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 2007 most of the effort was related to evaluating error sources for the proposed VLBI2010 system, primarily regarding the sensitivity and performance of the broadband development prototype hardware that has been installed on the MV-3 antenna at GGAO. Since atmosphere delay error continues to be a significant source of geodetic error, a potential method to improve the measurement of wet delay by Water Vapor Radiometer was investigated and is reported here.

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, Fortaleza, and Kokee Park VLBI sites, is supported by NASA through a contract from the Goddard Space Flight Center.

2. Possible Improvement in the Accuracy of Measurements of Atmosphere Wet Delay by Water Vapor Radiometer

Historically, comparisons of zenith wet delay (ZWD) as measured by water vapor radiometers and as estimated from VLBI observations have shown differences of about 1 cm that vary over hours, even though the shorter term variations may be similar. No alternative to the traditional calibration of WVR zenith wet delays through the use of radiosondes has been able to reduce or remove this characteristic difference.

A water vapor radiometer (WVR), when accurately calibrated, measures the brightness temperature of the atmosphere at one or more frequencies. The VLBI observables are delays. For a WVR to be used directly in the estimation of geodetic parameters the WVR brightness temperatures near the time of the VLBI observation must be related to delay. This has traditionally been achieved by using several weeks to several months of radiosonde data taken at a site of similar atmospheric conditions as that where the WVR is used in order to develop a set of regression coefficients between the brightness temperature and delay. Since the relation between brightness temperature and delay is not unique (the same delay can be produced by many distributions of atmospheric water vapor and temperature), there is generally a much larger uncertainty in the delay than would be obtained if the atmospheric distribution were known at the time of the observation.

A possible alternative is to use a Numerical Weather Model to obtain the relation between brightness temperature as measured by a WVR and the corresponding delay that would be produced by the same atmosphere. The proposal is that the NWM forecasts, while not providing delays or brightness temperatures that are accurate enough to be used directly in geodetic estimation, do provide the ratio of brightness temperature to delay with sufficient accuracy to add information. The WVR measurements in themselves will provide the temporal variation of brightness temperature and thus, through the scaling, will provide the temporal variation of the zenith delay. The VLBI measurements can then be used to estimate the offset, and, if necessary, a further scaling factor. By using the WVR data for the temporal variability, as few as one or two parameters might be estimated for the atmosphere within a 24 hour period, rather than from 24 values to more than 100. As long as the number of parameters is considerably smaller than would be required by the VLBI/GPS data alone, the geodetic results should be improved.

To evaluate this proposal, twelve hour forecasts were made using the MM5 Numerical Weather Model with a finest horizontal grid spacing of three kilometers. (The MM5 calculations were done by Mark Leidner of AER, Inc.) The WVR measurements were made at Kokee during CONT02 in October 2002 using a Radiometrics 1100.

The brightness temperatures and derived zenith wet delays, interpolated to the times of the VLBI observations at Kokee are shown in Figure 1. Periods of rain are seen as large increases in brightness temperature.

The MM5 forecasts were initiated every 6 hours and run for 12 hours. Pressure level humidities and temperatures for the last six hours of each forecast were used to calculate zenith wet delays and brightness temperatures at the times of the VLBI observations. The ratio of ZWD to 23 GHz brightness temperature was used to scale the values of 23 GHz brightness temperature measured by the WVR. The values of ZWD obtained the four ways are shown in Figure 2.

Two periods without rain were identified: Oct 22-23 and Oct 26-27. For each of these periods two differences are displayed in Figures 3 and 4: a) the uncorrected WVR ZWD minus ZWD estimated from VLBI, and b) the WVR ZWD obtained by scaling with MM5 minus ZWD estimated from VLBI. The anticipated result was that the biases would be reduced by using the MM5 scaling since it more closely represents the distribution of water vapor at the time of the WVR measurements than the time-averaged retrieval coefficients obtained from the radiosonde data. In fact the biases are reduced for both periods, though not to a negligible value. In the first period the median difference is reduced from 16 mm to 7 mm. For the second period the change is from 13.2 mm to 11.7 mm, but in fact the bias increases for much of the second day.

While the results are promising, the WVR-VLBI difference is not consistently reduced. Potential sources of the remaining error are lack of accuracy of the MM5 forecasts, errors in the calibration of the WVR brightness temperatures, and incorrect calculation of brightness temperatures from the MM5 forecast values of humidity and temperature.

3. Acknowledgements

I thank Mark Leidner for setting up and running MM5, Wolfgang Schlueter of BKG for providing the WVR for use at Kokee, and Walter Schwartz of BKG for running and maintaining the Kokee WVR and for processing data.

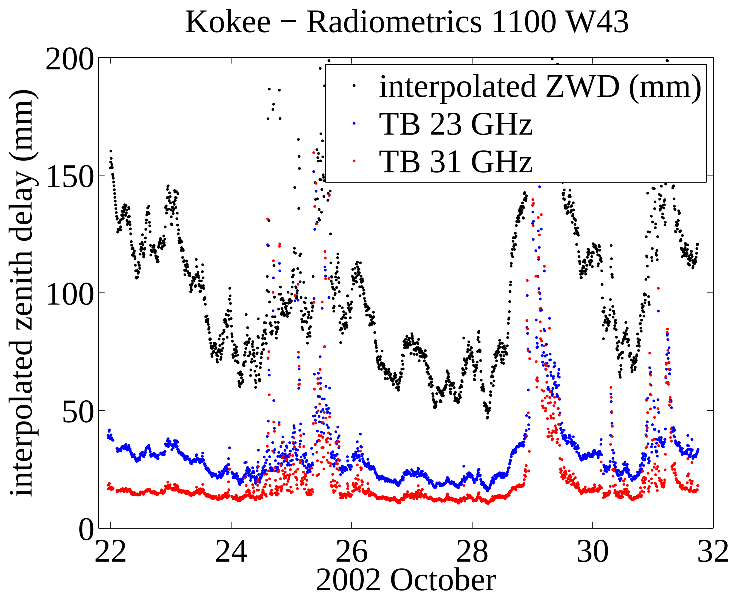

Figure 1. From top to bottom: Zenith Wet Delay (black), brightness temperature at 23 GHz (blue), and brightness temperature at 31 GHz (red) for Kokee during CONT02. The ZWDs are interpolated to the time of the VLBI observations.

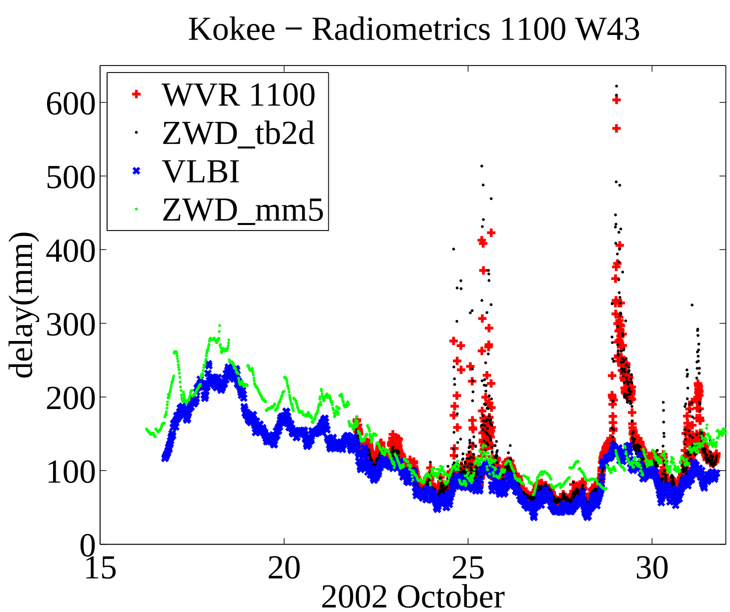

Figure 2. Zenith wet delays for Kokee during CONT02 at the times of the VLBI observations: red cross: as measured by the WVR; black dot (begins on Oct 22) - as calculated from the WVR value of brightness temperature at 23 GHz, scaled by the ratio of delay to brightness temperature from the MM5 forecasts; blue cross - as estimated from VLBI; green dot (begins on Oct 16) - as calculated directly from the MM5 pressure level values of humidity and temperature.

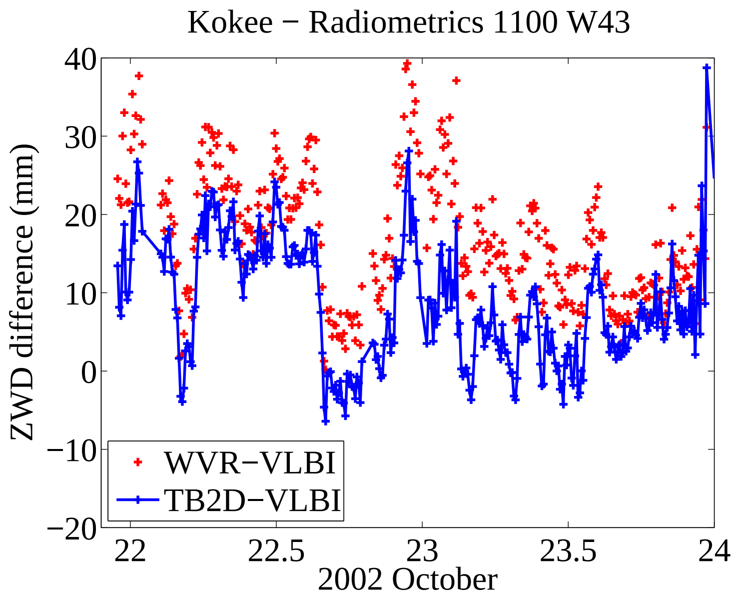

Figure 3. The differences in ZWD derived from WVR 23 GHz brightness temperature with respect to the VLBI estimates for Oct 22-23. red cross - WVR ZWD using radiosonde-derived regression coefficients; blue line - WVR ZWD using MM5 Numerical Weather Model forecast ratios of delay to brightness temperature.

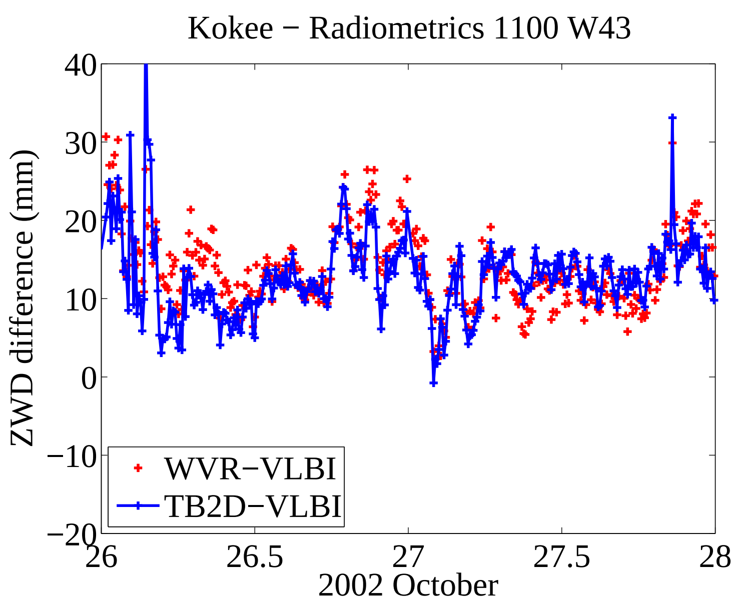

Figure 4. Same as for Figure 3 except for Oct 26-27.