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

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products could be generated on the new platform starting with June 4, 2000. The related 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.

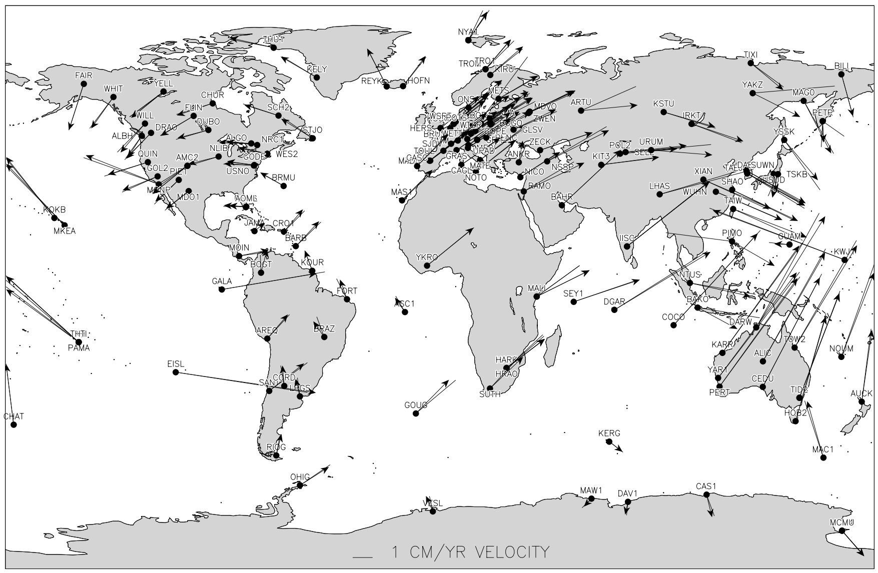

Figure 1: Velocity vectors estimates from a constrained solution (arrows) and from ITRF97 (lines).

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].

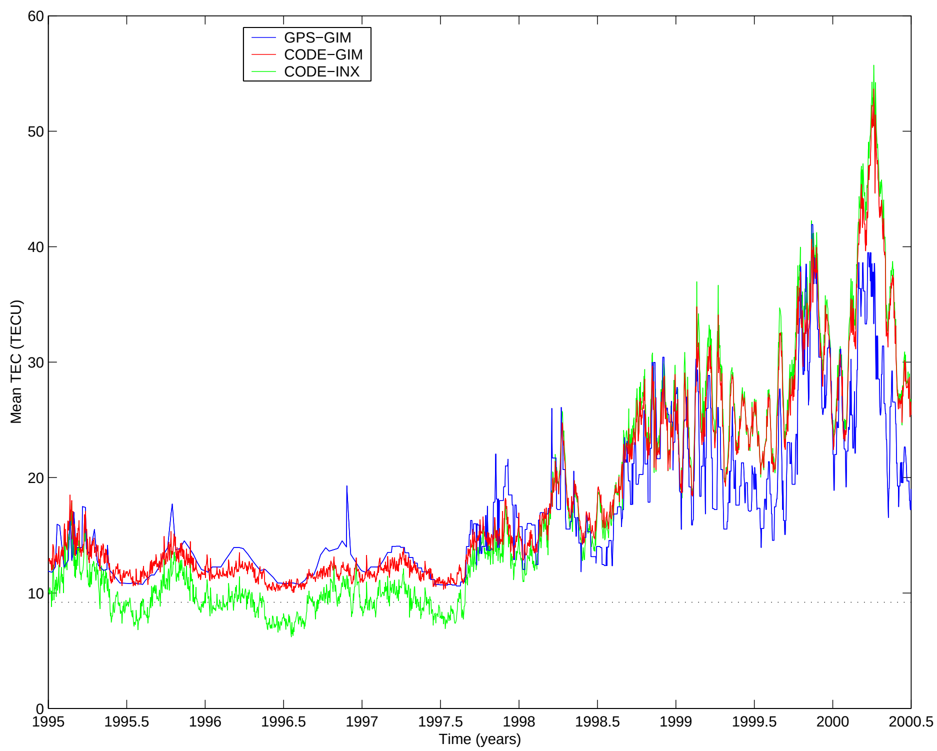

Figure 2: Mean TEC of the ionosphere derived from GPS broadcast model coefficients, CODE generated model coefficients, and CODE IONEX reference, compared from 1995.0 to 2000.5, gathered from [Schaer, 2001].

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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