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Linear Horizontal Gradients vs. 3D Raytracing

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Abstract

A simple way of determining linear horizontal gradients for VLBI and GPS analysis from numerical weather models is shown. Although downloading and computational efforts are small, it agrees very well with more sophisticated methods, what makes it applicable for a large number of geodetic sites on a routine basis. First VLBI results for CONT02 are very promising.

1. Introduction

In VLBI and GPS analysis it is important to take into account azimuthal asymmetries of the neutral atmosphere delays at the stations. State of the art is the estimation of total (hydrostatic plus wet) north and east gradients G_n and G_e for a certain time interval (e.g. 24 hours) within the least-squares adjustment. Equation 1 shows the total delay ΔL as the sum of a symmetric part (zenith delay L^z times mapping function m) and a gradient term that is dependent on the azimuth α of the observation (MacMillan, 1995 [4]).

$$\Delta L\,(\epsilon,\alpha) = L^z \cdot m(\epsilon) + m(\epsilon) \cdot \cot(\epsilon) \cdot (G_n \cdot \cos\alpha + G_e \cdot \sin\alpha) \qquad (1)$$

The Vienna Mapping Function 1 (VMF1, Boehm et al., 2006 [2]) is the most accurate mapping function for the elevation-dependence of the delays that is currently available. The accuracy at 5° elevation is below $1cm$, which corresponds to station height errors of less than $2mm$. On the other hand, $1cm$ at 5° elevation corresponds to a gradient of $0.1mm$. Thus, it would be desirable to get a priori gradients from numerical weather models with an accuracy of $0.1mm$.

If no local measurements from water vapour radiometers (WVR) are available, 3D-raytracing through numerical weather models of highest resolution and accuracy is the best way to extract delays in the neutral atmosphere for observations at arbitrary elevations and azimuths. However, since these delays are not yet accurate enough to serve as fixed values in GPS and VLBI analysis, we again use the concept of (azimuth-dependent) mapping functions as rigorous reference of exploiting numerical weather models. For CONT02, a two-weeks continuous VLBI campaign in October 2002, the Vienna Mapping Function was determined not just once per site every six hours but also every 30° in azimuth (VMF2). This huge effort covers the download and the processing of hundreds of refractivity profiles at each station (Boehm et al., 2005 [1]).

By definition, the linear horizontal gradients (LGH) as introduced by Davis et al. (1993 [3]) only depend on the gradients of refractivity above the site (equation 2).

$$G_n = \int\limits_{z=H}^{\infty} dN_{ns} \cdot z \cdot dz \qquad (2)$$

Thus, only two more profiles of refractivity – one towards north and one towards east – are needed to derive the profiles of north-south (dN_{ns}) and east-west (dN_{ew}) refractivity gradients and to determine the north and east gradients G_n and G_e. Figure 1 shows the north gradients of refractivity (weighted with height) at the site Algonquin Park (Canada) on 15 October 2002 at 0:00 UT. The LHG can be derived by vertical integration and the application of a reduction factor that accounts for the curvature of the Earth (and the troposphere).

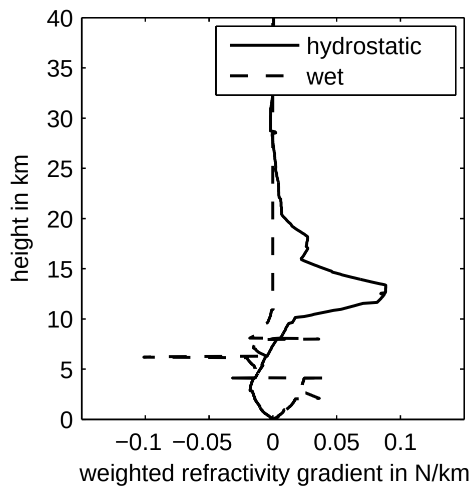

Figure 1. Hydrostatic (solid) and wet (dashed) refractivity weighted with height in Neper/km.

The maximum contribution to hydrostatic LHG can be attributed to heights between 10 and 15 km, whereas the maximum contribution to wet LHG is due to variations in the first few kilometers above the site. Some outliers in the wet gradients of refractivity can be neglected because the LHG result from vertical integration, i.e. they correspond to the area w.r.t. zero gradients.

2. Results for CONT02

Figure 2 shows the total east gradients at the site Algonquin Park (Canada) during CONT02 as derived from vertical integration (equation 2), from VMF2 (Boehm et al., 2005 [1]), and as estimated in VLBI analysis as 24-hour offsets. Typically, the RMS delay differences at 5° elevation are at the 1 to $3cm$ level between VMF2 and LHG and at the 2 to $6cm$ level between VMF2 and the gradients estimated with VLBI.

Although the agreement between VMF2 and LHG is significantly better, this does not necessarily mean that the LHG are more accurate than the gradients estimated with VLBI. To assess the quality of the different types of gradients, baseline length repeatabilities are determined for CONT02 with (1) LHG fixed (no estimation of additional gradients), and (2) estimation of total gradients as 24-hour offsets. Approach (1) yielded slightly better repeatabilies (by $1mm^2$ median and $7mm^2$ mean improvement), what seems to be an indication that the application of LHG from high-accuracy numerical weather models is superior to the estimation of gradients.

3. Outlook

The application of LHG as derived by equation 2 improves baseline length repeatabilities for CONT02 w.r.t. standard solutions, i.e. with estimation of gradients. Compared to VMF2, the

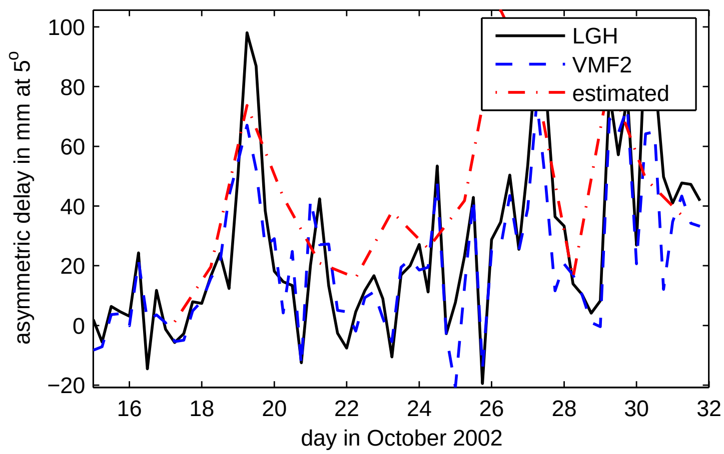

Figure 2. Total east gradients at Algonquin Park during CONT02 expressed as asymmetric delay in mm at 5° elevation.

downloading and computational efforts for these gradients are significantly reduced, allowing the provision of these parameters for a large number of stations on a routine basis. However, further investigations need to be done, e.g. on the use of LHG as a priori gradients plus the estimation of residual gradients with strong constraints.

4. Acknowledgements

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