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Gradient Mapping Functions for VLBI and GPS

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Abstract

A hydrostatic gradient mapping function based on *in situ* meteorological data has been developed to provide an *a priori* correction to the hydrostatic delay. In the same way that the symmetric atmosphere estimation is improved by first removing the hydrostatic delay, application of the *a priori* hydrostatic gradient delay correction allows the use of a more accurate partial derivative for the asymmetric wet component, to the extent that it can be described by the gradient formulation. Application of the *a priori* hydrostatic gradient delays prior to estimating a wet gradient improves the repeatability of baseline lengths for the twelve days of CONT94 compared to estimating a hydrostatic gradient.

1. Background

The Niell mapping function [3] (NMF) provides accuracy and precision comparable to mapping functions using surface meteorology as input, but without the need for external input. It has been clear for some time that, to improve the accuracy of the atmosphere delay estimation further, some form of *in situ* information is needed to follow the mapping function variations on daily and sub-daily time scales. Such data can be obtained from a numerical weather model (NWM). Niell (2000) [4] described one possible implementation: the 200 hPa geopotential heights provide input for the azimuthally symmetric hydrostatic mapping function, IMFh, and the vertical distribution of wet refractivity is used to calculate the azimuthally symmetric wet mapping function, IMFw. Comparison of baseline lengths among the seven antennas for the twelve days of CONT94 [5] demonstrated that the use of IMFh/IMFw for the atmosphere estimation reduced the RMS scatter compared to using NMF. The amount of reduction corresponds to removing ∼4 mm of vertical height error (Figure 1).

2. The *a priori* Hydrostatic Gradient

The estimation of gradients was included for both the NMF and IMFh/IMFw analyses by using the hydrostatic gradient model of [1] (CH). Although Chen and Herring showed, both analytically and by raytracing one year of data from a numerical weather model, that the hydrostatic and wet gradients have a slightly different elevation dependence, as would be expected for the difference in scale heights, up to now no *a priori* model has been proposed. However, it occurred to one of us (AEN) that the same isobaric surface that is used to provide the input for IMFh could represent the "tilt" of the hydrostatic atmosphere corresponding to the hydrostatic gradient. This would allow the separation of the hydrostatic and wet components contributing to the azimuthally asymmetric delay of the troposphere, analogous to separation of the symmetric mapping functions.

The "tilt" of the hydrostatic atmosphere is calculated as the normal to the surface defined by the 200 hPa geopotential heights at the four grid points surrounding the site of interest. The

NWM that has been used to determine the inputs for both IMF and the hydrostatic gradient is the re-analysis of the Data Assimilation Office of the Goddard Space Flight Center [6]. The grid spacing is 2° by 2.5° in latitude and longitude. The normal to the 200 hPa surface above the point of interest is estimated along with the geopotential height of the surface. The geopotential height is the input parameter for IMFh, and the gradient is accommodated by adjusting the zenith direction to coincide with the direction of the normal to the 200 hPa surface. Although the mapping function value at an elevation of 90° is no longer exactly one, the error in delay is less than 0.2 mm. As a check on the consistency with the gradient functions of Chen and Herring, the delay difference was confirmed to be less than one millimeter at all elevations down to 5° (the minimum elevation validated for Chen and Herring) for the tilt corresponding to 1 mm of gradient in the sense used by Chen and Herring.

The *a priori* hydrostatic gradient mapping function, designated GMFh, when multiplied by the *a priori* zenith hydrostatic delay, gives the hydrostatic delay at the observation elevation. The model values of the NWM from DAO are tabulated every six hours beginning at 0 UT, and the mapping function is obtained by interpolation to the time of the observation for each VLBI or GPS antenna. By using a global gridded NWM the mapping functions are available for a site anywhere on the surface of the Earth.

3. Evaluation of GMFh

The best evaluation of the "tilt" model would be comparison with raytracing of the three-dimensional distribution of refractivity of the NWM, but this has not been done yet. A second test is to compare the repeatability of estimated site position using the different atmosphere models. An improvement in the atmosphere model is likely to improve the repeatability (unless the poorer model has been compensating for the error in some other model component, such as a seasonal effect in antenna position). The data of CONT94 were again used, thus allowing comparison with NMF and IMFh/IMFw.

The positions of six antennas were estimated relative to a fixed position for the Fairbanks antenna using the *solvk* analysis package [2]. The *a priori* hydrostatic delay was calculated using GMFh, IMFw was used for the symmetric wet mapping function, and the residual gradient was estimated using the Chen and Herring (1997) wet gradient model. The baseline length repeatabilities for the NMF and the GMFh analyses are shown in Figure 2. The improvement in repeatability going from NMF with the CH hydrostatic gradient model, to GMFh as *a priori* and CH wet as the gradient model, is shown in Figure 3. Only one baseline is not improved. The greater improvement for longer baselines is consistent with a reduction in the error in the local vertical component of site position. For this set of data the reduction is approximately 4.5 mm.

4. Caveats and Future Plans

It is promising that baseline repeatability is improved when a better model is incorporated. However, there are other possible explanations that must be eliminated to strengthen the case that inclusion of the hydrostatic gradient model is responsible. In addition to the possibility mentioned above, the time scale for variability of the gradient must be explored. The time scale for the estimated gradient variability was set to roughly twelve hours, while the *a priori* hydrostatic gradient had significant change over the six hour separation between input values. The effect of increasing the allowed variability of the estimated gradients must be investigated.

The other investigation that is important is the comparison of the hydrostatic delay change due to the tilted atmosphere with actual raytraced delays from the NWM. Higher horizontal resolution weather models will also allow improvement in the wet gradient mapping function and perhaps will provide evaluation whether the form assumed for the gradients is correct.

References

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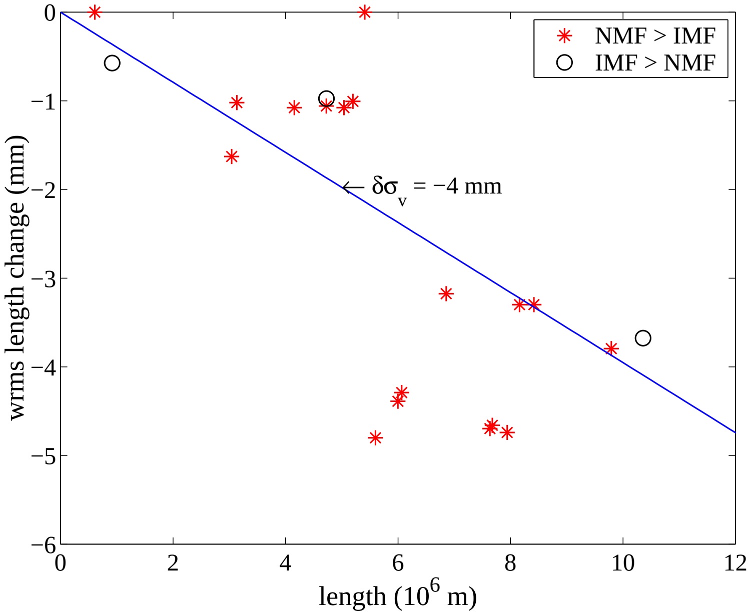

Figure 1. Reduction of baseline length scatter for the CONT94 campaign by using IMF instead of NMF. The line corresponds to removing 4 mm of vertical error at each site.

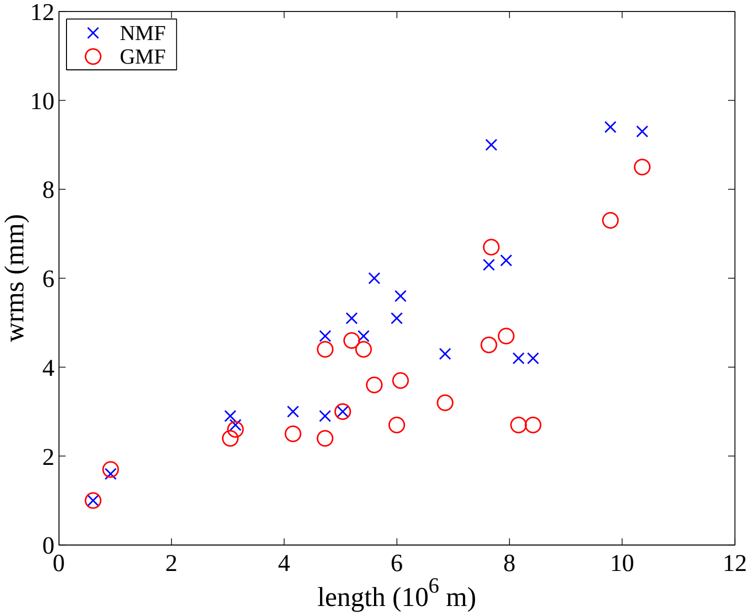

Figure 2. Baseline length repeatability for the CONT94 campaign showing the improvement using an *a priori* hydrostatic gradient and wet gradient mapping function instead of NMF and a hydrostatic gradient mapping function. The minimum elevation is 5°.

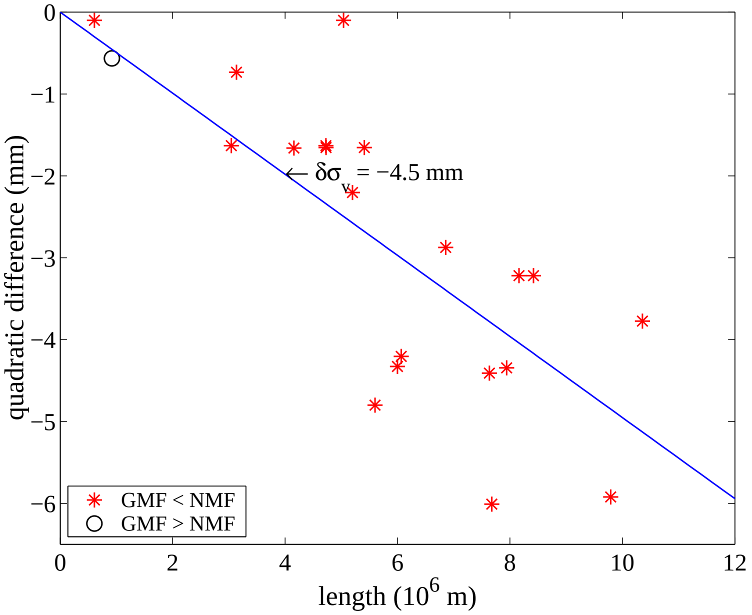

Figure 3. Reduction of baseline length scatter for the CONT94 campaign by using an *a priori* hydrostatic gradient and wet gradient mapping function instead of NMF. The line corresponds to removing 4.5 mm of vertical error at each site.