Estimating Zenith Total Delay Residual Fields by using Ground-Based GPS network

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Presented at EUREF Symposium 2010 Gävle, 02-05.06.2010

Abstract

Tropospheric refraction is one of the major error sources in GNSS positioning. The delay of radio signals caused by the troposphere ranges from 2m at the zenith to 20m at lower elevation angles. Climatological models can help to correct these delays, but they are limited in accuracy and spatial resolution resulting in up to a few decimetres error in positioning solutions. In this paper we present a method for estimating Zenith Total Delay (ZTD) residual fields interpolating the residuals between GPS-derived and model-computed ZTDs.

1 Introduction

The present availability of dense ground-based GPS networks delivering ZTD estimates in Real and in Near-Real-Time allow to generate ZTD residual fields which can be continuously updated as soon as fresh ZTD estimates are available.
Atmospheric effects are no more negligible in accurate geolocation (at 1-m level) of the products generated by the most advanced Synthetic Aperture Radar (SAR) satellite missions, as the recent Italian Cosmo-SKYMed and German Terrasar-X. At those frequencies (~10GHz) the SAR ray path is delayed mostly by the troposphere, being a non-dispersive medium at the microwave frequencies and thus directly related to the ZTD that can be modeled or estimated by the GNSS measurements. Even if a routinely correction on a global scale of the SAR images can be more easily implemented by means of a tropospheric model, specific and refined applications for a given area may profit from the experimental GNSS ZTD residual fields, especially in area where a dense GNSS network is available.
Furthermore ZTD residual fields may also serve to derive tropospheric correction, to be removed from the GNSS signal, at the desired user location for positioning services.
The availability of reliable ZTD residual fields in the area of the occultation location let us to use the ZTD as additional data in the lower troposphere, being it the integral of the refractivity from the ground GNSS antenna to a certain atmospheric height, and to set-up a retrieval system based only on GNSS.
We present a method for estimating ZTD residual fields interpolating, trough Ordinary Kriging, the residuals between GPS-derived and model-computed ZTD.

2 Tropospheric models

To generate ZTD residual fields, we need ZTD residuals between GPS-derived and model-computed ZTD of a continuously operating ground-based GPS network. From these pointwise residuals, ZTD residual fields at mean sea level are generated over the network coverage through Ordinary Kriging interpolation. To select the tropospheric model, we compare model-computed ZTD values obtained from the UNB3m [2] and GPT&SAASTAMOINEN [1] models. They both model the hydrostatic and wet part of the delay.
The UNB3m computes the hydrostatic and wet zenith delays according to the Saastamoinen model and a prediction of the meteorological parameters based on a look-up table with annual mean and amplitude for temperature, pressure and relative humidity. These parameters are computed for a particular latitude and day of the year using a

cosine function for the annual variation and a linear interpolation for latitude.
In GPT&SAASTAMOINEN the hydrostatic and wet zenith delays are modelled according to the Saastamoinen equations using pressure and temperature values derived from Global Pressure and Temperature (GPT) model. GPT is based on a spherical harmonic expansion of degree and order nine of pressure, temperature and humidity derived from three years of ECMWF (European Centre for Medium—Range Weather Forecasts) data.

To choose the tropospheric model, we consider 3 sites at 3 different latitudes: MILO (Sicily Island, Italy/South Europe), ZIMM (Switzerland, Central Europe), ONSA (Sweden, North Europe) [Figure 1].

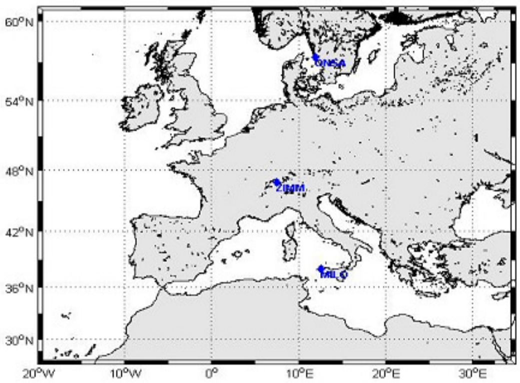

Figure 1 ONSA, ZIMM and MILO geographical location.

For each site we compare ZTD values computed using UNB3m and GPT&SAASTAMOINEN against GPS-derived and Radiosonde-derived ZTD values (for ONSA radiosonde data are not available) over the whole 2009 [Figure 2].

We notice that both model-computed ZTD follow the seasonal cycle of the atmosphere, with UNB3m ZTD closer than GPT&SAASTAMOINEN to GPS and Radiosonde-derived ZTD during the spring-autumn period. This is true especially at ZIMM and ONSA sites. On the base of these results, which need however to be investigated further, we choose to model ZTD using UNB3m.

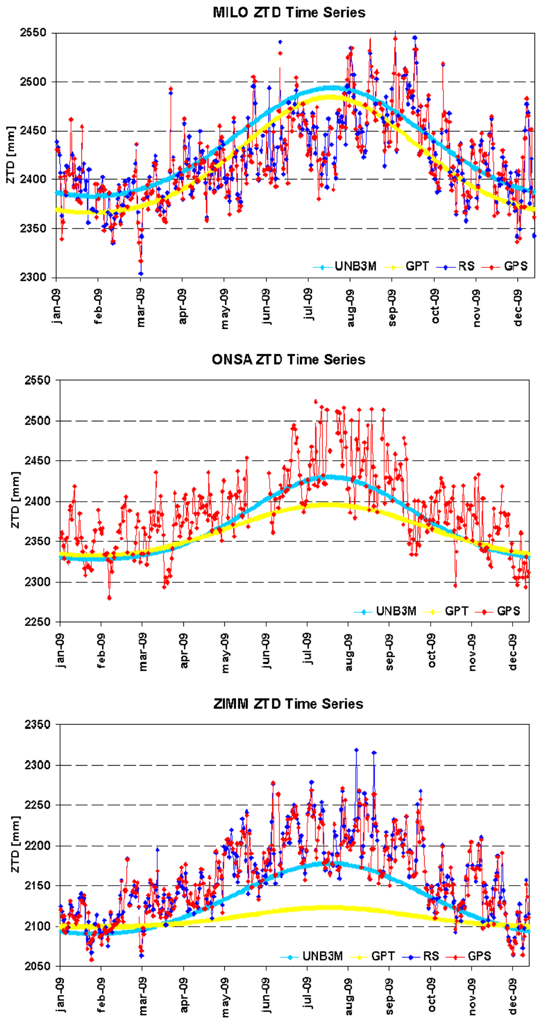

Figure 2 MILO, ONSA and ZIMM ZTD time series computed using UNB3m and GPT&SAASTAMOINEN against GPS-derived and Radiosonde-derived ZTD values over the whole 2009.

3 From pointwise ZTD estimates to ZTD residual fields

The ZTD estimates derived from GPS measurements are considered as "true delays", while the differences between model computed and GPS-derived ZTD estimates are defined as "ZTD residuals".

To obtain ZTD residuals at mean sea level, we need estimated and modelled ZTD values. Following UNB3m and its look-up table, barometric pressure (P), temperature (T), relative humidity (RH), temperature lapse rate (β) and water vapour pressure height factor (λ) are determinated for a given latitude and day of the year.

Zenith Hydrostatic (ZHD) and Wet (ZWD) delays are computed according to the following equations:

$$\mathrm{ZHD}_{\mathrm{MOD,\ MSL}} = \frac{10^{-6} k_1 R}{\mathrm{g_m}} P_0 \left(1 - \frac{\beta H}{T_0}\right)^{\frac{g}{R\beta}}$$

$$\mathrm{ZWD}_{\mathrm{MOD,\ MSL}} = \frac{10^{-6}(T_{m0} k_2' + k_3) R}{\mathrm{g_m}\lambda' - \beta R} \frac{\mathrm{e}_0}{T_0} \left(1 - \frac{\beta H}{T_0}\right)^{\frac{\lambda g}{R\beta}-1}$$

where 'MOD' stands for 'modelled', e_0 (water vapour pressure) is carried out following the IERS conventions (2003) [3], H is the orthometric height in m, R is the gas constant for dry air, $\mathrm{g_m}$ is the acceleration of gravity at the atmospheric column centroid, g is the surface acceleration of gravity, $\lambda' = \lambda + 1$, and k_1, k_2' and k_3 are refractivity constant.

ZTD residuals are obtained by subtracting GPS-derived from model-computed ZTDs:

$$\mathrm{RES}_{\mathrm{MSL}} = \mathrm{ZTD}_{\mathrm{GPS}} - \mathrm{ZTD}_{\mathrm{MOD,\ MSL}}$$

Then residual grid (0.5°x0.5°) at mean sea level are obtained using Ordinary Kriging interpolation. From this, to get the residual at a given location, a bi-linear interpolation is performed with the four nearest points surrounding it:

$$\mathrm{RES} = \sum_{i=1}^{4} \omega_i RES_i$$

with the general weight function:

$$\omega(x, y) = x^2 y^2 (9 - 6x - 6y + 4xy)$$

for $0 \le x \le 1$, $0 \le y \le 1$ [4]. The x and y parameters are calculated from:

$$x = \frac{\Delta\lambda}{\text{longitude grid interval}}$$

$$y = \frac{\Delta\varphi}{\text{latitude grid interval}}$$

4 Experimental data

We test our procedure over 1 week (from 10MAR14 to 10MAR20) of ZTD estimates coming from 130 European GPS stations [Figure 3] mostly belonging to the EPN Network.

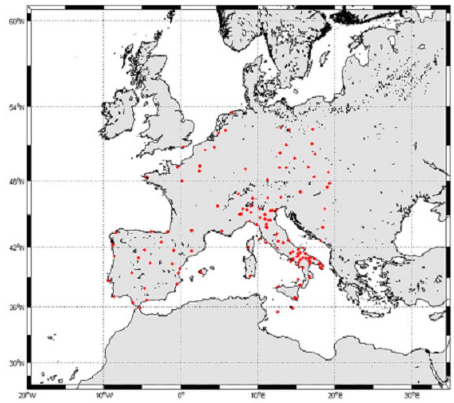

Figure 3 GPS ground-based network

GPS data are analyzed on daily basis with the Precise Point Positioning approach [5] using GIPSY OASIS II for data reduction and fixing JPL fiducial-free products. A sampling rate of 5 minutes and a cut-off angle of 10° are applied. ZHD is modelled as an exponential functions of the altitude. ZWD is estimated every 5 minutes with a stochastic model (random walk) and a constraint of 20 mm/($\sqrt{h}$)). The Niell dry and wet mapping functions and the ocean loading corrections (FES2004) are applied together with the information on the absolute antenna phase centre variation provided by IGS.

Following the method described in the previous section, ZTD residual fields are generated at mean sea level [Figure 4].

The residual fields are of the order of 50-100mm, reaching a peak of 150mm in area characterized by complex orography. The related error field indicates that the error is higher over seas (where no GPS site is available) or in inland area where the GPS network is less dense.

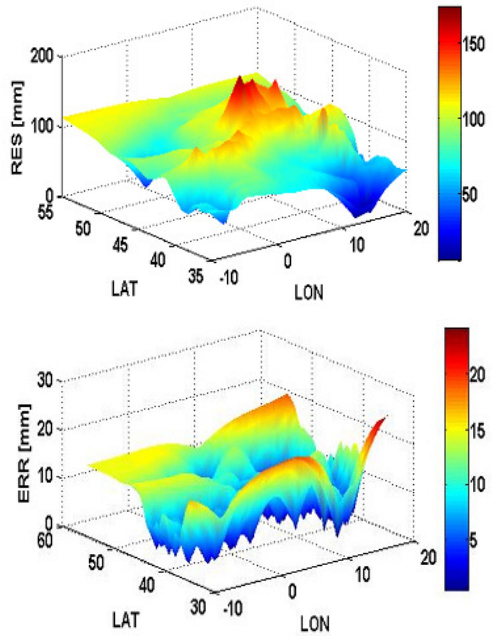

Figure 4 Residuals field (top) and errors field (bottom).

5 ZTD residual field validation

At known GPS sites, we obtain ZTD values (hereafter "Gridded") by the sum of the gridded-ZTD residual and the modelled-ZTD values .
We compare Gridded against GPS-derived ZTDs and Site Specific ZTD values (VMF1_Site) [Figure 5].
Site Specific ZTD values are those computed by the University of Technology of Vienna from ECMWF data and are available every 6 hours (http://ggosatm.hg.tuwien.ac.at/DELAY/readme.html).
The overall mean and std in the comparison "GPS vs Gridded" are -1.1mm and 2.8mm with a correlation coefficient equal to 0.99; while in the comparison "GPS vs VMF1_Site" they are -2.3 mm, 8.1mm respectively with a correlation coefficient equal to 0.93 [see Figure 6]. The agreement of "GPS vs Gridded" is better than "GPS vs VMF1_Site"_and it is partly to be expected since GPS-derived ZTDs are the input data for computing the ZTD fields.

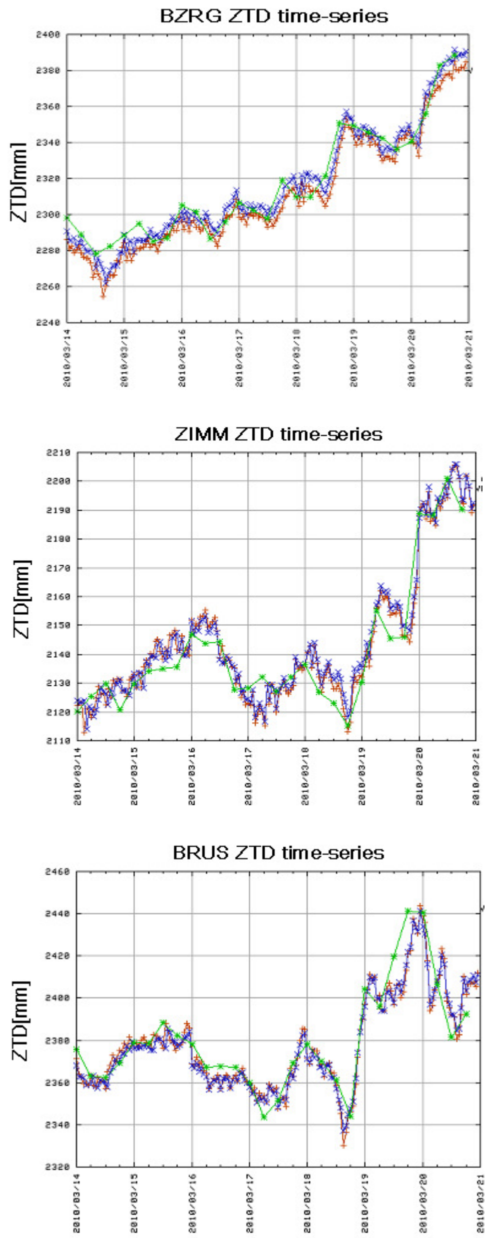

Figure 5 ZTD time-series: in red GPS-derived, in blue Gridded, in green VMF1_Site.

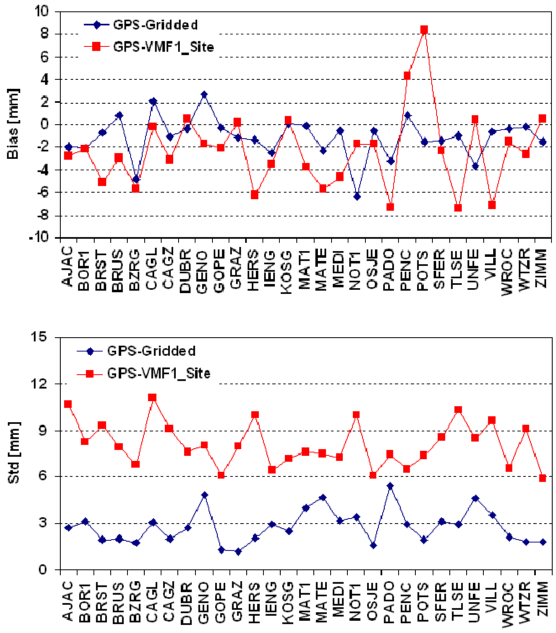

Figure 6 Bias (top) and std (bottom) of the difference between GPS-derived and Gridded ZTD (in blue) and GPS-derived and VMF1_Site ZTD (in red).

6 Summary

We present a method for estimating ZTD residual fields by using ground-based GPS network and we foresee some fields of applications. Further work is needed for tuning the procedure and improving the field reliability. More sites will be included to the GPS network in order to have a denser and more homogenous coverage. The validation activities will continue by considering a longer time series and other ZTD fields as those provided by the University of Technology of Vienna
We will improve the ZTD residuals computation by considering the tropospheric gradients.

References

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