Analysis and Research at the Haystack Observatory

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Abstract

The IMF mapping functions for the atmospheric delay that use a global numerical weather model for input have been implemented in the geodetic VLBI analysis package *solve* by Leonid Petrov. The improvement in baseline length repeatability observed for the CONT94 sessions, which spanned only twelve days, is found to persist for the twenty years of well-observed baselines. The reduction in WRMS corresponds to an improvement in vertical error by about 4 mm.

Additionally, the use of IMF reduces the seasonal dependence of baseline length for at least some of those baselines observed more than 100 times. On the Westford-Wettzell and Gilcreek-Kashima baselines the improvement corresponds to a reduction in vertical error also by about 4 mm.

For estimation of the baseline lengths and rates, improvement in the hydrostatic component is most important. For reducing the seasonal variation, the wet component has the most effect.

The hydrostatic mapping function includes an estimate from the Numerical Weather Model of the hydrostatic gradient, based on the tilt of the 200 mb isobaric surface. When wet gradients are estimated from the VLBI data for Onsala for CONT94, the mean north-south component agrees better with the estimates of the ASTRID water vapor radiometer when the *a priori* hydrostatic gradient is included.

1. Geodetic Research at the Haystack Observatory

Improving the accuracy of the geodetic VLBI modeling and data analysis has always been pursued in parallel with the development of hardware at the Haystack Observatory. The current analysis effort is concentrated on improving models of the delay through the neutral atmosphere, while efforts to improve the correlator model continue as well.

Atmosphere models

A pair of parameterized azimuthally symmetric mapping functions for the hydrostatic and wet delays (designated IMF) has been developed (Niell 2000) and was evaluated (Niell 2001) for a limited VLBI data set using meteorological input from the re-analysis of the Data Assimilation Office (DAO) of the Goddard Space Flight Center. That evaluation indicated that the expected improvement in geodetic and atmospheric results might be achieved.

An important feature has been added since that publication, which is the possibility of including an *a priori* hydrostatic gradient, also determined from the data of the NWM. Inclusion of this model with IMF (designated IMFg) offers two advantages: a) the estimated gradient will more accurately reflect that due to water vapor; and b) a more accurate gradient mapping function can be used for the wet component (this has not been implemented for the results reported here).

Previously, the improvement obtained by using a NWM was shown for the twelve days of data of CONT94 for which the WRMS repeatability was improved for all but one baseline, compared to using NMF [4] [3]. The improvement in repeatability might have been artificially enhanced for such a short period because seasonal effects are not included. To evaluate the long-term quality, the data from 1993 January through 2002 October were analyzed with *solve* , using the National Center for Environmental Prediction (NCEP) NWM. The repeatabilities for baselines observed more than 100 times are shown in Figure 1. Approximately three quarters of the baselines are improved. The improvement in WRMS corresponds to a reduction in the error in the vertical contributed by the atmosphere of approximately 4 mm. (I thank Leonid Petrov of NVI/GSFC for creating the tools for retrieving the NCEP data, for implementing IMF in *solve*, and for running the solutions.)

Baseline length repeatability

The baseline length uncertainties were significantly larger before 1993. In order to obtain the best estimate of the impact of using a different atmosphere model, only data from 1993.0 to the most recent sessions are used. A further restriction to include only those baselines with more than 100 days of data was imposed in order to have reasonable statistics. The quadratic difference in WRMS for the forty-one baselines is shown in Figure 1. For thirty of the baselines IMFg gives smaller WRMS. For only ten is NMF better.

Assuming that the improvement is due to a reduction of error in the vertical that is approximately the same at all stations, the solid line in the figure corresponds to a reduction of four millimeters.

When the hydrostatic and wet mapping functions are changed independently, a larger improvement is made when NMFh is replaced by IMFh than when NMFw is replaced by IMFw.

Seasonal improvement

After removing a constant rate and offset from the entire set of Westford-Wettzell measurements, the lengths residuals were folded in one year intervals. The weighted averages for ten equally spaced bins are shown in Figure 2.

From this example and for the Gilcreek-Kashima baseline it appears that IMF, with or without a priori hydrostatic gradient, reduces the amplitude of a seasonal variation in baseline length from about 5 mm to approximately 3 mm. For all atmosphere models the maximum length occurs in mid-September.

The only other baseline that has been looked at by season is Gilcreek-Kokee. There is no reduction in seasonal variation.

Effect of a priori hydrostatic gradient

Removal of the hydrostatic gradient would leave primarily any gradient due to water vapor in the atmosphere as the estimated quantity. This allows evaluation of the effectiveness of the *a priori* hydrostatic gradient by comparison with the wet gradient inferred from measurements by a water vapor radiometer.

The north-south component of the gradient at Onsala during CONT94, estimated by VLBI with and without the *a priori* hydrostatic gradient, is shown in 3. Also indicated is the average value and WRMS scatter of the same quantity estimated from the collocated ASTRID WVR. The mean difference is reduced when the hydrostatic gradient is removed before estimation, suggesting that the agreement of the wet gradients is improved. (These solutions were made using *solvk* [2] which permits stochastic variation in the estimated atmosphere and clock parameters.)

2. Outlook

Evaluation of IMF has just begun. A further modification of the analysis is to evaluate using the gradient model of [1]. IMF is also being implemented by Johannes Boehm for the OCCAM analysis package using the NWM of the European Center for Medium Range Weather Forecasting (ECMWF). It is important to compare the results for the two implementations to evaluate both the method of analysis and the source of the atmosphere data.

References

[1] Chen, G. and T. A. Herring, Effects of atmospheric azimuthal asymmetry on the analysis of space geodetic data, J. Geophys. Res., 102, B9, 20,489-20,502, 1997.

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[3] Niell, A.E.: Global mapping functions for the atmosphere delay at radio wavelengths, J. Geophys. Res., 101, B2, 3227-3246, 1996.

[4] Niell, A.E.: Improved atmospheric mapping functions for VLBI and GPS, Earth, Planets, and Space, 52, 699-702, 2000.

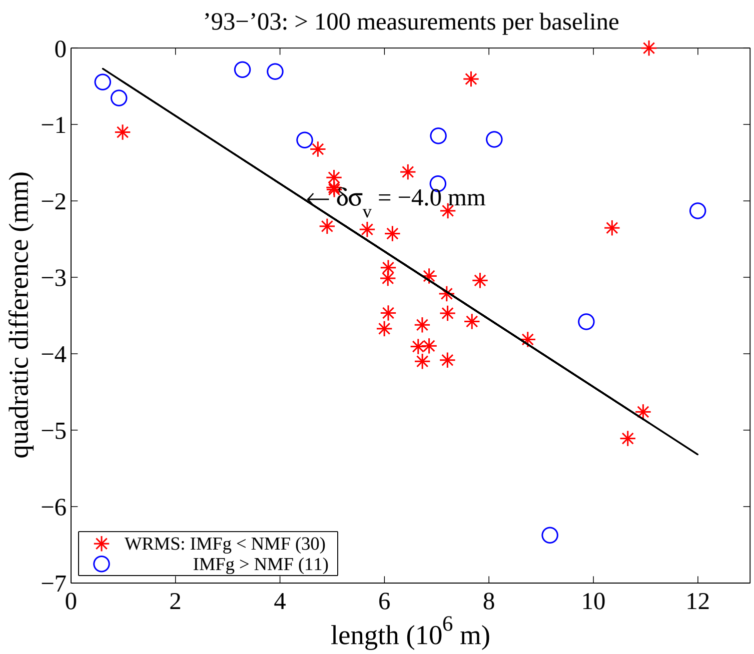

Figure 1. Baseline length repeatability for the forty-one baselines having more than 100 observations in the period 1993-2002. Red asterisks indicate that using IMFg gives smaller WRMS; blue circles indicate that NMF gives better results.

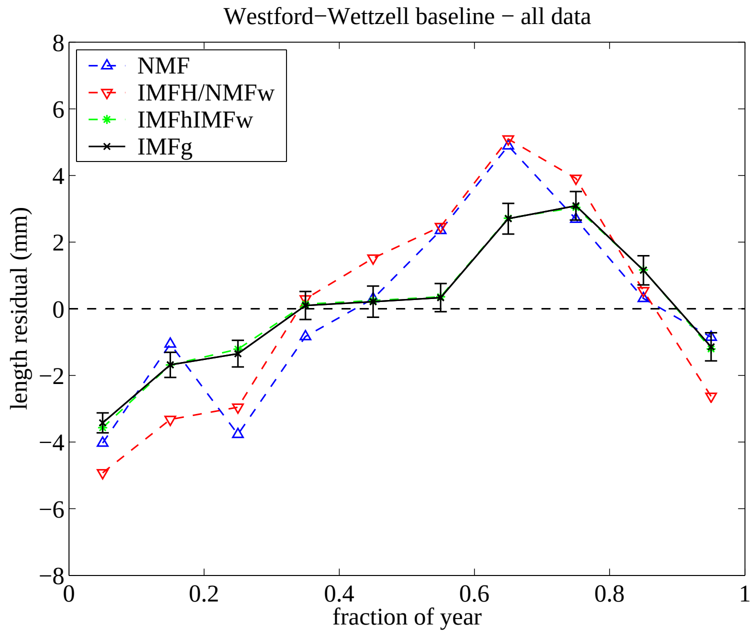

Figure 2. All data on the Westford-Wettzell baseline folded to one year and averaged in ten bins to look for seasonal dependence. up triangle - NMF; down triangle - IMFh/NMFw; green asterisk - IMFh/IMFw; black x - IMFg. IMFh/IMFw and IMFg are almost indistuinguishable.

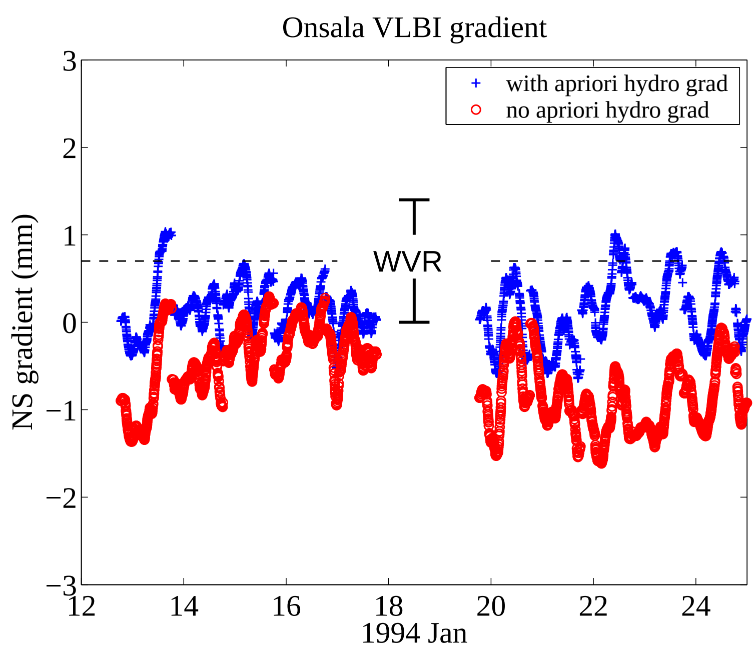

Figure 3. N-S gradients at Onsala during CONT94 estimated by VLBI with and without *a priori* hydrostatic gradient, and estimated from water vapor radiometer measurements using the ASTRID WVR.