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Improving the Homogeneity of Meteorological Data to Minimize Resulting Errors in Geodetic Analysis

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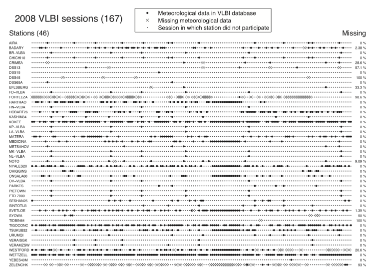
Abstract. *Errors in site pressure and temperature translate directly into errors in geodetic site position estimates. These errors are clearly significant compared to the mm-level accuracy that we are trying to attain. Applied to the VLBI technique, we looked at the pressure and temperature data in the database used at GSFC to process VLBI data and found errors in meteorological data including biases in pressure, abnormal values, especially in temperature, missing data, and globally, inhomogeneity in time of those two parameters. In this study, we show some examples of impacts of such errors in VLBI processing. We propose a better alternative to the current VLBI processing strategy using a homogeneous set of meteorological data that we derived at GSFC from the European Centre for Medium Range Weather Forecasts (ECMWF) weather model. We show the improvements observed in terms of Weighted RMS when processing VLBI data from R1 and R4 sessions for 2002-2011 as good quality regular weekly sessions.*

Erroneous Pressure and Temperature Data and impacts on VLBI Processing

We investigated the different Meteorological ("met") data in the databases (called MK3DB) used to process VLBI data and we compared with different alternative sources (other meteorological sensors, numerical weather models). Met data is used in VLBI processing in two distinct ways:
1/ The pressure is used to calculate the a priori atmospheric delay along the line of site using the Saastamoinen formula for the zenith delay, and a function which 'maps' the zenith delay to the line-of -sight.
2/ More recently, temperature measurements are used to calibrate the thermal deformation of the antennas.

We noticed different problems:

- **Missing data**: The VLBI analysis package *Solve* uses default values for the met data which depend only the site latitude in the absence of met data. This option is sometimes significantly used. For example, in 2008, Fortaleza and Zelenchukskaya, two of the major VLBI stations, are missing respectively 98.6% and 93% of their met data. As an example, we studied Westford, another major VLBI station, which misses 20.6% of its met data in 2008. Figure 1 shows these met data as well as the default value used in *Solve*. We then considered two strategies for processing R1 and R4 sessions from January 2002 to April 2010: for Westford, we use the pressure from 1/ the databases (default value if no met data) and 2/ series computed from UT Vienna and derived from a numerical weather model (ECMWF) that will be called V-ECM, and for the other stations, we keep the same configuration. The Figure 2 plots the differences in WRMS between using the databases values (MK3DB) and using V-ECM for Westford. The WRMS is improved significantly, especially in the case of the baselines with Westford, and up to 0.93mm. Using a default value to replace missing data, even at the level of 20%, is not a satisfactory method.



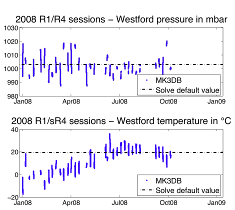


Figure 1: Pressure and temperature data as read in the MK3DB for Westford in 2008.

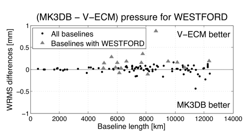


Figure 2: Differences in baseline length repeatability between using the MK3DB pressure or default value and using V-ECM pressure for Westford. R1 and R4 sessions from January 2002 to April 2010.

- **Biases in pressure**: The pressure is used in the atmospheric delay processing. A bias in the surface pressure causes an erroneous vertical component for the station, impacting the vertical component and the baseline length estimates. When we compared pressure data from the MK3DB with other sources, we noticed biases up to 10mbar, impacting the vertical component determination by 1mm or more.
- **Abnormal behavior of the temperature**: Figure 3 shows an example of an abnormal behavior: a daily drop of the temperature of almost 40ºC is seen for the station Westford for the data in the databases. The temperature is used in VLBI processing to compute the thermal deformation of the antenna. An error in temperature causes an erroneous position for the station, and can affect the height of the VLBI reference point by as much as 20mm for the largest telescopes (Nothnagel, 2009).

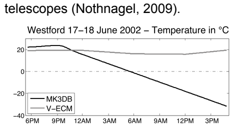


Figure 3: Temperature for Westford on the 17th of June 2002, showing temperature from MK3DB and from a numerical weather model-based solution (V-ECM).

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G-ECM series – GSFC Met data service website: *http://lacerta.gsfc.nasa.gov/met/*

Computing the G-ECM series

In this study, we use European Centre for Medium-Range Weather Forecasts (ECMWF) models, available publicly on www.ecmwf.int. The data provided is given on grid points (1.5º x 1.5º equal angular). The datasets contains date, latitude, longitude, temperature, pressure and humidity, in a netCDF format.
We select the ERA-Interim reanalysis model (Dee et al., 2011). From the datasets, we extract the surface pressure and 2-meter layer temperature.
For a given station S, we determine the four points of the ERA Interim grid (Q_{ij},i,j=1,2) in the neighborhood of the station (Figure 4). Four time series of meteorological data (pressure and temperature) at geopotential height are extracted for each point Q. The time series are then extrapolated from the grid height to the station height. For the temperature, after calculating the geometric height difference, we apply the lapse rate of Γ = 0.006499ºK/m to height adjust the temperature series. For the pressure, we use the barometric height formula (Zdunkowski and Bott, 2004):

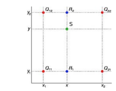

Figure 4: Scheme for the interpolation of met data from ECMWF to the VLBI station S.

$$p(z)=p_0(T_0-\Gamma\,\Delta z)/T_0)^{g/R\Gamma}$$

where p_0 is the reference pressure, T_0 [K] the reference temperature, Γ [K/m] the lapse rate, g [m/s²] the acceleration due to gravity, R the gas constant, and Δz [m] the difference in geopotential height.
When all four time series are known, a bilinear interpolation remains: first a linear interpolation in the x-direction followed by a linear interpolation in the y-direction.

Temperature and Pressure service:
http://lacerta.gsfc.nasa.gov/met/

The service provides temperature and pressure time series every 6th hour from 1979 to 2012 for all VLBI sites, interpolated and extrapolated from the ERA-Interim ECMWF model. Those time series are updated when new data is released by ECMWF.

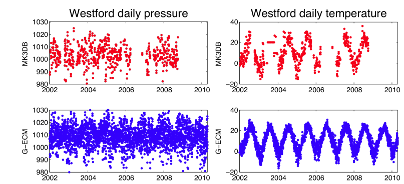

Figure 5: Pressure and temperature plots for the station Westford, MA.
The top plots show the Mark3 databases meteorological data (MK3DB), which are used by default at GSFC (measurements from on-site sensors). The bottom plots are our series G-ECM derived from ECMWF. The G-ECM solution is homogeneous and continuous, in contrast to MK3DB.

Using G-ECM series in VLBI Processing

WRMS improvement

We processed R1 and R4 sessions over the period 2002-2011 and then compared using the MK3DB met data with using the G-ECM (or V-ECM) met data (see Figure 6). When using the pressure data from G-ECM, the weighted RMS is improved for 55% of the baselines considered, 8% unchanged and 37% degraded. Also, 15 of the stations are improved, with a WRMS reduction up to 0.22 mm (Kokee). When using the temperature data from G-ECM, the weighted RMS is improved for 47% of the baselines considered, 19% unchanged and 34% degraded. 14 out of the 19 stations are improved, with a WRMS reduction up to 0.07 mm (Westford).

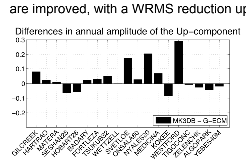

Figure 7: Differences in the annual amplitude of the Up-component between using G-ECM temperature and using the MK3DB temperature.

Annual amplitude reduction

We computed the differences in annual amplitude estimated from the stations Up-component time series obtained when using either the temperature from the MK3DB or the temperature from G-ECM (Figure 7). Westford shows a significant reduction of 0.29mm, Svetloe 0.20mm and Ny-Alesund 0.17mm.

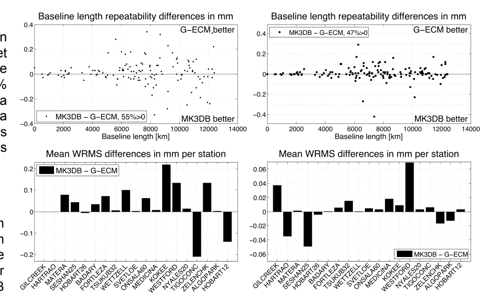

Figure 6: WRMS improvements per baseline (top) and per station (bottom) when using the G-ECM solution for pressure (left) and temperature (right) data.

Perspectives and discussion

When processing VLBI data, the use of G-ECM series improves significantly the Weighted RMS of the solution: up to 0.35mm per baseline and 0.22mm per station for the pressure and up to 0.30mm per baseline and 0.07mm per station for the temperature.

To combine data from the different techniques at co-located sites, it is essential that the same models be applied for common error sources of the different techniques to avoid inter-technique discrepancies. Therefore, to avoid bias between techniques, our strategy could be used in processing for each technique, using the same set of meteorological data for all techniques at each co-location site in the geodesy network.

References

D. P. Dee, S. M. Uppala, A. J. Simmons, et al. The ERA-Interim reanalysis: configuration and performance of the data assimilation system. In *Q J R Meteorol Soc 2011*, volume 137, pages 553-597, 2011.

A. Nothnagel. Conventions on thermal expansion modelling of radio telescopes for geodetic and astrometric VLBI. In *Journal of Geodesy*, volume 83(8), pages 787-792, 2009.

W. Zdunkowski, and A. Bott. In *Thermodynamics of the Atmosphere: A Course in Theoretical Meteorology.* Cambridge University Press, Cambridge, U. K., page 251, 2004.

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