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Tropospheric Zenith Path Delays Derived from GPS Used for the Determination of VLBI Station Heights

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Abstract

The variable tropospheric refraction is a major error source for the estimation of geodetic parameters by GPS and VLBI. As both techniques use microwave signals, tropospheric zenith delays derived by GPS are comparable to those obtained by VLBI. In the investigation presented here, zenith delays which were provided by the IGS (International GPS Service) at 2h time intervals were entered and constrained in the VLBI analyses. This procedure avoids the correlation between station height parameters and zenith delay parameters and reduces the number of unknowns in the VLBI least-squares fits. The formal errors and repeatabilities of several VLBI station heights were compared with results of standard VLBI analyses where no external information about the troposphere had been used. About 100 VLBI NEOS-A experiments in 1999 and 2000 were analyzed. The results show that the repeatability of VLBI station heights has significantly improved (up to 40%) when constraining the GPS zenith delays.

1. Introduction

Modeling the tropospheric refraction in VLBI and GPS is usually done by the equation

$$dL(e) = dL_h^z \cdot mf_h(e) + dL_w^z \cdot mf_w(e) \tag{1}$$

dL(e) is the total delay at a certain elevation e, dL_h^z and dL_w^z are the zenith path delays due to the hydrostatic and wet component of the troposphere, respectively, and mf_h and mf_w are the corresponding mapping functions. Correlation matrices of analyses of typical VLBI sessions show that station heights and zenith path delays are correlated by about -0.4. Equation 1 implies that station heights and zenith path delays can only be de-correlated if observations at low elevations are available. In terms of geometry, the determination of station heights is the better the lower elevation angles are used. On the other hand, the accuracy of the mapping function becomes worse for lower elevations. Based on these considerations, the introduction of independent information about the troposphere avoids the correlation between station heights and zenith path delays, and, as a result, the repeatability (scatter around the mean) of VLBI station heights is expected to improve if the external information is sufficiently good. In this project the official IGS (International GPS Service) total zenith path delays (Gendt, 1996 [2]) are introduced as external information into the VLBI analyses. They are provided in weekly files per station at 2h time intervals as a combined series of several solutions submitted by individual IGS Analysis Centers (AC). These ACs apply different analysis strategies (mapping functions, cutoff angles, ..). In most cases the ACs fix the station coordinates to the current ITRF, so that the IGS total zenith path delays are not directly affected by the correlation described above.

2. Constraining IGS Total Zenith Path Delays in the VLBI Solutions

About 100 VLBI NEOS-A experiments in 1999 and 2000 were analyzed. In a first step VLBI total zenith path delays were determined by the OCCAM 5.0 software package (Titov et al., 2001 [3]). All station coordinates were fixed to the ITRF2000. As can be seen from figures 1 and 2 top and centre plots, the VLBI and GPS total zenith path delays agree quite well except for an offset that is always negative over the two years (Boehm, 2002, this issue [1]). Thus, one mean offset per station between IGS and VLBI zenith path delays for the total time span (1999 and 2000) was calculated and removed from the IGS series. These corrected path delays, now also taking into account e.g. different estimation strategies or different heights of VLBI telescopes and GPS antennas, were entered and constrained in the VLBI analyses. One height parameter per station of the 24h session was estimated, all horizontal coordinates were fixed to the ITRF2000 and no tropospheric gradients were allowed. The cutoff angle was set to 10° elevation. The formal errors and repeatabilities of the station heights obtained by the approach described above were then compared to those obtained from standard VLBI analyses.

3. Results

A considerable improvement of up to 40% can be seen in the repeatability of the station heights of all VLBI stations (see figures 1 and 2, bottom plot, and tables 1 and 2, column 2). For example, the scatter of the individual height components around their mean at Fortaleza has decreased from ±1.88 cm to ±1.48 cm. There is also a significant decrease of the mean one-sigma formal errors of station heights when constraining external zenith delays from IGS (see tables 1 and 2, column 3). It can be explained by the fact that the correlation between zenith delay and station height parameters does not appear for this approach (because zenith delays are not estimated) and by the smaller number of unknowns in the least-squares fits. On the other hand, it is clear that the root-mean-square values of the residual delays get worse when constraining external information (see tables 1 and 2, column 4).

Table 1. Statistics for station Fortaleza, Brazil, without and with external tropospheric zenith delays from IGS for NEOS-A sessions in 1999 and 2000

Fortaleza	scatter around the mean station height [cm]	mean formal error of station heights [cm]	mean rms of fit [cm]
no external tropospheric zenith delays	1.88	1.43	1.61
with external tropospheric zenith delays	1.48	0.68	1.80

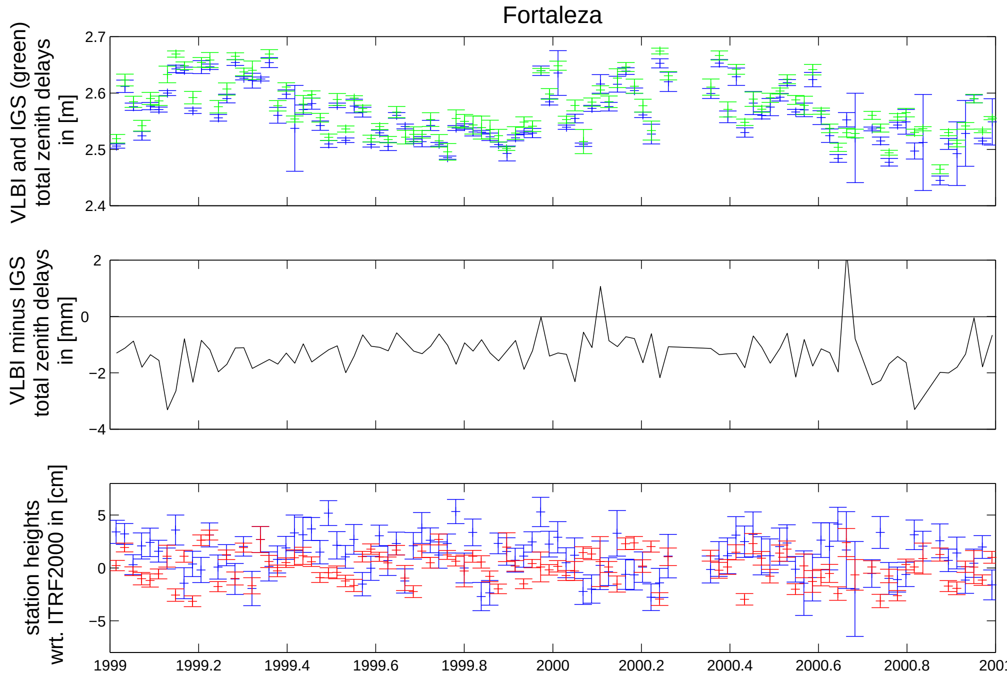

Figure 1. VLBI NEOS-A (blue) and IGS (green) total zenith path delays (top) and differences between the total zenith path delays (centre); station heights with (red) and without (blue) IGS zenith path delays at Fortaleza (bottom)

Table 2. Statistics for station Wettzell, Germany, without and with external information from IGS for NEOS-A sessions in 1999 and 2000

Wettzell	scatter around the mean station height [cm]	mean formal error of station heights [cm]	mean rms of fit [cm]
no external tropospheric zenith delays	1.07	0.93	1.61
with external tropospheric zenith delays	0.66	0.44	1.80

4. Conclusions and Outlook

Once again, the mutual benefits between the different space geodetic techniques could be demonstrated. Introducing GPS total zenith path delays into VLBI analyses improves the repeatability of station heights, because the correlation with zenith path delays is avoided. The offsets between GPS and VLBI total zenith path delays are still an open question (see also Boehm et al., 2002, this issue [1]). They could be due to the systematic influences on the GPS measurements, e.g. by multipath effects or by phase center variations, or due to different elevation cutoff

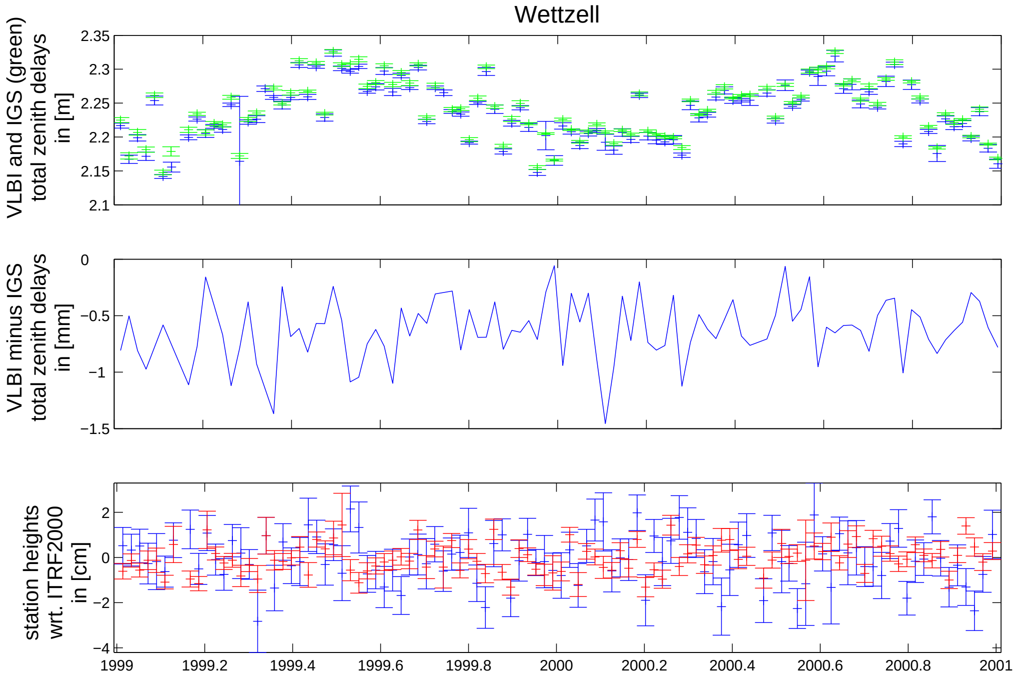

Figure 2. VLBI NEOS-A (blue) and IGS (green) total zenith path delays (top) and differences between the total zenith path delays (centre); station heights with (red) and without (blue) IGS zenith path delays at Wettzell (bottom)

angles. VLBI could support the investigation of these effects. Future investigations should deal with water vapour radiometer data and numerical weather models as means to complement VLBI and GPS analyses.

References

[1] Boehm, J., E. Messerer and H. Schuh, Comparison of tropospheric parameters submitted to the 2nd IVS Analysis Pilot Project, in: IVS 2002 General Meeting Proceedings, edited by N. R. Vandenberg and K. D. Baver, NASA/CP-2002-210002, 2002.

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[3] Titov, O., V. Tesmer and J. Boehm, OCCAM Version 5.0 software. User Guide. AUSLIG Technical Reports 7, AUSLIG, Canberra, 2001.