# Annual Report 1996 of the CODE Analysis Center of the IGS

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## 1. INTRODUCTION

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

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

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

- About one third of the sites included in the global CODE solutions are European sites. This should guarantee that the CODE orbits are of best possible quality over *Europe*.
- A network of about 35 European sites is processed on a daily basis since day 204 (July 23), 1995, using different processing options.

- The CODE Analysis Center has also been appointed to combine the weekly solutions (in SINEX format) of presently 10 regional processing centers in Europe into one official weekly EUREF (European Reference Frame) solution.

More details concerning the latter two activities may be found in the contribution "The CODE EUREF Analysis Center" by Tim Springer et al. in this volume.

CODE is located at the AIUB. All solutions and results were produced with the latest version of the Bernese GPS Software [*Rothacher and Mervart*, 1996].

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

- major changes in the routine processing (Section 2.2),
- reprocessing of the 1995 and 1996 data (Section 3), and
- product quality and results (Section 4).

The developments *till April 1996* are described in previous Annual Reports of the CODE Analysis Center [*Rothacher et al.*, 1995], [*Rothacher et al.*, 1996].

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

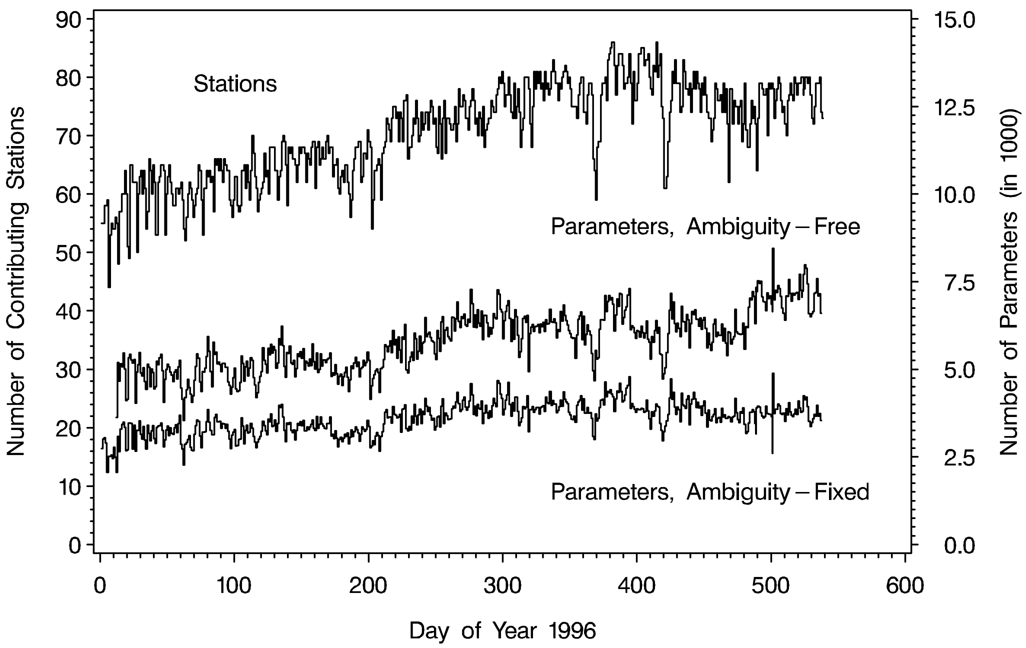


Figure 1. Statistics of Global 1-Day Solutions Computed at CODE.

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

# 2. CHANGES IN THE ROUTINE PROCESSING AND PRESENT STATUS AT CODE

## 2.1 Overview of Changes

The major changes implemented in the routine CODE analysis since April 1996 are listed in Table 2.1. Previous modifications have already been reported in last year's annual report [*Rothacher et al.*, 1996].

| Date | Doy/Year | Description of Change at CODE | Section |
|---|---|---|---|
| 02-Apr-96 | 093/96 | Start of a new European solution using a 15 degree cut-off angle. | — |
| 07-Apr-96 | 098/96 | Improved a priori pole file generated by integrating the GPS-derived UT1-UTC drifts starting with a VLBI value (Bulletin A) about 15 days in the past. | — |
| 23-Apr-96 | 114/96 | 48-hour predicted orbits deduced from IGS rapid orbits and submitted to the AC coordinator. | — |
| 13-May-96 | 134/96 | Rapid orbit solution switched to the extended solar radiation pressure model (parameters: direct and Y-bias and the periodic terms in these directions, but no X-terms). Pseudo-stochastic pulses now set up for all satellites. | 4.2 |
| 21-May-96 | 142/96 | Predicted orbits generated based on our own X- and Y-pole predictions (better than Bulletin A). | — |
| 08-Jun-96 | 160/96 | 3-day arcs used for rapid orbit estimation (previously 5-day arcs). | — |
| 30-Jun-96 | 182/96 | Change of the reference frame to ITRF94. Phase center corrections with model `IGS_01.PCV`. Model by R.D. Ray [*McCarthy*, 1996] for sub-daily variations in the Earth rotation introduced as a priori model. | — |
| 30-Jun-96 | 182/96 | Orbit force model changed: JGM3 (previously GEMT3); General Relativity term implemented; Love number changed from 0.285 to 0.300 (IERS Standards [*McCarthy*, 1996]). | 4.2 |
| 01-Jul-96 | 183/96 | Rapid Global Ionosphere Models (GIMs) produced and used for ambiguity resolution in rapid orbit computation. | 4.5 |
| 15-Jul-96 | 197/96 | Predicted orbits now based on UT1-UTC values predicted from our UT1-UTC estimates (not Bulletin A values). | — |

| Date | Doy/Year | Description of Change at CODE | Section |
|---|---|---|---|
| 07-Aug-96 | 220/96 | Change in the set of parameters of the extended radiation pressure model that are estimated in the rapid orbit solution: constant terms in all three directions and periodic X-terms are set up. | 4.2 |
| 29-Sep-96 | 273/96 | CODE final orbits are now based on a solution using the extended radiation pressure model (the same parameters as in the rapid orbit computation, see previous entry). In addition, several minor improvements of the force field were implemented. | 4.2 |
| 07-Nov-96 | 312/96 | 15 degree cut-off angle for rapid orbit solution. | — |
| 29-Dec-96 | 364/96 | Degree and order of spherical harmonics expansion for European ionosphere models increased from 5 to 8. | — |
| 19-Jan-97 | 019/97 | Satellite clocks estimated using phase-smoothed code observations. | 4.3 |
| 04-Apr-97 | 094/97 | New daily European test solutions activated with following features: Niell mapping function, 5-degree cut-off angle, elevation-dependent weighting of the observations, estimation of troposphere gradients. | — |
| 05-Apr-97 | 095/97 | CODE contribution to EUREF combination based on 15-degree solution from now on. | — |
| 27-Apr-97 | 117/97 | Troposphere SINEX file generated once per day for all site. | 4.5 |
| 30-Apr-97 | 120/97 | First experiments with a 5-degree cut-off angle in the global solution. | — |

Table 1. Modification of Processing Scheme at the CODE Analysis Center from April 1996 to April 1997.

## 2.2 Daily and Weekly "Routine" Activities

The general scheme of the *daily* routine processing (going from 1-day to 3-day solutions) is still the same and may be found in [*Rothacher et al.*, 1995], page 155. Four additional solutions related to troposphere modelling were implemented in the processing of the European network: the Niell mapping function [*Niell*, 1993], elevation-dependent weighting of the observations, processing of data down to 5 degrees elevation, estimation of troposphere gradients were implemented. Test series are described and discussed in [*Springer et al.*, 1997]. Depending on the success of these strategies, they will be tested for our global solutions, too, and might eventually be implemented into the global routine processing.

A few new *weekly* activities should be mentioned that are now part of the CODE procedures:

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

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

### 2.3 Products

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

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

Our anonymous ftp area is divided into three product directories: the directory `CODE` containing our official IGS products and the Bernese Software User directory `BSWUSER` with Bernese-specific information like daily coordinates and troposphere estimates. A new directory `EUREF` contains the official EUREF SINEX files. More details may be found in [*Rothacher et al.*, 1996].

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

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

Table 2. New CODE Products Available Through Anonymous FTP.

## 3. REPROCESSING OF GPS DATA

In order to improve CODE solutions and products, a continued development of software and strategies is necessary. With such changes we try to maintain the highest possible quality level for our routine products. The time series of solutions, however, become very inhomogeneous and difficult to interpret due to such modifications (see Table 2.1). Occasional reprocessing of older GPS data is therefore a necessity to generate consistent time series over long time intervals using the best currently known strategies and models.

The reprocessing took place in two phases and covered the data span from January 1, 1995 (day 001) to March 23, 1996 (day 083, where our routine series with the new orbit model started):

- *Phase 1:* Reprocessing of the data span from *March 1995 (day 127) to March 1996 (day 083)* by Ronald Stolk from the Delft University of Technology in spring 1996.

- *Phase 2:* Reprocessing of the data span from *January 1995 (day 001) to March 1995 (day 083)* by Serge Botton from the Institut Géographique National, Paris, in November 1996.

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

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

# 4. PRODUCT QUALITY AND RESULTS

## 4.1 Coordinates and Velocities

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

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

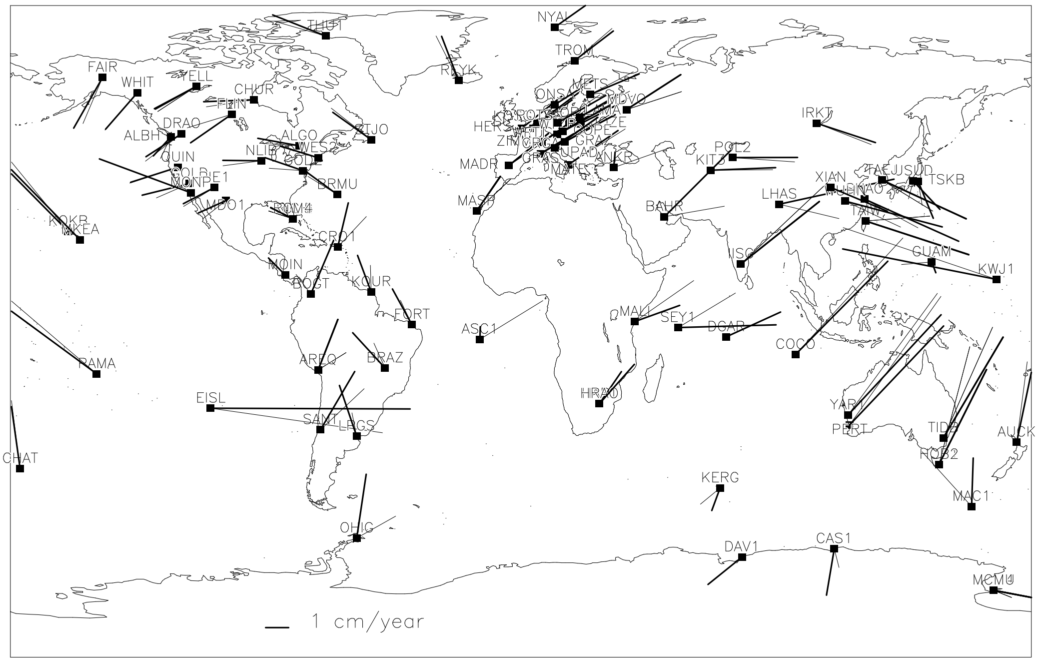


Figure 2. *Horizontal* Site Velocities Estimated From 4 Years of GPS Data. CODE velocities are indicated by thick, ITRF94 values (for comparison) by thin lines.

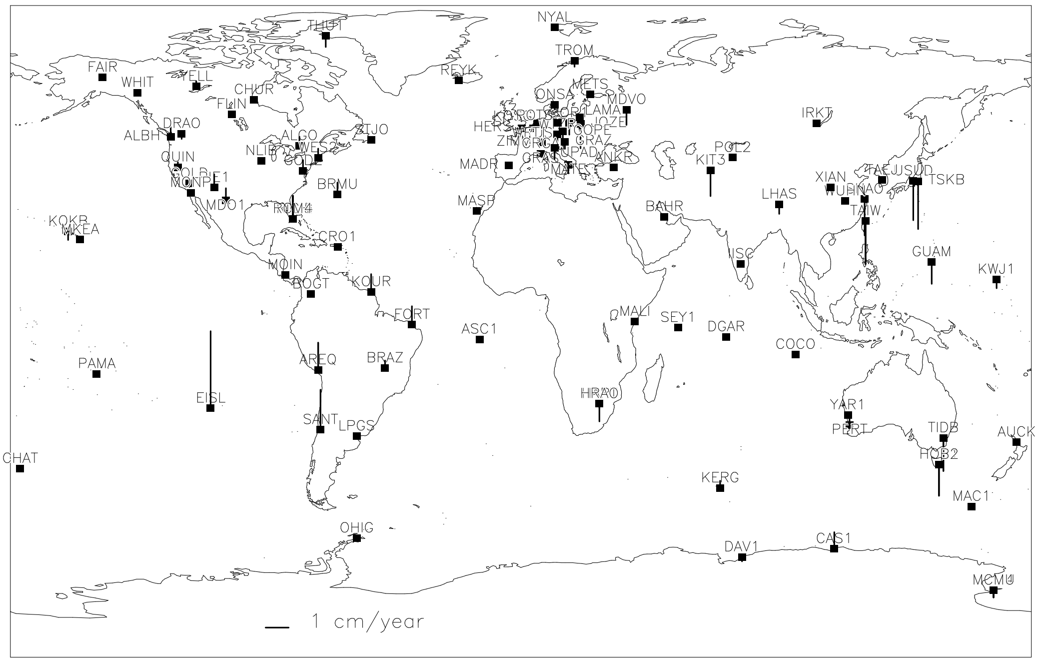


Figure 3. *Vertical* Site Velocities Estimated From 4 Years of GPS Data (Only for Sites With More Than 1.5 Years of Data).

## 4.2 Orbit Modelling

The most significant change in the quality of the CODE precise orbits could be achieved by implementing the so-called extended solar radiation pressure model [*Beutler et al.*, 1994]. This model is defined by

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

where

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

and

| | | |
|---|---|---|
| $\vec{a}_{rpr}$ | ... | Total acceleration due to solar radiation pressure |
| $\vec{a}_{ROCK}$ | ... | Acceleration according to the ROCK4/42 models |
| $\vec{e}_D$ | ... | Unit vector in the direction Sun-satellite |
| $\vec{e}_Y$ | ... | Unit vector in the direction of the solar panel axis |
| $\vec{e}_X$ | ... | Unit vector forming a right-hand system with $\vec{e}_D$ and $\vec{e}_Y$ |
| u | ... | Argument of latitude of the satellite |

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

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

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

- When comparing the 3-day orbits from CODE using the extended model with, e.g., the orbits of JPL, a much higher agreement is found for the first and last day of the 3-day arcs than in the case of the classical model. (A comparison with the final IGS orbits is not too instructive because the CODE solutions using the classical model contributed to the final IGS orbit combination with a considerable weight).

- The orbit overlap study performed for a time interval of 126 days (beginning of 1995) during the second reprocessing phase (see Section 3) compares the satellite positions of one 3-day solution at the *end* of the middle day (24h UT) with the positions of the consecutive (overlapping) 3-day solution at the *beginning* of the middle day (0h UT). The satellites were divided into eclipsing and non-eclipsing satellites, and a mean position difference was computed for each group of satellites and for each day. Figure 4 reveals quite a dramatic improvement in the overlap quality (about a factor of three) for the extended model compared to the classical model in the case of the non-eclipsing satellites. The difference between the two models is even more pronounced for the eclipsing satellites.

- The pseudo-stochastic pulses in radial and along-track direction, that are estimated every 12 hours (in addition to the five parameters of the extended model and the initial conditions) are considerably smaller in absolute value with the new model. In Figure 5 the radial pulses are shown for all satellites for a time span that includes the change from the classical to the extended model (day 273, 1996; GPS week 873).
- The sub-daily ERP values of the first and third day of a 3-day solution are much more consistent if the extended radiation pressure model is used (see Figures 9 and 10 in Section 4.4).
- The global site coordinates show a slight improvement when using the extended model.

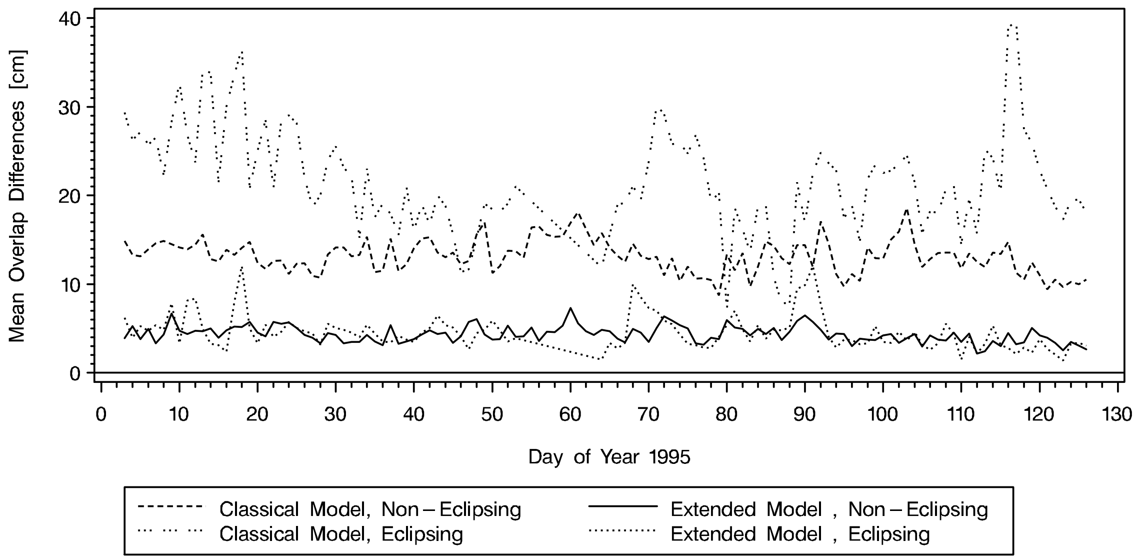


Figure 4. Orbit Overlap Results for the Extended 5-Parameter and the Classical 2-Parameter Solar Radiation Pressure Model. Mean Overlap Differences in Position for the Eclipsing and Non-Eclipsing Satellites.

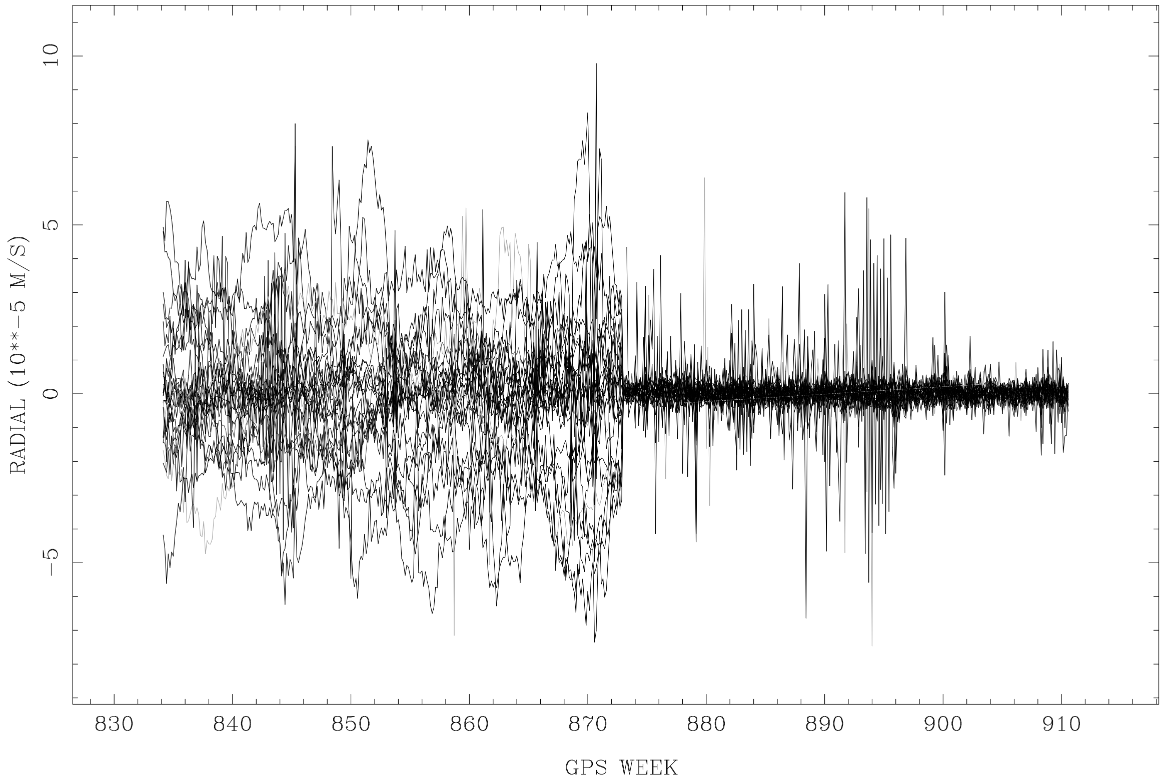


Figure 5. Radial Component of the Pseudo-Stochastic Orbit Pulses Estimated Once per Revolution for all Satellites Using the Classical (till GPS Week 873) and the Extended Radiation Pressure Model (afterwards).

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

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

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

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

## 4.3 Satellite Clock Estimation

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

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

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

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

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

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

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

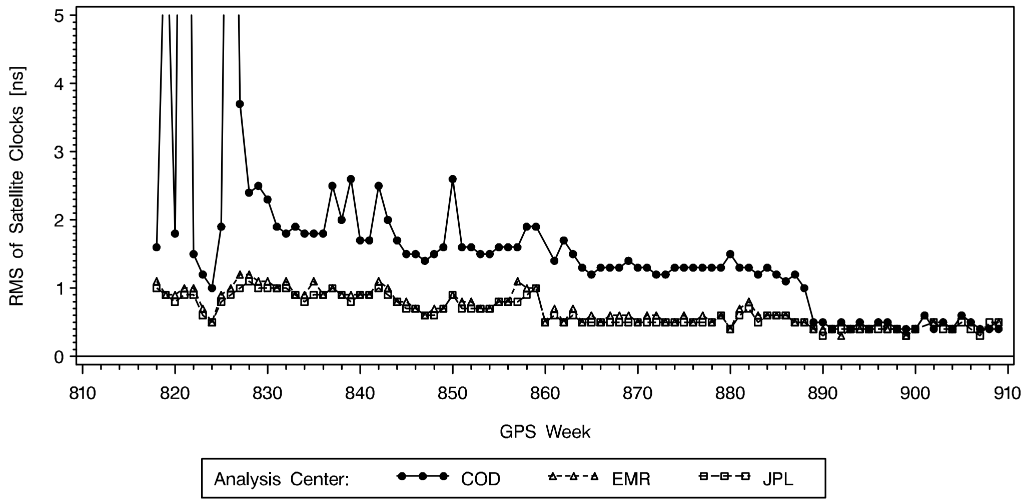


Figure 6. Evolution of the Quality of the CODE Satellite Clock Estimates. For Comparison, the Results from EMR and JPL are Plotted, too.

## 4.4 EARTH ROTATION PARAMETERS AND NUTATION

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

Due to the reprocessing steps mentioned in Section 3, a series of sub-daily ERP estimates is available at CODE covering a time span of almost 2.5 years (about 860 days, January 1995 to the present). A small section of 10 days of this series (the x- and y-pole components) is shown in Figures 7 and 8 to illustrate that the sub-daily variations very neatly follow the Ray model (IERS Standards, see [*McCarthy*, 1996]) derived from ocean tide models. A similar consistency — although not shown here — can be seen in the sub-daily UT1-UTC values. Using these ERP series, amplitudes for the major ocean tide terms were computed that are of a quality similar to those derived from many years of VLBI data. Our GPS-derived series are much denser in space and time, however.

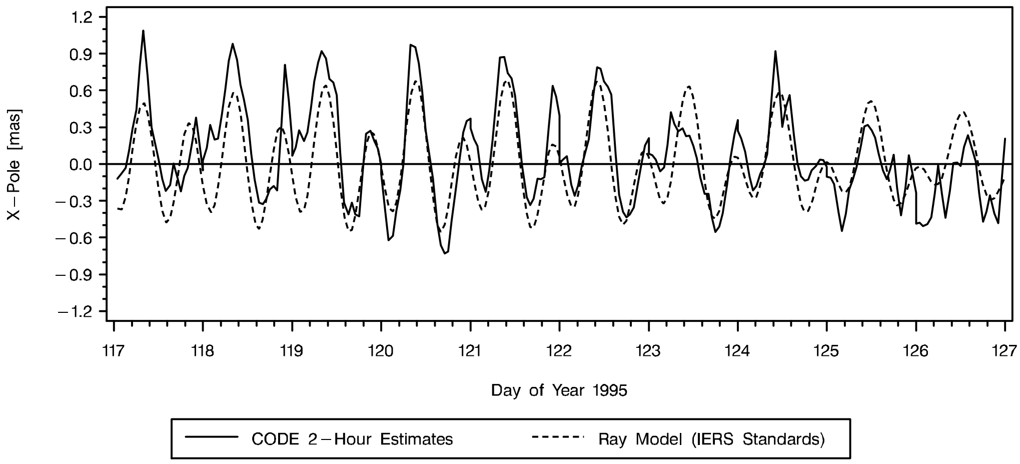


Figure 7. Zoom on 10 Days of Sub-Daily X-Pole Estimates Compared to the Model by R.D. Ray (IERS Standards).

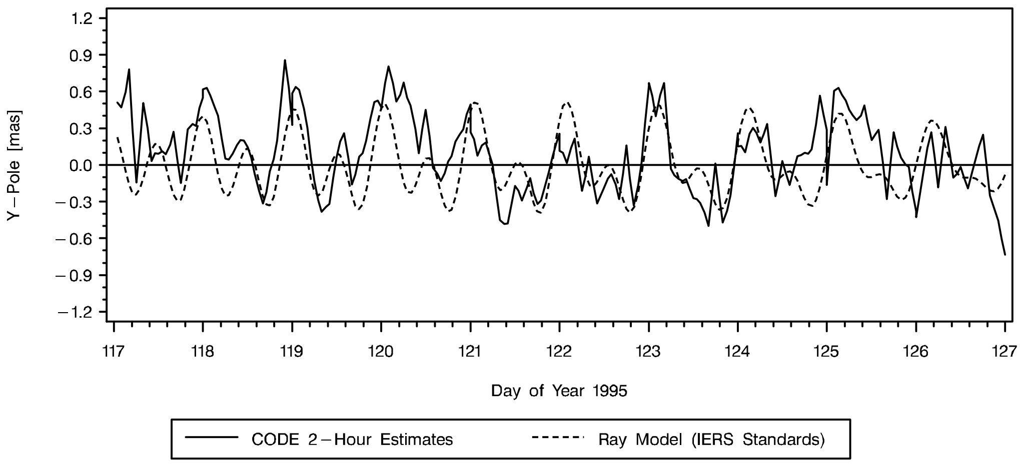


Figure 8. Zoom on 10 Days of Sub-Daily Y-Pole Estimates Compared to the Model by R.D. Ray (IERS Standards).

It should be mentioned that a considerable improvement in the quality of the sub-daily ERP estimates could be obtained by switching from the "classical" 2-parameter radiation pressure model to the extended model described in Section 4.2 for the satellite orbit parameterization. This can be seen in Figures 9 and 10, where the differences in the x-pole values between the GPS estimates and the Ray model are shown for the classical and extended radiation pressure model, respectively. The three GPS series stem from extracting the values of the first, then of the middle, and finally of the last day, respectively, from the overlapping 3-day solutions. The degraded quality of the series stemming from the first and last days of the 3-day solutions is evident in the case of the classical orbit model. Such a behaviour may be expected if the orbit parameterization is insufficient. With the extended radiation pressure model all three days of the 3-day solutions are in much better agreement and the differences to the Ray model are smaller.

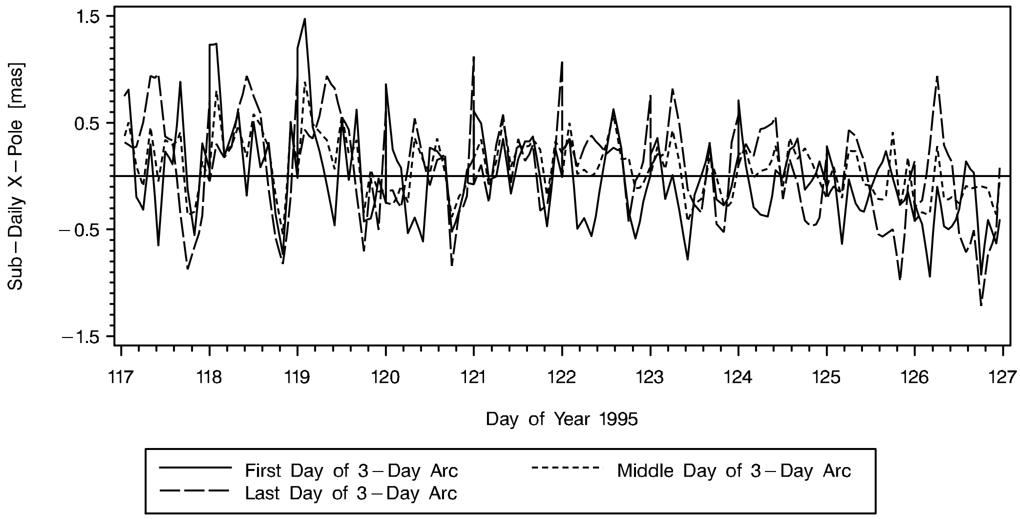


Figure 9. Comparison of Sub-Daily X-Pole Estimates From the First, Middle, and Last Day of the Overlapping 3-Day Solutions Using the *Classical* Radiation Pressure Parameterization (2 Parameters).

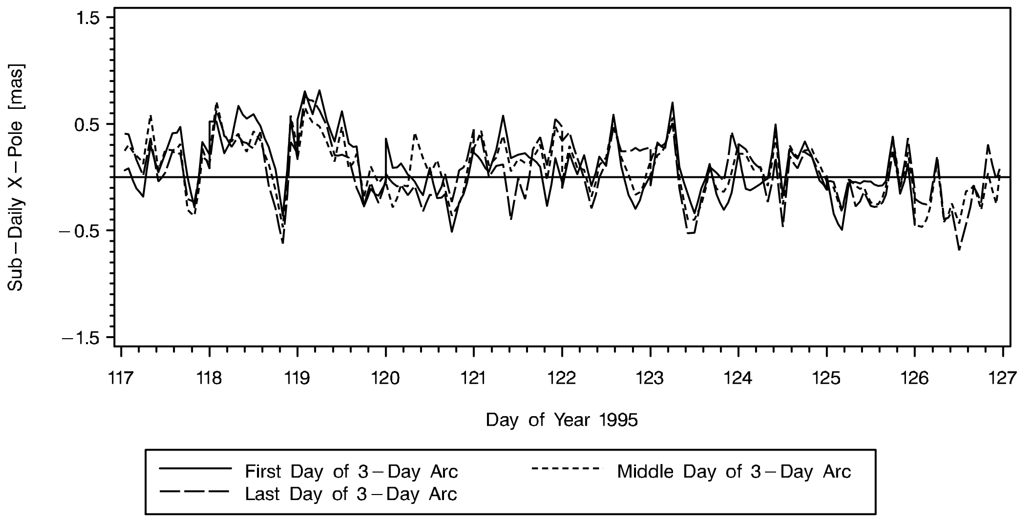


Figure 10. Comparison of Sub-Daily X-Pole Estimates From the First, Middle, and Last Day of the Overlapping 3-Day Solutions Using the *Extended* Radiation Pressure Parameterization (5 Parameters).

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

## 4.5 ATMOSPHERIC MODELLING

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

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

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

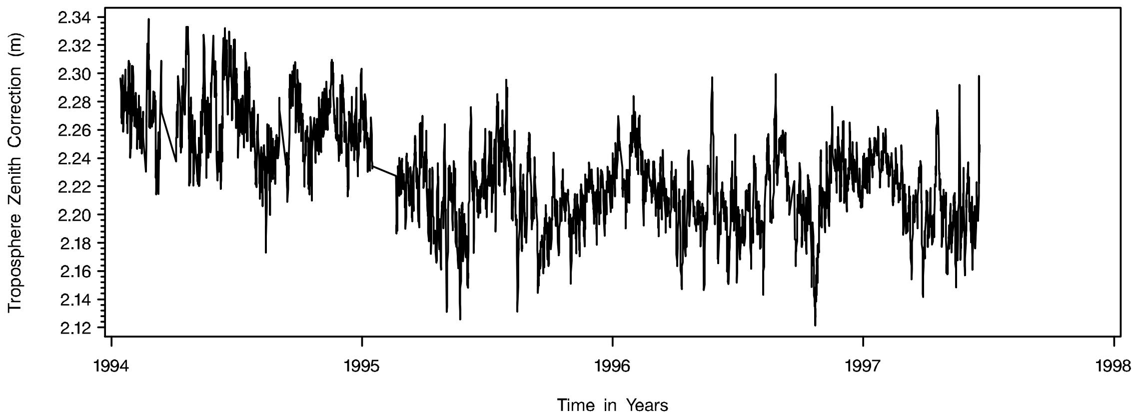


Figure 11. Total Troposphere Zenith Delays for McMurdo (Antarctica) Estimated at CODE Using Global 3-Day Solutions.

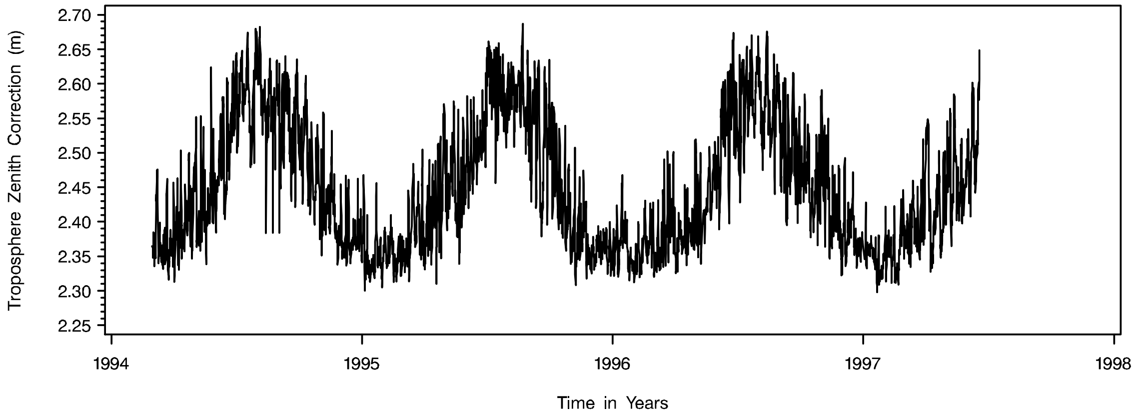


Figure 12. Total Troposphere Zenith Delays for Tsukuba (Japan) Estimated at CODE Using Global 3-Day Solutions.

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

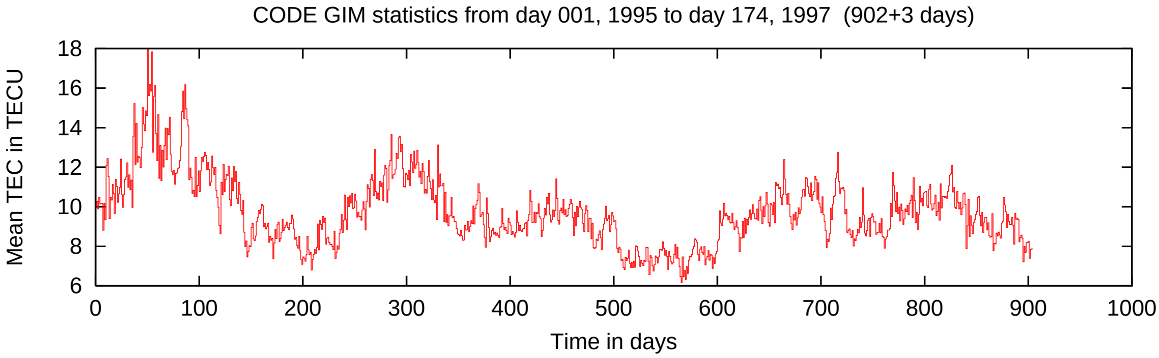


Figure 13. Global Ionosphere Models from CODE. The TEC values for the last three days stem from rapid GIM solutions (available about 12 hours after data collection), all other values from final solutions.

## 5. OUTLOOK

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

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