GPS Meteorology in the Swiss Alps: Interpolation Accuracy for different Alpine Areas and Near Real-time Results

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Abstract

The Swiss Federal Office of Topography (swisstopo) has been building up and operating an automated GPS network for Switzerland (AGNES) since 1998. The final expansion of 29 permanently operating GPS tracking stations was reached at the end of 2001. Since 1997 the data are analyzed in a post-processing mode, and since the end of 2001 a near real-time processing is established.

The station density is an important factor for deriving a precise 4-dimensional field of zenith total delays (ZTD). Using the post-processed zenith total delays of the years 2000 and 2001, we investigate how well we can interpolate the field as a function of the region, the station density, the station heights and the actual weather condition. Validations of the zenith path delay field derived from the AGNES network are also realized using data of local GPS campaigns and using meteo data of the Swiss Meteo network ANETZ.

Fig. 1: The AGNES network of permanent sites and the EUREF sites used within the hourly data processing at swisstopo

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2 Processing in near real-time

Since December 2001, swisstopo contributes hourly zenith total delay estimates to the COST-716 project.

Figure 1 shows the stations used for the hourly data processing. In addition to the AGNES stations, the data of 20 EUREF stations are used in order to allow a comparison of the estimates between different processing centers and in order to achieve better results when using an enlarged station network.

The time schedule of the hourly data processing is given in Figure 2. Our deadline for finishing the data processing is set to hh:45 minutes (hh hour). Approximately half of the time (25 minutes) is used for the data downloading of the EUREF sites. The time used for downloading the AGNES sites and the IGS ultra rapid orbits is negligible. The processing time is approximately 12 minutes (40 sites, Dell PC operated under Linux). About 95% of all possible submissions in the time interval Dec. 2001 - Jan. 2002 were successfully sent in the COST format to UKMO (UK Met-office) within the given deadline.

The GPS data are checked for outliers in the observations and for degraded orbit quality by a scheme based on residual screening. Maximally 2 satellites may be removed in case of a bad orbit quality.

The final product (zenith total delay values in the COST format) is presently checked on the basis of formal rms values from the adjustment process, only.

Figure 3 gives an example of the estimates for station Zimmerwald (ZIMM) derived from 3 different analysis centers.

3 Zenith Total Delay Interpolation

3.1 Motivation

The dense station network of AGNES (approximately 50 km station density) is a pre-requisite for modeling the complex weather situation in the Swiss Alps. The uncertainty of the zenith total delays propagate an uncertainty in the station heights. This fact is therefore also relevant for the positioning aspects of AGNES.

Using the post-processed zenith total delays of the year 2001, we examine how well we can interpolate the field of zenith total delay estimates with a simple collocation.

3.2 Interpolation

Using the collocation method, an interpolated value can be computed for each hour for each AGNES station from the nearest 6 sites (excluding the zenith path delay estimates of that site from the interpolation). For the interpolation no information of ZTD values before or after this hour is used. Fig. 4 shows the difference between the interpolated values and the estimates for a number of AGNES sites (10 days in June 2001). Figure 5 shows the same information for a single site (ETHZ) for the entire time interval of 2001.

It can be seen clearly that the interpolation quality depends on the time interval (generally worse in summer than in winter) and also on the individual site.
Fig. 4: Comparison of interpolated ZTDs and estimated ZTDs for 14 AGNES stations (May, 29 - June, 9 2001).

Fig. 5: Differences of interpolated ZTDs and estimated ZTDs for AGNES site ETHZ (2001). The standard deviation of the agreement is 5.0 mm (5570 differences).

Fig. 6: Standard deviation of the differences (data of 2001 using 14 AGNES sites) between interpolated and estimated ZTD values as a function of the mean distance to the next 6 sites.

Figure 6 shows the standard deviation of the differences between interpolated and estimated ZTD values as a function of the mean distance to the next 6 sites. The standard deviation is usually below 15 mm ZTD for mean distances to the next sites less than 80 km. It has to be mentioned that the two "outliers" with values larger than 25 mm are associated with the sites Andermatt (ANDE) and Locarno (LOMO). Both sites are located at a height approximately 1000 m different from the average height of the neighboring sites.

A plot for Andermatt (ANDE) containing the same information as Figure 5 is given in Figure 7. The drastic improvement at the end of 2001 is due to the fact that 5 additional sites were installed in Dec. 2001 which significantly reduces the interpolation distance. Another positive influence is the winter, because interpolations are much more easier than in summer.

Fig. 7: Differences of interpolated ZTDs and estimated ZTDs for AGNES site ANDE (2001). The standard deviation of the agreement is 27.0 mm (5480 differences).

3.3 Validation using a local GPS campaign

The interpolation method was applied to a local GPS campaign which was measured in August 2000 in an alpine area of the southeastern part of Switzerland (Graubünden - Tessin 2000: GRTI00).

Furthermore we used the meteorological data of the ANETZ stations operated by MeteoSwiss and data of a subset of the European radiosonde network to derive a ZTD model for this area for the requested time interval [Troller et al., 2002].

Other ZTD values are derived from the post-processed AGNES sites (AGNES) and from the post-processed local GPS campaign (GRTI00). Alternatively, ZTD values were estimated from the local campaign (some AGNES sites are included) by using the ZTD estimates of the AGNES sites as a-priori information (solution is called AGNES, too).

The ZTD estimates from IGS and MAGIC (both derived from GPS data analyses) are also available for comparison (station Zimmerwald, only).
Tab. 1: Comparisons (offset, rms and standard deviation) for 4 different stations and several different ZTD data series

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<th>Station</th>
<th>[mm]</th>
<th># values:</th>
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<td></td>
<td>offset</td>
<td>rms</td>
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<td>24.3</td>
<td>27.4</td>
</tr>
<tr>
<td>ZTD Interp. 1</td>
<td>-2.2</td>
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</tr>
<tr>
<td>ZTD Interp. 2</td>
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<tr>
<td>AGNES</td>
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<td>MAGIC</td>
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We used the interpolation presented in the previous section (called Interp. 2) and as an alternative a much smoother interpolation because ZTD values 6 hours before and after the requested time were used as additional information (Interp. 1).

Table 1 shows a comparison (offset, rms and standard deviation) of all the different ZTD data sets. The mean value of all available data sets (per epoch) is used as the reference.

For all "GPS ZTD series" (GRTI00, AGNES, MAGIC, IGS) and the interpolations from GPS (Interp. 1 and 2) the offsets are usually below 10 mm ZTD. The offsets are larger if meteorological information (COMEDIE model) is used. In terms of standard deviation the ZTD interpolations are of a good quality (below 8 mm ZTD), even better than the ZTD estimates from the local GPS campaign GRTI00, where a small spatial extension of the network weakens the ZTD estimation.

4 Conclusions

swisstopo operates quite a dense GPS network from which ZTD values are being submitted to COST-716 since the end of Dec. 2001 in near real-time.

An analysis of post-processed ZTD values in 2000 and 2001 and an attempt to interpolate ZTD values from neighboring sites shows that the interpolation accuracy is mainly a function of the distance to the next sites. With the completion of the AGNES network to 29 sites at the end of 2001 a homogenous station distribution allows an interpolation accuracy of approximately 8 mm ZTD (standard deviation) for all regions in Switzerland. In summer and in times of rapid weather changes this accuracy might be exceeded.

We are very optimistic that the present station density will allow a ZTD interpolation with sufficient accuracy for positioning applications and also for numerical weather prediction.

For positioning applications we need precise ZTD values in order to guarantee good station heights (8 mm ZTD correspond to about 25 mm station height). This should also be possible in real-time.

For numerical weather prediction applications we showed that especially in summer we have situations which cannot be handled by the interpolations. Mainly for these cases the dense GPS network can provide important information for the numerical weather prediction.

References


