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Interaction of Atmosphere Modeling and VLBI Analysis Strategy

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Abstract

Estimates of the height component of station position are sensitive to the minimum elevation of observations included in the analysis, which is usually a global parameter that applies to all antennas. Two effects are strongly elevation dependent and compete in determining what minimum elevation should be adopted: the formal uncertainty of the height estimate from each 24-hour session, and the additional uncertainty not included in the session formal uncertainties that is due to errors in the atmosphere delay mapping functions. The parameter estimate uncertainties for a session depend on many things, but, in general, the lower the elevation that can be observed, the smaller the uncertainty in the height component. On the other hand, the error due to the inadequacy of the atmosphere mapping function increases as the minimum elevation is reduced.

The dependence of the combined height uncertainty on minimum elevation has been calculated for the antennas of the CONT94 continuous observing campaign and for four different atmosphere delay mapping functions. For best height estimation with current antenna sensitivities the VMF1 mapping functions should be used, and observations down to 5° elevation should be observed.

1. Introduction

In geodetic applications of VLBI and GPS both the value and the uncertainty of the estimate of the height of an antenna are sensitive to the minimum elevation of the observations. Two choices made during the planning and analysis stages of a VLBI session, typically composed of 24-hours of data, compete in determining what minimum elevation should be adopted. In planning the observations better height precision can be obtained by including observations at lower elevations, thus improving the geometric strength. However, the standard deviation of the session values about some long term value or trend, due to errors in the atmosphere model, will be increased as data are included at lower elevations.

In this paper the magnitudes and dependence on minimum elevation of these competing effects are illustrated, and a quantitative basis for choosing among available atmosphere models and deciding what minimum elevation to use is given. In Section 2, the errors due to atmosphere models and to geometry are described. The available mapping functions and trade-offs among them are provided in Section 3. The uncertainties in height due to the combined effect of geometry and atmosphere model are illustrated in Section 4. Finally, some choices are recommended in Section 5.

2. Height Uncertainties

The height uncertainty is dominated by the geometry of the observations and by the accuracy of the atmosphere model. The lower in elevation to which observations are made at a site, the smaller will be the formal uncertainties for the UP coordinate. The uncertainties for seven stations for one day of the CONT94 campaign are shown in Figure 1. Although this is referred to as "geometric" uncertainty, the improvement in height uncertainty is in general less than anticipated because of the lower signal to noise ratio (SNR) for observations at low elevations due to increased system temperature and other effects.

Acting in the opposite direction is the increase in height uncertainty due to errors in the mapping functions. While the mapping function errors are also a function of latitude, the dependence on minimum elevation in a fractional sense is similar at all latitudes. This dependence has been investigated by calculating the atmosphere delay at three elevations, 15°, 7.5°, and 5°, using the IMF hydrostatic mapping function [5] for one year of data every six hours then finding the RMS deviation about these values using the NMF hydrostatic mapping function [4]. The data used were for 1992 from the National Center for Environmental Prediction (NCEP). The hydrostatic zenith delays were calculated from the NCEP data for use with both mapping functions. The delay differences were scaled to height error using a coefficient of 0.056*minimum elevation, which was determined from simulations using GPS geometry. This gives errors about 20% larger than the dependence found by MacMillan and Ma [3]. From Figure 2 it can be seen that, relative to the value at 5°, the error decreases to about 60% at 7.5°, and to about 20% at 15°. The implication of using a different scaling factor will be addressed in Section 4.

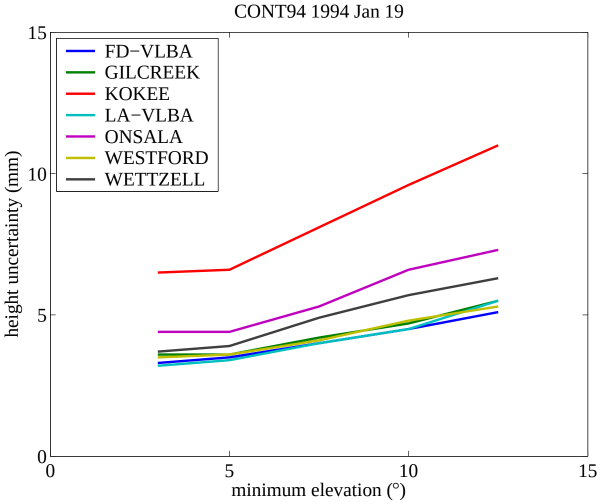

Figure 1. The per session height uncertainty for the antennas of CONT94 as a function of minimum elevation. From top down, the upper three lines are for Kokee, Onsala, and Wettzell.

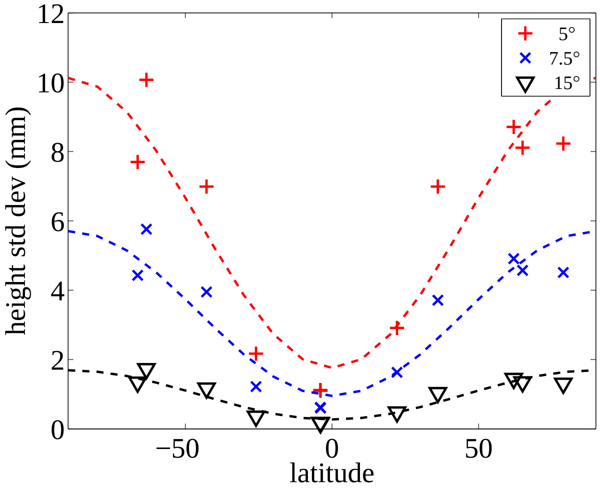

Figure 2. The expected height standard deviation as a function of latitude, and for minimum elevations of 5°, 7.5°, and 15°, from using the NMF hydrostatic mapping function. See text for significance.

3. Trade-Offs Among Atmosphere Mapping Functions

There are four mapping functions available in the current generation, with varying attributes for ease of use and accuracy. NMF [4] is widely used for both VLBI and GPS because it is independent of external data, depending only on station latitude and height and on day of year. The new GMF [1] uses the same input plus station longitude and reduces the largest errors in NMF. Two other mapping functions utilize data from a Numerical Weather Model. They are IMF [5] and VMF1 [2]. These have the advantage over NMF and GMF of reflecting actual sub-daily changes in the properties of the atmosphere at the locations of interest.

The accuracies of these mapping functions can be evaluated by comparison with mapping functions calculated from radiosonde profiles. Both the mean difference and the standard deviation are important. Aside from NMF, which has larger errors for the hydrostatic component in the far southern latitudes and around Japan, the mapping functions agree well in the mean with the radiosondes and with each other. The equivalent scatters in height, calculated for 5° minimum elevation as described above, are shown in Figure 3 for the hydrostatic and wet components as a function of latitude.

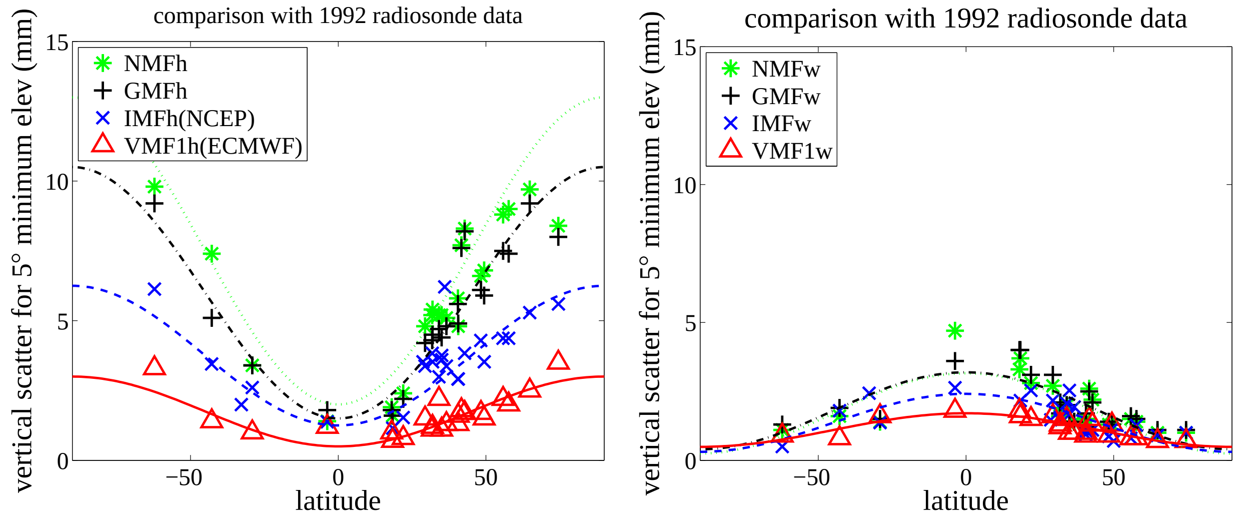

Figure 3. Height-equivalent scatter for 5° minimum elevation due to hydrostatic (left) and wet (right) components of the mapping functions.

An important improvement in the NWM-based mapping functions, compared to those based only on day of year, is clearly the reduced error in the high latitude regions. This is easily understood since the atmosphere has significant variations on a time scale of several days that cannot be reproduced by a seasonal model, and these variations are larger in the higher latitudes. Similarly, hydrostatic VMF1 (VMF1h) is more representative of the atmosphere as measured by radiosondes than is IMF since VMF1h makes use of all levels of the atmosphere provided by the NWM while IMFh uses only a single level.

The primary difference between IMF and VMF1 is the availability. IMF is produced on a global grid and is thus calculable for any location on the surface of the Earth, while VMF1 requires a separate calculation of the parameters for each individual location. For VLBI this has not been a problem because of the small number of sites, so the VMF1 parameters have been calculated for all VLBI sites from the earliest possible use.

On the other hand, the number of GPS sites is very large so the amount of calculation for VMF1 is inhibiting. As a consequence VMF1 is available only for a subset of GPS sites and as of this writing only for data taken since 2005 Jan 1. In contrast IMF may be calculated for any site for any epoch since 1979 Jan 1. The possible consequence of using the lower accuracy IMF will be seen in Section 4.

4. Combination of Atmosphere and Geometric Uncertainties

The errors due to the two competing choices are uncorrelated, so the total effect will be close to the quadratic sum. An example is shown in Figure 4, for Gilcreek. An important result can be seen from this figure: as the average geometric error over all elevations decreases, i.e. as an antenna becomes more sensitive, the optimum minimum elevation increases.

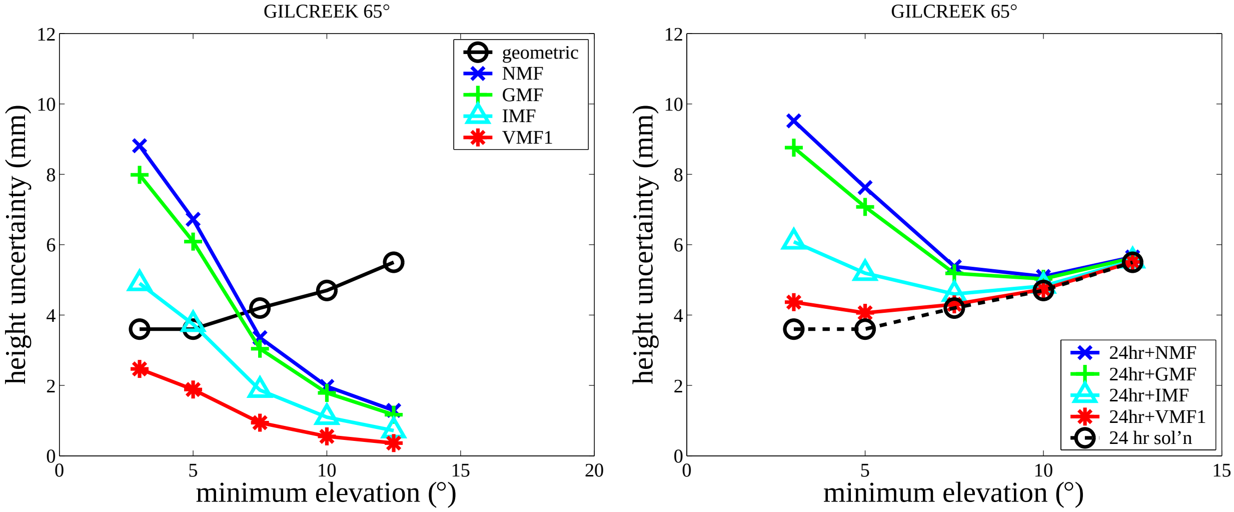

Figure 4. Height uncertainty for Gilcreek as a function of minimum observed elevation when combining the effects of the 24-hour session formal uncertainty and the mapping function error. On the left the effects are shown for each total mapping function and for the geometric uncertainty. On the right the effects are combined quadratically; the 24-hour uncertainty is included for reference as the lowest (dashed) line.

The total combined uncertainties are shown in Figure 5 for two antennas that have relatively low and high sensitivities for each of the four mapping functions. The 24-hour session height uncertainty (the "geometric" uncertainty) is also shown. It is apparent that making use of the NWM-based mapping functions should result in smaller height uncertainties for all but the weakest antenna (Kokee). Furthermore using VMF1 provides better precision than IMF for the more sensitive antennas. Finally, if VMF1 is used, data down to 5° elevation should be scheduled and included in the solution.

As indicated above in Section 2, the conversion from delay error at the lowest elevation to height uncertainty is in itself uncertain, perhaps by as much as 25%. Since the effects are added quadratically and the minimum of the resultant spans several degrees in elevation, and since there are likely to be other errors that have not been included, this lack of precision should not have a significant impact on the choice of minimum elevation.

It is important to note that the only way to reduce the combined height uncertainty is by reducing the per-session uncertainty. This will permit raising the minimum elevation and reducing the relative contribution of the atmosphere modeling error. This may already be the case for recent sessions such as CONT05 or for the RDV series, and this analysis should be applied to the antennas for each type of session if the per-session height uncertainties are different. (Ideally the analysis would be made for each session, but that is probably not justified because of the uncertainties in the method.)

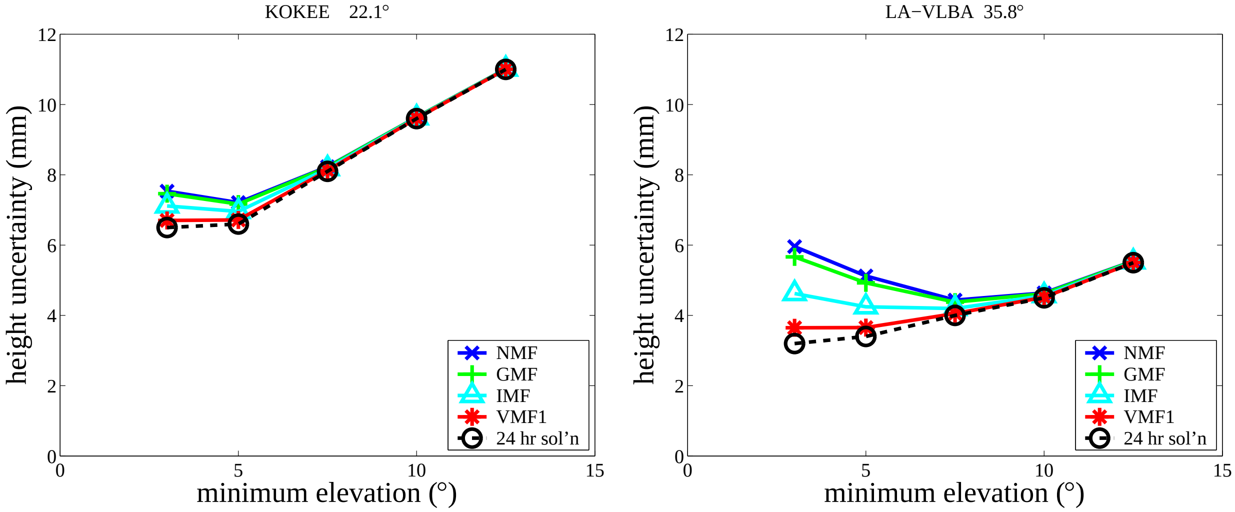

Figure 5. Height uncertainty for the low latitude sites Kokee (22°) and LA-VLBA (35°) as a function of minimum observed elevation for the combined effects of the 24-hour session formal height uncertainty and the mapping function error.

5. Recommendations

- The VMF1 mapping functions should be used for geodetic VLBI analysis.
- With the height uncertainties attained by the current antennas, observations should be scheduled for elevations down to 5° when using VMF1.
- The IMF mapping function can be used with little loss of accuracy at most sites, although the minimum elevation should be tailored to the sensitivity and location of the antenna.

References

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