CODE IGS Analysis Center Technical Report 2002

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Introduction

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

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

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

This report covers the time period from January through December 2002. It focuses on major changes taken place in the routine processing during this period and shows new developments and products generated at CODE. The processing strategies used in previous years are described in earlier CODE annual reports [Rothacher et al., 1995, 1996, 1997, 1998, 1999, Hugentobler et al., 2000, 2001].

A wide variety of GPS solutions are computed at CODE. Tables 1 and 2 give an overview of the products which are made available through anonymous ftp. In addition, a regional analysis considering about 50 stations of a sub-network of a European permanent network are processed on a daily basis. Weekly coordinate solutions in SINEX format are regularly delivered to EUREF (European Reference Frame, Subcommission of IAG Commission X).

In 2002, no real ultra-rapid orbits were computed at CODE. The solutions delivered to the IGS by CODE were pure predictions on the basis of our daily rapid orbit solutions (i.e., NRT hourly data is not yet considered). Nevertheless the quality of the orbits is

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entirely competitive with other AC orbit products. The orbits are delivered to the IGS for comparison and are excluded from the IGS ultra rapid orbit combination process but still treated for comparison purposes. The computation of ultra-rapid solutions based on hourly observation data is foreseen for 2003.

Table 1: CODE products made available through anonymous ftp.

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

Table 2: CODE products made available through anonymous ftp.

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

Changes in the Routine Processing

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

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

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

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

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

Refined Ambiguity Resolution

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

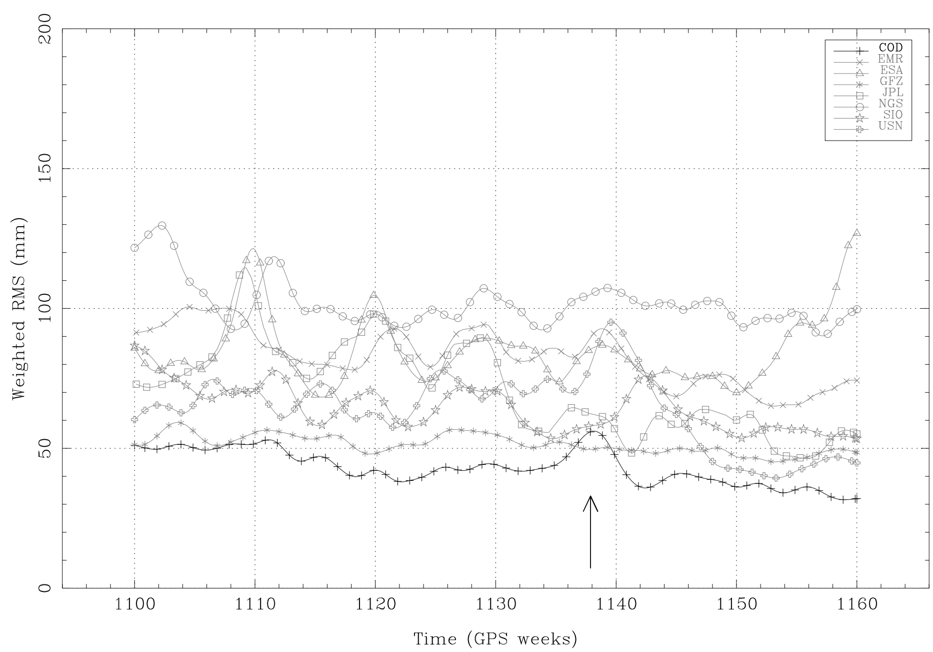

Figure 1: Smoothed weighted rms for each IGS Analysis Center rapid orbit solution with respect to the IGS-combined orbit product. The arrow indicates the period during which ambiguity resolution was by mistake deactivated at CODE.

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

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

b) In a second step, unresolved ambiguities on baselines up to a length of 2000 km are fixed using the quasi-ionosphere-free (QIF) strategy.

c) A subsequent step solves widelane and narrowlane ambiguities (relying on phase data only) up to a maximum baseline length of 200 km.

d) Finally, ambiguities on very short baselines (up to 20 km length) are resolved directly on the two carriers.

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

Estimation of Satellite and Receiver Clock Parameters

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

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

Ionosphere

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

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

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

Determination of Differential Code Bias Values

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

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

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

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

GPS Satellites in Moon's Penumbra

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

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

Kinematic and Dynamic Orbit Determination for Low Earth Satellites

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

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

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

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

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

Outlook

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

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

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

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