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Improving VLBI Processing by using Homogeneous Data for Pressure and Temperature

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Abstract

Pressure and temperature affects the processing of VLBI data via the atmospheric delay and the thermal deformation of the antenna. Errors in meteorological data cause errors in the estimation of station coordinates, predominantly local Up, of up to several mm, and degrade baseline length repeatability. To improve the homogeneity of the meteorological data, we enhanced *Solve* to give users the ability to use external meteorological data. Initially we used pre-derived pressure and temperature series from ECMWF obtained from the Institute of Geodesy and Geophysics at the Vienna University of Technology. However these series contain jumps due to strategy changes, which will affect the VLBI calculations. Therefore we derived time series for all the VLBI sites from the ECMWF model ERA-Interim, using the same model for the entire period. Using this homogeneous pressure series derived from ECMWF improves the WRMS repeatability for 52% of the baselines, with 12% having unchanged WRMS repeatability, while using the temperature series derived from ECMWF improves the WRMS repeatability for 47% of the baselines considered, with 19% having unchanged WRMS repeatability.

1. Introduction. Meteorological Data Used by *Solve*

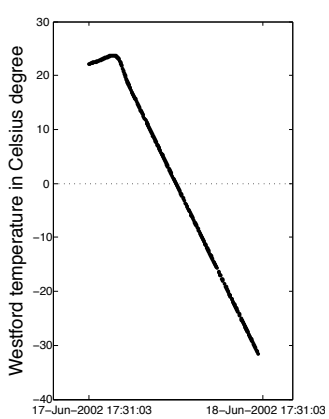

Figure 1. Westford temperature on 17/18 June 2002 according to the Calc/Solve databases. The temperature is in Celsius degrees.

Pressure and temperature are used in Very Long Baseline Interferometry (VLBI) data processing. The hydrostatic delay used to calibrate the measured delay is directly proportional to pressure. Temperature is used to calculate the linear expansion of the telescope components as VLBI telescopes are deformed by time-dependent temperature effects. Because of these effects, biases, discontinuities, and outliers in the meteorological data will affect the quality of the VLBI solutions.

Previously, in [4], we showed that the meteorological data in the *Mark III* databases (denoted MK3DB in the following) used by *Solve* in routine VLBI processing contains missing, biased, and inaccurate data. For example, at Westford we noticed discontinuities in the MK3DB pressures due to a change of sensors: after the MET3 sensor broke down, it was replaced by a GPS network meteorological sensor located 100m away from the antenna. Another example is shown in Figure 1. An abnormal temperature behavior at Westford shows a daily drop of more than 50°C during the 17/18 June 2002 session.

Another significant problem of the MK3DB is missing data. In 2008, 46 stations participated in 167 sessions, twelve of which have some missing meteorological data. Two of the major stations of the network, Zelenchukskaya and Fortaleza, were missing more than 90%. In the case of missing data, the strategy of *Solve* is to use a constant default value computed from the position of the station. In [4] we showed that the impact on the quality of the VLBI processing is significant: using the *Solve* default values, we found a degradation of the WRMS of baseline scatter of 0.12 mm over two weeks in the case of Zelenchukskaya, and of up to 1 mm over 9.5 years in the case of Westford. Hence using a constant default value to replace missing data is not a satisfactory solution. The vertical component determination is also affected by erroneous meteorological data. Simulations have shown that it varies significantly with a change in pressure (-0.12 mm/mbar for Svetloe for example).

Our results show that it is necessary to have a homogeneous meteorological data record in the MK3DB. The optimal solution would be to have a homogeneous network of meteorological sensors for VLBI, as specified for VLBI2010. As this has not been the case, we investigated another solution: using homogeneous time series of pressure and temperature derived from a model. For that, we computed pressure and temperature from the ECMWF weather model (ERA-Interim) for each VLBI site. We modified *Solve* to accept this external data.

In Section 2 we describe two alternative sources for time series of pressure and temperature: a set developed by the Vienna University of Technology (TU Vienna) for computing VMF1 and another set developed at GSFC derived from the ECMWF model ERA-Interim. In Section 3, we will quantify the improvement using these two sets of time series compared with using the data from the MK3DB.

2. Alternative Sources for Pressure and Temperature Data

Among the various possibilities for alternative sources of meteorological data, we used two sources derived from different weather models from the European Centre for Medium-Range Weather Forecasts (ECMWF).

2.1. Pressure and Temperature Time Series Developed for VMF1 Computation

The GSFC VLBI group uses the Vienna Mapping Function (VMF) provided by the IVS group of TU Vienna. The VMF was first introduced, and then updated with VMF1 [1], using a different strategy for computing the mapping function coefficients. Both VMF and VMF1 are computed using the 40 years of reanalysis data (ERA-40) from 1979 to 2001 and then operational models since 2002.

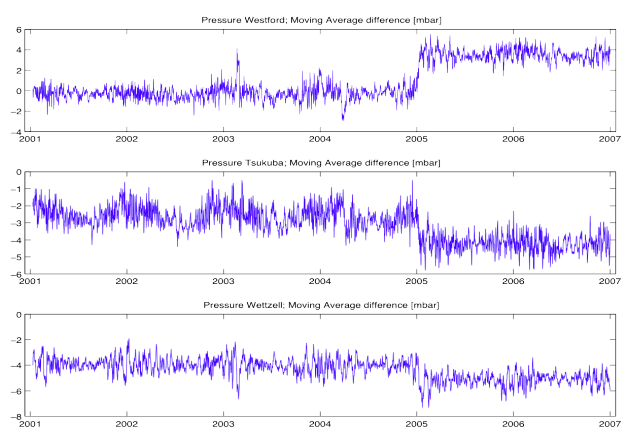

Figure 2. Moving average (window = 10 days) differences of V-ECM pressure relative to MK3DB pressure for three stations: Westford, Tsukuba, and Wettzell.

The VMF files contain the coefficients of VMF (hydrostatic coefficient and wet coefficient, hydrostatic zenith delay and wet zenith delay) as well as temperature and pressure at the site. This data is given every six hours, the same resolution as ECMWF. First, we compared these time series (called V-ECM in the following) with the data extracted from MK3DB. Figure 2 displays the moving average differences in pressure for Westford, Tsukuba, and Wettzell. Westford has a large discontinuity of 3.2 mbar, while the discontinuity for Tsukuba is −1.1 mbar and for Wettzell −1.6 mbar. This occurred when VMF was replaced with VMF1. Kouba [3] confirms our conclusions. Kouba compared the hydrostatic zenith path delays of the gridded VMF1 with the site-dependent VMF1 zenith path delays and detected biases and discontinuities up to 4 cm.

2.2. Pressure and Temperature Time Series Developed at GSFC from the ECMWF Model ERA-Interim

We select the ECMWF ERA-Interim reanalysis model [2], which is available at a 1.5° resolution from January 1, 1979. We extract the surface pressure and 2 meter layer temperature on the 1.5° × 1.5° equal angular grid for the entire Earth. Then, we extrapolate the pressure and temperature to the station height and interpolate to the position of the VLBI stations as explained below.

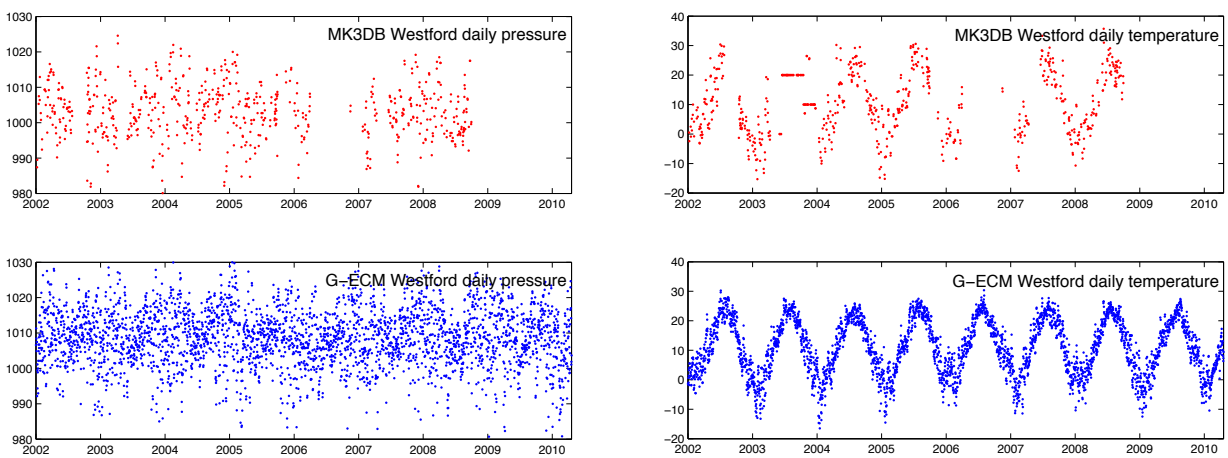

Figure 3. Daily pressure (left) and temperature (right) time series for Westford from MK3DB (top) and G-ECM (bottom).

For a given station S, the first step is to determine the four points of the ERA-Interim grid $(Q_{ij}, i, j = 1, 2)$ in the neighborhood of the station. We obtain time series of pressure and temperature given every six hours at geopotential height for each of the points Q. Then, we extrapolate the time series from the grid height to the height of the station S. After calculating the geometric height difference, we apply the lapse rate of −0.006499°K/m to adjust the temperature series to the height of the station. For the pressure, we use the barometric height formula [5]:

$$p(z) = p_0 \left(\frac{T_0 - \Gamma \Delta z}{T_0}\right)^{\frac{g}{R\Gamma}}$$

where p_0 is the reference pressure, T_0 (K) the reference temperature, Γ (K/m) the lapse rate, g the acceleration due to gravity, R the gas constant, and Δz (m) the difference in geopotential height. The third step is the bi-linear interpolation of the four sets of pressure and temperature time

series: a linear interpolation in the x-direction first and then in the y-direction. This information is publicly available for 171 VLBI sites at http://lacerta.gsfc.nasa.gov/met/ from 1979 until the current time. These time series are called G-ECM in the following. Figure 3 gives an example of the time series obtained for the station Westford, compared with the data extracted from MK3DB.

3. Using Homogeneous Data for Pressure and Temperature

In this section, we show the improvement in results obtained using external data for pressure and temperature from V-ECM or G-ECM instead of MK3DB.

3.1. Impact of the Improvement in Homogeneity of Pressure Time Series

In Figure 4 we show the improvement in results for the R1 and R4 sessions from 2002 to 2011, using the pressure from G-ECM or V-ECM rather than using the pressure from MK3DB. Using G-ECM instead of MK3DB improves 52% of the baselines while 36% get worse, and 12% are unchanged. The results for V-ECM are 51% improved, 33% worse, and 16% unchanged. When looking station by station, using G-ECM or V-ECM improves the WRMS significantly (more than 0.03 mm) for nine stations.

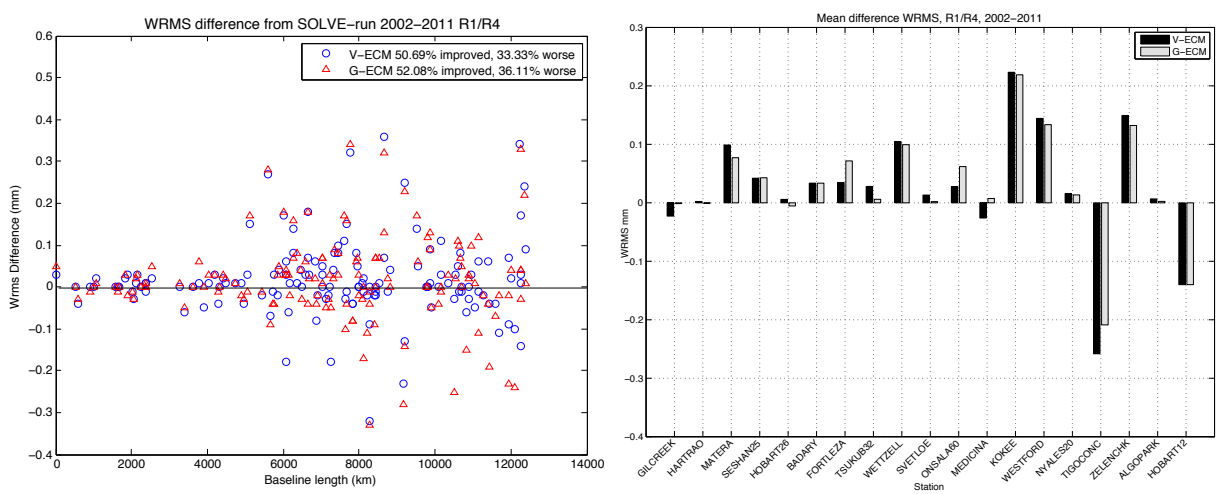

Figure 4. Left: Baseline repeatability differences, using the pressure from either G-ECM or V-ECM compared with using the pressure from MK3DB. Right: WRMS differences per station. Positive G-ECM or V-ECM values indicate improvement.

3.2. Impact of the Improvement in Homogeneity of Temperature Time Series

In Figure 5 we show results for the R1 and R4 sessions from 2002 to 2011, using the temperature from either G-ECM or V-ECM compared with using the temperature from MK3DB. Using G-ECM instead of MK3DB improves 47% of the baselines while 35% get worse, and 18% are unchanged. The results for V-ECM are 45% improved, 43% worse, and 12% unchanged. When looking station by station, using G-ECM or V-ECM improves the WRMS significantly (more than 0.01 mm) for seven stations.

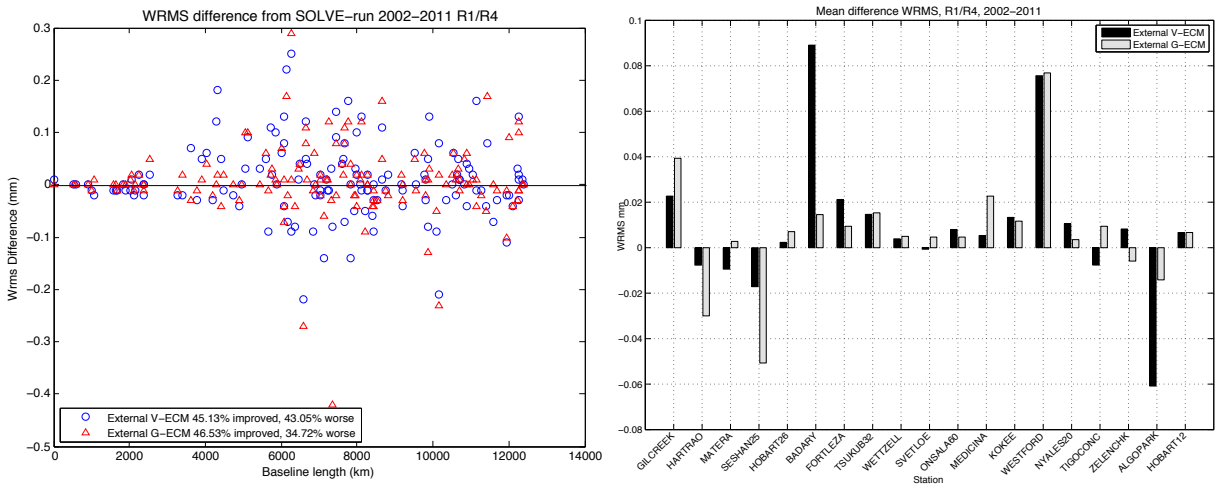

Figure 5. Left: Baseline repeatability differences, using the temperature from either G-ECM or V-ECM compared with using the temperature from MK3DB. Right: WRMS differences per station.

4. Conclusions

The *Mark III* databases used to process VLBI data with *Solve* contain missing and inaccurate data that affects the quality of the solutions. Using external sources of data derived from ECMWF such as V-ECM or the G-ECM newly developed at GSFC significantly improves the WRMS of the solutions. G-ECM is available online for 171 VLBI sites and can be extended to other stations, upon request.

Since the processing results are significantly affected by the homogeneity of the data, a global reanalysis of the VLBI data may be necessary.

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