Six hourly time series of horizontal troposphere gradients in VLBI analysis

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1. Summary

Application of the new ray-tracer RADIATE allows for the **creation of ray-traced delays for all observations ever made in geodetic VLBI history**, that is, since 1979. Apart from that, ray-traced delays for uniform azimuth and elevation angles were created which could further be **used to determine horizontal troposphere gradients** for all VLBI stations on Earth. These gradients are used to describe azimuthal asymmetry of signals reaching an antenna. The temporal resolution was chosen in such a way as to be consistent with the NWM epochs, that is, at four epochs a day. Although it is common usage to estimate gradients in a least squares adjustment directly in the VLBI analysis, a priori gradients have a high potential to improve the accuracy of the results, especially for sessions with a comparatively low number of observations.

2. Theoretical background

Modeling tropospheric delays by simply multiplying zenith delays with a mapping function assumes no azimuthal variations in the delays (equation (1)).

$$\Delta L_0(e) = \Delta L_h^z * mf_h(e) + \Delta L_w^z * mf_w(e) \qquad (1)$$

However, signals reaching the antenna from different cardinal directions experience different delays. These variations consist of a systematic component due to the fact that the earth's atmosphere is thicker at the equator and thinner at the poles, and a random component resulting from varying weather conditions around the site. Therefore, a term describing this anisotropy must be added to equation (1).

In common practice, the azimuthally asymmetric part of a tropospheric delay is described on the basis of equation (2) as noted below (Chen and Herring, 1997), comprising of a north gradient G_n and an east gradient G_e multiplied by an elevation-dependent gradient mapping function mf_g.

$$\Delta L(a,e) = \Delta L_0(e) + mf_g(e)[G_n \cos(a) + G_e \sin(a)] \qquad (2)$$

$$\Delta L(a,e) = \Delta L_0(e) + mf_g(e)\left[G_n \cos(a) + G_e \sin(a) + G_{n_2} \cos(2a) + G_{e_2} \sin(2a)\right] \qquad (3)$$

a, e.............azimuth, elevation
ΔL(a,e).......total delay with gradients
$\Delta L_0(e)$........total delay without gradients

Furthermore, an extended gradient model suggested by Landskron et al. (2015a) is considered (equation (3)), which in addition to the standard gradient model contains two supplementary gradient variables G_{n_2} and G_{e_2}. Thus, in theory, the residuals between the modeled delays and the ray-traced delays decrease by 10% (Landskron et al., 2015b).

3. Determination and application of gradients

The horizontal tropospheric a priori gradients are determined in a least squares adjustment based on ray-tracing data carried out by the **ray-tracer RADIATE** (Hofmeister and Böhm, 2014) through **numerical weather models** (NWM) with a horizontal resolution of 1°x1° and 25 pressure levels. Ray-traced delays were produced at **8 constantly distributed azimuths (0°:45°:315°) and 4 elevations (3.3°, 5°, 15°, 30°)** for each VLBI station at **4 epochs per day**, namely 00h, 06h, 12h and 18h. These gradient values G_n, G_e, G_{n_2} and G_{e_2} are then saved in yearly text files which can soon be downloaded from http://ggosatm.hg.tuwien.ac.at/DELAY/. The desired gradient values for the exact times of the observations must be interpolated from the surrounding epochs, preferably by means of a Lagrange interpolation considering at least 4 epochs before and after.

3. Performance of a priori gradients

In the following, the performance of the newly determined a priori gradients is assessed using the **Vienna VLBI Software** (VieVS, Böhm et al. 2012). In a first run of the VLBI analysis, only the a priori gradients are applied (*case a*), while in a second run the gradients are additionally estimated in VLBI analysis using the standard gradient formula (*case b*). In order to draw conclusions about the performance of the gradient application, **baseline length repeatabilities (BLR)** are determined. BLR are absolute reference values that represent the standard deviations of a set of baseline lengths less a linear trend, which constitutes the horizontal motion of a site due to plate tectonics. The lower the BLR, the better.

For comparison, the horizontal troposphere gradients by Böhm and Schuh (2007) are tested as well, hereinafter referred to as LHG. Unlike the gradients presented in this poster, the LHG were not determined from ray-traced delays but directly from refractivity distributions in NWM.

For two time frames, the mean BLR over all measured baselines is calculated:

1. A combination of the three continuous VLBI campaigns CONT08, CONT11 and CONT14 (43 sessions)

a priori gradients	BLR [cm] a)	BLR [cm] b)
none	1.22	1.02
LHG	1.29	1.02
standard gradient model	1.13	1.02
extended gradient model	**1.13**	**1.01**

Tab. 1

The results correspond to those of Landskron et al. (2015a), namely that best performance is achieved with a priori gradients from the extended gradient model and that additional estimation of the gradients in VLBI analysis is imperative for attaining best performance.

2. All VLBI observations from 2006 through 2014 (1339 sessions, some individual sessions were excluded); baselines containing TIGOCONC and HARTRAO show extraordinarily high BLR, therefore baselines containing one of these two stations were excluded from the analysis:

a priori gradients	BLR [cm] a)	BLR [cm] b)
none	1.90	1.73
LHG	1.82	1.75
standard gradient model	1.74	1.73
extended gradient model	**1.74**	**1.73**

Tab. 2

Surprisingly and unlike the results from 1., there is hardly a difference whether a priori gradients are applied only or if the gradients are additionally estimated in VLBI analysis.

For this reason, it was tested how BLR alter when sessions with a very high number of observations are excluded; it is almost impossible to define a boundary value for the number of observations of a certain station during a session and even if, the user would have no chance to apply it. Therefore, simply all sessions whose NGS files are larger in data size than 3 MB (~4500-5000 observations) were excluded. The resulting BLR clearly state that for sessions with fewer observations, a priori gradients shall be applied solely:

a priori gradients	BLR [cm] a)	BLR [cm] b)
none	2.62	2.54
LHG	2.51	2.54
standard gradient model	2.45	2.53
extended gradient model	**2.43**	**2.52**

Tab. 3

5. Conclusions

- It is very important to consider azimuthal asymmetry in VLBI
- The **new a priori gradients yield considerable improvement** in BLR of up to 8%
- Application of a priori gradients only slightly improves the results in case the gradients are additionally estimated in VLBI
- Gradients calculated with the extended gradient model cause only a marginal improvement, however, this may be due to the fact that ray-tracing was carried out for 8 azimuths only
- For **sessions with a high number of measurements** (like CONT campaigns), additional **estimation of gradients in VLBI analysis is indispensable** in order to achieve best results
- For **sessions with a smaller number of observations**, however, best results are achieved when **applying only a priori gradients**

References:

Böhm J. and H. Schuh (2007): Troposphere gradients from the ECMWF in VLBI analysis. J Geod, 81:403–408

Böhm J. et al. (2012): The new Vienna VLBI Software VieVS. In: Geodesy for Planet Earth, Proceedings of the 2009 IAG Symposium, issued by: International Association of Geodesy Symposia; Springer, 2012, ISBN: 978-3-642-20337-4, 1007 - 1012

Chen G. and T.A. Herring (1997): Effects of atmospheric azimuthal asymmetry on the analysis of space geodetic data. J. Geophys. Res . 102 (B9): 20489–20502

Hofmeister A. and J. Böhm (2014): Ray-traced delays in the Atmosphere for Geodetic VLBI. In: IVS 2014 General Meeting Proceedings , D. Behrend, K. Baver, K. Armstrong (eds.); Science Press, Beijing, China, 2014, ISBN: 978-7-03-042974-2, 283 - 287

Landskron D. et al. (2015a): Refined and site-augmented tropospheric delay models in the analysis of VLBI observations. 26th IUGG General Assembly , Prague, Czech Republic

Landskron D. et al. (2015b): Refined Tropospheric Delay Models for CONT11 . International Association of Geodesy Symposia, DOI 10.1007/1345_2015_56

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