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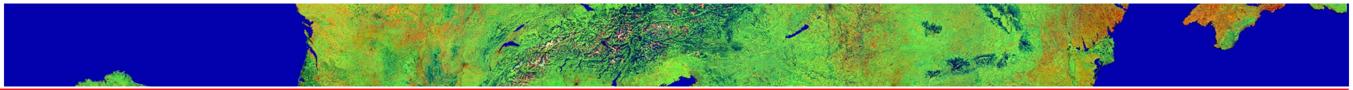

Improved troposphere modeling for near real-time and post-processing GPS applications at swisstopo

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Abstract

For several years, swisstopo has being involved in data analysis of GPS permanent networks. One main activity concentrates on the computation of troposphere parameters in near real-time. Zenith total delay estimates are delivered every hour with a time delay of about 45 minutes to various partners, such as EGVAP (EUMETNET GPS water vapour programme) and the Federal Office of Meteorology and Climatology (MeteoSwiss), with the goal to use the data for numerical weather prediction.

At present, a network of 85 permanent sites is processed on a routine basis. In line with the switch from Bernese GPS Software Version 4.2 to 5.0, a number of new features related to troposphere parameter determination became relevant. The modeling of the troposphere delay is now done using a continuous, piece-wise linear parameter representation, and the dry-Niell in conjunction with the wet-Niell mapping function are applied.

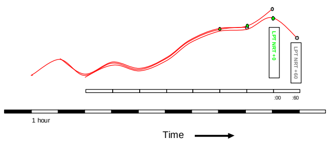
The influence of these and other model changes on the resulting troposphere analysis products, comparisons with solutions coming from a real real-time positioning software (GPSNET) and comparisons with products from other institutions (IGS, CODE, GFZ) are presented in this poster.

Switch from Bernese V4.2 to V5.0

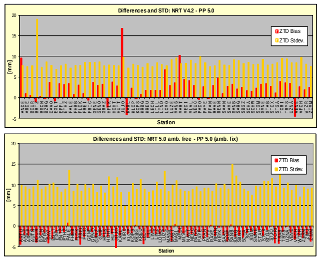
The processing was switched to Bernese GPS Software V5.0 in April 2005 for the post-processed solutions and in August 2005 for the near real-time solution. The table below summarizes the changed processing options between V4.2 and V5.0 for the near real-time (NRT) processing:

Processing option	Version 4.2	Version 5.0
Processed observation interval	One hour for observation adjustment, afterwards combination on normal equation level with the last six hourly solutions (coordinates and troposphere)	Eight hours for observation adjustment, afterwards combination on normal equation level with the solutions of the last 7 days (coordinates only)
Sampling rate Cut-off angle Weighting	30 seconds 10 degrees $\cos(z)^2$, z = zenith angle	90 seconds 10 degrees $\cos(z)^2$, z = zenith angle
Ambiguity fixing	Baselines up to 205 km: L5/L3 strategy Others: No ambiguity fixing	All baselines: L1/L2 strategy up to 20 km L5/L3 strategy up to 200 km QIF strategy up to 2000 km
Ionosphere model	No model used	CODE model (prediction)
GPS orbits	IGS ultra orbits	IGS ultra orbits (or CODE)
Ocean loading	FES95.2	GOT00.2
Number of clusters	Up to three clusters, depending on the number of processed sites	One cluster, Option of processing in several clusters implemented
Definition of datum	All stations fixed to ITRF2000 coordinates (transformed to current epoch with ITRF2000 velocities)	Sliding 7-day coordinate averages, aligned with no net translation condition to ITRF2000
Troposphere modeling	One constant value for each hour	Continuous, piece-wise linear function, represented with values at the beginning and end of each hour
A priori model Mapping function	No a-priori model Dry-Niell mapping function	Saastamoinen / Dry-Niell m. f. Wet-Niell mapping function
Weighting of troposphere parameters	Absolute: 5.0 m (nearly free) Relative: 1.2 mm (optimized w.r.t. the sampling rate)	Absolute: None Relative: 3mm, since DOY 087, 2006 optimized to 1 mm
Number of sites	75	Max. 85 (New: French sites + enlarged network)

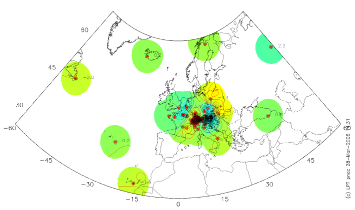
The processing scheme of the V5.0 near real-time processing is visualized in the graph below: Data processing is done using a sliding 8-hour observation window. The ZTD values at the beginning and the end of the last hour are contained in the hourly delivered result file in the COST format.



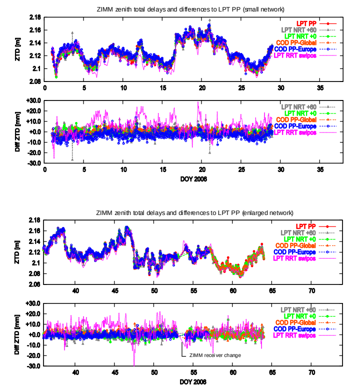
The solution types V5.0 and V4.2 are compared for a time interval of two weeks (DOY 205 – 218, 2005). The influence of the changed mapping functions, the changed realization of the datum definition, and different antenna calibration values applied for site JUJO is visible in the resulting ZTD biases. The V5.0 estimates are generally 2-3 mm "dryer" than the V4.2 estimates, leading to a reduced bias compared to ZTDs determined by other techniques (radiometer, radio sondes, numerical weather models). The impact of the ambiguity resolution is considerable as summarized in the conclusions.



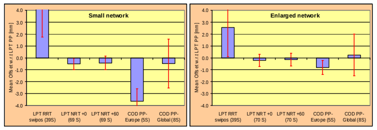
Enlarged observation network



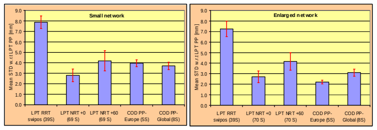
In addition to the network processed so far, seven additional sites (REYK, STJO, PDEL, MAS1, TRAB, ARTU, KIR0) were included in the data analysis. The main goal was to investigate whether the quality of the estimated ZTD values can be improved by this extended observation network (120º x 45º instead of 30º x 15º)



The plots show the ZTD values and differences to the post-processed LPT solution (LPT PP; IGS final orbits) for site ZIMM before adding the new sites to the processed network (DOY 001-028, 2006) and for the enlarged network (DOY 036-063, 2006). A real-time solution derived from the positioning service swipos (LPT RRT), two near real-time solutions (NRT +60,+0), and two solutions from CODE (COD PP-Global, COD PP-EUREF) are compared with swisstopo's post-processed solution (LPT PP).



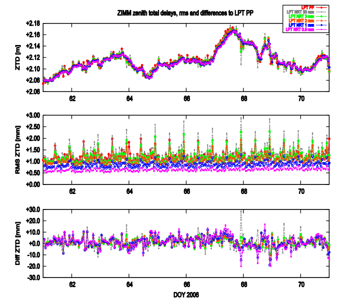
The mean offsets of the different solution types with respect to the post-processed solution (LPT PP) are computed for all common sites (number given in parenthesis). The largest improvement is observed for the comparison with CODE's EUREF solution (from -3.7 mm to -0.8 mm). Both near real-time solutions match very nicely with the post-processed solution and show almost no bias.



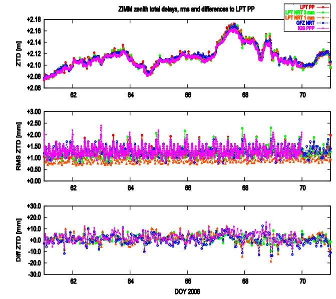
The standard deviations with respect to the post-processed solution range from 2-3 mm (for NRT+0) to 8 mm (for the real-time solution). Except for the CODE Europe solution, where the mean STD is reduced from 4.0 to 2.2 mm, the values are very similar between the two networks. Solution NRT+0 is a factor of 1.5 better than NRT+60 benefiting from one additional hour of GPS observation data. The smaller improvement for the comparison to CODE's Global solution may be explained by the 2-hour sampling of this solution type.

Relative constraining of the ZTDs

Test series of near real-time solutions with different relative constraining of the estimated ZTDs were computed for a time interval of 10 days (DOY 061 – 070, 2006). So far, we used a value of 3 mm for our official solution. The test solutions were computed with relative constraints varying from 30 to 0.3 mm. In addition, these solutions were compared internally with our post-processed solution (LPT PP, no relative constraints) and externally with a near real-time solution computed by GFZ (GFZ NRT) and a post-processed solution of the IGS (IGS PPP).

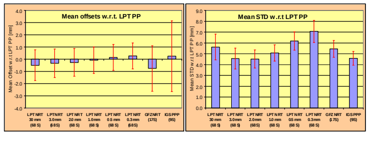


Shown in the plots are the estimated ZTDs, their formal errors (RMS ZTD) and the difference to the post-processed swisstopo solution. Applying only weak constraints (30 mm) leads to larger differences with respect to the other solution types. These peaks often occur at epochs where the corresponding formal errors are weak and coincide with the repeating GPS satellite constellation. Applying stronger relative constraints leads to formal errors with smaller variations and reduced outliers compared to the post-processed solution.

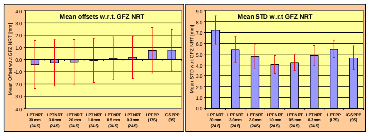


The comparison of the post-processed solution and two NRT solutions with GFZ (sampling 30 min) and IGS PPP (sampling 5 min) show improved coincidence when applying stronger relative constraints for site ZIMM (compared at the full hour).

In general one may state, however, that applying relative constraints which are too tight causes a smoothing of the observed signal which is too strong with regard to the real troposphere behaviour and leads to a time delay in the observed signal. An optimal compromise has to be found.



For all solutions a mean offset and a mean standard deviation with respect to the post-processed swisstopo solution (which is calculated without relative constraints) are plotted. Whereas the mean offsets are small for all test solutions (below 0.5 mm), the lowest standard deviations (4-5 mm) are found for the solutions computed with relative constraints of about 2 mm. The agreement with the external IGS and GFZ solutions is at a very similar level.



When comparing the test solutions to a near real-time solution from GFZ, the mean offsets are negligible for all NRT test solutions and the lowest standard deviation is found for the NRT solution constrained with 1 mm leading to the assumption that GFZ also uses a relative weighting scheme.

Conclusions

- The software change from Bernese V4.2 to V5.0 was successfully implemented together with several other model changes resulting in 2-3 mm "dryer" ZTD estimates.
- Ambiguity resolution in NRT is essential. Formal rms estimates are 2.5 times smaller and the agreement with post-processing is 1.5 times better (5.0 instead 7.8 mm std). Astonishingly, ambiguity free results are about 2 mm "dryer" compared to ambiguity fixed results.
- Enlarging the processed network gives results which are closer to CODE's Europe solution. The internal consistency between the near real-time and the post-processed solution does not significantly improve.
- swisstopo solution NRT+0 is a factor of 1.5 better than NRT+60 in terms of formal rms and in terms of comparison with post-processing due to the benefit from one additional hour of GPS observation data, but is one hour delayed.
- The relative constraining reduces peaks in the observed ZTDs at epochs with a weak satellite geometry. For future swisstopo solutions, an optimal relative constraining of 1 mm (for NRT solutions) and 3 mm (for post-processed solutions) was identified.

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