MIT Haystack Observatory Analysis Center

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Abstract

The contributions of Haystack Observatory to the analysis of geodetic VLBI data focus on improvement in the accuracy of the estimation of atmospheric delays and on the reduction of instrumental errors through analysis. In the past year progress was made in two areas: 1) understanding the value of Numerical Weather Models for troposphere correction and 2) evaluating the contribution of polarization impurity to uncalibrated post-fit delay residuals.

1. Geodetic Research at the Haystack Observatory

The MIT Haystack Observatory is located approximately 50 km northwest of Boston, Massachusetts. Geodetic analysis activities are directed primarily towards improving the accuracy of geodetic VLBI results, especially through the reduction of errors due to the atmosphere and to instrumentation. This work, along with operation of the geodetic VLBI correlator and with support of operations at the Westford, GGAO, Gilmore Creek, Fortaleza, and Kokee Park VLBI sites, is supported by NASA through a contract from the Goddard Space Flight Center.

2. High Resolution Numerical Weather Model for Atmosphere Anisotropy

A numerical weather model provides the most information about the atmospheric conditions over a large volume. Sequential twelve hour forecasts with three kilometer horizontal resolution are being generated using the MM5 numerical weather model (NWM) for the eight sites of CONT02 to see if the high resolution can be used to improve the treatment of inhomogeneities in the atmosphere. However, the usefulness of the information is dependent on the accuracy of the calculated parameters. Lacking any better measurements, and by tradition, the standard of accuracy is the radiosonde.

Comparisons have been made at the positions of radiosondes in the fields of three of the sites, Westford, Kokee, and Hartebeesthoek, for the zenith delays and for the delay at 5° for the CONT02 period. The values from the NWM were calculated at the surface heights of the NWM, then corrected to the height of the lowest radiosonde level. As an example, the means of the differences of the delays at 5° are shown in Figure 1.

The height of the surface at the grid points nearest to the radiosonde launch site varies with horizontal resolution. After correction to the height of the lowest radiosonde vertical level, the agreement among the different resolutions improves. The largest mean difference for the 3-km grid is 4 mm, corresponding to approximately 1 mm of height error. Note that this is for a forecast of six hours.

3. Impact of Mapping Function Error on Choice of Minimum Elevation

Two effects compete for determining the minimum elevation of data that should be included in a geodetic VLBI solution. The geometric precision of the vertical coordinate (formal UP error) improves as lower data are included, but any atmosphere errors, such as mapping function, are

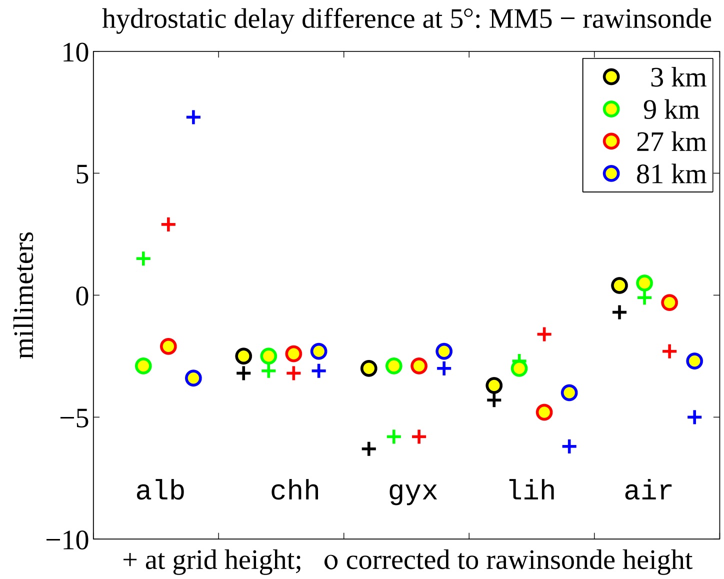

Figure 1. Mean difference of hydrostatic delays at 5° between MM5 numerical weather forecast and radiosonde for three radiosonde sites near Westford and one each near Kokee (LIH) and Hartebeesthoek (AIR). For each horizontal resolution the profiles of temperature and humidity at the four nearest grid points of the MM5 forecast are interpolated to the position of the radiosonde.

increased. Four mapping functions are available for VLBI analysis, and the contribution of each to the long-term scatter is shown as a function of latitude in Figure 2.

The magnitude of the RMS scatter decreases rapidly with increasing latitude, being reduced by a factor of almost two even by 7.5°.

As an example of the difference in strategy that should be used depending on the choice of mapping function, consider Gilcreek and Kokee in the CONT94 sessions. The formal height errors for Gilcreek and Kokee are, respectively, approximately 3 mm and 7 mm at 5° and rise to 5 mm and 11 mm at 12.5°. The combined uncertainties due to mapping function and geometry are shown in Figure 3 for Kokee and Gilcreek. Because the geometric error dominates for Kokee, data should be kept to the lowest possible elevation, regardless of mapping function. For Gilcreek, on the other hand, the mapping function error will dominate below about 10° if NMF or GMF is used, but the UP error can be reduced by using VMF1 and retaining (or scheduling) data down to 5°.

This type of analysis should be conducted for every session to determine the minimum elevation, which might be different for each antenna, and which may also vary between sessions for a given antenna.

4. Cross Polarization as a Source of Instrumental Error

A significant source of instrumental error in geodetic VLBI is imperfect polarization response of the antenna feeds, which are nominally right circularly polarized (RCP). If the feeds at two stations have some left circular (LCP) contamination, the LCP signals will correlate and thereby

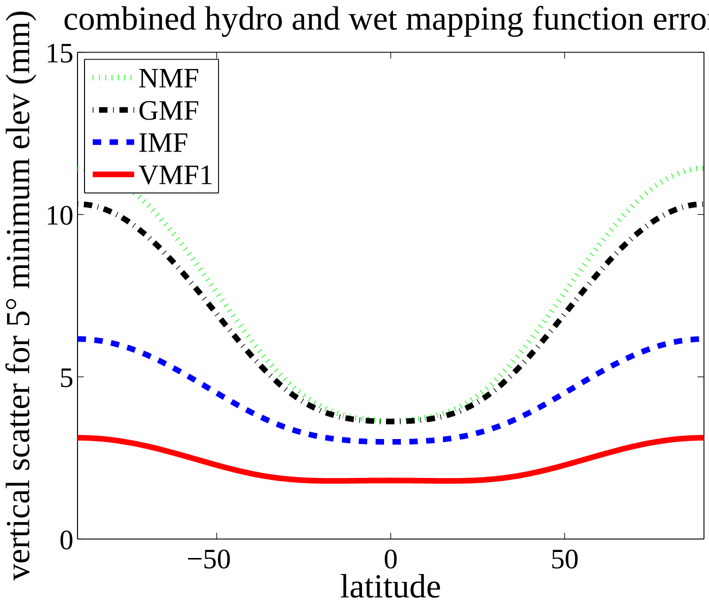

Figure 2. Contribution of mapping functions to long-term RMS of vertical component of site position as a function of site latitude for minimum elevation of 5°. The effects of the hydrostatic and wet mapping functions have been added quadratically. NMF - [3]; GMF - [1]; IMF - [4]; VMF1 - [2]

bias the estimated delay. In the worst case of fringe phase frequency dependence, two antennas that are –14 dB cross-polarized can have their multiband delays biased by 18 ps for wideband (720 MHz) X-band observations.

In order to set limits on the magnitude of such errors, data were analyzed from a July 1996 R&D polarization experiment (RDPLR1), which was carried out concurrently with two normal geodetic sessions (GTRF11 and NAPS2). In RDPLR1, six VLBA antennas observing with both polarizations at both S and X tracked three calibration sources for 8 hours; they then tagged along with the two geodetic sessions. From the correlator output for the 8 hours, one can estimate the cross-polarization responses of the VLBA antennas. With the VLBA characteristics known, one may then estimate, or at least set limits on, the LCP contamination in the geodetic RCP feeds.

The analysis to date has been based only on fringe amplitudes, without regard to fringe phases, and only baseline-based estimates of cross-polarization are available. Station-based limits on LCP contamination can be inferred in only a few cases. Even with that limitation, it is possible to draw some preliminary conclusions. Typical cross-hands amplitudes on VLBA-only baselines are 2–4% and 3–8% as strong as parallel-hands at X and S, respectively, which implies cross-polarization power responses at each antenna of <–28 dB and <–22 dB, respectively. The LCP contamination of the geodetic RCP feeds is generally much higher, with values ranging from –20 dB to –12 dB at X, depending on frequency, for Algonquin, Fortaleza, Gilcreek, Hobart, Westford, and Yellowknife; at S-band, the cross-polarization exceeds –10 dB at Yellowknife at some frequencies.

The analysis is currently being extended to include the fringe phase information and to produce a complete set of station-based estimates of the LCP response at the geodetic stations.

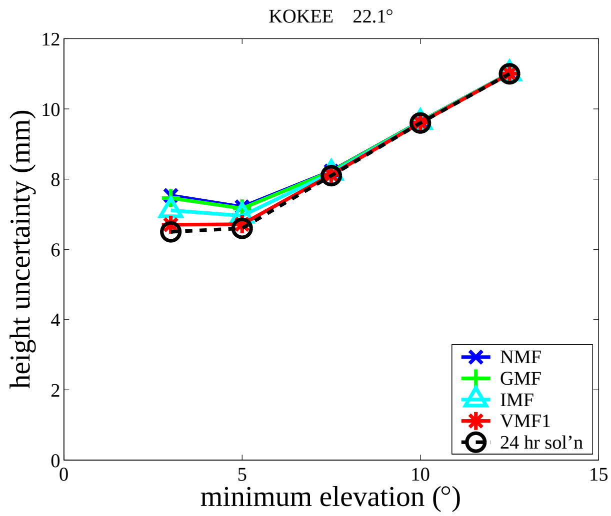

Fig 3a.

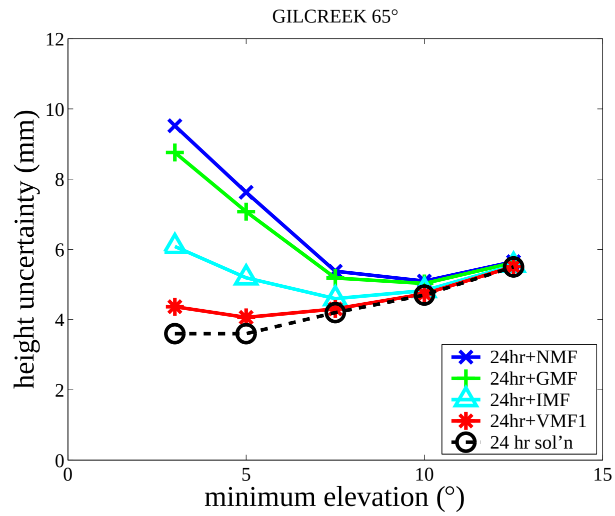

Fig 3b.

Figure 3. Height uncertainty for 3a) Kokee and 3b) Gilcreek for CONT94, as a function of minimum elevation, formed by combining the formal UP error (24 hour solution) with the total mapping function error, adjusted for each minimum elevation, for four different mapping functions.

5. Outlook

For the high-resolution NWM studies the goal is to complete the forecasts for the remaining five sites and to investigate the impact of the inhomogeneities seen in the 3 km grids on the horizontal and vertical coordinates of the stations in CONT02.

On completion of the analysis of the cross-polarization impurity, the results will be applied to a subset of the geodetic data to evaluate the change introduced by the correction.

An objective of both studies is to understand the magnitude of the errors that should be added to the parameter estimates, but which have not yet been considered.

References

[1] Boehm, J., A.Niell, P.Tregoning, and H.Schuh: The Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data, Geophysical Research Letters, in press 2006.

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