Biases in the estimated ZTD related to elevation cutoff angle

How to find the optimal minimum elevation angle for climate studies, when it's affect differently the ZTDs at different stations?

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Introduction

For the GPS observations it is well-known that observations at very low (less than 5°) elevation angles are more erroneous due to the signal propagation effects (e.g., atmospheric delay, multipath or antenna phase centre variations) than those at high elevation angles. On the other hand, Davis et al. [1986] showed that higher cutoff elevation angles result in greater uncertainty in estimated height and higher correlation between estimated height and zenith tropospheric delay (ZTD). Consequently, for many years scientists were forced to reduce modeling errors at low elevation angles to break this correlation and decrease the uncertainty of the estimated parameters. Progress in this field led to the situation nowadays where low elevation angles are used in routine analysis. However, Espe ronde et al. [2013] showed for climatological GPS observations that at nadir (i.e.) 2.5° gives better compatibility with the radiosondes data.

Method

To better understand how exactly the adopted cutoff angle affects the estimated tropospheric delay, we computed ZTD annual time series for the year 2013 for 45 EPN stations using different cutoff elevation angles: from 0° to 40°; every 5°. Except this, all the rest parameters of GPS data processing remained unchanged and were identical to our contribution to EPN rep03. ZTD time series obtained from solutions with different elevation mask angles (EMAs) were taken as reference. Next, the remaining eight ZTD datasets were compared to it.

Software:
- GAMIT 10.50
- Period: 01.01.2015-31.12.2015 (1 year)
- Observations:
  - GPS, 30 sec.
- Elevation mask:
  - 0°, 5°, 10°, 15°, 20°, 25°, 30°, 35°, 40°
- Orbits:
  - CODE
- Antennas:
  - type mean (lg08_1800_ab) + (EPN)
- Troposphere:
  - VFM1, ZTD(3h) + q20 (24h)
- Ionosphere:
  - IONFREE + HCl (CODE VTEC + IGRF11)
- EOP:
  - IERS2010
- Tides:
  - IERS2010
- Loadings:
  - ocean (FES2004), atmosphere (INCEP + ECMWF)
- Reference frame:
  - IGG08

Results

No doubt a minimum elevation angle affected the estimated ZTDs as well as their formal error. In general, the higher minimum elevation angle the higher formal error. However, formal error is not the best factor of reliability of the estimated ZTD. In general, it grows together with the decreasing number of observations and it can be helpful to evaluate the quality of estimated ZTD in the same solution (not to compare them).

![Fig. 1](image1.png)

What is worth noting, changes between solutions in the estimated ZTD are high correlated (negative correlation) with the changes in the estimated height. Fig. 2, Fig. 3. It probably means that changes in the estimated height are somehow compensated by the ZTD estimates. It can be assumed that ZTD time series derived from solutions for which higher elevation mask was applied are flawed by the higher uncertainty in the estimated height.

![Fig. 2](image2.png)

Changes in ZTD, resulted from increasing the cutoff angle, are different for individual stations (Fig. 2). In some cases, it causes large and systematical differences (e.g. KOR), after the seasonal (semiannual) oscillations (e.g. CASC, SFER) or even linear trends (e.g. BRUX). Almost no correlation between ZTD and elevation angle of the stations show that there are not altitude dependent effects. At least 5° is not the key factor. The reason must lie elsewhere and it is more locally. Three cases of close stations (KOR/KU, POZ/POF, ZIM3/ZIM4) - Fig. 4 show that beside site-dependent biases (related to the wind condition or direct impact of the observation geometry, that in general are identical in the same site), there appear also station-dependent biases (related to the specific signal propagation at each station).

![Fig. 3](image3.png)

To investigate how the signal propagation is "mismodelled" we analysed the post-fit phases residuals (Fig. 6). All effects related to the signal scattering, like antenna phase centre modelling, multipath effect or atmospheric delay should be reflected in this. What is shown with others (e.g. Espéronde et al. [2019]), the tropospheric changes are in general dependent on the changes in ZTD when one increases the minimum elevation angle of observation. This kind of propagation effect is usually visible in tomographic solutions below 20° elevation angle and should be resolved from other effects (day e.g. KOR/KU, KOR/POZ, POF/FU). For selected stations, when mainly this phenomenon is visible, the bias in height and ZTD for solution 10° are obtained clearly. However, the highest biases appeared together with the highest fit residuals in the whole range (MARS - inappropriate antenna model) or in high elevation angle (CSMT). As it was noticed also for few Nordic stations, higher biases (together with the higher post-fit residuals) appear also during winter (VAAS - Fig. 7).

![Fig. 4](image4.png)

Summary

Switching elevation mask from 0° to 40° cause changes in estimated value of ZTD. These changes were, however, various for various stations and there were no significant altitude dependency between them. For some of stations, applying higher cutoff angle elevation caused increasing of ZTD value and for the others it caused decreasing. Despite the character of these biases (positive or negative), they appeared together with changes in estimated Height. Negative correlation proves that these biases are of rather artificial effects related to increasing uncertainty of estimated Height than real improvements. Additionally, performed analysis of between stations showed that despite local weather conditions and related to them atmosphere modelling, also other factors have to be taken into account or estimated biases

![Fig. 5](image5.png)

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