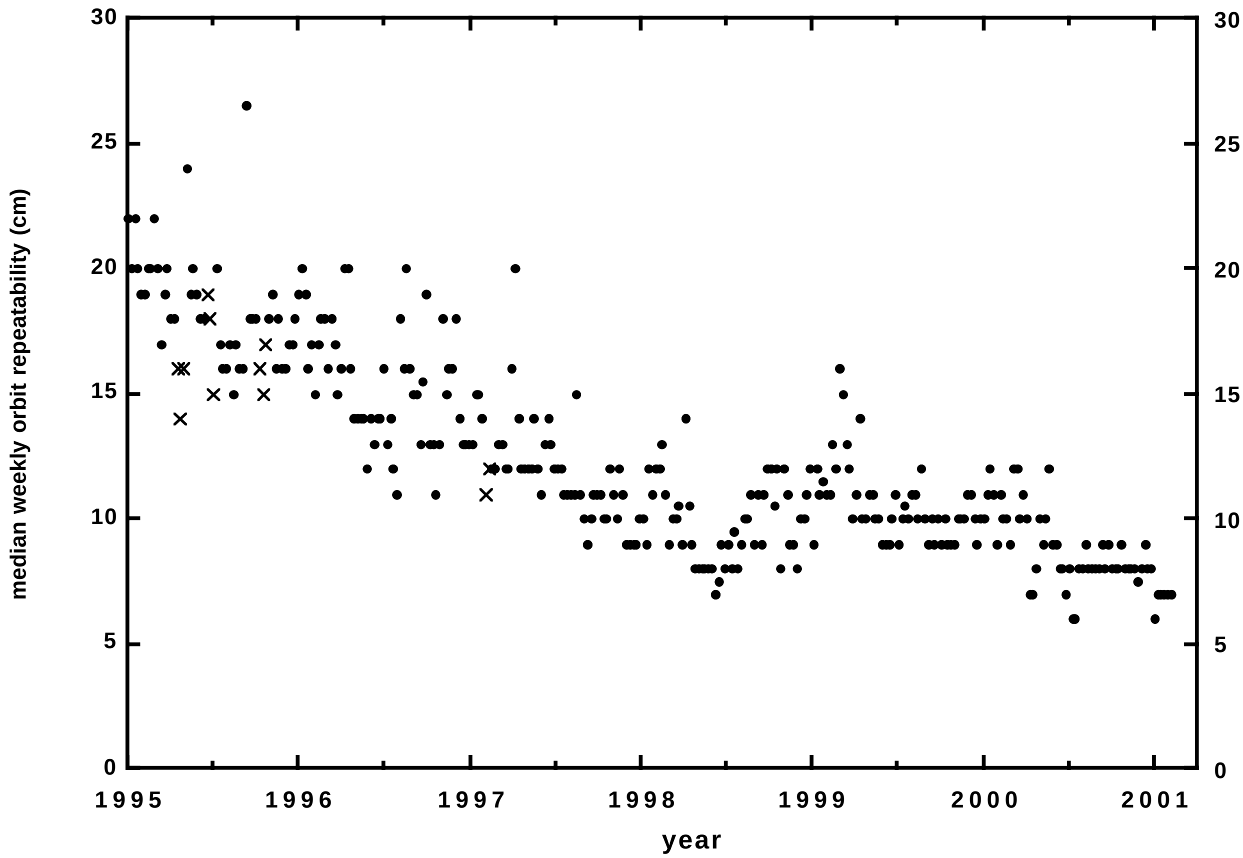

Figure 1: JPL orbit repeatability (3drms) since 1995. Each data point represents the median over all satellites and days for a particular GPS week. (The daily number for a given satellite indicates the degree to which the precise orbit agrees with those of adjacent days near the midnight boundary.) Weeks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

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

Table 6: Geodetic Velocity Comparisons

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

Acknowledgment

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

References

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

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

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

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

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

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

Introduction

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

Station Network

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

Software Changes

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

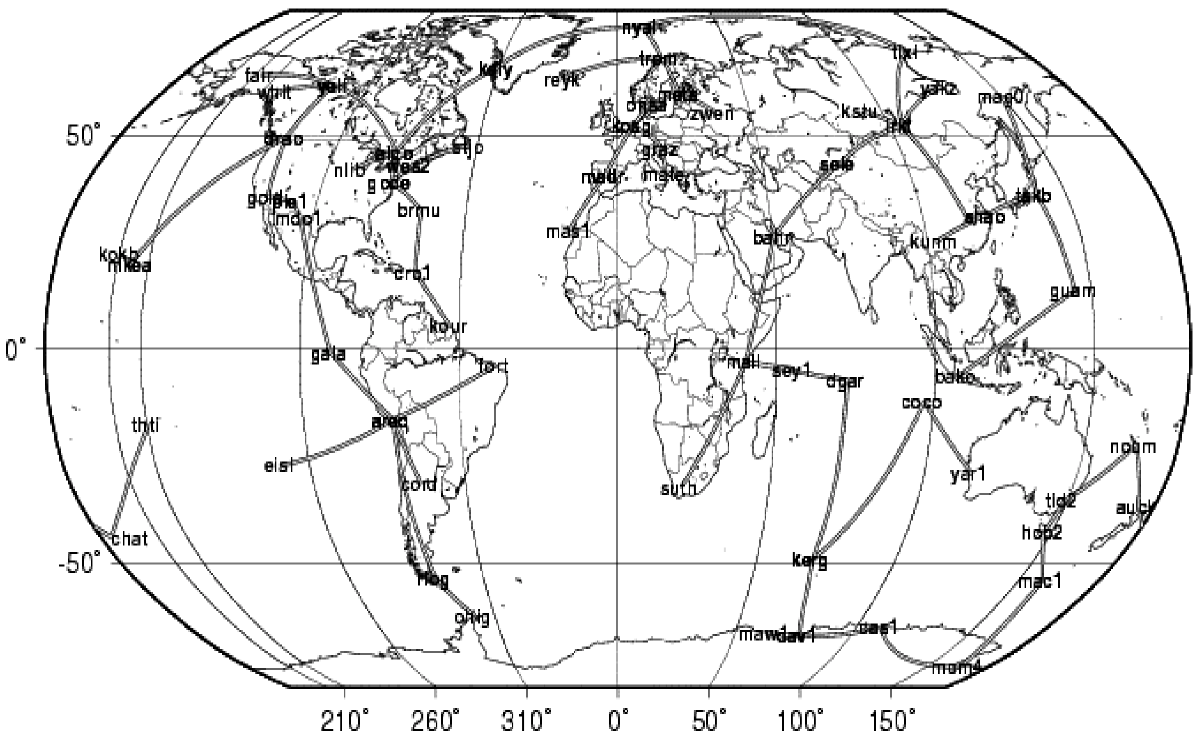

Figure 1.

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

Product Evaluation

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

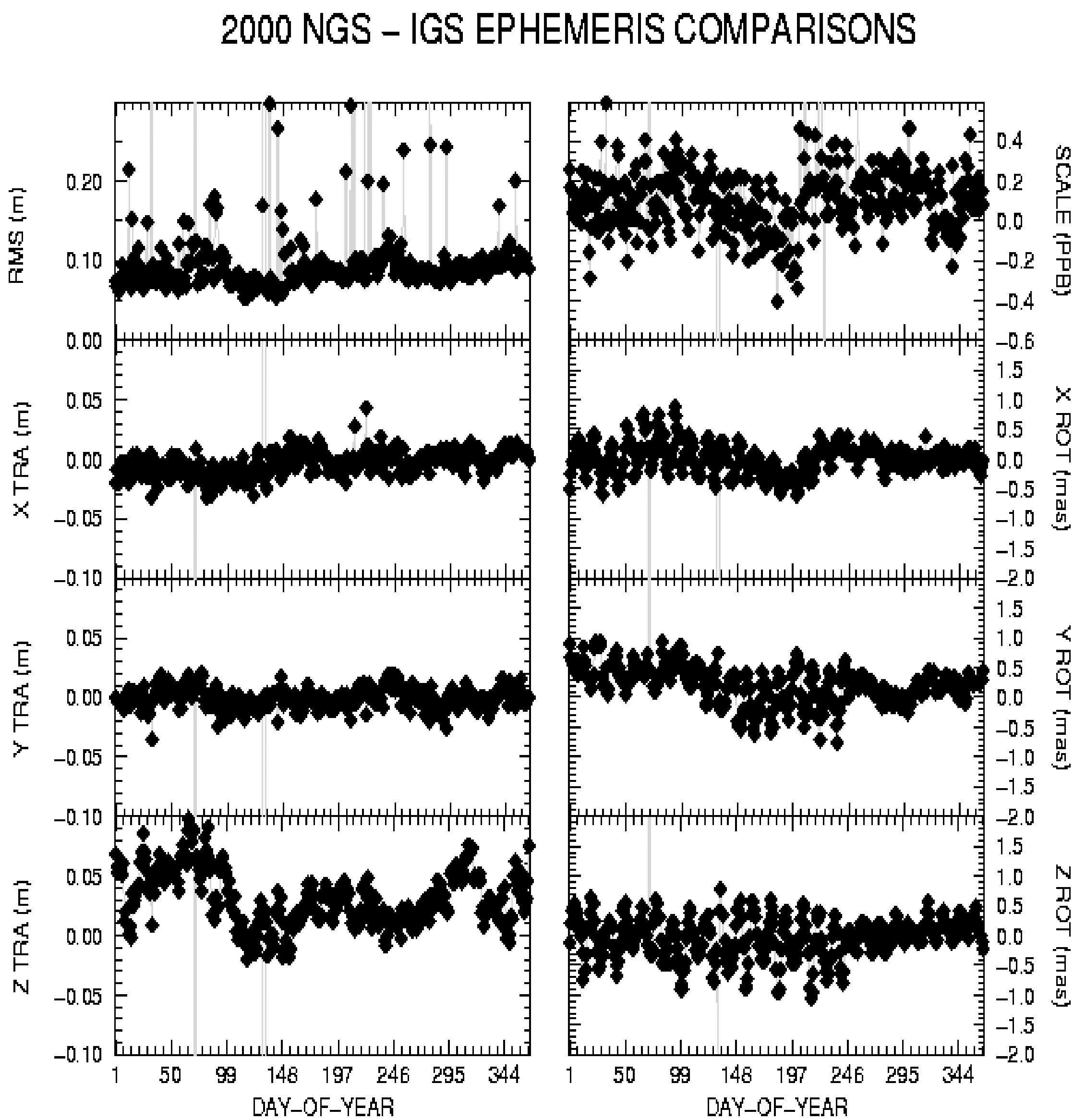

Figure 2

Orbit Products

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

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

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

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

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

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

References

Schwiderski, E., 1983, "Atlas of Ocean Tidal Charts and Maps, Part I: The Semidiurnal Principal Lunar Tide M2", Marine Geodesy, 6, 219-256.

NRCan IGS Analysis Center Report for 2000

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

The Classical IGS Products

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

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

Table 1. Final/Rapid Processing Strategies Modifications and Improvements

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

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

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

Table 2. GPS Constellation Changes in 2000

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

EMR Regional Processing

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

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

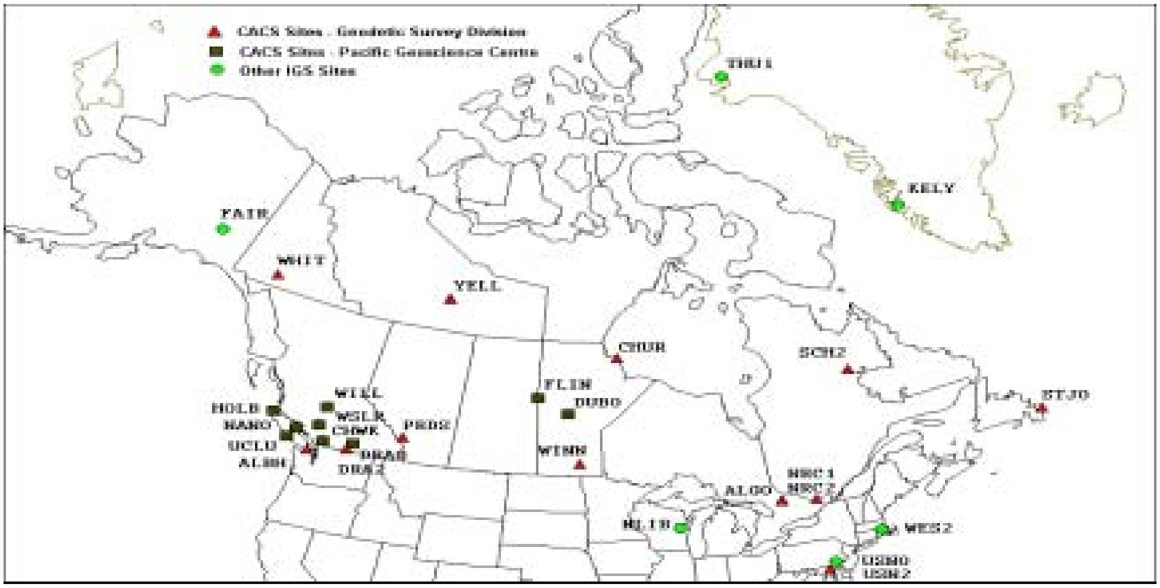


Figure 1. Stations included in NRCan Regional Processing

NRCan Ultra Rapid Products

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

Processing Strategy

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

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

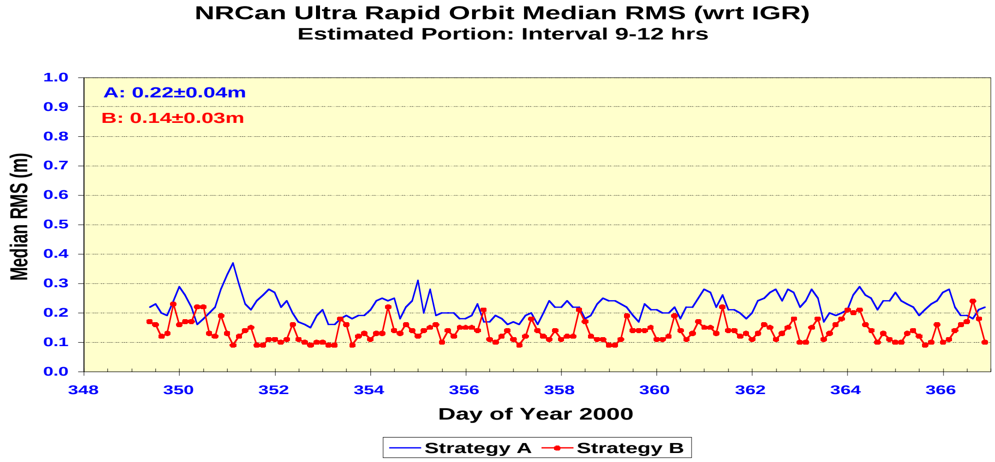
A number of different sources of apriori orbits can be used ranging from our own Ultra Rapid products to the less precise Broadcast ephemeris. As far as the apriori Earth Rotation Parameters (ERP) are concerned, we use the IERS Bulletin A at all times. IERS Bulletin A has been very reliable and is one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

Products Generated and Results

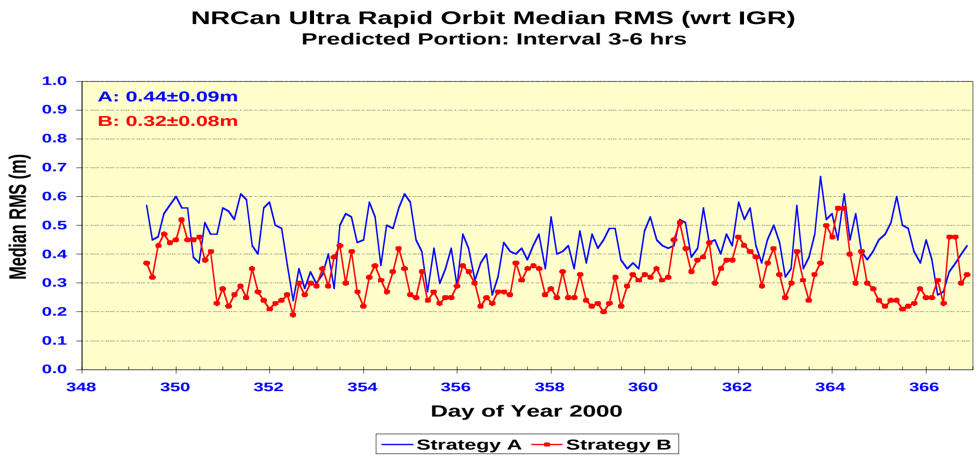
NRCan Ultra Rapid products consist of a 48-hr orbit file (24h estimated and 24h predicted) along with a 2-day ERP file (the first day is estimated and the second day is predicted). Although NRCan produces such product every 3 hours, only the sessions ending at 0h0m UT and 12h0m UT are sent to the ACC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

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

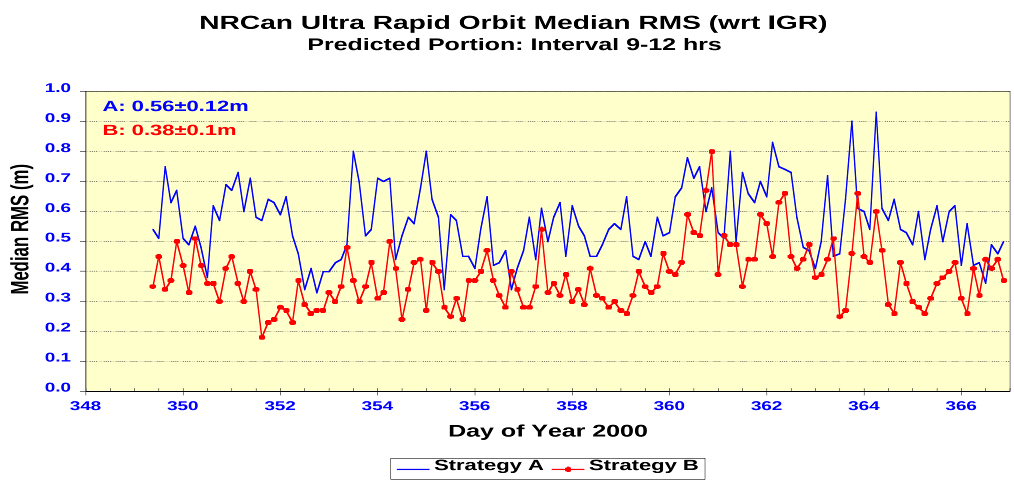
Strategy B proved to be very beneficial for the NRCan Ultra Rapid orbit precision. Depicted in Figure 2 is the NRCan daily Ultra Rapid orbit Median RMS (with respect to IGR) for both strategies A and B and for 3 different time intervals. Interval 9-12 hours of the estimated portion is shown on Figure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



(a)



(b)



(c)

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

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

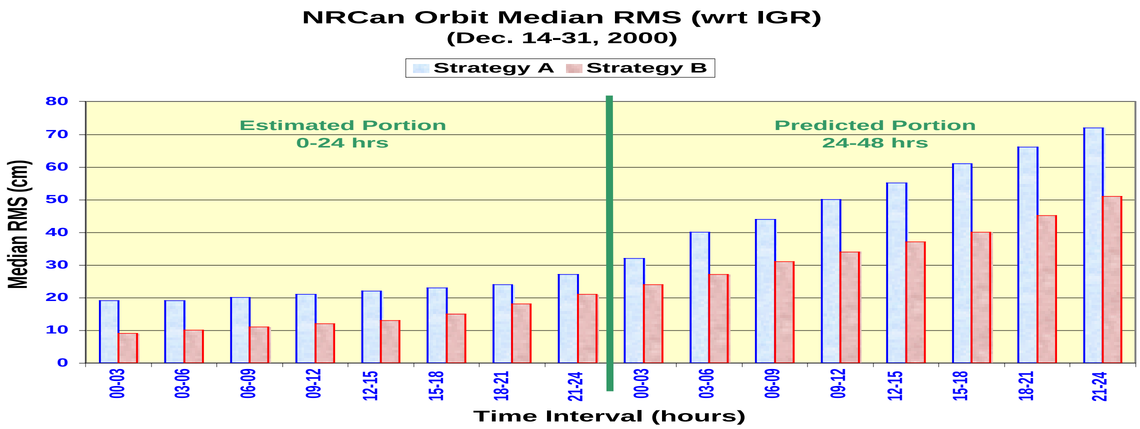


Figure 3: NRCan Ultra Rapid Orbit Median RMS (wrt IGR) for all 3-hour Intervals of Strategies A and B. Period covered: December 14-31, 2000.

Future Work

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

Acknowledgment

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

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Fang P, G. Gendt, T. Springer and T. Mannucci (2001). *IGS Near Real-Time Products and their Applications*, GPS Solutions, Vol. 4, No. 4, John Wiley & Sons, Inc., pp. 2-8.

ASSOCIATE ANALYSIS CENTERS

IGS

GLOBAL NETWORK ASSOCIATE ANALYSIS CENTERS

The Newcastle GNAAC Annual Report for 2000

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

G-network Results

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

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

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

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

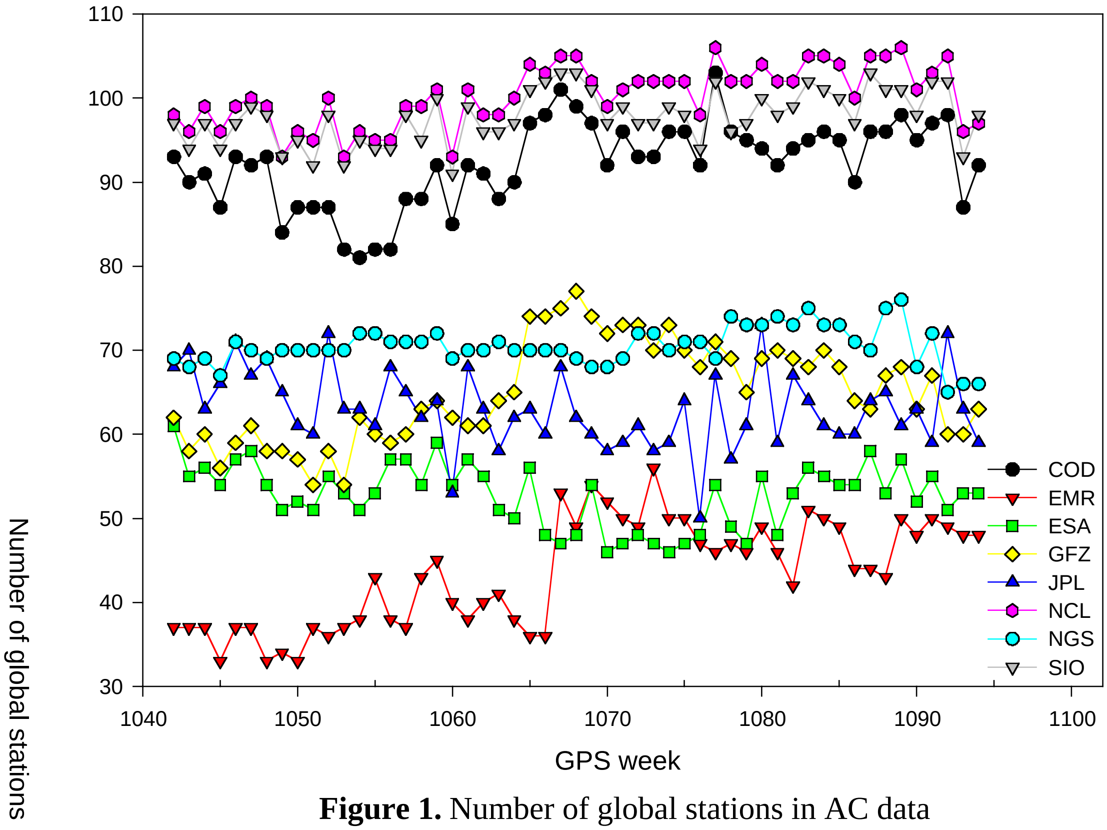

Figure 1. Number of global stations in AC data

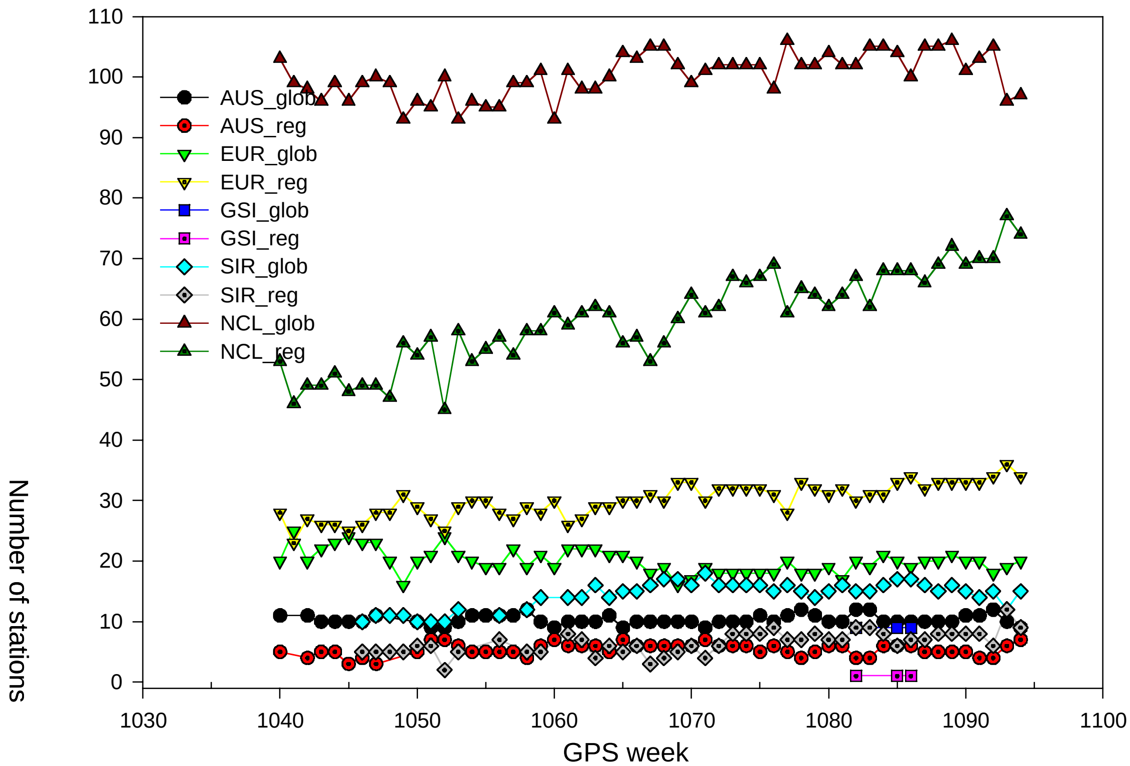

Figure 2. Number of global and regional stations in RNAAC and P-network solutions

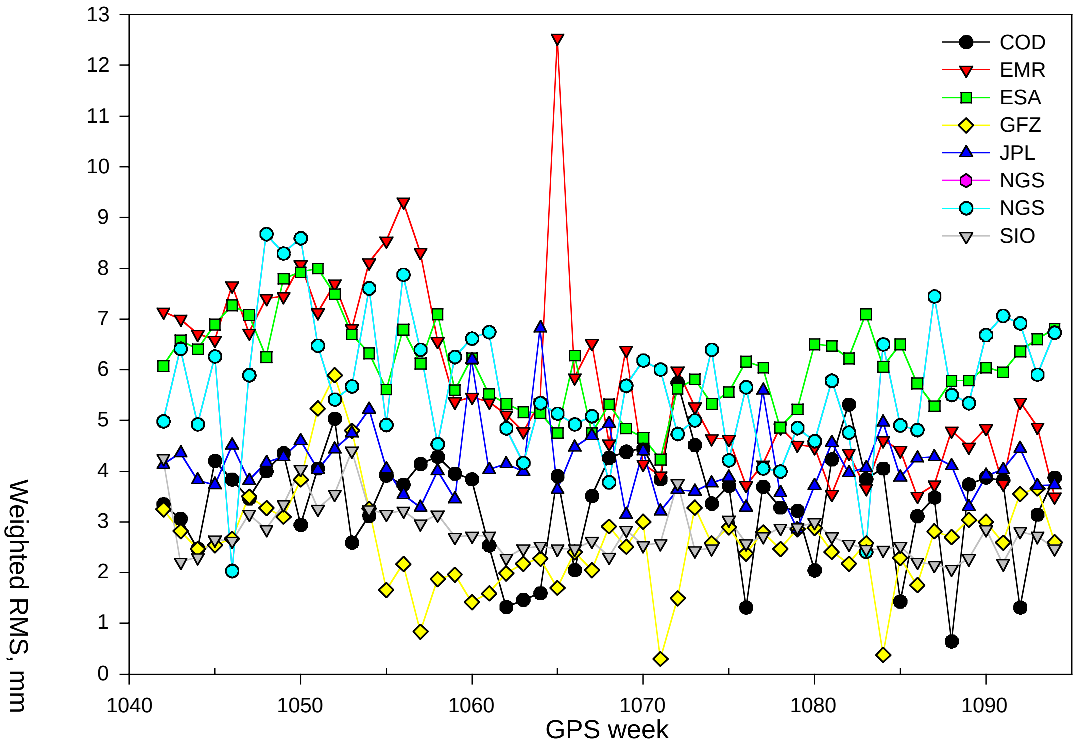

Figure 3. Weighted RMS of residuals for AC network transformation to loose NCL G-network

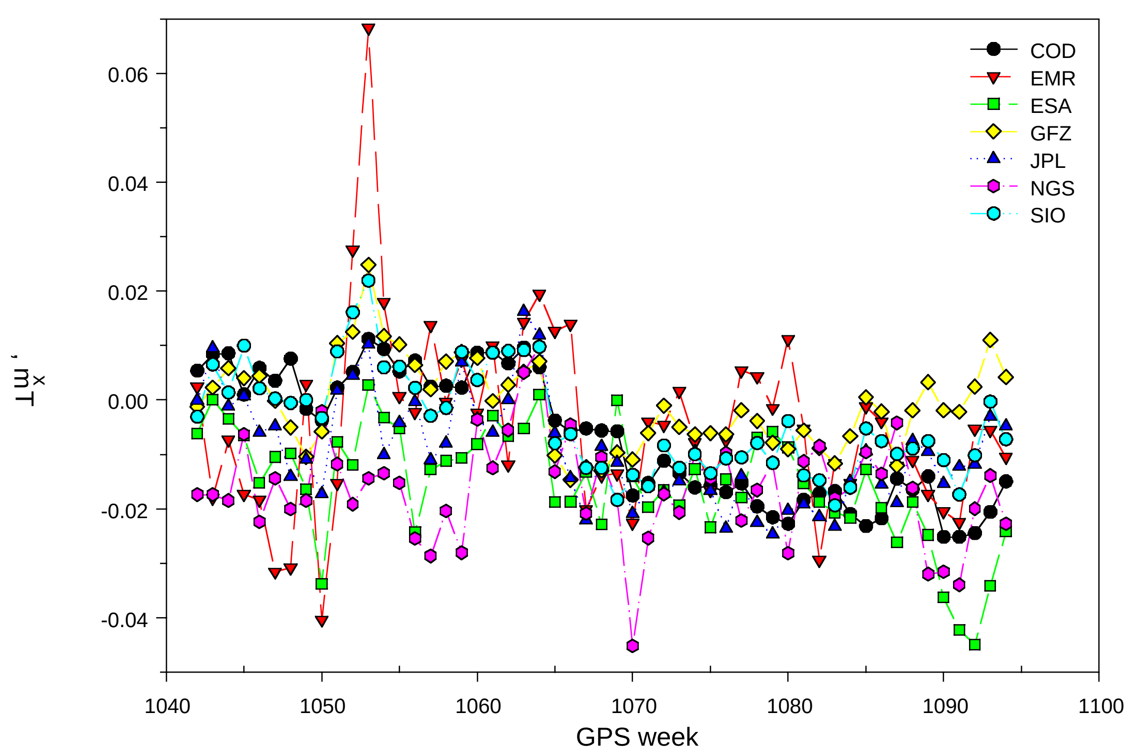

Figure 4. Time series of T_x transformation parameter for the ACs to ITRF

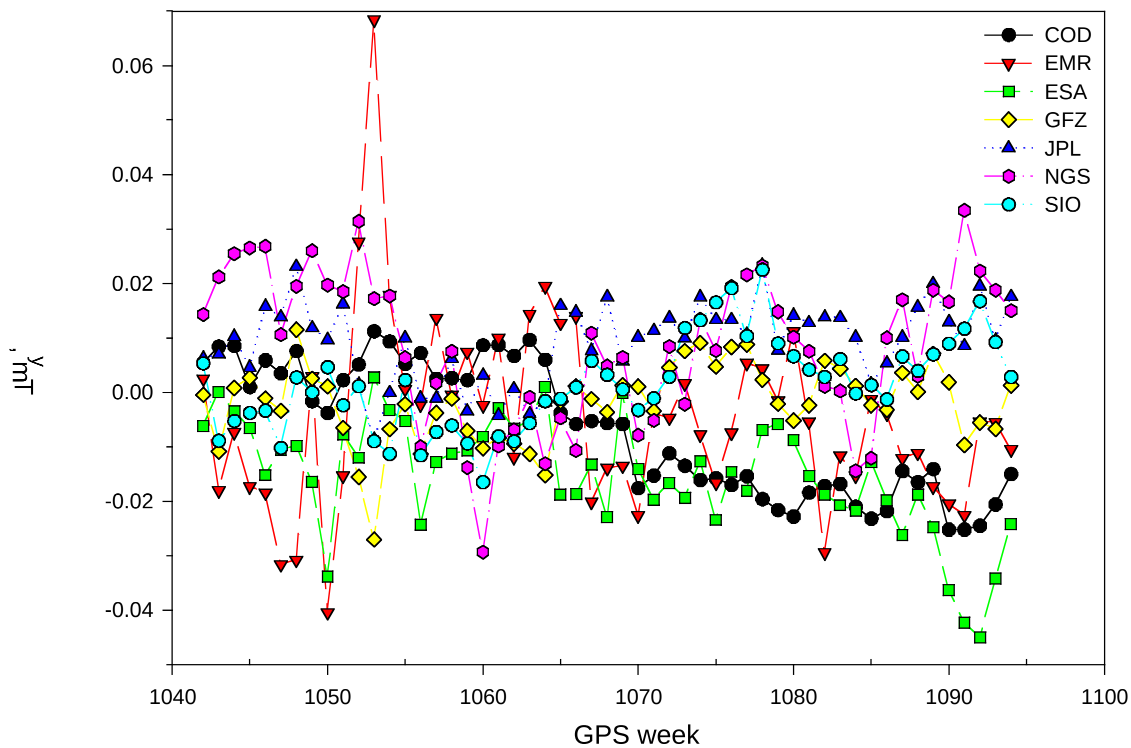

Figure 5. Time series of T_y transformation parameter for the ACs to ITRF

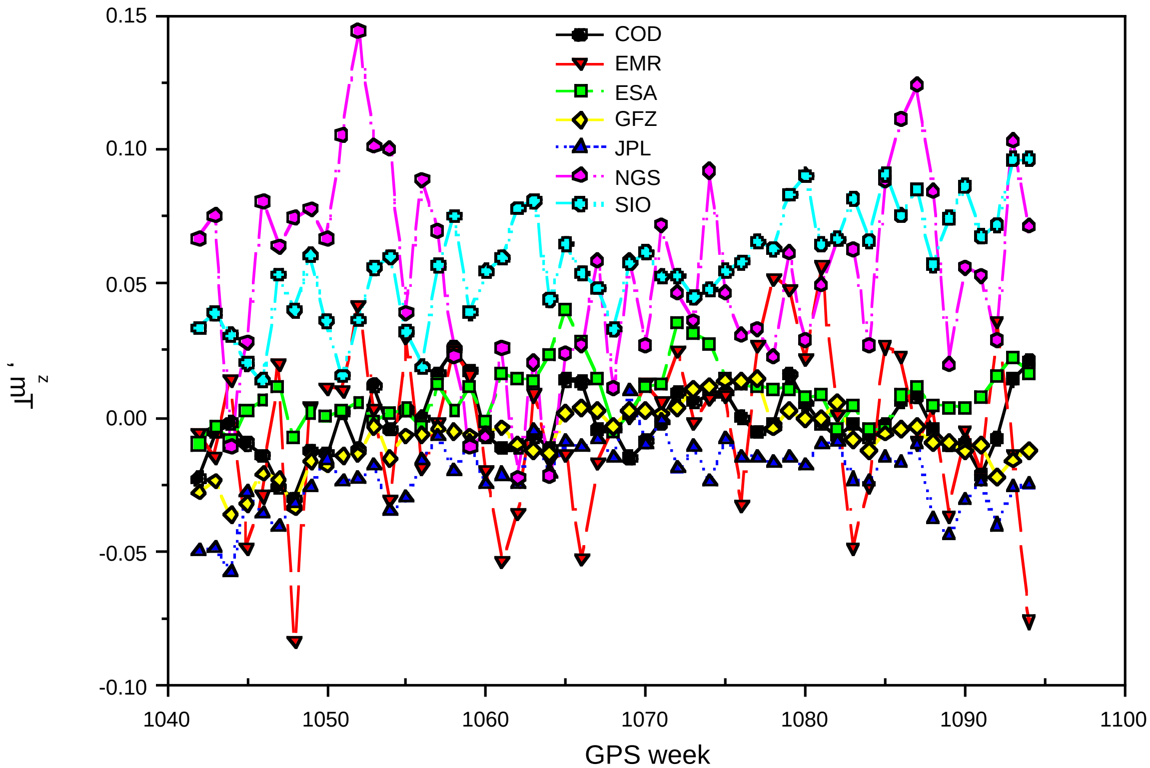

Figure 6. Time series of T_z transformation parameter for the ACs to ITRF

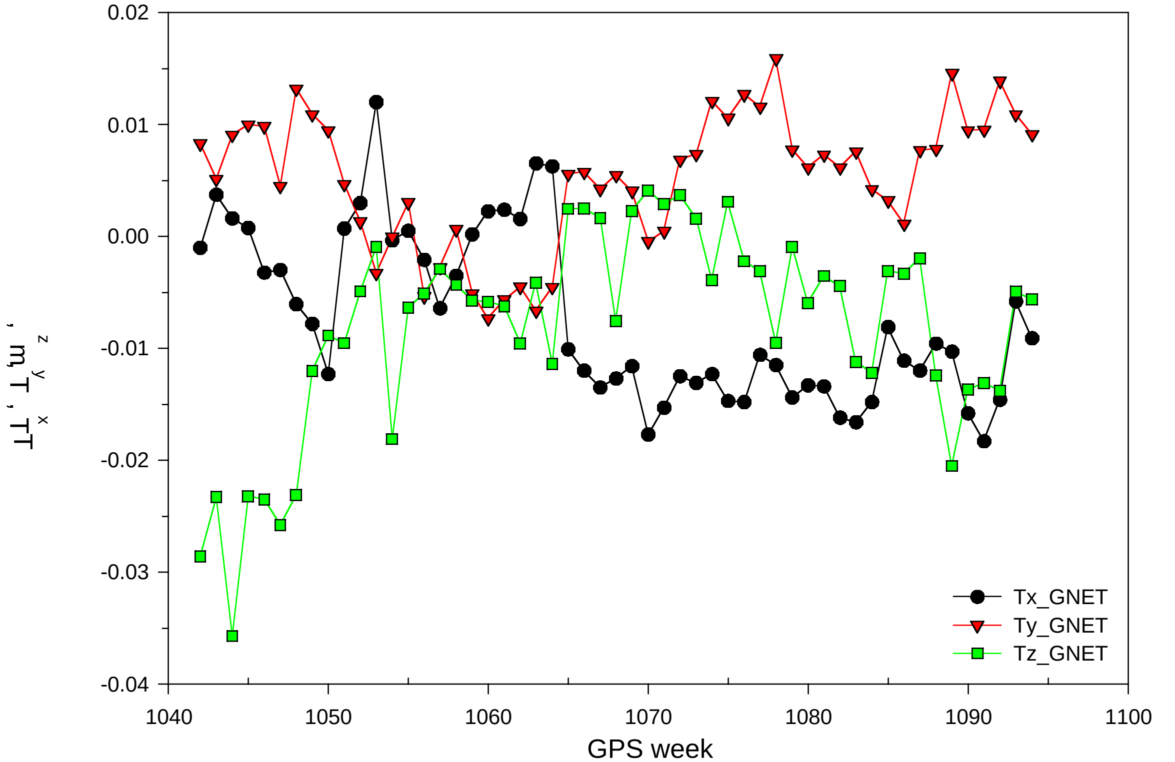

Figure 7. Time series of T_x , T_y , T_z transformation parameters for the NCL GNET to ITRF

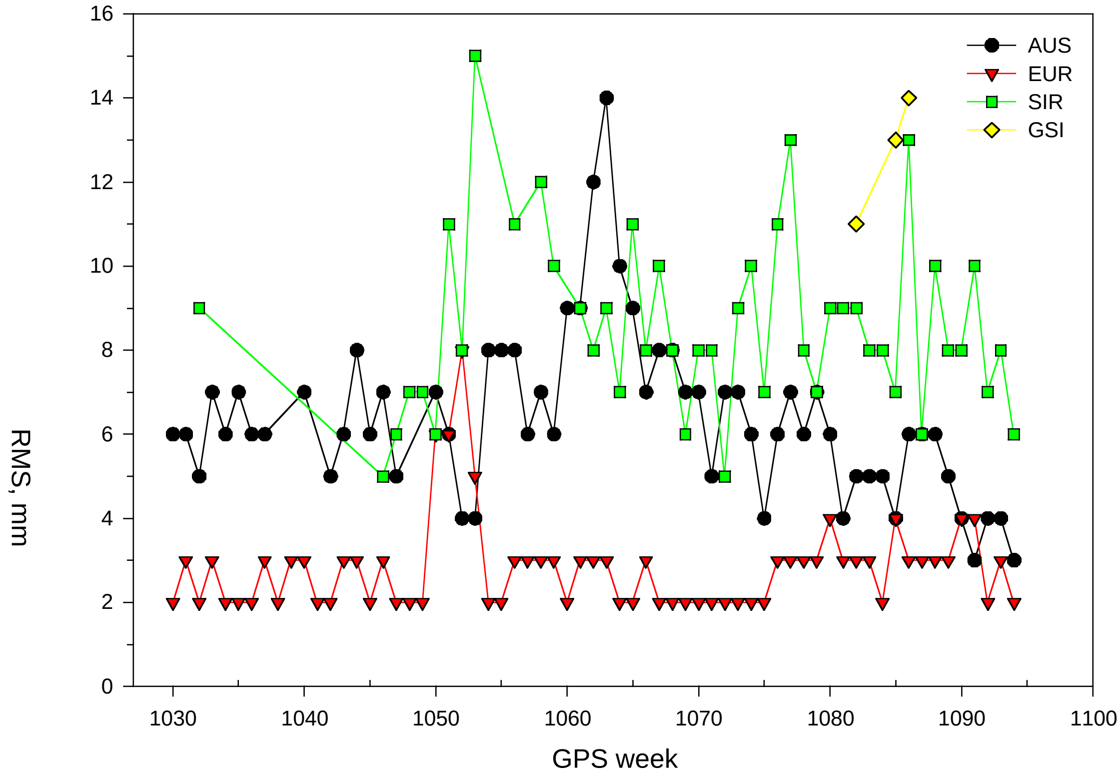

Figure 8. RMS of residuals for RNAAC R-network transformation to loose NCL G-network

P-network Results

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

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

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

Other activity

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

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

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

Summary and Outlook

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

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

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IGS

REGIONAL NETWORK ASSOCIATE ANALYSIS CENTERS

The EUREF Permanent Network Report 2000

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Introduction

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

EPN Management and new Structure

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

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

Extensions of the EPN Tracking Network

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

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

Figure 1 – EPN tracking network, as of June 2001

EPN Data Flow

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

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

Recommended checks are:

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

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

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

Data Analysis

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

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

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

Combination Scheme

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

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

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

Introduction of a new Local Analysis Center

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

Weighting of Solutions

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

Time Series Special Project

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

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

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

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

Troposphere Special Project

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

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

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

Outlook

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

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Acknowledgements

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

AUSLIG RNAAC – 2000 Annual Report

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Introduction

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

Station Network

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

Data Analysis and Results

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

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

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

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

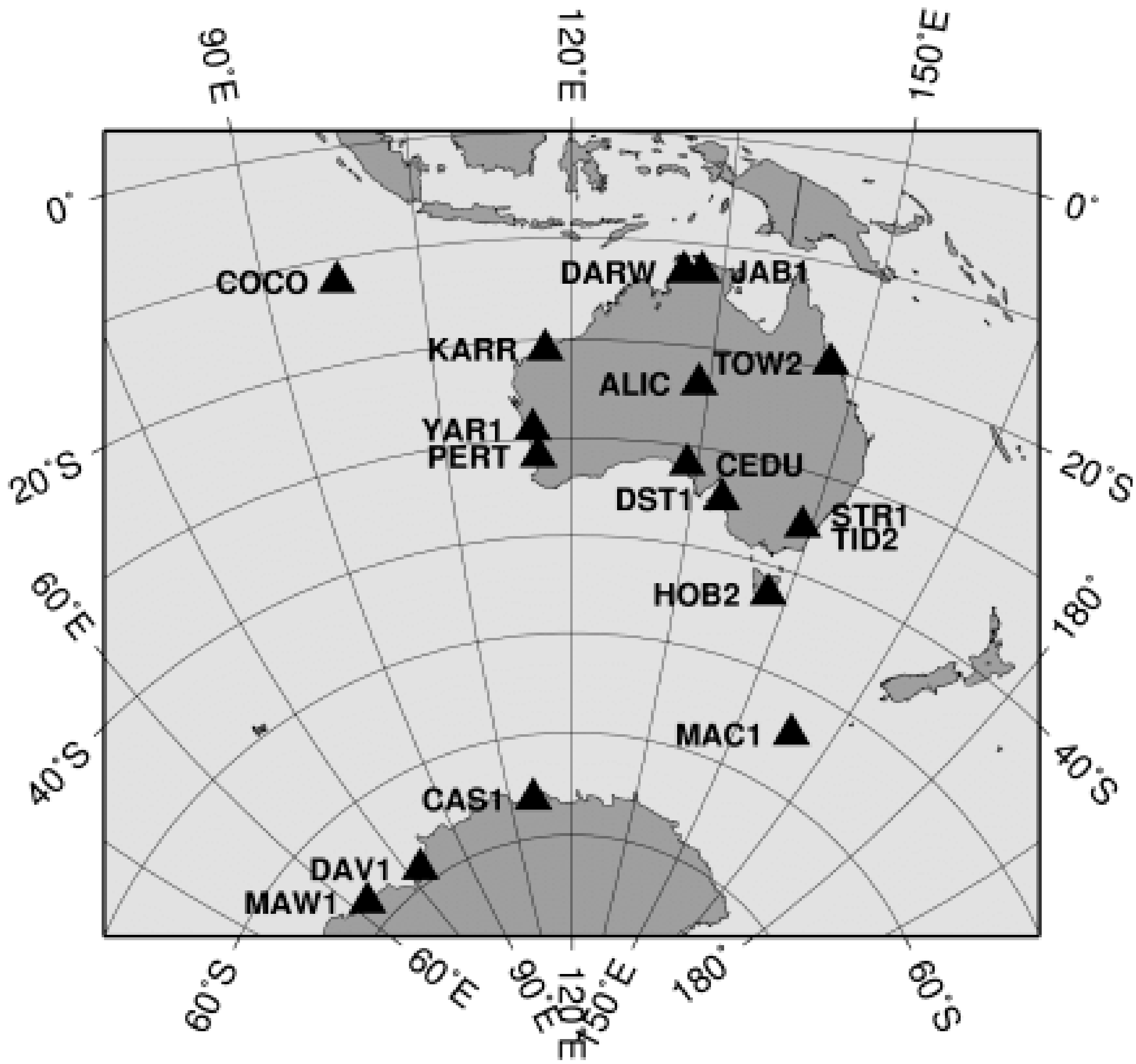

Figure 1. AUSLIG RNAAC station network as of 31 December 2000

Future Plans

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

References

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GSI RNAAC Technical Report 2000

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Introduction and Overview

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

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

Outline of Processing

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

Characterizing features of the performed solutions are as follows;

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

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

Current State

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

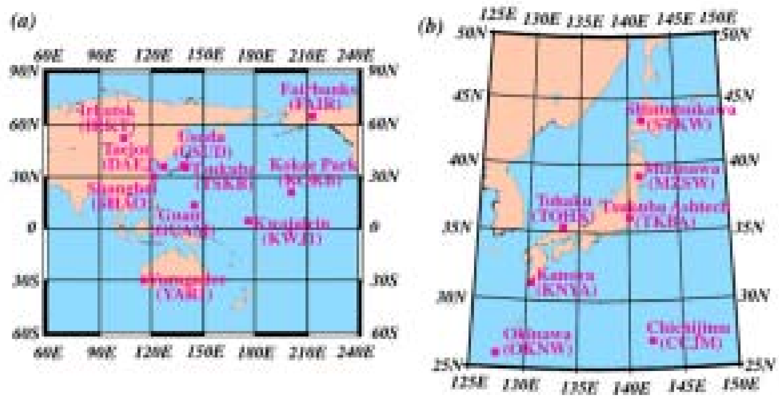

Figure 1. GPS observation sites for GSI RNAAC analysis
(a) IGS global sites (b) domestic sites

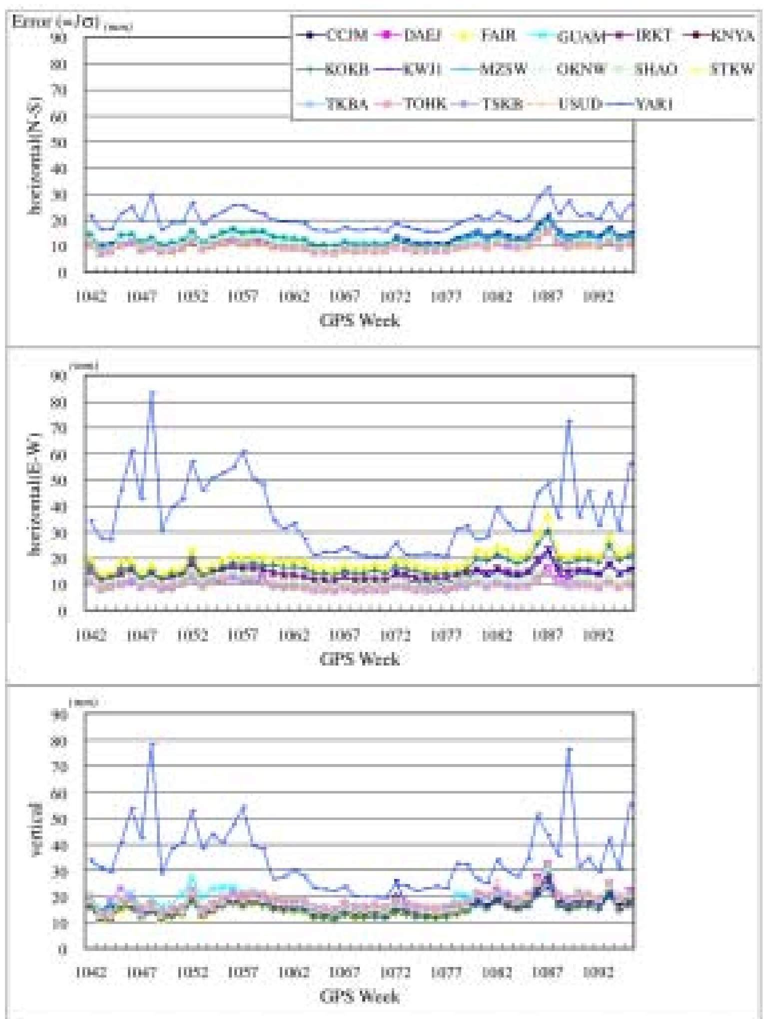

Figure 2. Standard Deviation of GSI RNAAC weekly solution

Annual Report 2000 of IGS RNAAC SIR

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Introduction

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

Station Network

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

Solutions

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

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

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

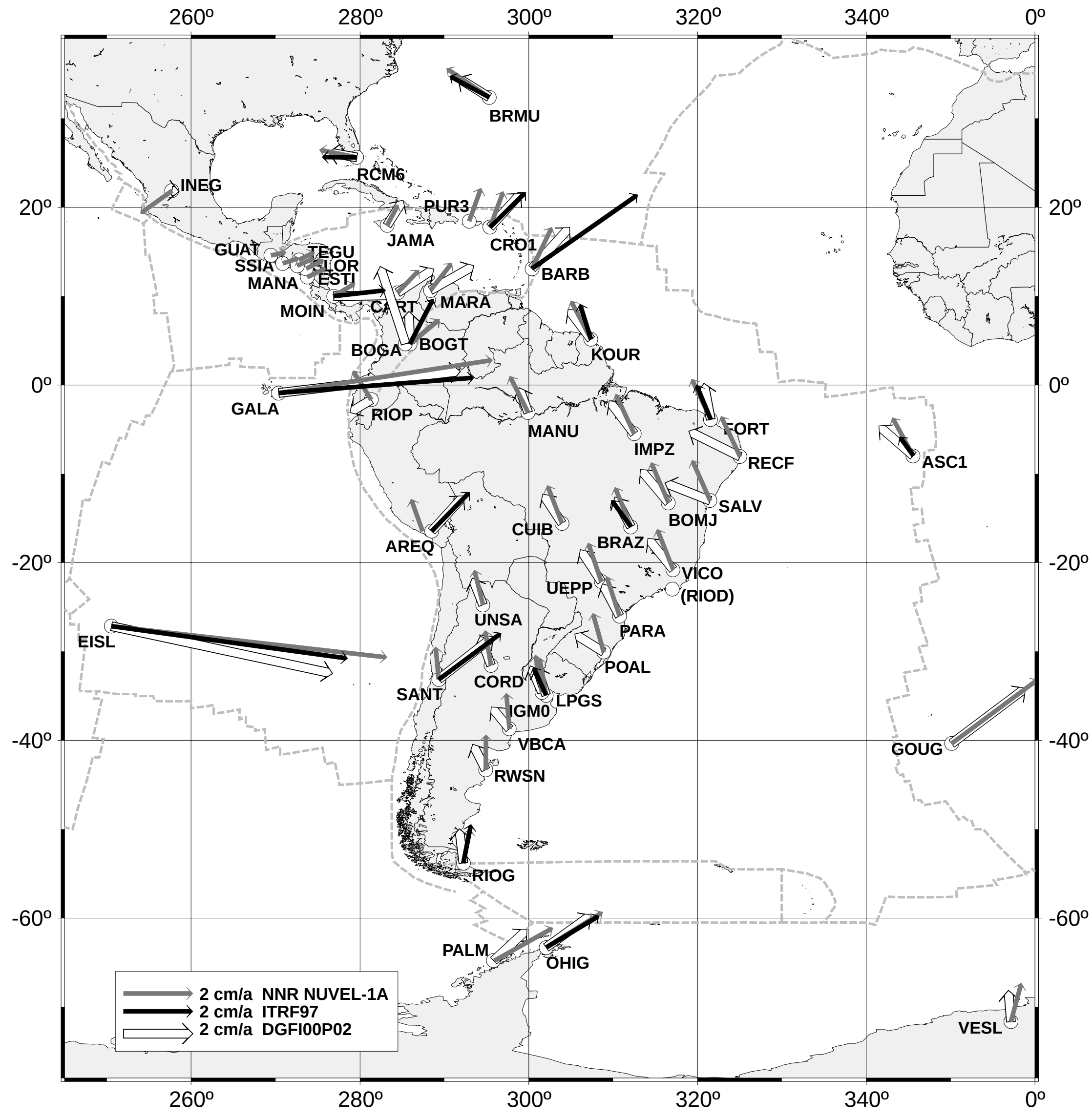

Figure 1: Horizontal velocities of IGS RNAAC SIR stations

Conclusion

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

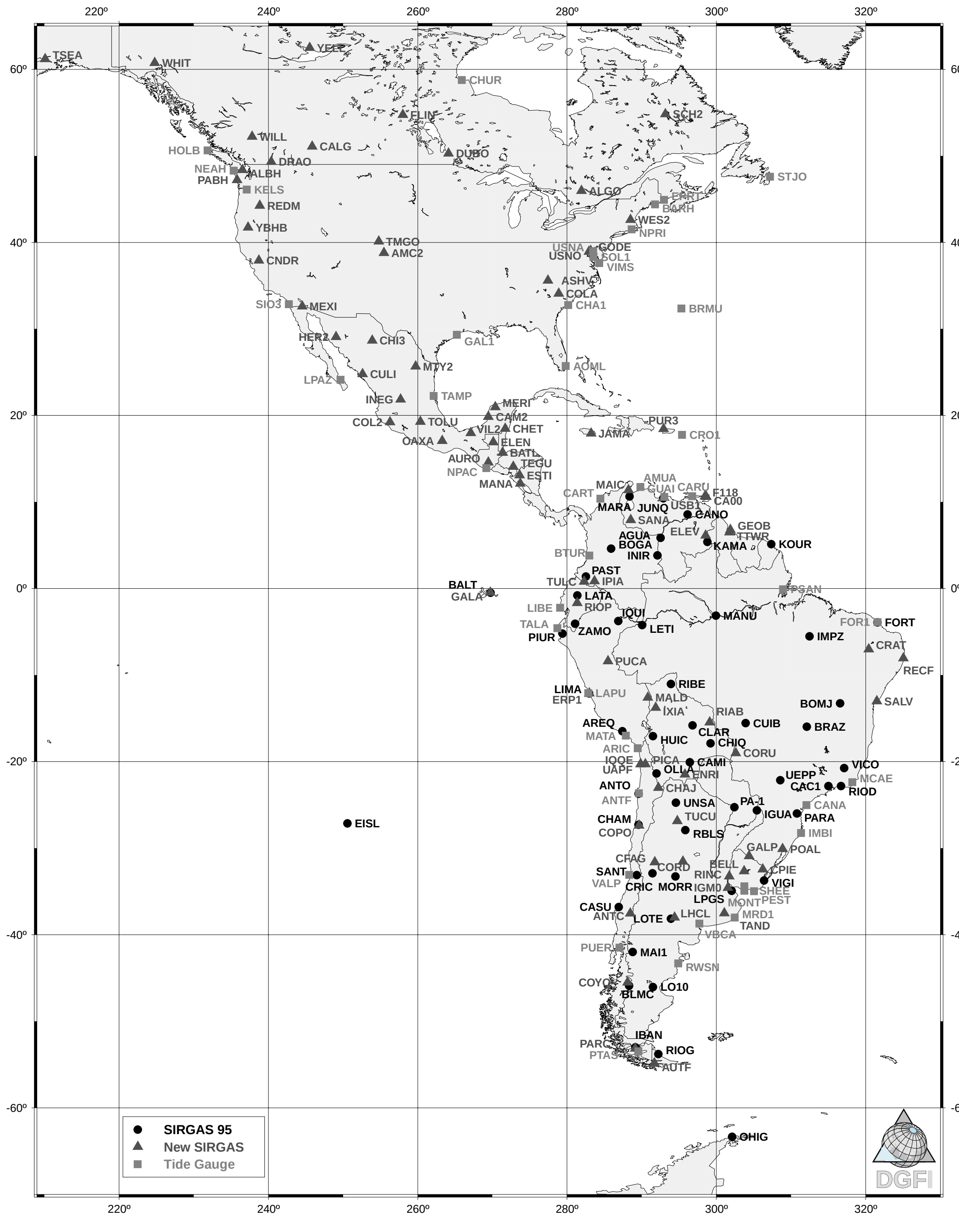

Figure 2: Network of the SIRGAS 2000 campaign

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IGS

IERS CONTRIBUTIONS

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

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Introduction

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

ITRF and IGS Relationship

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

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

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

ITRF2000

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

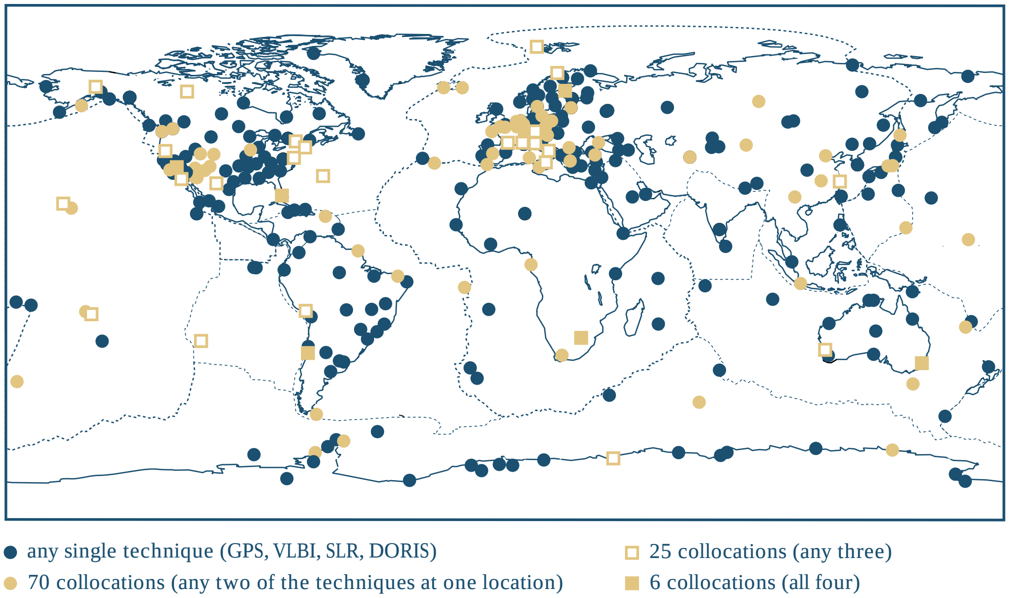

Figure 1. The ITRF2000 primary network. Symbols indicate collocations of space geodetic techniques (GPS, VLBI, SLR, DORIS).

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

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

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

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