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Effects of Surface Pressure and Temperature on the VLBI Reference Frames

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Abstract. We quantify and compare effects on the VLBI reference frames and tropospheric parameters obtained by VLBI analysis applying meteorological input data from various sources: in situ measurements at the VLBI sites, interpolated values from analysis data of the European Centre for Medium-Range Weather Forecasts (ECMWF), empirical values obtained from the Global Pressure and Temperature model (GPT), and constant values for each site from the Berg model. While the surface pressure is necessary to separate hydrostatic and wet tropospheric delays, the thermal deformation models of the VLBI antennas depend on the temperature. While significant effects can be found on ZWD, vertical position time series, and sessionwise scale factors, the celestial reference frame and Earth orientation parameters show no significant variations applying meteorological data from the various sources.

1. Introduction

The analysis of space geodetic techniques at radio wavelengths (GNSS, VLBI, DORIS, etc.) is usually refined using meteorological quantities such as surface pressure and temperature at each site. In the case of VLBI, meteorological surface data can be used for three models to reduce the group delay, the primary observable of VLBI data analysis:

- hydrostatic (a priori) zenith delay,
- atmospheric (pressure) loading,
- antenna thermal deformations.

While the first two models require pressure values, the thermal deformations depend on the outside temperature, or the inside temperature in case the antenna is covered by a radome. In this study effects of atmospheric loading are not considered, i.e. atmospheric loading corrections [5] are applied but remain unchanged throughout the study. We investigate how pressure from various sources affects the determination of hydrostatic zenith delays and how temperature from various sources changes the antenna thermal deformation corrections, both leading to variations in the primary geodetic parameters of interest: Terrestrial Reference Frame (TRF), Celestial Reference Frame (CRF), and Earth Orientation Parameters (EOP). Since the effects on the CRF and EOP are insignificant and of non-systematic nature, we focus on the TRF, vertical station position time series, and tropospheric zenith wet delays (ZWD). The reference temperature for the thermal deformation is realized as the mean temperature value from the in situ data over the whole observational history at the site (Malkin, pers. comm.).

2. Sources of Meteorological Data

Various sources of meteorological data maintain pressure and temperature and can be applied for VLBI analysis, e.g.:

- in situ data,
- numerical weather models,
- the Global Pressure and Temperature model (GPT),
- the Berg atmosphere model.

Since meteorological data (pressure and temperature) are continuously recorded during experiments at the VLBI sites and reported in standard VLBI data files (station log file or NGS file) the usual way for VLBI analysis is to simply use these records. However, with in situ data care has to be taken for two reasons: One reason is, that often some registrations are missing, and some other values are obviously outlying. It is necessary to replace both, missing values and outliers by an adequate substitute. For replacement, we suggest to interpolate from numerical weather models (NWM) such as the ERA-40 reanalysis model of the ECMWF. Such values can be accessed for all VLBI sites and throughout the VLBI observational history (1979.0 until today) from the URL http://mars.hg.tuwien.ac.at/~ecmwf1/VLBI/. The other reason is, that in some of the meteorological records significant shifts of the running mean value are present; the time series need to be homogenized. Shifts of the pressure records exceeding 2 hPa were already reported [3]. The temperature records show shifts of the running mean value, too. Due to missing meta data about the meteorological sensors, i.e. epochs and results of sensor calibration and reductions of pressure readings to the mean sea level (geoid), we cannot rely on the presently available mean value of the in situ data. Thus, we suggest to shift the mean value of sensor registrations to the mean value represented by the NWM. In doing so, we concatenate the global consistency of NWM and the higher temporal resolution of met sensors recording in situ.

If neither in situ data nor NWM data are available, we suggest to obtain meteorological data by the Global Pressure and Temperature model [2] which is a spherical harmonic expansion of degree and order nine of the mean values and annual signals of pressure and temperature. In this respect, GPT should replace the simple Berg model [1].

Fig. 1 shows bias and RMS of temperature and pressure w.r.t. in situ values of twelve representative IVS network stations. The largest biases can be found between Berg and the in situ data. GPT shows still significant but much smaller biases. The biases between NWM and the in situ data are almost zero, since the mean values of the in situ data were shifted to match the NWM. They are not perfectly zero, because for the adjustment of the mean value inherent outliers were considered, though outliers were not considered for the determination of the biases shown in the plot. The RMS of GPT is slightly smaller than that one of Berg in the case of pressure and significantly smaller for the temperatures. This is due to the fact that pressure variations are more pronounced at weekly time scales, whereas the temperature clearly shows a seasonal pattern, which is well modelled by GPT's annual term. Variations at weekly time scales are not considered in both models, neither GPT nor Berg.

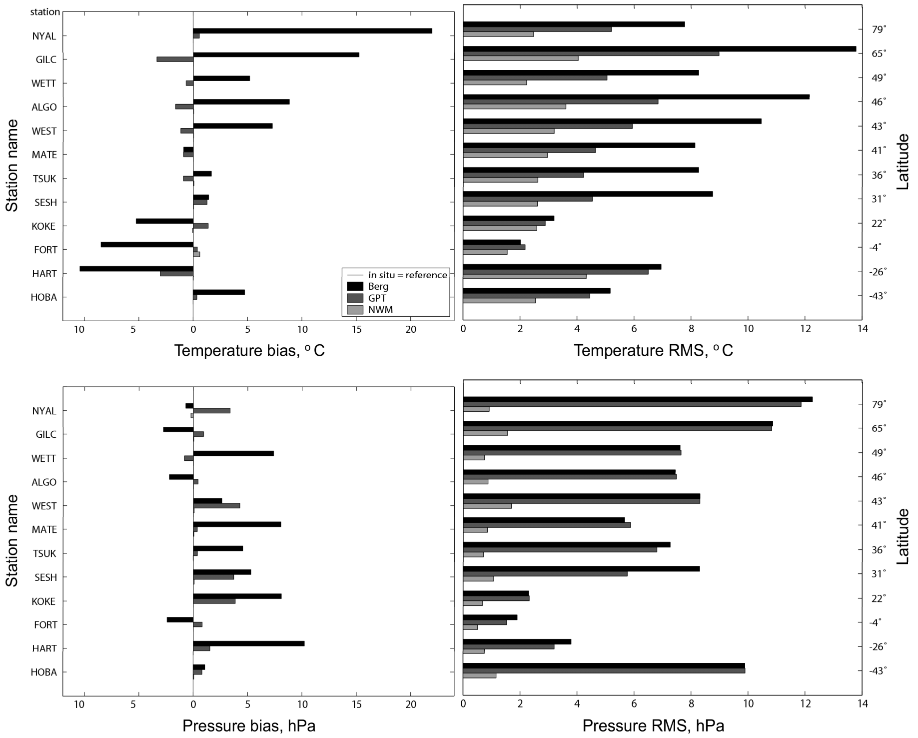

Figure 1. Bias and RMS of temperature and pressure w.r.t. in situ meteorological data of 12 IVS network stations ordered from northern latitudes (*top*) to southern latitudes (*bottom*)

3. Effects of Atmospheric Pressure and Temperature on Geodetic Parameters

Since pressure biases are not systematically positive or negative most of the impact on the TRF as a whole gets balanced out using one of the prior introduced pressure sources. The seven parameters of a similarity transformation between a TRF using in situ pressure data and a TRF applying one of the other sources are almost all insignificant. Nevertheless, the scale differs by 0.16 ppb, what equals 1.0 mm at one Earth radius, between TRFs derived using in situ or Berg pressure, respectively. Investigating time series the effects become more obvious: an assumed change of pressure of $\delta p = 1$ hPa corresponds to a change of zenith hydrostatic delay (ZHD) of $\delta ZHD = 2.3$ mm. A large fraction of δZHD can be absorbed by the zenith wet delay (ZWD), however, since hydrostatic and wet mapping functions do not exactly equal, a smaller fraction of δZHD affects the adjustments of other (geodetic) parameters. Due to correlations the station vertical position gets deformed in particular. The amount of deformation of geodetic parameters depends on how much the hydrostatic and wet mapping functions differ, and this difference depends on the latitude of the site and the elevation angle under which a specific observation is carried out. Stations at high latitudes more often observe at low elevations, therefore, the station latitude turns out to be the key factor for pressure dependent station height errors. In addition, pressure variations are more pronounced at higher latitudes. At station GILCREEK, Gilmore Creek, Alaska, USA, e.g. the vertical station position shows variations of up to 10 mm from peak to peak between Berg and in situ data, solely depending on the type of pressure data used. At some stations e.g. HARTRAO, Hartebeesthoek, South Africa, the pressure biases induce biases of the vertical station positions (Tabl. 1).

The temperature generally shows the well known diurnal and annual cycles. At high latitudes the annual cycle is more pronounced, whereas at low latitudes it can barely be found. GPT and Berg models do not consider diurnal cycles at all and thus, it is impossible to model diurnal antenna thermal deformations with temperatures of these models, whereas the NWM with its six-hourly resolution is capable to reproduce diurnal cycles. Significant differences in sessionwise scale factors can be found using Berg temperature where the annual amplitude

Table 1. Bias and RMS of pressure, ZWD and station height w.r.t. the solution using in-situ atmospheric pressures at station HARTRAO

	NWM		GPT		Berg	
	bias	RMS	bias	RMS	bias	RMS
Pressure, hPa	0.00	0.34	1.56	2.93	10.14	3.58
ZWD, mm	0.32	1.72	−2.08	7.18	−21.04	8.54
Station height, mm	−0.01	1.23	−0.46	1.54	−1.45	1.77

reaches 0.2 ppb (1.3 mm at one Earth radius), whereas in case of the GPT the amplitude stays well below the 1 mm level. A more detailed paper [4] is going to be published soon.

4. Conclusions

Since significant effects can be found on zenith delay and vertical position estimates the usage of precise and homogeneous pressure data is mandatory for the analysis of space geodetic techniques at radio wavelengths. To avoid seasonal deformations of the TRF determined by VLBI, thermal antenna deformations should be accounted for using precise and homogeneous temperature data. The most precise and accurate meteorological data for the analysis are in situ data after shifting the running mean value to match a global numerical weather model, e. g. ERA-40 of the ECMWF. For the replacement of missing values a numerical weather model should be used. For each VLBI site, such values are accessible from the URL http://mars.hg.tuwien.ac.at/~ecmwf1/VLBI/ and can be linearly interpolated to the epoch of the observation.

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