EUREF LAC Analysis at swisstopo/CODE Using the Bernese GPS Software Version 5.0

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Abstract

The EUREF LAC processing scheme at swisstopo was changed from Version 4.2 to Version 5.0 based on the BPE example RNX2SNX, which is included in the new release of the Bernese GPS Software. This update was also used as an opportunity to review the general processing environment, e.g. data management, and to adjust some processing options. The influence of these changes on the results will be presented by comparing the analysis resulting from the two versions 4.2 and 5.0. For this purpose, several weeks of EUREF GPS data are processed parallel. Of particular importance are the treatment of troposphere parameters, the antenna phase center models, and the settings for the options of the normal equation stacking program ADDNEQ2.

Since September 2004, the collaboration between swisstopo and the Astronomical Institute of the University of Berne (AIUB) has become more extensive, thus gaining synergies, increasing the transfer of know-how, and considerably reducing duplicate work related to routine GNSS data analysis.

Increased collaboration between swisstopo and AIUB

For swisstopo, a new form of participation at the Center for Orbit Determination in Europe (CODE) was established by creating a dedicated project position. Nominally 30% of the duties of this position are assigned to activities concerning the permanent network analysis center (PNAC) operated at swisstopo and 70% to activities concerning CODE (located at AIUB). The newly created position has been occupied by S. SCHAER since September 2004.

The regular physical presence of the position holder at the two institutions enables optimal transfer of know-how and constant exchange of information. Alternation of the working place every week turned out to be reasonable.

Synergies may be gained through the increased collaboration between swisstopo and AIUB/CODE. It is possible to reduce duplicate work related to routine GNSS data analysis which is performed at both institutions. The use of shared Perl scripts and modules has already been established at swisstopo and CODE. Moreover, a two-way computer alerting scheme has been activated between both analysis centers [HUGENTOBLER et al., 2005b].

A side effect of the increased collaboration is that requests with respect to the Bernese Software in terms of *national* GNSS surveying (and related applications) can be better accounted for.**LAC analysis at swisstopo**The EUREF station subnetwork considered at swisstopo consists of 24 stations (at the beginning of 2005). 23 of them are actually active, 21 are contained in our EUREF weekly SINEX solutions (labeled LPT). The swisstopo station subnetwork is shown at http://www.epncb. oma.be.

An important aspect is that GPS observation data of all stations of the Automated GPS Network for Switzerland (AGNES) completed by a significant number of EUREF or IGS stations surrounding Switzerland are processed in a manner very similar to that applied to the EUREF data set. The “AGNES+” network thus considered includes nominally 29+50 stations [BROCKMANN et al., 2002; SCHNEIDER et al., 2005].

Transition from Bernese Software V4.2 to V5.0

The new Version 5.0 of the Bernese GPS Software, released in April 2004, offers a variety of new features [HUGENTOBLER et al., 2005a]. Apart from general improvements concerning the modeling of GNSS observables, this version includes a new, GUI-based menu system, additional options and tools for automated data processing, and a completely new BPE (Bernese Processing Engine) frontend. The interested reader is also referred to *http:// www. bernese.unibe.ch/docs/ Berneseflyer.pdf*. For the EUREF GPS network data analysis, refinements in regard to troposphere modeling and the provision of a re-written normal equation stacking/manipulation program (ADDNEQ2) are of particular importance.

Overview of the EUREF BPE processing scheme

The EUREF processing scheme at swisstopo was changed from Version 4.2 to Version 5.0 on the basis of the BPE example RNX2SNX, which is included in the new software release (in form of a Processing Control File, called RNX2SNX.PCF).

As implied by the name, this BPE example is a “RINEX-to-SINEX” converter designed for analyzing regional GNSS (specifically GPS plus GLONASS) permanent networks following state-of-the-art strategies. Primary analysis products are ITRF coordinates and tropospheric parameters for each station of the network. The session length anticipated by RNX2SNX is 24 hours, or 1 day. It might, however, be easily adapted to a processing scheme with sub-daily time resolution, if desired.

The most important modifications made with respect to RNX2SNX.PCF (for derivation of EUREF. PCF) are:

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- A weekly analysis sequence was added. This sequence includes computation of weekly station coordinates, a reliability check concerning geodetic datum definition, and finally a resubstitution step for daily retrieval of tropospheric parameters (ensuring continuity at day boundaries).
- Checks (using ADDNEQ2) were implemented in order to assess day-to-day and week-to-week station coordinate repeatability on a longer time scale (7 weeks).
- The ambiguity resolution scheme was refined. In addition to the QIF (Quasi-Ionosphere-Free) strategy, phase-based widelane/narrowlane as well as direct L1/L2 ambiguity resolution is performed in a sequential manner, depending on the baseline length. CODE ionosphere (ION) data is used to support all ambiguity resolution strategies.
- Additional GPSEST and ADDNEQ2 program steps were implemented for generating parallel test solutions (specifically using low-elevation observation data and solving for tropospheric gradient parameters, respectively).

The EUREF (and AGNES+) analysis is commonly done during the weekend. Processing is started automatically as soon as the required IGS final analysis products (GPS orbits and ERPs) become available. In principle, processing could be carried out in the so-called "super-BPE" mode (analyzing a number of sessions parallel).

The satellite problem (SAT CRX) files maintained at CODE/AIUB are used according to the recommendations. These files do not only list PRN/slot numbers of temporarily misbehaving GPS/ GLONASS satellites (to be excluded from precise GNSS analyses) but also (mean) epochs of Delta-V GPS repositioning events, epochs that are needed for the successful reconstruction of an uninterrupted orbit for a GPS satellite being repositioned. Note that corresponding IGS orbit information (satisfying highest accuracy standards) has been produced exclusively by CODE, namely from the beginning of 2004 [HUGENTOBLER et al., 2005b].

The most important changes with respect to the (predefined) BPE processing options for fulfilling the current EPN (EUREF Permanent Network) analysis guidelines are:

- The elevation mask angle was increased from 3 to 10 degrees (solely for the computation of the "official" final solution).
- Possible GLONASS observations are filtered out (in the RXOBV3 processing step).
- Increasing the maximum number of stations to be accepted for daily session analysis (predefined: 50) was not necessary (in the RNXGRA processing step).
- Tropospheric horizontal gradient parameters are set up, but remain unconsidered while computing the "official" final solution (they get deleted from the normal equation system at that stage).

The selected processing options should be conform to the EPN analysis guidelines.

An interesting detail concerns the selection (and decompression) of RINEX observation files for BPE processing. Both swisstopo and CODE started to use a generic Perl function developed for this purpose. This function will be part of a next release of the Bernese Software.

Comparison of Bernese V4.2 and V5.0 analysis results

EUREF daily/weekly results

Six weeks were analyzed parallel using both software versions for validation purposes (GPS weeks 1309–1314, DOYs 037–078, 2005).

Figure 1 shows daily station coordinate differences between V4.2 and V5.0 analysis results for two stations of the EUREF network. Differences for the horizontal (North and East) components are on the level of ±0.1 mm. The agreement is significantly worse for the vertical (Up) component. This is mainly caused by differences in troposphere modeling and parameterization, respectively (see also Listing of the most important V5.0 model changes). In relation to the corresponding (V4.2) coordinate repeatability, plotted for comparison purposes, differences in Up are still relatively small. There is, however, a systematic network effect. The observed scale change of +1.7±0.2 ppb may be attributed to the fact that the dry-Niell troposphere mapping function is now used in conjunction with the wet-Niell counterpart (now distinguishing between an a priori hydrostatic part and an estimated wet part).

The daily station coordinate repeatability for the 23 EUREF stations considered at swisstopo is compared in Figure 2. The RMS deviation is plotted for both horizontal components. In this comparison, a third type of solution is included: a test solution from the V5.0 analysis solving for tropospheric gradient parameters specific to each station of the network (responding to azimuthal asymmetries in the troposphere). The elevation mask angle imposed on the "gradient" solution remains unchanged (10 degrees).

Figure 3 gives a summary of the repeatability results shown in Figure 2. The average values calculated from median values are more meaningful for interpretation than those calculated from the RMS values. The performance for the North and East components resulting from the two software versions is absolutely comparable. A remarkable improvement may be noticed regarding the solution with gradients, whereas this solution has—as expected – no effect on the repeatability of the Up component (with regard to the median value). Finally, it is interesting to notice that the performance for the Up component gets slightly better when changing from V4.2 to V5.0. By the way, this seems to legitimate the magnitude of the station coordinate differences (particularly for the vertical component) as seen in Fig. 1.

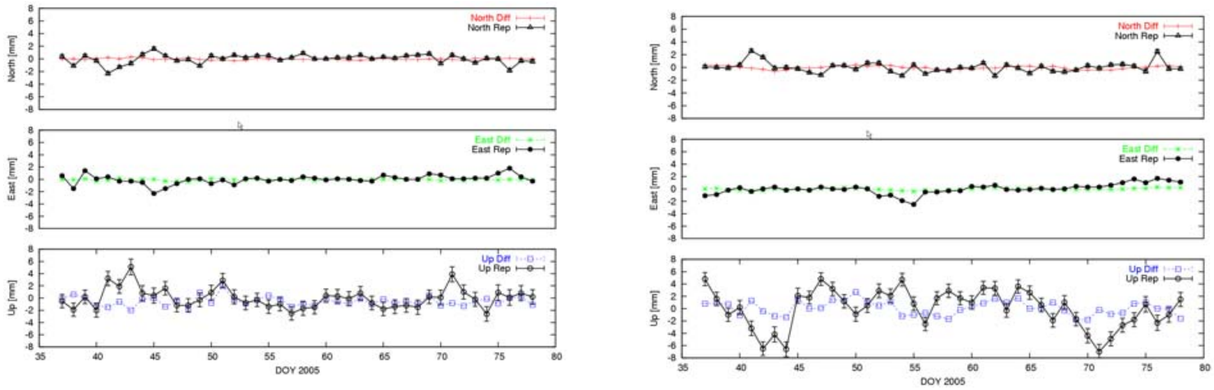

Figure 1: V4.2/V5.0 daily station coordinate differences and V4.2 repeatability for station EUSK, Euskirchen, Germany (left) and for station TERS, Terschelling, The Netherlands (right).

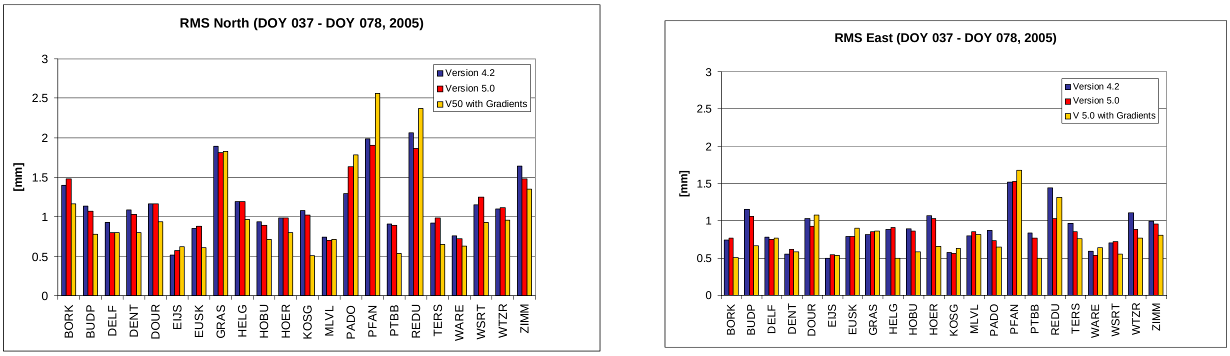

Figure 2: Daily station coordinate repeatability for 23 EUREF stations considered at swisstopo for North component (left) and for East component (right).

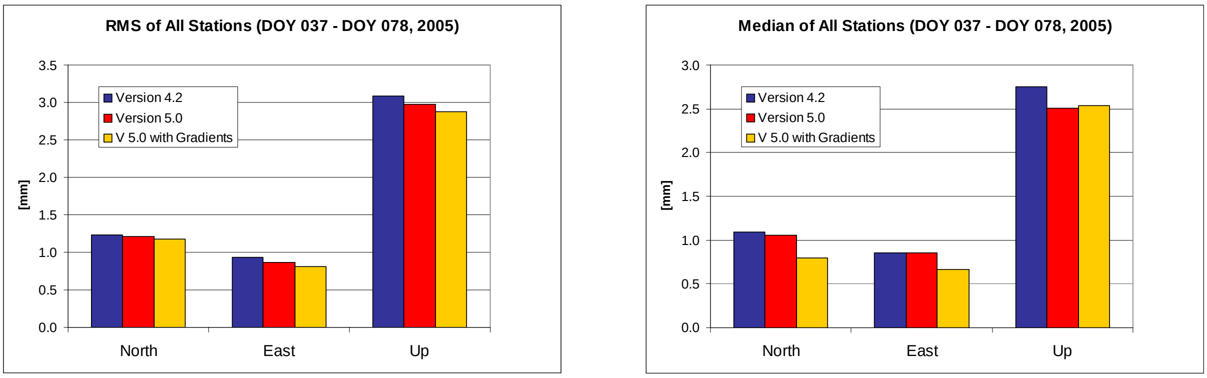

Figure 3: Average daily station coordinate repeatability for North, East, and Up components: RMS values (left) and median values (right).

AGNES multi-year combination using ADDNEQ (V4.2) and ADDNEQ2 (V5.0)

An accumulated solution is regularly computed on the basis of weekly normal equation (NEQ) information generated in our AGNES+ network analysis. Corresponding NEQ files are available from GPS week 973 (end of 1997) onwards.

The combination analysis includes the estimation of a set of station coordinates (at mean epoch) plus one velocity vector for each station, or group of nearby stations (by defining relative constraints between station-specific velocity vectors). A supplementary set of station coordinates is set up after each recorded GPS receiver antenna change (common when the type of antenna was changed). About 90 stations are thus considered for combination. In view of the time scale of about 7 years, a rather complex station constellation scenario has to be dealt with.

The combination was done using both the ADDNEQ program of V4.2 and the (completely redesigned) ADDNEQ2 successor included in V5.0 of the Bernese software package [HUGENTOBLER et al., 2001; HUGENTOBLER et al., 2005a]. It should be mentioned that a conversion step was needed to convert V4.2 NEQ into V5.0 NEQ (NQ0) binary files.

According to Figure 4, the two sets of station coordinates and velocities obtained from these different combinations agree on the level of approximately ±0.1 mm (coordinates) and ±0.1 mm/year (velocities). There are a number of slightly larger differences. Those differences, typically belonging to short station observation periods, are mainly caused by improved relative velocity constraining in the V5.0 combination.

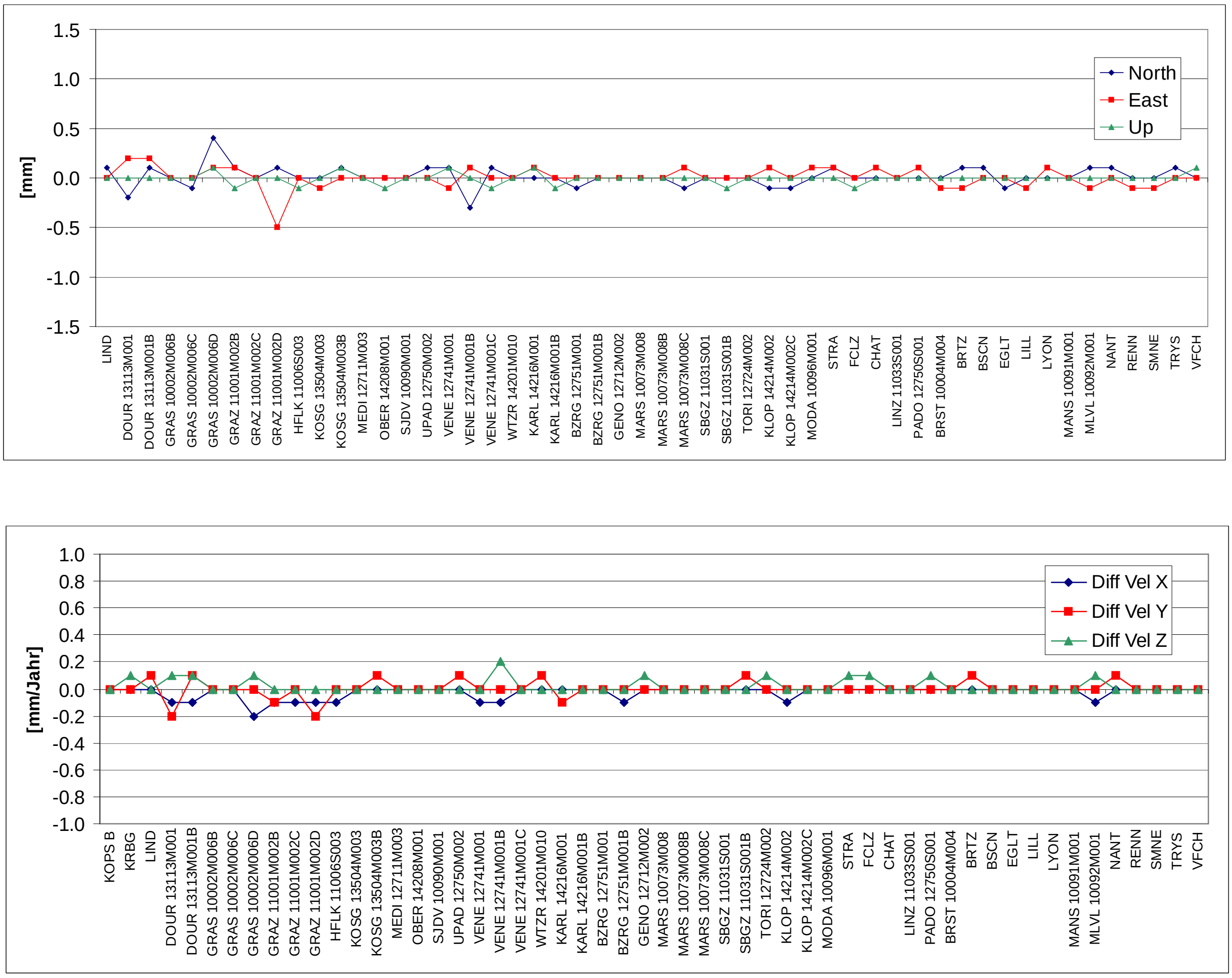

Figure 4: Subset of AGNES+ station coordinate (top) and velocity (bottom) differences: ADDNEQ2 (V5.0) minus ADDNEQ (V4.2) results, derived from a 7-year combination.

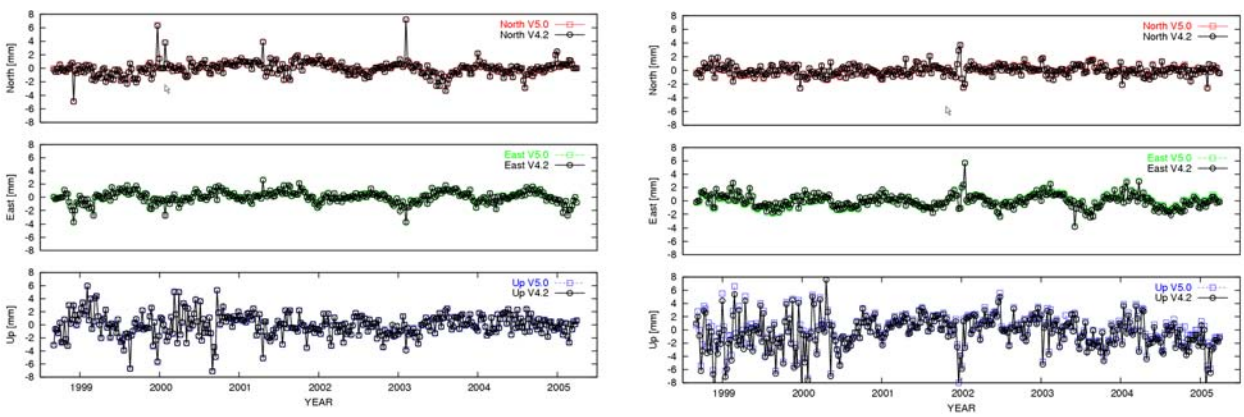

Figure 5: AGNES+ weekly station coordinate residuals, for station ETHZ, Zurich, Switzerland (left) and for station WTZR, Wettzell, Germany (right), coming from a 7-year combination using ADDNEQ (V4.2) and ADDNEQ2 (V5.0). Differences between the estimates are negligible.

Figure 5 shows the time series of station coordinate residuals (between individual weekly solutions and the combined solution) as obtained from the two combination analyses for two representative stations. The V4.2 and V5.0 results are in good agreement. Again, marginal differences may be explained by the use of different parameter constraining models (stations with a setup change within a week got pre-eliminated in V5.0).

Summary

We could demonstrate that the reproduction of the V4.2 analysis results is possible on the highest level using V5.0 of the Bernese Software. This is true for daily session processing (even when relying on a completely new BPE processing chain) as well as for multi-year NEQ combinations (involving velocity estimation). Differences between V4.2 and V5.0 analysis results are negligible or may be explained by existing model differences, provided that similar program options are used.

We have to emphasize here that the reproduction of two independent analysis solutions as identical as possible must be considered as a very demanding task in view of the (steadily increasing) complexity of the analysis software. Keeping the software up to date with respect to the V5.0 buglist (made available at *http://www.bernese.unibe.ch*) is a must for all users of the Bernese Software.

Listing of the most important V5.0 model changes

The following list gives an overview of the most important V5.0 model changes:

- IERS 2000 conventions:
  - Earth tides: TIDE96 replaced by TIDE2000 (provided by ROB).
  - Step-2 correction (bugfix reported in BSW Mail 190, June 15, 2004).
  - Nutation: IAU2000 (old: IAU80).
  - Subdaily pole model: IERS2000 (old: RAY96).
- Ocean loading correction model: GOT00.2 (file: GOT002_EUR.BLQ).
- Tropospheric modeling using piece-wise linear functions.
- Mapping using dry-Niell in conjunction with wet-Niell MF possible.
- Estimation of tropospheric gradient parameters fully supported in ADDNEQ2 (optional deletion of corresponding parameters on the NEQ level).
- Consideration of P1-C1 bias values possible (file: P1C1.DCB or CODE.DCB).
- GNSS data import (using RXOBV3):
  - Consideration of antenna radome codes possible.
  - Various new and useful options with regard to automatic data import.
  - Selection of GPS *or* GPS/GLONASS (in RXOBV3 as well as GPSEST).

Outlook regarding upcoming and future model changes

The consideration of "absolute" GNSS receiver and satellite antenna phase center offset and pattern models is expected to be one of the next (IGS) model changes affecting the EUREF LAC analysis. Future model

- Inclusion of low-elevation observation data (down to 3 degrees).
- Refinement or standardization of SINEX data generation steps at LACs (e.g. two-step ADDNEQ2 procedure).
- Estimation of tropospheric gradient parameters.
- Inclusion of GLONASS observation data.
- Consideration of improved (potentially meteo-data-based) tropospheric mapping functions.
- Correction for atmospheric loading effect.
- Use of improved ocean loading models.

Finally, one may start from the assumption that "reprocessing" capabilities will become more and more important, not only for the IGS but also for the EUREF analysis community in order to generate consistent time series for station coordinates.

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