CODE IGS Analysis Center Technical Report 2003/2004

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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., 2005].

This report covers the time period from January 2003 through December 2004. 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 [Hugentobler et al, 2002] and earlier CODE annual reports.

A highlight was the IGS Workshop and Symposium 2004 that was hosted at the Bern University from March 1 to 5, 2004, celebrating a decade of the IGS [Meindl, 2005].

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

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Table 1: CODE GNSS analysis products made available through anonymous ftp.

CODE ultra-rapid GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE`	
`COD.EPH_U`	Ultra-rapid GNSS orbits (latest update)
`COD.ERP_U`	Ultra-rapid GNSS ERPs belonging to ultra-rapid orbits
`COD.TRO_U`	Ultra-rapid GNSS troposphere product, SINEX format
`COD.ION_U`	Ultra-rapid GNSS ionosphere product, Bernese format

CODE rapid GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE`	
`CODwwwwd.EPH_R`	Rapid GNSS orbits
`CODwwwwd.EPH_P`	24-hour GNSS orbit predictions
`CODwwwwd.EPH_P2`	48-hour GNSS orbit predictions
`CODwwwwd.EPH_5D`	5-day GNSS orbit predictions
`CODwwwwd.ERP_R`	Rapid GNSS ERPs belonging to rapid orbits
`CODwwwwd.ERP_P`	Predicted GNSS ERPs belonging to 1-day predicted orbits
`CODwwwwd.ERP_P2`	Predicted GNSS ERPs belonging to 2-day predicted orbits
`CODwwwwd.ERP_5D`	Predicted GNSS ERPs belonging to the 5-day predicted orbits
`CODwwwwd.CLK_R`	Rapid GPS clock product, 5-minute values for stations, 30-second values for satellites, clock-RINEX format
`CODwwwwd.TRO_R`	Rapid GNSS troposphere product, SINEX format
`CORGddd0.yyI.Z`	Rapid GNSS ionosphere product, IONEX format
`COPGddd0.yyI.Z`	1-day or 2-day GNSS ionosphere predictions, IONEX format
`CODwwwwd.ION_R`	Rapid GNSS ionosphere product, Bernese format
`CODwwwwd.ION_P`	1-day GNSS ionosphere predictions, Bernese format
`CODwwwwd.ION_P2`	2-day GNSS ionosphere predictions, Bernese format
`GLOwwwwd.EPH_5D`	5-day GLONASS orbit predictions (based on broadcast info)
`CGIMddd0.yyN_R`	Improved GNSS 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
`P1P2.DCB`	Sliding 30-day GNSS P1-P2 DCB solution, Bernese format
`P1C1.DCB`	Sliding 30-day GPS P1-C1 DCB solution, Bernese format
`CODE.DCB`	Merged P1-P2 and P1-C1 DCB product, Bernese format

CODE final GNSS products, available at `ftp://ftp.unibe.ch/aiub/CODE/yyyy`	
`CODwwwwd.EPH.Z`	Final GNSS orbits
`CODwwww7.ERP.Z`	Final GNSS ERPs belonging to final orbits, values for full week
`CODwwwwd.CLK.Z`	Final GPS clock product, 5-minute values for stations, 30-second values for satellites, clock-RINEX format
`CODwwwwd.TRO.Z`	Final GNSS troposphere product, SINEX format
`CODwwwwd.ION.Z`	Final GNSS ionosphere product, Bernese format
`CODGddd0.ION.Z`	Final GNSS ionosphere product, IONEX format
`CGIMddd0.yyN.Z`	Improved GNSS Klobuchar-style coefficients, RINEX format
`CODwwww7.SNX.Z`	Weekly GNSS SINEX product
`CODwwww7.SUM.Z`	Weekly GNSS analysis summary files
`P1P2yymm.DCB.Z`	Monthly GNSS P1-P2 DCB solutions, Bernese format
`P1C1yymm.DCB.Z`	Monthly GPS P1-C1 DCB solutions, Bernese format

Changes in the Daily Data Processing Carried out for IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. Table 2 gives an overview of the major changes implemented during the years 2003 and 2004. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (specifically at `ftp://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn`).

Table 2: Modifications in the CODE processing, from January 2003 through December 2004.

Date	Doy/Year	Description
19-Feb-03		Extraction of GPS broadcast group delay (GD) values in form of Bernese DCB files started
27-Mar-03	082/04	Specific ocean loading coefficients corrected (FES95.2)
01-Apr-03	088/03	Ocean loading coefficients based on a new model (GOT00.2)
01-Apr-03	082/03	The set of reference sites used for geodetic datum definition is checked automatically and adjusted in case of inconsistencies/outliers (e.g. due to earthquakes)
28-Apr-03	117/03	Troposphere time resolution changed from 4 to 2 hours in rapid analysis
30-Apr-03	117/03	GPS/GLONASS-combined ionosphere analysis commenced
01-May-03	120/03	Rapid GNSS (GPS/GLONASS-combined) analysis started (announced in [Schaer et al., 2003a])
29-May-03	147/03	Isolated IGLOS stations included in final (GPS) analysis
08-Jun-03	158/03	Final GNSS analysis started (announced in [Schaer et al., 2003b])
26-Jun-03	158/03	Troposphere parameterization switched from piecewise constant to piecewise linear representation (including gradient parameters)
29-Jul-03		Usage of a completely new version (5.0) of the Bernese Processing Engine (BPE) generally established for the CODE processing
30-Jul-03	211/03	Real ultra-rapid GNSS orbit generation started (announced in [Schaer et al., 2003c])
09-Sep-03	252/03	Refined weighting scheme for ultra-rapid GNSS orbits
16-Sep-03	257/03	Geometric part of phase windup considered in zero-difference processing
29-Oct-03	299/03	IERS 2000 subdaily pole model implemented
01-Nov-03	303/03	Hourly RINEX observation files are merged for daily processing in order to support data flow of daily RINEX files
05-Jan-04	005/04	Uninterrupted orbit generation for GNSS (particularly GPS) satellites being repositioned (announced in [Schaer et al., 2004])
15-Jan-04	018/04	Regular estimation of GNSS satellite antenna phase center patterns (in addition to corresponding offsets) initiated
01-Apr-04	092/04	Refined procedure when merging hourly observation files
06-Apr-04	095/04	Generation of high-rate (30-second) GPS satellite clock corrections
29-Apr-04	120/04	POD on the basis of phase-only tracking data enabled (specifically for R06, the first GLONASS-M satellite)
07-Jul-04	186/04	Tidal step 2 corrections updated to IERS standards
14-Jul-04	193/04	Computation of solid Earth tides step 2 corrected
06-Aug-04	214/04	Unintended GLONASS ambiguity resolution stopped in final analysis

14-Sep-04	257/04	Generation of a GNSS-based ionosphere product for NRT (or ultra-rapid) applications started
01-Dec-04	333/04	Data from fast-moving polar station Amundson-Scott (AMUN) considered in GNSS ionosphere, GNSS orbit and GPS clock computation (see also IGS Report 12031)
15-Dec-04	347/04	Update from JPL DE200 to DE405 ephemeris; ocean tide model changed to CSR30
21-Dec-04	355/04	Maintenance of “endless” orbit prediction with respect to all temporarily inactive (or “disappearing”) GNSS (particularly GLONASS) satellites established (for orbit initialization purposes)

Besides various improvements concerning analysis scheme refinements and model updates, there were a few changes entailing a widespread impact. A major step forward was the incorporation of the GLONASS satellite system throughout all analysis steps, with the exception of the determination of precise clock offsets. This led to strictly integrated GPS/GLONASS-combined products (with best possible consistency in terms of geodetic datum definition). Starting on July 30 in 2003, CODE’s preliminary ultra-rapid orbit product (a pure prediction generated on the basis of daily rapid orbit solutions) was replaced by a near-real-time product now generated on the basis of hourly observation data. As a consequence of this, our ultra-rapid submissions were officially included in the corresponding IGS ACC combination process. It is worth mentioning that the newly established CODE ultra-rapid orbit product did cover both the GPS and the GLONASS satellite constellation from the beginning.

Since the beginning of 2004, CODE GNSS orbit products include positions and clock offsets for repositioned (GPS) satellites. The estimated time (mean epoch of event) and velocity change components are reported in the CODE analysis summary files.

Finally, we have to emphasize the model change related to the generation of high-rate satellite clock corrections (started on April 5, 2004). Resulting clock-RINEX files containing 30-second clock values for all active GPS satellites are provided to the IGS community.

The following sections detail on the respective changes mentioned above.

General Model Changes and Refinements of Analysis Strategy

Several model changes were related with the implementation of the IERS Conventions 2003 (see Table 1). In October 2003, the IERS 2000 subdaily pole model was enabled. Since December 2004, the DE405 JPL ephemerides and CSR3.0 ocean tide model are used. At the beginning of July 2004, the IERS 2000 tide model for computation of site displacements due to solid Earth tides was implemented. Shortly after, a bug in the computation of the step 2 correction (frequency-dependent part) was identified (incorrect time argument). The error was already present in the IERS 1996 implementation.

The effect of the error is a regionally correlated station height error of up to about 1 cm. CODE SINEX submissions starting with GPS Week 873 (September 29, 1996) up to GPS week 1278 (July 10, 2004) are affected. Starting with GPS week 1279, CODE analysis results are no longer affected by this software bug. As the corresponding error cannot be compensated in a strictly correct way at SINEX level, correspondingly corrected SINEX files were not resubmitted to the

IGS. However, a subroutine that applies a mean correction to the station position part of the solution vector in SINEX files is available from CODE side (at request) and was provided to Rémi Ferland for coarse correction of CODE SINEX files for the IGS cumulative solution and ITRF2004 contribution.

Since April 2003 the ocean tide loading coefficients used are no longer based on FES95.2 but on GOT00.2. Since September 2003, the geometric part of the phase windup is considered for computation of clocks. To be more precise, solely the part of the phase windup due to the varying relative position of a satellite and the stations (but not of the satellite's attitude) is taken into account. Station troposphere modeling was refined in June 2003 by implementing a piecewise linear representation for zenith delays as well as gradients (as already implemented for all other time-dependent parameterizations). The analysis procedure guarantees a continuous representation (even) over midnight. In October 2003, an automatic ionosphere re-analysis scheme with a delay of 30 days was implemented. In February 2004, the priority for stations at timing laboratories was increased for clock analysis.

In April 2003, a procedure was implemented into the final weekly analysis allowing for an automatic check of IGS reference sites for datum definition: Helmert residuals of coordinates from IGS fiducial sites derived from a minimum-constrained solution with respect to the a priori coordinates are analyzed. Sites with residuals bigger than 10 mm in horizontal and 30 mm in vertical direction get rejected from the datum definition. This allows, e.g., automatic exclusion of stations affected by an earthquake from the list of datum defining IGS fiducial stations.

Since December 2004, the South polar non-IGS station Amundsen-Scott (AMUN) is considered in orbit and clock analysis (in ionosphere analysis already since January 2003). Linear motion due to displacement on the glacier of 2.7 cm per day (10 m/year!) is taken into account in the daily analysis. The AMUN station does help to improve the station network layout in Antarctica due to its isolated location . In addition, we may gain experience in data analysis from a (comparably) fast moving station (that is moreover exposed to extreme weather conditions).

The automatization of the processing was further refined, on one hand by making use of the new version (5.0) of the Bernese Processing Engine (BPE) in July 2003, on the other hand by a sophisticated alerting mechanism in case any irregularities in the processing sequence are identified. Automatic checkers do not only verify the quality and completeness of the products but identify any failure in processing chains, of computers, disks, archiver, tools, ftp access, etc. Connections to data centers, the near-real-time data flow, as well as the GNSS satellite constellation status are checked every 30 minutes. If problems are identified, corresponding alarms are issued by e-mail and short messages to the cellular phone (or computer terminal) of the operator in duty.

GPS/GLONASS-Combined GNSS Analysis

After careful monitoring of GLONASS data availability, latency, and completeness from GPS/GLONASS combined IGS/IGLOS receivers, combined GPS/GLONASS analysis was switched on in several steps: Starting on April 18, 2003, consistency of GLONASS frequencies in broadcast navigation data was checked, on April 30, GPS/GLONASS-combined ionosphere analysis was commenced, and on May 1, combined rapid orbit analysis started [Schaer et al., 2003a]. GLONASS orbits had to be filtered out for the IGS submission at that stage. After inclusion of data from isolated combined receivers on May 29, first GLONASS orbits were computed in the final analysis and submitted to the IGS as of doy 159/2003 (GPS week 1222)

[Schaer et al., 2003b]. Since then all CODE analysis products, except of clocks, are based on a fully combined GNSS analysis. CODE final, rapid as well as ultra-rapid submissions do cover the complete GLONASS constellation.

Initially, 37 GNSS satellites (29 GPS plus 8 GLONASS) were included in the solutions. This number increased to 41 satellites (30 GPS plus 11 GLONASS) at the end of 2004, including the new GLONASS-M satellite, R06. The combined analysis started with a typical number of a dozen GPS/GLONASS baselines. The number of available baselines increased to typically 25 at the end of 2004 (see Figure 1). Particularly harmful are occasionally missing data from Australian stations for the rapid and ultra-rapid analysis. Since a significant number of mixed receivers does not track unhealthy satellites, the number of baselines for these satellites is typically between 1 and 10 baselines. At several occasions, the orbit of a GLONASS satellite was estimated with a single baseline only (in a specific case even just on the basis of phase-only tracking data). Thanks to 3-day arc analysis, thus obtained orbits were still of acceptable quality.

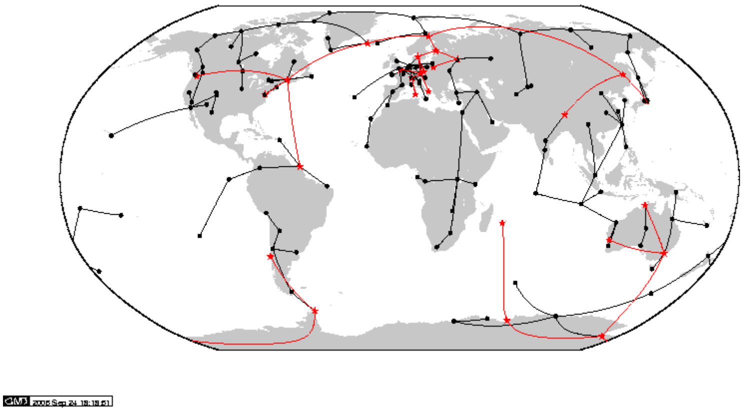

Figure 1: Baselines as processed at CODE on doy 365/2004. Mixed GPS/GLONASS baselines are indicated in red.

Orbit overlaps as well as SLR validation indicate an orbit quality for the CODE GLONASS final orbits of about 5 cm 1-D RMS. Figure 2 shows O-C SLR residuals covering a time interval of one year for the three satellites R04, R22, and R24 that are tracked by the ILRS. Table 3 gives the mean bias and standard deviation of the residuals for the three defined GLONASS and the two GPS satellites equipped with retro-reflectors [Urschl et al., 2004]. Note that the observed SLR bias is significantly smaller for GLONASS satellites than for GPS satellites, for which the (still unexplained) bias of 5–6 cm persists.

Table 3: SLR residual statistics wrt CODE final orbits, for the GNSS satellites tracked by ILRS.

Satellite		Time period	# Normal points	Bias [cm]	Std [cm]
GLONASS	R05	2003.4–2004.4	3911	–2.2	±5.0
GLONASS	R22	2003.4–2004.4	8149	–2.6	±4.4
GLONASS	R24	2003.4–2004.4	4441	–2.2	±5.2
GPS	G05	2001.0–2004.3	9380	–5.4	±2.6
GPS	G06	2001.0–2004.3	9216	–6.1	±2.9

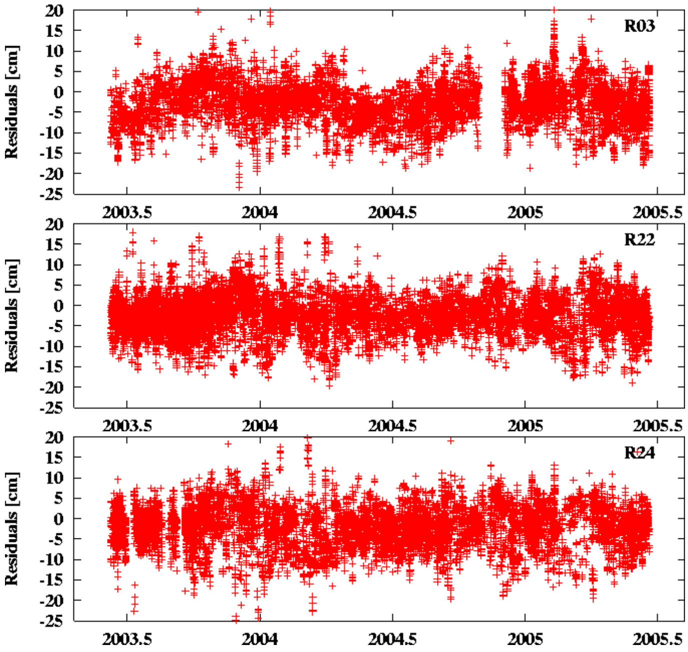

Figure 2: O-C SLR residuals wrt GLONASS satellite orbits from CODE.

Ultra-Rapid Products

Prior to June 30, 2003 (GPS week 1225-1), CODE generated ultra-rapid orbits which were pure extrapolations of daily rapid orbits. Due to this preliminary product status, the submissions were not used in the IGS AC combination process, i.e., they did not contribute to the official IGS ultra-rapid product, but were included for comparison purposes, only.

The situation changed on doy 181/03 when a revised processing scheme came into operation at the CODE analysis center [Schaer et at., 2003c]. The ultra-rapid produced from that day on is now strictly based on near real-time (NRT) GNSS tracking data. The orbit updates are strengthened by incorporating historical rapid information for long-arc orbit combination on normal equation level. The generated orbits are complete with respect to all transmitting satellites, even the GLONASS constellation was covered from the very beginning. Consequently, CODE's ultra-rapid contribution now is fully included in the IGS ACC combination process, the effects of which can be nicely observed in Figure 3.

An elaborate procedure to determine reliable accuracy codes for all GNSS satellites was implemented. The scheme is based on orbit fits of differing arc length, the historical performance of GPS satellites in previous IGS orbit combinations, eclipse intervals, health status, and several other parameters. Orbit predictions are based on a fit interval that gets optimized individually for each satellite.

No clocks are computed for the ultra-rapid delivery due to very limited computer resources. For the same reason, the 06-UT ultra-rapid update is generated o the basis of the previous 24-UT update and the following rapid analysis, respectively.

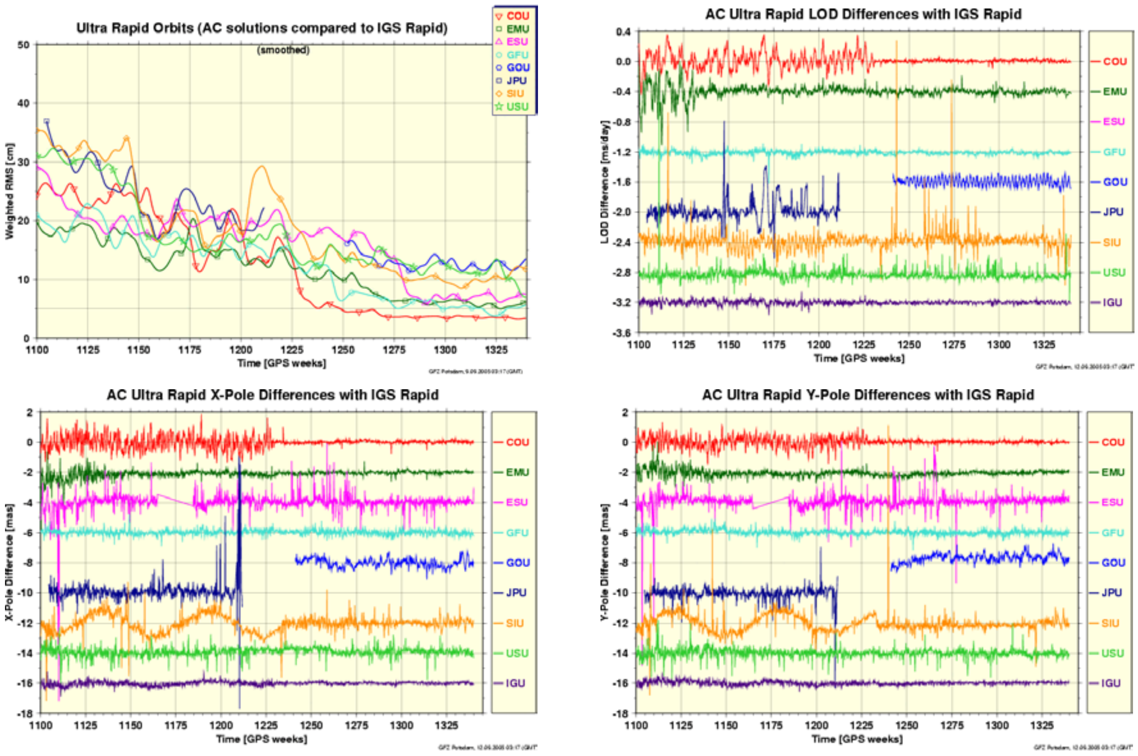

Figure 3: Comparison of individual AC solutions (orbit, X-/Y-pol, LOD) wrt IGS rapid (plots downloaded from IGS ACC website, `http://gfz-potsdam.de/pb1/igsacc/index_igsacc.html`).

Observation Data Management and Monitoring

Being now, for the ultra-rapid analysis, relying on the near real-time (hourly) RINEX observation data, a significant effort was put into the development of download procedures to maintain a reliable and solid data flow. Data is downloaded from all accessible global and regional data centers – and some data is downloaded even directly from local servers – to get the data as early as possible. Data files from different sources are merged in order to get complete data files. The GNSS datapool maintained at CODE is, in particular wrt mixed GPS/GLONASS station data, probably the most complete data source (with shortest data latency).

The same procedures allow for a detailed monitoring of observation file availability, latency, and completeness at the different data centers, an undertaking that revealed numerous problems. To identify and sort out such data-flow problems several extensive statistics are created on a regular basis and made available via anonymous ftp (`ftp://ftp.unibe.ch/aiub/igsdata/`). These files include information on, e.g., completeness, reliability, observed satellites, minimum and mean delay at the different data centers for all available hourly RINEX files. A number of encountered data flow problems were addressed via IGS Mail.

Handling of Brand New and Repositioned Satellites

Starting with beginning of 2004, satellite maneuvers are monitored, maneuver epoch and velocity change are determined and orbits before and after the event are provided in the precise orbit files (making use of the maneuver flag available in SP3c.) Maneuver parameters are documented in CODE's weekly analysis summaries beginning with GPS week 1252.

As initial information for a satellite maneuver the approximate repositioning epoch published in the NANU messages is used. The orbit for the satellite is split at this orbit and independent arcs are computed before and after the maneuver. The closest approach of the arc before and after the maneuver defines the maneuver epoch, the velocity difference of the two arcs at this epoch defines the velocity change induced by the boosters.

The orbit arc after the maneuver is initialized using double-differenced GPS/GLONASS pseudorange observations (from those stations tracking unhealthy satellites). Maneuver epoch and velocity change are improved iteratively. Using phase double-differences the orbit parameters of the two arcs are improved further and finally stabilized by combining the arcs with arcs from the previous and finally from the following day (see Figure 4, left). The entire procedure runs automatically and allows it to determine the middle epoch of the maneuver up to one second. The procedure does not require any broadcast information. Note that the maneuver is not modeled physically but the orbit representation is replaced by a new arc at the maneuver epoch.

Phase data residuals reveal the period (typically a few minutes, depending on DV) during which the data has to be removed before and after the maneuver. Note that consistency of orbits and clocks through the maneuver are guaranteed at the phase level. It is important to note, too, that the procedure is inflicted by a reduced number of observations due to the fact that a significant number of IGS/IGLOS stations do not sample satellites marked unhealthy. Furthermore, it is worth mentioning that users of the Bernese GPS Software V5.0 (also V4.2) did probably not really realize that IGS (de facto CODE) orbit information with respect to repositioned satellites got successfully processed in their analysis (e.g., EUREF analysis).

The main component of velocity changes induced by maneuvers is along-track. Velocity changes of the 27 maneuvers observed in 2004 typically have a magnitude of a few 100 mm/s. The largest velocity change found was 2653 mm/s (PRN G02, doy 336/2004) followed by a maneuver of a similar size for the same satellite the following day; the smallest velocity change was 46 mm/s (PRN G28, doy 226/2004).

The orbit initialization procedure allows it to determine the orbit of a brand-new satellite as soon as signals are tracked by the IGS/IGLOS ground network, even before broadcast information of the new satellite is available. As initial information the announced orbital plane and slot number are sufficient. Beginning with PRN G22, launched on December 20, 2003, orbit and clock products are delivered to the IGS for new satellites as soon as first tracking data is available. The sequence of events following the launch of G22 is shown in Figure 4 (right). In 2004, the described procedure was successfully applied to the new satellites R04 (doy 029), R06 (doy 031), R02 (doy 043), G19 (doy 085), G23 (doy 181), and G02 (doy 318).

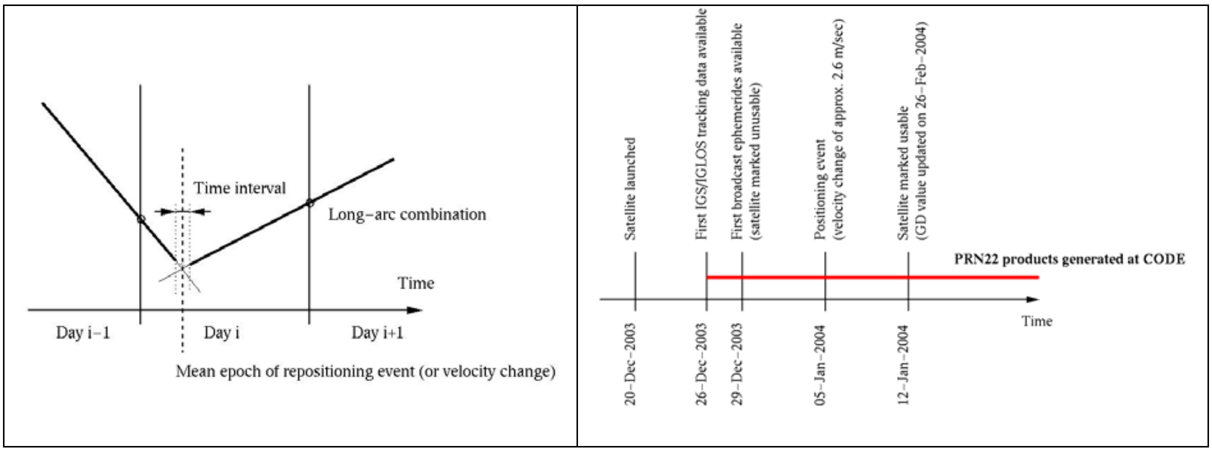

Figure 4: Left: Orbit determination scheme for repositioned satellites. Right: Chronology of GPS Block-IIR satellite launch (PRN22/SVN43).

Estimation of High-Rate Clock Corrections

On April 5, 2004, the CODE analysis center started to generate high-rate (30-second) satellite clock corrections on a daily basis for the rapid as well as for the final product. All clock-RINEX files delivered to the IGS contain high-rate clock corrections for all GPS satellites starting with doy 095/2004 for the rapid, and with doy 094/2004 for the final product submissions (see IGS Mail 4913).

The high-rate clock corrections are based on a phase-consistent interpolation of precise 5-minute clock results using time-differences of phase observations [Bock et al., 2000]. Data from 90 stations (rapid) and 120 stations (final) are used, respectively. Coordinates, troposphere parameters, and orbits are introduced from a global double-difference GNSS network analysis and kept fixed. 5-minute clock corrections from a global zero-difference GPS network analysis are used as anchor points. Care is taken that orbits and coordinates used for the zero-difference analysis and for the clock interpolation are consistent.

Phase observation time-differences are formed whereby the phase ambiguities are eliminated. The phase-differences are screened for outliers and cycle slips are identified. Based on these cleaned differences of phase observations, time-differences are estimated for all clocks in the system. In a next step, clock values are generated, basically by integrating the clock time-differences. Constraining the time series of clock values to the 5-minute input clocks eliminates the remaining arbitrary offset. A drawback of the efficient procedure is that covariance information for the estimated clock values is not available.

The interpolated clock values are written in a clock-RINEX file together with the unchanged 5-minute clock values. Alignment and reference clock are taken over from the 5-minute clocks. Validation using precise point positioning showed that the quality of these clock interpolations is comparable with that of the original 5-minute clock values.

Outlook

A major focus in the IGS is the switch to absolute antenna phase patterns. As this subject is closely related to satellite antenna patterns, CODE commenced the routine estimation of GNSS satellite antenna patterns (in conjunction with offsets) in January 2004. As a matter of course, GLONASS antenna offsets and patterns are estimated in the same procedure and will be made available.

Currently not yet possible due to limited computer resources is the computation of satellite clocks for the ultra-rapid deliveries. We look for alternatives allowing to solve the current problems with available computing power. Precise GLONASS clock corrections, too, are not yet computed (for GNSS PPP applications). Implementations are planned to cope with frequency dependency of differential code biases (concerning GLONASS observation data).

Future developments will cover time transfer with GPS carrier phase measurements, comparisons of SLR and microwave observations in order to reinvestigate the origin of the persistent 5-cm bias between the two observation techniques. Consideration of higher-order ionospheric corrections is intended. Orbit determination techniques for Low Earth Orbiters are further refined and more experiments for combined analysis of high and low orbits are foreseen. Experiments with orbit determination for geosynchronous EGNOS satellites are underway [Meindl et al., 2004]. Last but not least, implementation of GALILEO into our software is planned in a project with Bundesamt für Kartographie und Geodäsie, Frankfurt, Germany, in order to be ready for the new constellation as soon as signals get available.

References

Beutler, G., U. Hugentobler, M. Ploner, M. Meindl, T. Schildknecht, C. Urschl (2994), Determining the orbits of EGNOS satellites based on optical or microwave observations, Adv. Space Res., in press.

Dach, R., T. Schildknecht, U. Hugentobler, L.-G. Bernier, G. Dudle (2004), Continuous Geodetic Time Transfer Analysis Method, submitted to IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control.

Hugentobler, U., S. Schaer, T. Springer, G. Beutler, H. Bock, R. Dach, D. Ineichen, L. Mervart, M. Rothacher, U. Wild, A. Wiget, E. Brockmann, G. Weber, H. Habrich, C. Boucher (2002), CODE IGS Analysis Center Technical Report 2000, in IGS 2000 Technical Reports, edited by K. Gowey et al., IGS Central Bureau, JPL, Pasadena.

Hugentobler, U., G. Beutler (2002b), Strategies for Precise Orbit Determination for Low Earth orbiters Using the GPS, to appear in Earth Gravity Field from Space – From Sensors to Earth Sciences, G. Beutler, M. Drinkwater, R. Rummel, R. von Steiger (Eds.), Space Science Reviews, Kluwer Academic Publishers.

Hugentobler, U., R. Dach, M. Meindl, P. Fridez (Eds.) (2005), Bernese GPS Software, Version 5.0, Draft version, Astronomical Institute, University of Berne.

Jäggi, A., G. Beutler, U. Hugentobler (2004), Reduced-dynamic orbit determination and the use of accelerometer data, Adv. Space Res., in press.

Meindl, M., U. Hugentobler, T. Schildknecht, M. Ploner, G. Beutler (2004), Precise Orbit Determination for ESTB Satellites Using Microwave and Optical Observations, NAVITEC, Proceedings, December 8-10.

Meindl, M. (Ed.) (2005), Celebrating a Decade of the International GPS Service, Proceedings of the IGS Workshop and Symposium 2004, March 1-5, Bern, Switzerland, Printing Office of the University of Bern.

Schaer, S., et al. (2003a), IGS GLONASS tracking data, IGS/IGLOS Mail 4371/736, available at IGS CB, `http://igscb.jpl.nasa.gov/mail/`.

Schaer, S., et al. (2003b), CODE GNSS final orbits, IGS/IGLOS Mail 4474/770, available at IGS CB, `http://igscb.jpl.nasa.gov/mail/`.

Schaer, S., et al. (2003c), CODE ultra rapid GNSS orbits, IGS/IGLOS Mail 4530/821, available at IGS CB, `http://igscb.jpl.nasa.gov/mail/`.

Schaer, S., et al. (2004), GPS satellite repositionings, IGS Mail 4782, available at IGS CB, `http://igscb.jpl.nasa.gov/mail/`.

Urschl, C., W. Gurtner, U. Hugentobler, S. Schaer, G. Beutler (2004), Validation of GNSS Orbits Using SLR Measurements, Adv. Space Res., in press.