1 Introduction

Regional GNSS reference networks allow to obtain accurate tropospheric information for a multitude of applications like climate studies, weather forecast or precise positioning. We are focused on the latter and present a method which allows to reduce the tropospheric residual error for precise positioning. Especially users operating tropospheric models in so-called „blind mode“, i.e. without input about the actual state of the atmosphere, will benefit.

2 From where do we get Slant Wet Delays?

GNSS Water vapour tomography makes use of the humidity information contained in the slant delay data and reconstructs the spatial distribution of the humidity in the troposphere. Different methods are available deriving slant wet delays, the most promising are using:

1. Meteorological data from Numerical Weather Models (e.g. ECMWF data)
2. GNSS observations processed in double difference of single point positioning mode

The dashed blue line in Figure 2 represents, exemplarily for IGS station ORAZ, the zenith wet delays (ZWD) determined every six hours by numerical integration through temperature and water vapour pressure data from ECMWF. The solid green line represents the hourly ZWD, estimated with a formal error centered around 0.6 mm from GNSS data and pressure data from a meteorological station nearby. The solid red line shows the difference between both time series. The uncertainty of SWDs derived from ECMWF analysis is on centimetre level in the zenith and on a sub-decimetre level for an elevation angle of 5°.

In order to get slant wet delays the zenith delay has to be mapped to certain elevation angles. Therefore different mapping functions like NMF, GMF, IMF or VMF1 are available. The impact of the mapping function on the estimated STD is approx. 1-2 mm (see IERS Annual Report 2010) for a GNSS receiver in Austria. VMF1 is the mapping function which is currently providing the best accuracy. The GMF was used to estimate the ZWD in Figure 1 and is an „easiest to implement“ mapping function, consistency with the VMF1 [Boehm et al. 2006b].

3 GNSS reference network

The GNSS observations used in this study are provided by the Austrian reference network provider EPOS („Echtzeit Positionierung Austria“) which operates 38 nation-wide distributed GNSS reference sites, see Figure 3.

The distance between the GNSS stations is 50 km to 80 km and the height difference between lowest and highest station is approx. 2000 m. All antennas are absolutely calibrated and installed on stable sites in an environment with possible less multipath and less obstructions. All stations are equipped with two frequency GPS/GLONASS receivers; some of them are already prepared to track Galileo satellites. Two control facilities are operational to enable integrity, stability and high availability of the collected data. At the moment hourly data with 1-s temporal resolution are available. A switch to real-time is planned and a network densification with single frequency receivers is under examination.

4 Double difference residuals

The approach to obtain slant wet path delays from GNSS observations is described by the equation

\[
\text{SWD} = \frac{\Delta_{\text{swd}}}{\text{m}(\varepsilon)} + \frac{\Delta_{\text{swd}}}{\text{m}(\varepsilon)} - \text{ZHD} = \text{m}(\varepsilon) + \text{PZDR}
\]

where \(\Delta_{\text{swd}}\) is computed by the formula from Saastamoinen (1972), using pressure values derived from a standard atmosphere model. The correction term \(\Delta_{\text{swd}}\) is estimated in an adjustment process every 15 min. Both are mapped to zenith using the wet (\(m_{\text{w}}\)) and dry (\(m_{\text{d}}\)) GMF. To obtain only wet delays, the hydrostatic delay has to be subtracted. Therefore atmospheric pressure values \(p_0\) at the antenna reference point are extrapolated from mesosensors nearby. They are used in equation (2) to calculate the zenith hydrostatic delay. Afterwards the zenith wet delay is mapped to a certain elevation angle by the wet GMF to obtain isotropic SWD.

The azimuthal-anisotropic part of the slant wet delay is described by the term PZDR (Pseudo-Residuals). It can be recovered from Double Difference Residuals (DDR) if they are normally distributed („Zero Mean assumption“). This assumption was tested with real observation data and the result is shown in Figure 4; exemplarily for baseline Dalaas - Saalfelden.

\[
\text{PZDR} = \frac{(0.0022768 \pm 0.0000005)}{\text{m}(\varepsilon)} \cdot p_0
\]

On the left hand site L is the optical path length and \(n_\varepsilon\) shows the components of the ray directions. It allows to find the slant delay directly along the true path. Nafisi et al. (2011) have used this relation to develop the Vienna Raytracer (2D and 3D) and found a positive impact on repeatability of baseline lengths.

Due to high data transmission rates and high computational efforts it is challenging to operate a valid ray-tracing software at user site. One solution to overcome this problem is to run the ray-tracing software in the operating centre and to forward either tropospheric residuals or zenith tropospheric delays with consistent coefficients of a high quality mapping function to the user.

5 Accurate range corrections

Recovering 3D humidity models from GNSS derived slant wet path delays ends up in a profoundly ill-posed problem. Several research groups have developed tomography models to overcome this problem; using different reconstruction techniques, see Rohm et al. 2012. We are working on our own tomography model as well. The output is in all cases a voxel model of the wet refractivity \(n_\varepsilon\) above the area of GNSS reference stations, see Chapter 3. On the one hand this information could be implemented into NWM to improve the resolution of water vapour measurements and with it the prediction of different weather phenomena. On the other hand it would allow to derive accurate tropospheric range correction. Forwarded to the user in real-time these corrections would help to reduce the tropospheric residual error and to get a faster ambiguity solution.

To obtain range corrections from the spatial and temporal high resolution 3D humidity model, ray-tracing is applied. The principle of direct ray-tracing is shown in Figure 5. It is using the Eikonol equation, which can be expressed as

\[
\text{PZDR} = \frac{\text{m}(\varepsilon)}{\text{m}(\varepsilon)} \cdot \text{p}_0
\]

The residuals are almost normally distributed:

\[
\text{Mean} = 0, \text{Sigma} = 1
\]

The success of recovering PZDR from DDR depends mainly on the number of stations and size of the network.

References

- Rohm W, Geiger A, Bender M, Shangguan M, Brenot H, Manning T, Inter-comparison and cross-validation of tomography models - aims, scope and methods, Poster, IGS workshop Poland, 2012

"Accurate tropospheric range corrections from regional GNSS networks"
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" SESSION 4: ACCURATE TROPOSPHERIC RANGE CORRECTIONS FROM REGIONAL GNSS NETWORKS"