Refined Tropospheric Delay Models for CONT11

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1. Summary

For the period of **CONT11**, a **VLBI** campaign which lasted from September 15 through September 29, 2011, new *a* coefficients for the mapping function and a new calculation strategy for horizontal gradients were applied. Yet, the ***a* coefficients** of the **Vienna Mapping Function 1** (VMF1, Böhm et al. (2006)) are calculated by ray-tracing through numerical weather models by the European Centre for Medium-range Weather Forecasts (ECMWF) with a spatial resolution of 0.25x0.25° every 6 hours. By enhancing the spatial resolution to 0.125x0.125° and using a new ray-tracing program called RADIATE, the actual refractivities are described in more detail, although this study gives no clear proof that thus the accuracy is enhanced. Moreover, existing equations for the calculation of the azimuth-dependent part of the slant delay by means of **horizontal gradients** are extended in order to achieve better accordance with the data from ray-tracing, which is obviously the case.

2. Calculation of gradients

Three different equations are presented which allow the calculation of the slant delays including azimuthal variation:

$$(1)\quad \Delta L(a,e) = \Delta L_0(e) + mf_g(e)[G_n\cos(a) + G_e\sin(a)]$$

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

$$(3)\quad \Delta L(a,e) = \Delta L_0(e) + mf_g(e)[G_n\cos(a) + G_e\sin(a) + X\cos(2a) + Y\sin(2a) + XX\cos(3a) + YY\sin(3a)]$$

a,e...............azimuth, elevation
ΔL(a,e).........total delay with gradients
$\Delta L_0(e)$..........total delay without gradients
mf_g...............gradient mapping function
G_n, G_e...........north and east gradient
X, Y, XX, YY...additional gradient variables

Equation (1) is the well-known gradient model by Chen and Herring (1997). Equations (2) and (3) are extensions in the form of a progression. For this study, **16 constantly distributed azimuths (a)** (0°:22.5°:360°) and **7 elevations (e)** were used (3°,5°,7°,10°,15°,30°,70°).
Figure 1 shows the **residuals between the ray-traced slant delays and those calculated** by using the three gradient equations for VLBI station WARK12M.

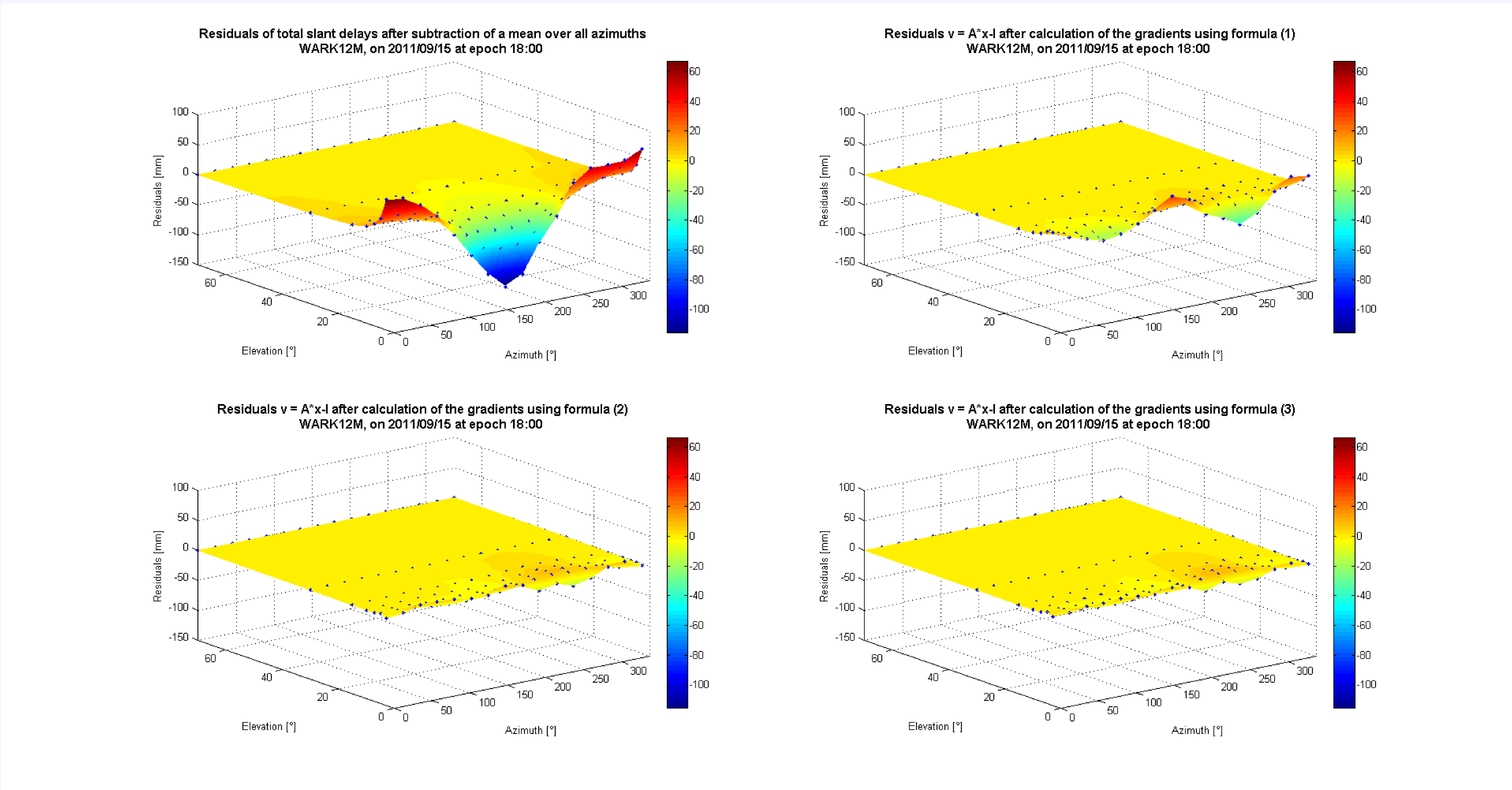

Fig. 1: <u>*top left*</u>: *the residuals of the total slant delays after subtraction of a mean over 16 constantly distributed azimuths. The high residuals in north (a = 0°) and south (a = 180°) direction are due to the high latitude location of the site, since the extension of the Earth's atmosphere is higher at the equator and lower at the poles.*
<u>*top right:*</u> *the residuals after applying gradients by using equation (1); this lowers the residuals significantly*
<u>*bottom left:*</u> *the residuals after applying gradients by using equation (2); again, the residuals are lowered considerably*
<u>*bottom right*</u>: *the residuals after applying gradients by using equation (3); residuals hardly change compared to equation (2)*

Averaged over all stations and epochs of the CONT11 campaign, the remaining residuals compared to the residuals after subtracting a mean over all azimuths are only **31%** when using equation (1), **22%** when using equation (2) and **20%** when using equation (3).
As a consequence of this study for the test period of CONT11, it would certainly make sense to think about a **revision of the description of the azimuthal asymmetry**. The additional gradient **variables X and Y** can be provided in near-real time in the same way as the gradients G_n and G_e. It remains undecided if the additional provision of the gradient variables XX and YY is reasonable, given the merely slight improvement.

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3. Calculation of new *a* coefficients

The continued fraction form by Herring (1992) allows the determination of a **mapping function** for a certain elevation:

$$mf(e) = \frac{1 + \cfrac{a}{1 + \cfrac{b}{1 + c}}}{\sin(e) + \cfrac{a}{\sin(e) + \cfrac{b}{\sin(e) + c}}}$$

In case of the VMF1, the coefficients *b* and *c* are determined by empirical functions, the coefficient *a* is calculated for the current weather situation and its values can be provided online. By means of ray-tracing through the nowadays available **0.125x0.125° numerical weather model data,** new values for the *a* coefficients can be obtained. However, the mean **baseline length repeatability** (BLR) **remains constant** with a value of 0.83 cm. The BLR corresponds to the standard deviation of a set of baseline measurements after subtraction of a linear trend (the latter is not needed for short-term projects like CONT11).
Due to unrealistically high BLR values, the VLBI station ZELENCHK was excluded from all sessions.

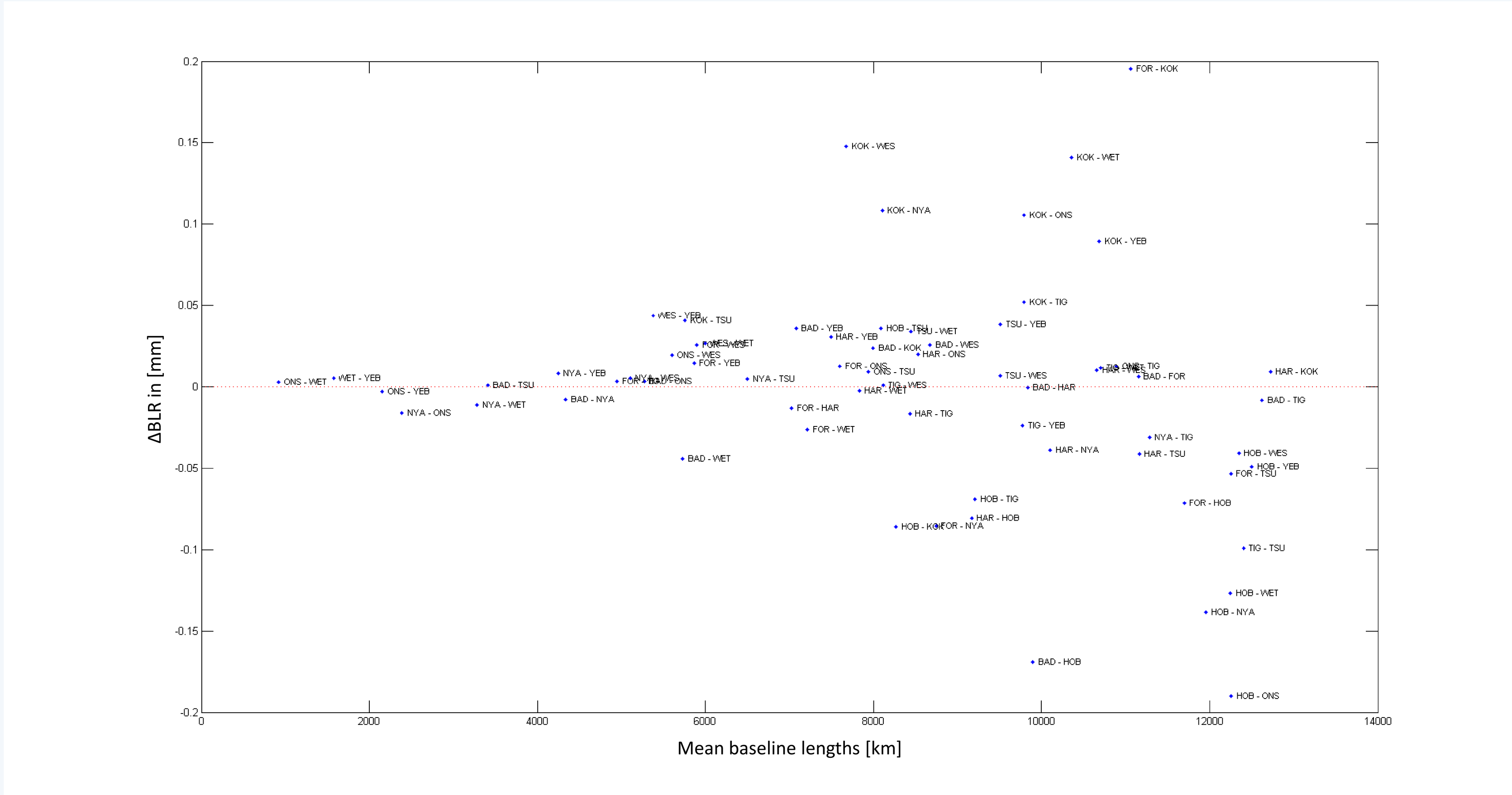

Fig. 2: *The differences in BLR between using the a coefficients from VMF1 and the new ones for each baseline (ΔBLR = BLR from new coefficients – BLR from VMF1 coefficients).*

In Figure 2 it can be seen that all baselines containing VLBI station **KOKEE** have a **distinctively worse BLR** when using the new *a* coefficients (above x-axis). On the other hand, all baselines containing VLBI station **HOBART12** show a **much better BLR** for the new *a* coefficients. The problems with KOKEE might arise from the rapid altitude changes of the island Kauai in the Hawaiian Islands, where the station is located. In addition, the 6 hour resolution may not be enough to gather the resulting refractivity changes. The same scenario might be the case at HOBART12, although in a converse way.
The BLR is better only for 43% of the baselines when using the new coefficients. However, when excluding the two stations KOKEE and HOBART12, this number increases to 56% and the mean BLR decreases to 0.66 cm. All in all, however, the **differences in BLR** for all baselines except for those containing HOBART12 and KOKEE **are very small** (sub-mm range), so that, considering the presented aspects, **it can't be clearly stated whether the new or the VMF1 *a* coefficients are better**.

4. Outlook

The final objective of the project "Radiate VLBI", of which this poster is a part of, is the **revision of the Vienna Mapping Functions 1** (VMF1), amongst others. In addition to the higher spatial resolution of the ECMWF numerical weather models, a way is to be found to overcome the problem of low-elevation (< 3°) observations, which VMF1 is not intended for. Moreover, **new ways of applying horizontal gradients** shall be discovered, in order to consider azimuthally-dependent changes in refractivity. The target is to find a compromise between accuracy and user-friendly usage of the calculated gradients.
With regard to this poster, the next step will be **combining sections 2. and 3.**, that is, analyzing BLR's of baselines that are calculated using equations (2) and (3) and comparing them to those of section 2. This will hopefully yield a further improvement in accuracy.

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