CODE Contribution to the First IGS Reprocessing Campaign

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Abstract

Since 1994, the analysis centers of the International Global Navigation Satellite System (GNSS) Service (IGS) have been generating GNSS-based products such as satellite orbits and station coordinates on a regular basis. In the past years, the methods and models to analyze GNSS data have been continuously improved. Therefore, the long time series of operational IGS products are inhomogeneous and the quality of the products of the early years is significantly worse than today. To provide the best quality of GNSS products available today for the full time interval, the IGS initiated a reprocessing campaign. The Center for Orbit Determination in Europe (CODE) is one of the global IGS analysis centers and also participates in the IGS reprocessing effort. The generation of the CODE contribution to the IGS reprocessing with the Bernese GPS Software on the Linux-Cluster of the Leibniz-Rechenzentrum (LRZ) München is discussed. Selected results regarding station coordinates, atmosphere parameters, and satellite orbits demonstrate the benefit of such a reprocessing of global GNSS data.

1 Introduction

Scientific applications of Global Navigation Satellite Systems (GNSS) such as the Global Positioning System (GPS) have attained an important role in geosciences within the past 15 years. Whereas the determination of precise satellite orbits and station coordinates in a global reference frame was the most important task in the first years, additional topics are of interest today, e.g., monitoring of the Earth's rotation, remote sensing of the troposphere as well as of the ionosphere, time transfer and orbit determination for low orbiting spacecrafts equipped with GNSS receivers. From the very beginning, the scientific community coordinated its GNSS-related activities under the umbrella of an international organization, namely the International GNSS Service (IGS; Dow et al., 2009). Currently, the IGS maintains a permanent network of 421 globally distributed GNSS tracking stations. Their observations as well as the products derived by the analysis centers (ACs) from these measurements are available at the IGS data centers (DCs). The most important products are the geometry of the GNSS satellite orbits, precise satellite and receiver clock corrections, Earth orientation parameters (EOPs), and weekly station positions.

The Center for Orbit Determination in Europe (CODE) is one of the 10 global ACs of the IGS. It is a joint venture of the Astronomisches Institut, Universität Bern (AIUB, Switzerland), the Bundesamt für Landestopografie (swisstopo, Switzerland), the Bundesamt für Kartographie und Geodäsie (BKG, Germany), and the Institut für Astronomische und Physikalische Geodäsie (IAPG) of the Technische Universität München (TUM, Germany). The operational CODE solutions are computed at AIUB and contribute to different product lines of the IGS (different latency and accuracy, see `http://igscb.jpl.nasa.gov/components/prods.html`). In addition to GPS, observations of the Russian counterpart of GPS (namely GLONASS) are consistently processed (Dach et al., 2009).

Since the establishment of the IGS in 1994, the models and processing strategies of the IGS ACs have been continuously improved. Some changes in the processing (e.g., changes in the reference frame) can be overcome by a very fast reprocessing of solutions based on variance-covariance information.

However, changes in the modeling or parameterization (e.g., troposphere model updates, improvements in the ambiguity resolution strategy or even in the pre-processing algorithms) require a complete reprocessing starting with the raw observation data to generate homogeneous results. Therefore, the IGS announced a call for participation for a reprocessing campaign in July 2005 to generate a set of consistent and homogeneous products based on GPS observations back to 1994 (Steigenberger et al., 2008). After several tests, this reprocessing campaign started in February 2008 and the major part of the work was finished in April 2010. The CODE contribution to the IGS reprocessing was computed by IAPG on the Linux-Cluster of the Leibniz-Rechenzentrum (LRZ) in Munich.

Section 2 briefly discusses the basic theory and the parameters of global GPS solutions. Section 3 introduces the Bernese GPS Software used for the GPS reprocessing on the LRZ Linux-Cluster discussed in Sect. 4. Finally, selected results regarding station coordinates, atmosphere parameters and satellite orbits are presented in Sect. 5.

2 Global GPS Solutions

There are many detailed descriptions of the active GNSS (in particular for GPS) and of the GNSS data processing published, e.g., Hofmann-Wellenhof et al. (2008), Kaplan and Hegarty (2006), Parkinson and Spilker (1996), Teunissen and Kleusberg (1998) and Xu (2007). We will give here only a short overview on the relevant parameters:

Station coordinates: 3-dimensional cartesian station coordinates are often the primary parameter type of interest of GNSS analyses.

Receiver clock parameters: When processing undifferenced data, receiver clock parameters have to be estimated every epoch to account for the offset of the receiver clock w.r.t. GPS time.

Troposphere zenith delays and gradients: Whereas the hydrostatic part of the tropospheric delay can be modeled quite well, troposphere parameters have to be estimated to account for the wet delay. Azimuthal asymmetries of the troposphere are taken into account by estimating troposphere gradients in north-south and east-west direction.

Carrier-phase ambiguities: Fixing the ambiguities to their integer values (ambiguity resolution) significantly improves the accuracy of the estimated parameters. Depending on the baseline length, different approaches are used, see lower part of Tab. 1.

Satellite orbits: In addition to the six Keplerian elements, radiation pressure parameters are estimated to account for non-conservative forces. Furthermore, pseudo-stochastic pulses (small velocity changes) are estimated to account for unmodeled effects and to improve the consistency of the orbits (Beutler et al., 1994).

Satellite clock parameters: When using undifferenced data, epoch-wise satellite clock parameters have to be made available. However, the work discussed in this paper is based on double differences, where the receiver and satellite clock corrections are eliminated.

Earth orientation parameters (EOPs): Polar motion, length of day, and nutation rates are estimated. UT1 and nutation offsets are not accessible for GPS due to correlations with the orbital elements (Rothacher et al., 1999). External information is needed for these quantities, e.g., from Very Long Baseline Interferometry (VLBI).

Global ionosphere maps: The largest part of the ionospheric delay is usually eliminated by forming the ionosphere-free linear combination of dual-frequency observations. However, a global representation (e.g., by spheric harmonic coefficients) of the total electron content (TEC) may be determined from the geometry-free linear combination of the observables. When using code observations, differential code biases (see below) have to be estimated in addition to get unbiased TEC estimates.

Satellite antenna phase center variations and offsets: The offsets of the transmitting antennas w.r.t. the center of mass of the satellites as well as the variations of the antenna phase center with the observation direction can be estimated.

Differential code biases (DCBs): When using code observations (e.g., for the Melbourne-Wübbena ambiguity resolution strategy), biases between different code observables have to be taken into account, e.g., by estimating DCBs.

From this list of parameters it becomes clear, that only a limited number of them are mainly station-dependent, namely the first four. If all other parameters are sufficiently known, it is possible to process only a limited number of stations with a regional or local distribution. With the precise point positioning approach (PPP; Zumberge et al., 1997), even the data of a single receiver can be processed.

To solve for the second group of parameters, a network of GNSS tracking stations with a global distribution is indispensable. Such global solutions with high accuracy requirements demand sophisticated models (e.g., for tidal effects, relativistic cor-

General measurement model	
Basic observable	GPS carrier phase, code observations only used for receiver clock synchronization and Melbourne-Wübbena ambiguity resolution
Modeled observable	Double differences, ionosphere-free linear combination
Antenna phase center model	igs05_1499.atx, Schmid et al. (2007)
Weighting	elevation-dependent with $\cos^2 z$ where z is the zenith distance
Station coordinates	
Solid Earth tides	IERS Conventions 2003, McCarthy and Petit (2004)
Pole tides	IERS Conventions 2003, McCarthy and Petit (2004)
Ocean loading	FES2004 (Lyard et al., 2006) including the center of mass correction for the motion of the Earth due to the ocean tides
Atmospheric loading	Not applied
Estimated parameters	Geocentric coordinates of all stations, datum definition by a no-net-rotation condition w.r.t. IGS05 reference frame
Earth orientation parameters	
Tidal UT1	IERS Conventions 2003, McCarthy and Petit (2004)
Subdaily EOP Model	IERS Conventions 2003, McCarthy and Petit (2004)
Nutation	IAU2000A, Mathews et al. (2002)
Estimated parameters	X- and Y-pole, UT1-UTC with 24 h parameter spacing, first UT1-UTC value fixed to a priori value, all other parameters estimated without constraints
Troposphere	
Hydrostatic delay	Computed from GPT (Boehm et al., 2007) according to Saastamoinen (1973), mapped with the hydrostatic GMF (Boehm et al., 2006)
Wet delay	No a priori model, wet delay estimated as piecewise linear function with 2 h parameter spacing
Gradients	Estimated in north-south and east-west direction every 24 h
Satellite orbits	
Estimated parameters	6 Keplerian elements plus 5 solar radiation parameters: constants in D-, Y- and X-direction, 2 periodic terms in X-direction (Beutler et al., 1994) Pseudo-stochastic pulses in radial, along-track, and out-of-plane direction every 12 h
Ambiguities	
Ambiguities are resolved in a baseline-by-baseline mode. The resolution strategy depends on the baseline length:	
Baseline $<$ 20 km	Direct L1/L2 approach, Dach et al. (2007)
Baseline $<$ 200 km	Widelane/narrowlane approach, Teunissen and Kleusberg (1998)
Baseline $<$ 2000 km	Quasi-Ionosphere-Free (QIF) approach, Mervart (1995)
Baseline $<$ 6000 km	Melbourne-Wübbena approach, Melbourne (1985); Wübbena (1985)

Table 1: Important models and estimated parameters of the CODE reprocessing. A full description of the analysis options is available at `ftp://igscb.jpl.nasa.gov/igscb/center/analysis/code.acn`.

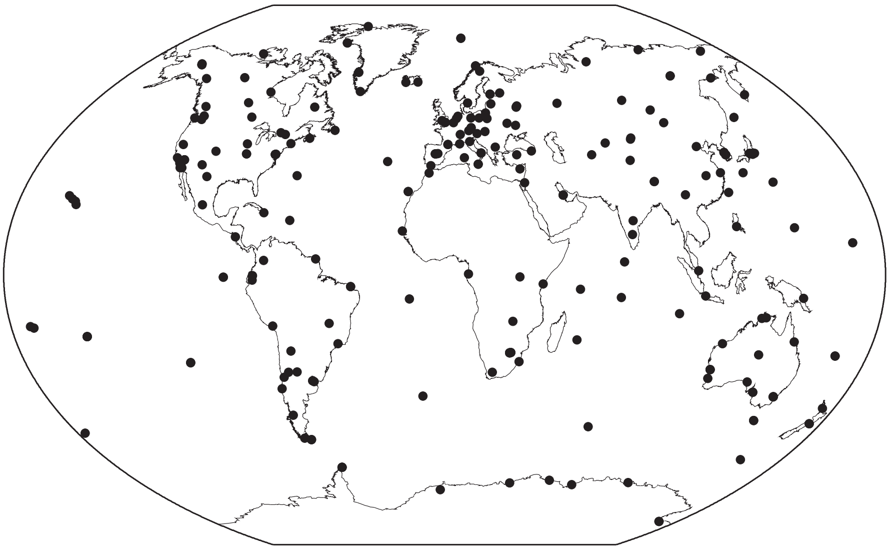

Figure 1: Global distribution of the tracking stations used in the CODE GPS reprocessing.

rections, etc.) preferably following the standards of the International Earth Rotation and Reference Systems Service (IERS; McCarthy and Petit, 2004). An overview of the applied models and the estimated parameters for the CODE reprocessing is given in Tab. 1. Such an advanced modeling is usually only implemented in scientific GNSS software packages because analysis modules from commercial manufacturers focus on regional and local engineering applications.

3 The Bernese GPS Software

The Bernese GPS Software (Dach et al., 2007) is a scientific multi-GNSS post-processing software package developed at AIUB since the early eighties. It is used at CODE for the generation of the products for the IGS. The software is written in standard Fortran whereas the user interface (GUI) is realized in C++ based on the QT library[1]. The source code is nearly system-independent and can be compiled on Windows as well as on Unix platforms. The software consists of about 100 individual programs for conversion of GNSS and auxiliary data, preprocessing, parameter estimation, and normal equation stacking. The total number of Fortran source lines of code (SLOC) is about 223,000.[2]

The software package is distributed worldwide – currently there are about 300 users from scientific institutions and private companies. Many of these users maintain large permanent GNSS networks and need to process the data regularly, for instance the Japanese GEONET consisting of about 1200 receivers (Hatanaka et al., 2001), the local analysis centers of the European EUREF Permanent Network (EPN; Bruyninx, 2004), or the CODE activities for the IGS contributions. Such applications require a highly automated processing.

The Bernese Processing Engine (BPE) is an automatization tool operating on top of the individual (Fortran) programs of the Bernese GPS Software. It is based on a sequence of user scripts starting the individual programs with well defined dependencies. The C++ menu acts as the distributor of the user scripts allowing to include different hosts also for a parallel processing of several scripts. The BPE is written in Perl in a client/server architecture whose communication with the C++ menu is based on TCP/IP. All input options of the BPE can be set via the GUI that is also used to control the software in interactive mode.

4 GPS Reprocessing on the LRZ Linux-Cluster

Experience in running the Bernese GPS Software on the LRZ Linux-Cluster and in reprocessing GPS data in general could already be gathered in an earlier reprocessing effort described in Steigenberger et al. (2006). For the CODE reprocessing effort, the current development version 5.1 of the Bernese GPS Software was used. The processing scheme ap-

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[1] `http://qt.nokia.com`

[2] determined with David A. Wheeler's SLOCCount

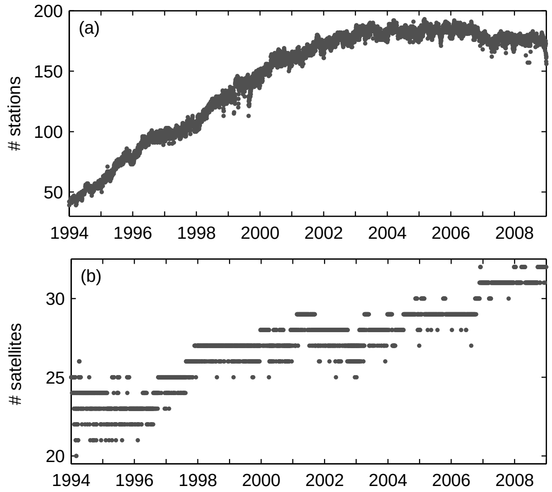

Figure 2: Number of (a) GPS tracking stations and (b) GPS satellites considered in the 1-day solutions of the CODE reprocessing.

plied for the operational CODE processing[3] had to be modified moderately to fulfill the requirements of the reprocessing.[4] A global network of 244 GPS tracking stations (see Fig. 1) covering the time period from January 1994 to December 2008 was processed.

In 1994 only about 40 stations provided observation data on an operational basis with 30 s sampling rate. As shown in Fig. 2(a), the station number increases with time until 2003 when the maximum number of about 190 stations per day is reached. This number differs from the total number of stations due to outages and changes in the network. Later on, the number of stations decreases due decommissioning of several stations. The number of satellites increases with time: from 20 – 25 satellites in 1994 to the maximum number of 32 in 2008, see Fig. 2(b).

4.1 Basic Processing Scheme

A total of four different solution types is computed to derive the products submitted to the IGS: 1-day solution, preliminary 3-day solution, weekly solution and final 3-day solution, see Fig. 3. The simplified processing scheme of the 1-day solution is shown in Fig. 4. Input data are RINEX (receiver independent exchange format; Gurtner and Estey, 2009) GPS observations provided by the IGS DCs and a priori orbits from a previous reprocessing run (Steigenberger et al., 2006) or the CODE operational processing (Dach et al., 2009). After the conversion of the RINEX files into an internal Bernese format and the preprocessing, single differenced observations (baselines) between pairs of stations are formed, thus the satellite clock corrections w.r.t. the GPS reference time are eliminated. A further differencing between pairs of satellites yields double differences (receiver clock corrections eliminated) that are used for a first solution estimating station coordinates, troposphere parameters, EOPs, and satellite orbits. Based on this solution, outliers on the observation level as well as anomalous stations and satellites are detected (based on a residual screening) and excluded from further processing.

A consecutive preliminary solution without the outliers serves as the basis for the quite time consuming (almost half of the total processing time) resolution of the ambiguity parameters to their integer values. An iterative approach consisting of four different methods depending on the baseline length (see Tab. 1) ensures a high ambiguity resolution rate. As the GPS code signals are used for the Melbourne-Wübbena ambiguity resolution strategy, DCBs have to be estimated to account for differences between receiver tracking technologies (Jefferson et al., 2001).

In the final 1-day solution, the resolved ambiguities are introduced and the other parameters listed in Table 2 are set up. Parameters whose numbers are given in brackets are heavily constrained to their a priori values in the standard solution discussed in this paper. These parameters are the nutation rates of the Earth's rotation axis and parameters describing the location and behavior of the transmitting antenna on board the satellites, namely the antenna phase center offsets (PCOs) and the antenna phase center variations (PCVs). These parameters are only considered in special solutions as, e.g., the contribution to the official IGS satellite antenna phase model described in Schmid et al. (2007).

The multi-day solutions are handled on the normal equation (NEQ) level (Brockmann, 1997). First, a preliminary 3-day solution is computed: coordinates and orbital elements are stacked to derive a more stable solution at the day boundaries, especially for the satellite orbit parameters. To save computation time and disc space, troposphere and orbit parameters are preeliminated before saving the 3-day NEQs. Seven of these 3-day NEQs are combined to the weekly solution resulting in the final EOP and coordinate solution. By keeping fixed the latter parameters in the final 3-day solution, satellite orbits are resubstituted from the 1-day NEQs that are fully consistent with the weekly solution. More details on the processing scheme can be found in Steigenberger (2009).

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[3] Analysis summary available at `ftp://igscb.jpl.nasa.gov/pub/center/analysis/code.acn`

[4] `http://www.ngs.noaa.gov/igsacc/reprocess/reprocess.html`

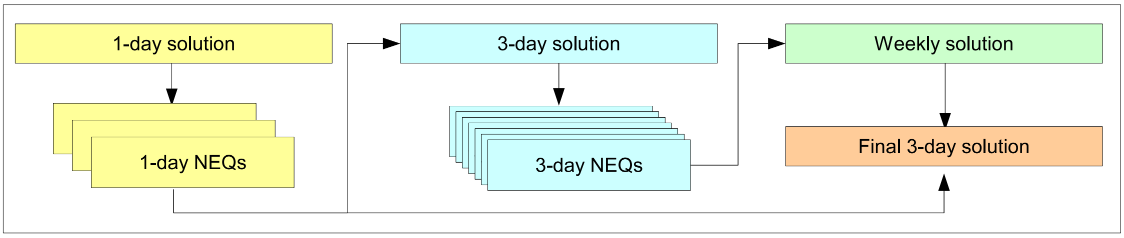

Figure 3: Overview of the individual solutions of the CODE GPS reprocessing.

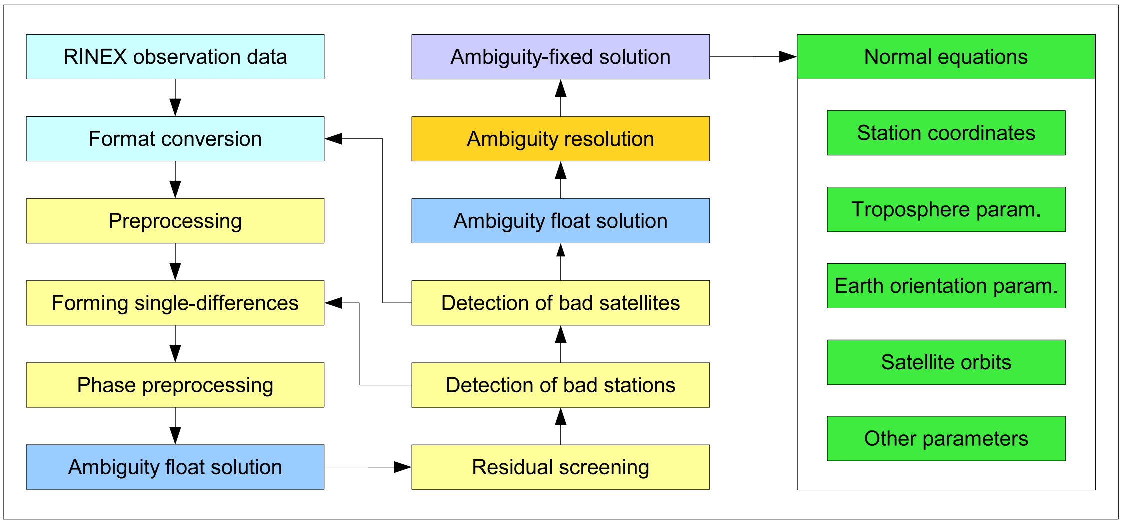

Figure 4: Simplified flowchart of the 1-day solution.

Parameter	# Parameter
Station coordinates	600
Earth orientation parameters	5 + (5)
Satellite orbits	420
Troposphere parameters	3400
Origin of the tracking network	3
Ambiguities	$\sim$ 2500 – 3700
Differential code biases	30
Satellite-specific PCVs	(450)
Satellite-specific PCOs	(90)

Table 2: Approximate numbers of parameters estimated in a typical 1-day solution (200 stations and 30 satellites). Parameters that are heavily constrained to their a priori values in the standard solution are given in brackets.

4.2 Technical Aspects of the Reprocessing

The CODE contribution to the IGS reprocessing was computed from August 2008 to April 2009. After an analysis of the preliminary time series to identify outliers, discontinuities (e.g., due to earthquakes and station equipment changes, see Sect. 5.1) and other systematic effects, some parts of the series had to be recomputed to generate clean solutions.

A full 1-day solution consists of several hundred individual program runs (runtime between 20 s and 20 min each), most of them for the ambiguity resolution that is performed on the baseline level. Depending on the configuration of the BPE, several program runs are executed in parallel, e.g., the format conversion, the preprocessing and the ambiguity resolution. However, as several program runs cannot be performed in parallel (e.g., the normal equation stacking) one complete 1-day solution is submitted to the Linux-Cluster as one serial job. The submission of the individual jobs is controlled by the BPE. Depending on the number of available nodes, up to 100 jobs (days) ran in parallel mainly on 2.6 GHz Opteron Dual-Core CPUs.

The total runtime of the 1-day solution strongly depends on the number of stations and typically varies between 20 min for about 40 stations in 1994 and 3 h for about 200 stations in 2008. The preliminary 3-day solution including several sub-solutions

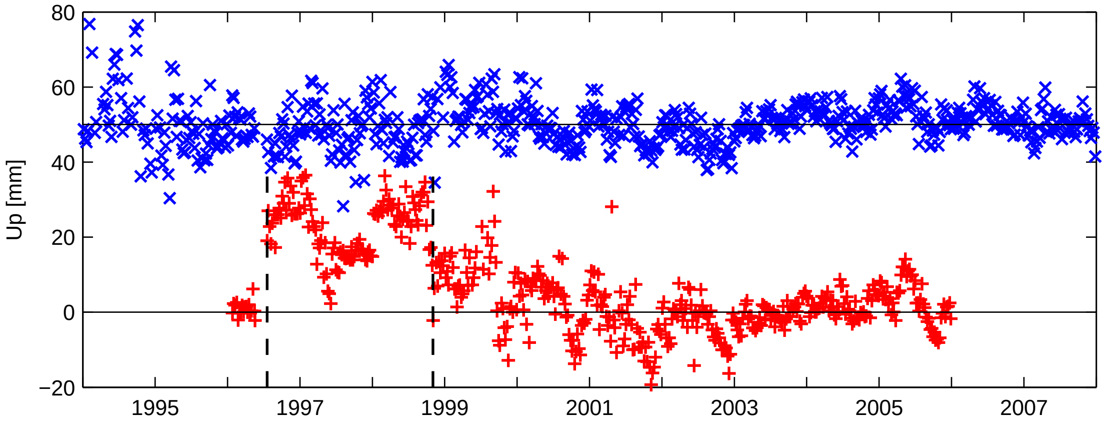

Figure 5: Station height time series w.r.t. a long-term mean of the IGS station Santiago (SANT, Chile) from ITRF2005 (red pluses) and the reprocessed CODE solution (blue crosses). The CODE solution is shifted by 5 cm. Discontinuities introduced in the ITRF2005 solution are indicated by vertical lines.

for special applications (e.g., polar motion and UT with a temporal resolution of 1 h instead of the default value of 24 h) takes about 5 – 40 min per day. The runtime for the weekly solutions is a few minutes per week due to the preelimination of satellite orbits and troposphere parameters in the 3-day solution as previously mentioned. Therefore, this solution is computed on a single node as a serial job. The final 3-day solution has a similar runtime as the preliminary 3-day solution. Altogether 44,649,112 parameters were estimated in 5478 daily solutions based on 2,428,232,302 GPS observations. The complete CPU time of all solutions needed to compute the final results was 36,918.6 h (about 4.2 years).

5 Selected Results

The focus of this paper are technical aspects of the reprocessing effort. Nevertheless, we present a few examples illustrating the benefits of a homogeneous processing of long series of GNSS data. First detailed scientific interpretations of the results from the CODE reprocessing can be found in Dach et al. (2010a), Dach et al. (2010b), and Collilieux et al. (2010).

5.1 Station Coordinates

In particular the station heights of GPS-derived long time series are affected by discontinuities, e.g., due to model updates or changes of the station equipment. The red pluses in Fig. 5 show the ITRF2005 (Altamimi et al., 2007) time series of the IGS station SANT (Santiago, Chile) based on the operational combined IGS solutions between 1996 and 2005. A clear discontinuity due to an antenna (and receiver) change in July 1996 can be seen. Further discontinuities of unknown origin are present at the turn of the year 1997/1998 and at the end of the years 1998 and 1999. Only two of these discontinuities were considered in the ITRF2005 solution. In addition, a non-linear behavior is visible in the time period from 2000 to 2005. Due to a more sophisticated antenna phase center model used for the CODE reprocessing, the antenna-related discontinuity in 1996 vanishes in the reprocessed series (blue crosses in Fig. 5) and also the other discontinuities are not visible anymore as well as the non-linear behavior. All this demonstrates the homogeneity that could be achieved by the reprocessing.

5.2 Troposphere Parameters

GNSS signals are delayed by the troposphere (neutral part of the atmosphere) mainly depending on the air pressure and the humidity. Therefore, troposphere parameters have to be estimated for high precision GNSS applications. As an example, the troposphere zenith path delays of the IGS station BRUS (Brussels, Belgium) are plotted in Fig. 6(a). An annual signal with minima in the dry winters and maxima in the humid summers can clearly be seen. The differences between the operational and the reprocessed troposphere zenith total delays (ZTDs) of BRUS revealed two changes in the operational processing:

1. In June 2003 the parameterization of the troposphere parameters was changed from one offset per parameter interval to a piecewise linear function resulting in a lower scatter of the ZTD differences in Fig. 6(b).

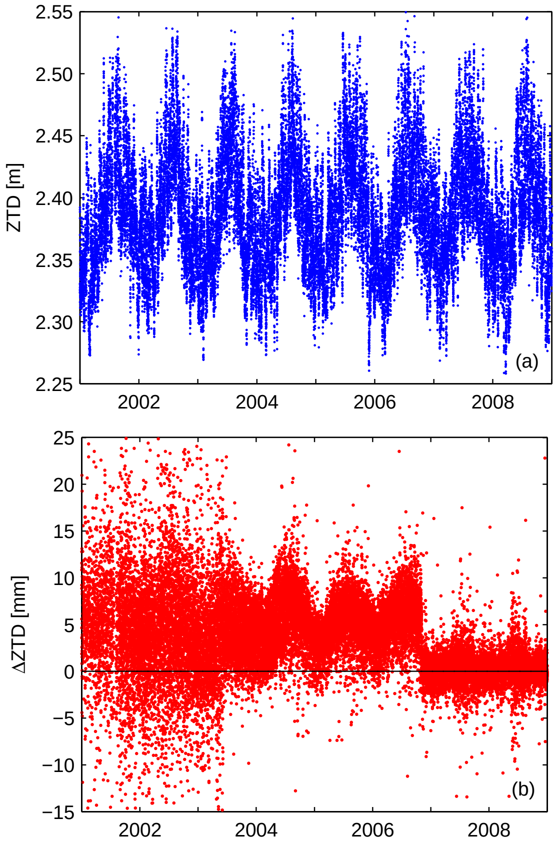

Figure 6: Troposphere parameters of the IGS station Brussels (BRUS, Belgium): (a) zenith total delay from the reprocessed CODE solution; (b) zenith total delay differences between the operational and the reprocessed CODE solution.

2. In November 2006 the IGS switched from the relative antenna model igs01 to the absolute model igs05 (Schmid et al., 2007) resulting in a clear discontinuity in the scale of the estimated station heights (Ferland, 2008). As the station heights are highly correlated with the troposphere parameters (Rothacher, 2002), this model change can be seen as a discontinuity in Fig. 6(b). In addition, the troposphere mapping function and the a priori model for the zenith delays were changed at the same date: from NMF (Niell, 1996) to GMF (Boehm et al., 2006), and from standard atmosphere (Berg, 1948) to the GPT model (Boehm et al., 2007), respectively.

In view of these inconsistencies of the operational series, it is obvious that only homogeneously reprocessed ZTD time series might be adequate for climatological studies (Gradinarsky et al., 2002). Further results on reprocessed troposphere parameters can be found in Steigenberger et al. (2007).

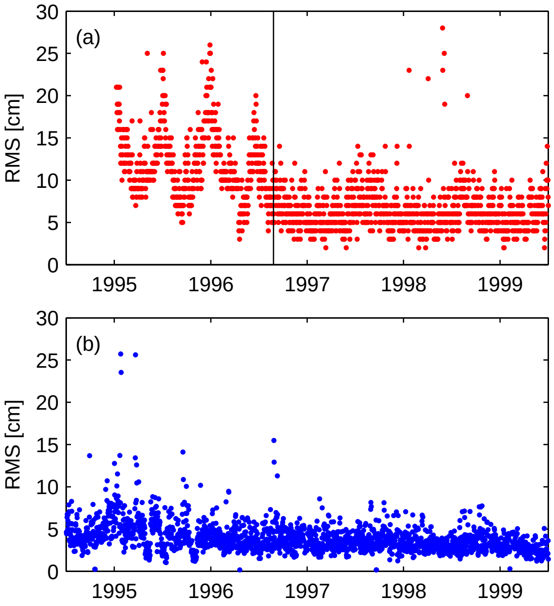

Figure 7: RMS of 3-day orbit fits for GPS satellite SVN17: (a) operational CODE solutions; (b) reprocessed CODE solutions. The orbit modeling change in the operational solution in August 1996 is indicated by a vertical line.

5.3 Satellite Orbits

The quality of 1-day satellite orbits can be evaluated by multi-day orbit fits. The RMS of three individual 1-day arcs w.r.t. the fitted 3-day arc is an indicator for the consistency and smoothness of the satellite orbits. Figure 7 shows such orbit fits of GPS satellite SVN17 (PRN17) for both, the operational and the reprocessed solution of CODE. At the beginning, the operational orbit fits show a periodic signal whose maxima depend on the orientation of the orbital planes w.r.t. the Sun. After changing the orbit modeling in August 1996 this periodic signal vanishes and the orbit quality improves. However, the operational orbit fits are still worse by a factor of about two for the time period shown in Fig. 7 due to the generally less sophisticated orbit modeling of the operational solution compared to the reprocessed one. More details on the quality of reprocessed GPS satellite orbits are given in Steigenberger et al. (2009).

6 Summary and Outlook

In the past, interpreting GPS-derived long time series was difficult due to inconsistencies caused by changes in the processing w.r.t., e.g., modeling and parameterization. This problem can only be overcome by a complete and homogeneous reprocessing starting with the raw observation data and using up-to-date models and analysis strategies. For the CODE contribution to the IGS reprocessing, all relevant parameters of a global GPS solution were estimated based on 15 years of GPS observation data of 244 tracking stations.

Although the set up of the processing, the detection of outliers and discontinuities, as well as the processing itself were time-consuming, the benefits of the reprocessing easily justify this effort. As shown in Sect. 5 for some examples, the quality and homogeneity of all types of parameters estimated within the reprocessing campaign could be significantly improved, particularly in the early years.

The processing scheme discussed in Sect. 4 is perfectly suited for a serial Linux-Cluster. Although the runtime of the individual jobs does not exceed several hours, the large number of jobs legitimates the use of a cluster system.

After submitting the CODE contribution to the IGS, the weekly normal equations in Solution INdependent EXchange (SINEX) format[5] were combined with the other individual AC submissions by the IGS reference frame coordinator to the official (reprocessed) IGS coordinate and EOP solutions. In a subsequent step the combined orbits were generated. These products were published in April 2010. The combined SINEX files were used as input for the computation of ITRF2008 (Altamimi et al., 2010).

A further advantage of the reprocessing is the possibility to update the antenna phase center model igs05 currently used by the IGS (Schmid et al., 2007) as satellite antenna offsets are included in the SINEX files of several ACs. igs05 is based on the analysis of two ACs only and lacks of antenna offset estimates of the most recently launched satellites. An update for the GLONASS antenna model has already been generated based on the GLONASS extension of the CODE reprocessing computed at AIUB (Dach et al., 2010b).

A variety of users will benefit from the reprocessed IGS products and the updated antenna model. Whereas long time series of station coordinates and EOPs can directly be used for geophysical studies, satellite orbits and EOPs can be used for the reprocessing of regional networks such as the EPN mentioned in Sect. 3 (e.g., Völksen, 2008). Preparations for a second reprocessing campaign including several model updates are already underway. This campaign is planned to start in 2011/2012 and will take advantage of the experiences gathered in the first campaign as well as of improvements in computer technology resulting in a much faster processing time.

The reprocessed CODE products as well as the products of other ACs and the combined IGS products are available at the global IGS DCs, e.g., `ftp://cddis.gsfc.nasa.gov/gps/products/repro1/`.

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[5] Format description available at `http://www.iers.org/IERS/EN/Organization/AnalysisCoordinator/SinexFormat/sinex__cont.html`

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