Slant Tropospheric Delays from GNSS observations - Precise Point Positioning vs. Double Difference Approach

Gregor Möller and Robert Weber

Technische Universität Wien, Department of Geodesy and Geoinformation (GEO)

e-mail: gregor.moeller@tuwien.ac.at

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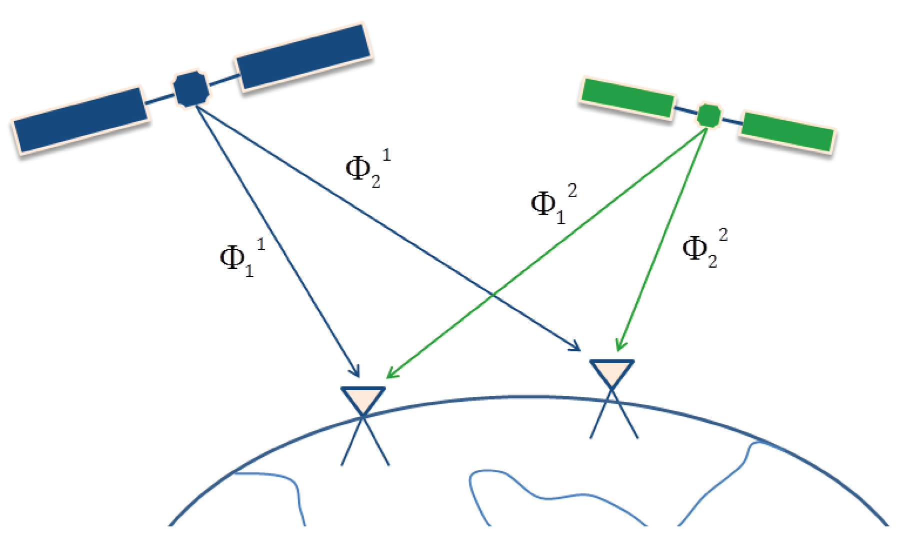
1 Processing strategy



The structure of the troposphere can be derived precisely from dual- or multi-frequency ground based GNSS observations. Therefore all other effects causing a delay on GNSS signals have to be known or estimated together with the tropospheric parameter in a least-squares adjustment.

$$\Phi_r{}^s + v_r{}^s = \rho_r{}^s + c\cdot(\Delta t_r - \Delta t^s) + STD^s - ION^s + MP_r + APC_r + \lambda\cdot N_r{}^s$$

The GNSS observations are either introduced undifferenced (PPP) or double differenced (DD). Latter combines 4 phase observations to one DD observation.

Double Differences (DD)

- \+ clock error is eliminated by differencing
- \+ integer character of the phase ambiguity remains
- \+ faster convergence time than PPP
- \- observation residuals remain differenced
- \- common tropospheric effects are cancelled out

Precise Point Positioning (PPP)

- \+ common tropospheric effects remain
- \+ allows single station / satellite processing
- \+ less affected by multipath / noise
- \- precise orbit and clock products required
- \- phase ambiguities usually not fixed

In order to study the ability to recover the structure of the troposphere GNSS observations were simulated (Chapter 2) and processed in PPP and DD approach to obtain Zenith Tropospheric delays (ZTD) every 30 min and N-E Gradients once per day. The remaining anisotropic part of the tropospheric delay is recovered from observation residuals (Chapter 3). The impact of the processing strategy on the STD estimation is validated by dSTD-plots (simulated minus estimated), see Chapter 4.

2 Simulated GNSS observations

Real GNSS observations are affected by many error sources like ionospheric refraction, multipath or observation noise. In order to study the impact of the processing strategy on the STD estimation process, a set of dual-frequency GPS observations was simulated for 12 stations in Austria. The settings are summarised in Table1.

Parameter	Setting
Observation period / rate	01.10.2013, 00:00 - 23:59:30 GPS time / 30 sec
Satellite position	IGS final orbits
Station coordinates	ITRF2008 coordinates, fixed
Satellite clock	IGS final clocks (high rate)
Earth Rotation Parameters	IGS final ERPs
Cut-off angle	0 degrees
Troposphere model	Saastamoinen + GPT + GMF + 4mm E-W gradients
Ionosphere model	none
Observation noise, Multipath	none

Table 1: Setting to simulate GPS observations using software package Bernese v5.2.

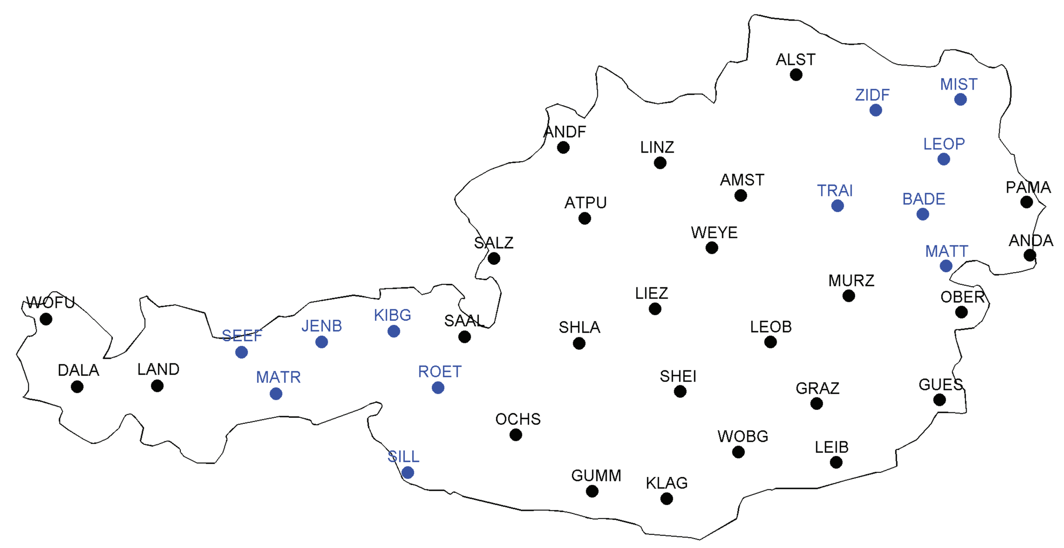


Figure 1: The 12 selected stations are highlighted in blue. The inter-station distance is about 40 km. The longest baseline (between KIBG and ZIDF) is 295 km. The station heights vary between 220 m in the rather flat east and 2200 m in the mountainous region of west Austria. The isotropic STD was added to all stations - the 4 mm E-W gradients just to the 6 stations in east Austria.

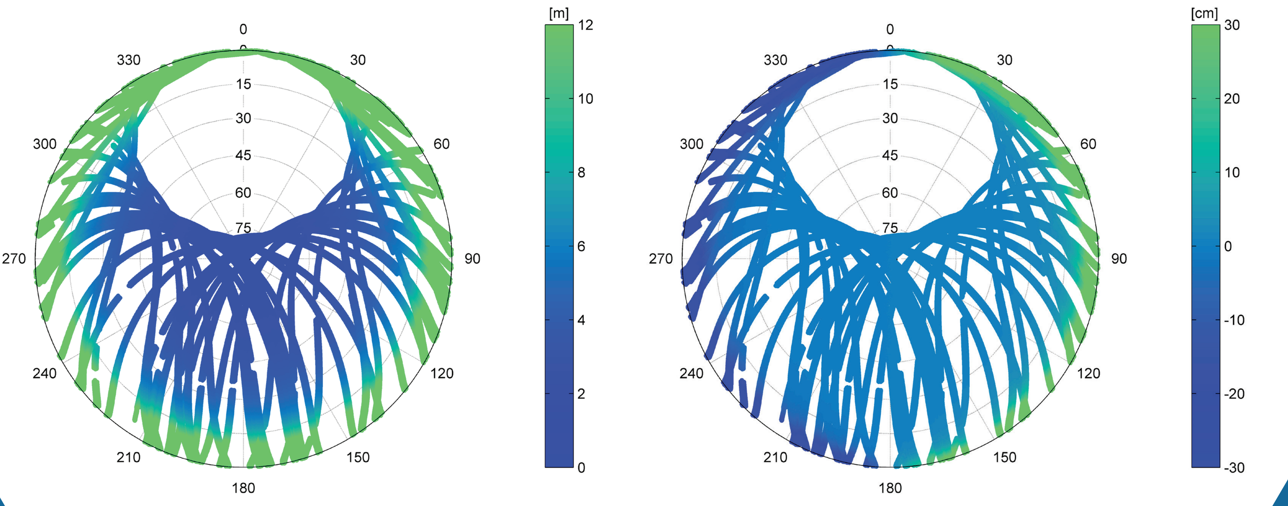
isotropic Slant Tropospheric Delays

$$STD(\varepsilon) = ZHD_{apr}\cdot mf_{dry}(\varepsilon) + ZWD_{est}\cdot mf_{wet}(\varepsilon) + ...$$

ZHD_{apr} ... a priori hydrostatic delay (GPT + Saastamoinen)

$mf_{dry}(\varepsilon), mf_{wet}(\varepsilon)$ ... dry / wet mapping function (GMF)

ZWD_{est} ... estimated wet delay



anisotropic part

$$+G_N\, \mathrm{m_{az}}(\varepsilon)\cos(az) + G_E\, \mathrm{m_{az}}(\varepsilon)\sin(az) + ZDR$$

G_N, G_E ... N-E gradient parameter

$\mathrm{m_{az}}(\varepsilon)$ ... gradient mapping function

ZDR ... Zero Difference Residuals

3 Observation residuals

The approach from Alber et al. (2000) was applied to recover Pseudo-Zero Difference Residuals (PZDR) from Double Difference Residuals (DDR). They are called „Pseudo" because constraints have to be applied in order to solve the equation system. Figure 2 shows that the reconstruction depends on the number of selected baselines. By taking just the eastern stations into account the PZDR getting smother but decreases significantly because common tropospheric effects were cancelled out by differencing and cannot be recovered anymore.

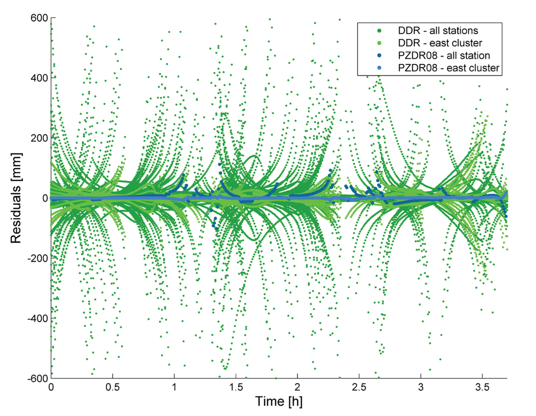


Figure 2: DDR and the recovered PZDR for PRN08 - based on different network sizes.

4 Results - STD estimation error

a) full recovered STD (ZTD + gradients + observation residual), elev: 0 °

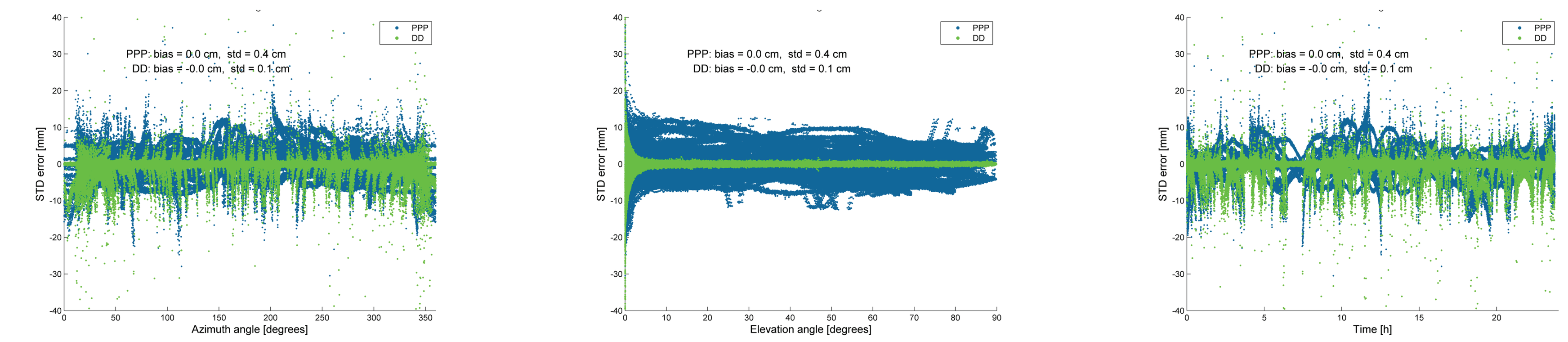


Figure 3: STD estimation error as function of azimuth (left), elevation angle (center) and time (right).

b) no gradients

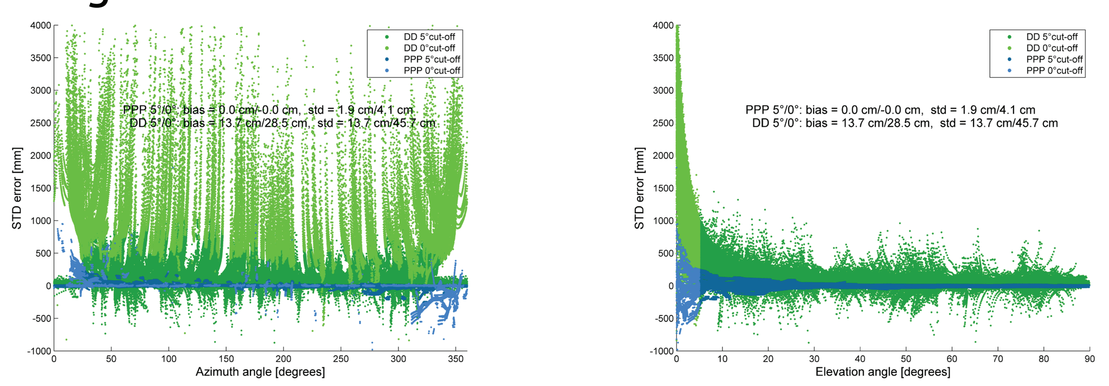


Figure 4: STD estimation error assuming no gradients. Observations at very low elevation angles (< 5°) are highlighted

c) no observation residuals

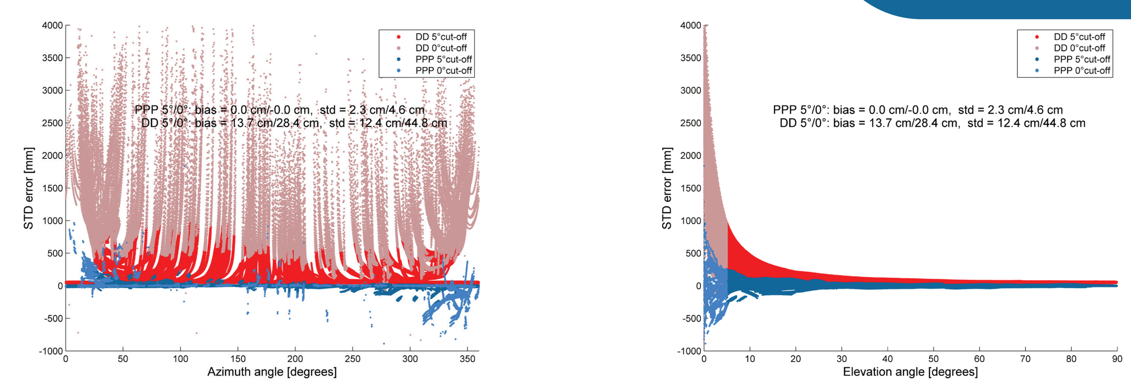


Figure 5: STD estimation error assuming no observation residuals. The anisotropic part is recovered better from the ZDR than from the PZDR.

d) orbit / clock products

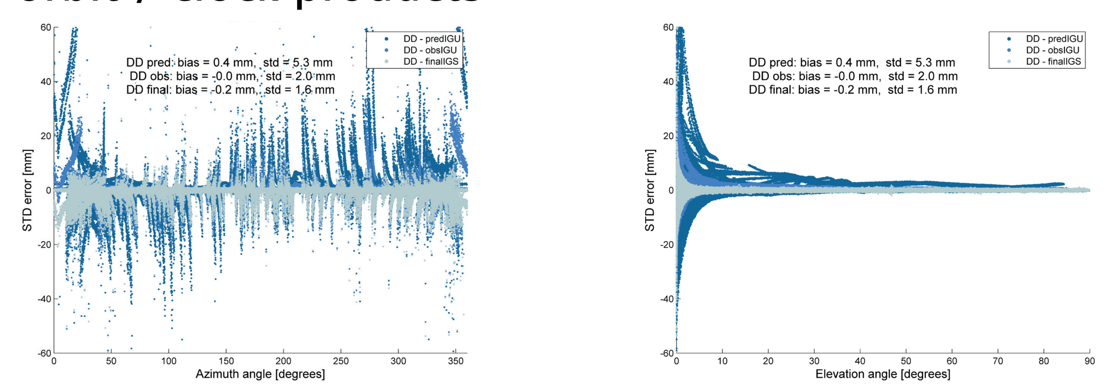


Figure 6: STD estimation error with the same settings as in a) but taking different orbit and clock products into account.

e) network size

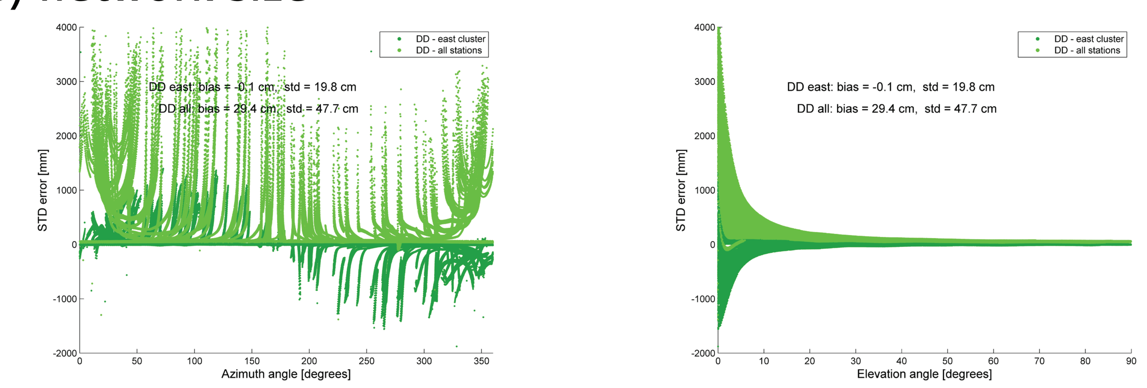


Figure 7: Impact of the network size on the double difference STD estimation error. The STD is estimated without bias only in the smaller network.

5 Conclusions

The impact of the processing strategy (PPP or DD approach) on the estimation of tropospheric products was analysed. The reconstruction of STD from DD observations should be favoured as long as the parameters ZTD and N-E gradients describe the integrated structure of the troposphere above the network quite well. In these cases the orbit and clock errors downgrades the PPP solution which makes the STD noisier. In all other cases, when the distribution of water vapour is more heterogeneous, PPP outperforms the DD approach - especially at lower elevation angles (< 20 °).

In addition the reconstruction of the anisotropic part from observation residuals has been studied. Taking ZDR into account helps to reduce the STD error, i.e. the anisotropic part can be recovered (at least to a certain extent) from ZDR. On the other hand the recovered PZDR (from DDR) degraded the results in every case.

References

Alber C., Ware R., Rocken C., Braun J., Obtaining single path phase delays from GPS double differences, Geophysical Research Letters, 27, pp 2661-2664, 2000

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