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"Validation of Mean Temperature Values as Provided by GPT"

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1. Introduction

For modeling the thermal deformation of VLBI telescopes, a reference temperature is needed. In the past, for this temperature the average of temperatures from the site/session log files recorded during a particular time interval was used. However, this approach is impossible with new telescopes and those with a short history of observations. Furthermore, the reference temperatures of all telescopes should refer to the same epoch and they should be easily calculable. A one degree Celsius change in the reference temperature affects the reference height of a 20 m telescope only by 0.1 mm assuming that the height of the elevation axis is generally at about half the telescope's diameter.

In this memo, we compare temperature values from three different sources (grid values from a numerical weather model, values from an empirical model, and values from meteorological sensors at the sites), and we give a summary about the advantages and disadvantages of each of them when being used to define the reference temperature for the thermal deformation of VLBI antennas.

2. Comparison of temperature values

The validation of temperature values is carried out at the surface of the Earth which is determined as follows: The geopotential in m^2/s^2 is downloaded from the ECMWF for the surface of the Earth with a resolution of 2.0° in latitude times 2.5° in longitude. Thereafter, the geopotential is divided by 9.80665 m/s^2 to get 'geopotential meters', and geoid undulations from the Earth Gravity Model EGM96 with the same grid resolution are added to get ellipsoidal heights of the Earth surface. These heights were used for the following comparisons.

Reference temperature from ECMWF data:
2.0° times 2.5° grids of surface temperature values at six-hourly epochs from 1994.0 to 2007.0 have been derived from pressure level data of the ECMWF, i.e. surfacetemperature values have been determined by interpolating vertically in the pressure levels. The mean grid (over al six-hourly grids) is used as reference for the following comparison.

Global Pressure and Temperature GPT (Boehm et al., 2007):

GPT is a spherical harmonic expansion up to degree and order nine. In fact, it contains spherical harmonic expansions for the geoid undulations and for proxies of mean sea level temperature (and pressure) values which were derived from surface temperature assuming a linear decrease of temperature with height (–0.65° C per 100 m). To get the temperature at any arbitrary location on the Earth surface, the spherical harmonic expansion at mean sea level is evaluated and the same linear decrease is applied to get the temperature values on the Earth surface. Since GPT accounts for an annual variation of the temperature, April 28 (mod. Julian date 44357.3125) has to be used to get the mean values.

Average of the temperature values from the session log files:

Zinovy Malkin determined averages of the recorded temperature values from the session log files which have been used for modelling the thermal deformation of VLBI telescopes so far. These values are distributed via the webpage of the IVS Analysis Coordinator.

2.1. Comparison between the reference values from the ECMWF and GPT

Figure 1 illustrates the temperature differences of GPT with respect to the ECMWF 'reference values' described above. The differences between GPT and the reference values are below 3° C for 94% of the whole Earth surface and 88% if only land is considered. Apart from a few isolated grid cells in the Himalayan region where the difference exceeds several tens of degree Celsius, the maximum differences stay below 5° C (see Table 1).

Relatively large deficiencies of GPT can be seen in regions with big height variations of the Earth surface. Reasons for the differences are: a) The limited resolution of a spherical harmonic expansion up to degree and order nine. b) The linear decrease of the temperature with height (0.65° C per 100 m) is not accurate enough for large height differences, and it might not be applicable for every region on the Earth.

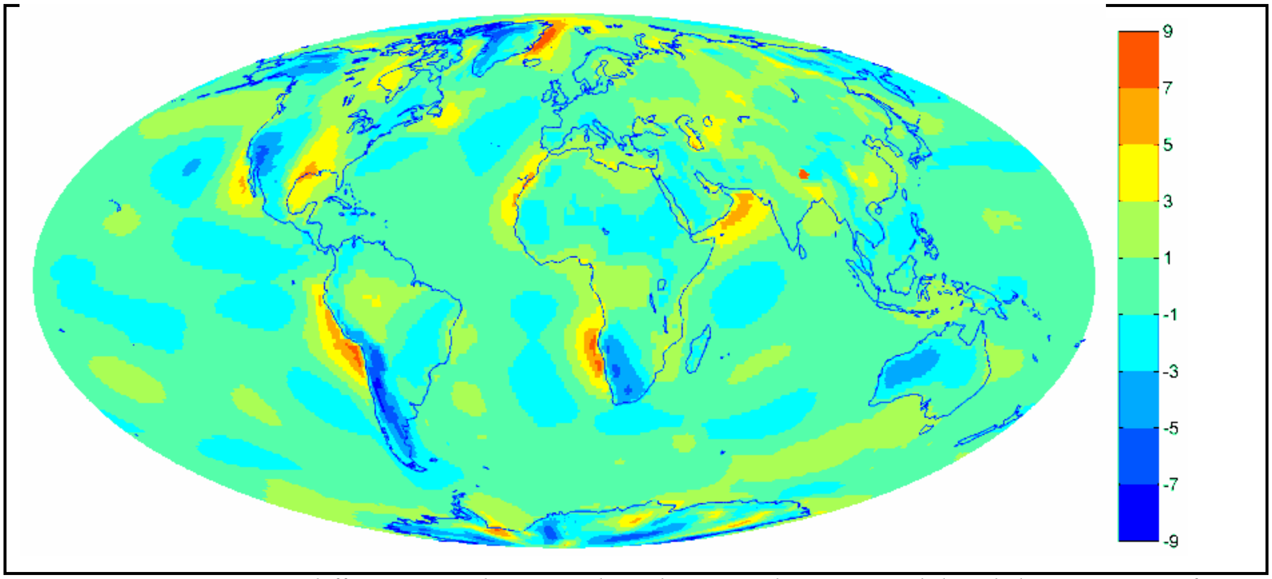

Figure 1. Temperature differences in degree Celsius between the GPT model and the ECMWF reference field.

Table 1. Percentage of the area with temperature differences below a certain threshold (3 and 5 degree Celsius) for GPT with respect to reference values from the ECMWF.

	< 3°	< 5°
land + ocean	94 %	98 %
land	88 %	97 %

2.2. Comparison between GPT and the mean temperature values from the session log files

Table 2 shows the differences of the temperature values as provided by GPT and as determined by averaging over the session log files (as provided by Zinovy Malkin). (The values are taken from an Email by A. Nothnagel of 12 February 2008). Apart from a few stations, the differences stay below 5° C.

Table 2. Values from A. Nothnagel's Email of 12 February 2008. The columns are station name, mean temperature from meteorological sensors (provided by Z. Malkin), mean temperature from GPT, and the difference in degree Celsius. The stations are ordered by difference in the temperature. It has to be mentioned here that stations like SEST or YELLOWKN participated only in a small number of sessions. Thus, the mean value of the temperature recordings in the log files is far from being representative for the yearly average.

FD-VLBA	17.0	25.9	-8.9
DSS45	13.0	18.5	-5.5
DSS15	16.0	19.0	-3.0
DSS65	15.0	17.9	-2.9
NL-VLBA	11.0	13.9	-2.9
BR-VLBA	12.0	14.0	-2.0
EFLSBERG	10.0	11.8	-1.8
URUMQI	3.0	4.5	-1.5
NOTO	19.0	19.9	-0.9
MEDICINA	14.0	14.6	-0.6
NRAO_140	9.0	9.4	-0.4
NRAO20	9.0	9.4	-0.4
NRAO85_1	9.0	9.4	-0.4
NRAO85_3	9.0	9.4	-0.4
HOBART26	13.0	13.2	-0.2
KAUAI	17.0	17.0	0.0
MATERA	14.0	14.0	0.0
PENTICTN	10.0	10.0	0.0
KOKEE	17.0	16.9	0.1
SESHAN25	19.0	18.9	0.1
TIGOWTZL	8.0	7.9	0.1
WETTZELL	8.0	7.8	0.2
RICHMOND	25.0	24.6	0.4
HATCREEK	10.0	9.3	0.7
GOLDVENU	20.0	19.0	1.0
PIETOWN	9.0	7.7	1.3
KASHIM34	16.0	14.5	1.5
KASHIMA	16.0	14.5	1.5
SC-VLBA	27.0	25.5	1.5
OHIGGINS	-1.0	-2.6	1.6
CRIMEA	16.0	14.1	1.9
HARTRAO	18.0	16.1	1.9
LA-VLBA	12.0	10.1	1.9
JPL_MV1	18.0	15.9	2.1
NYALES20	-2.0	-4.1	2.1
FORTLEZA	29.0	26.7	2.3
HAYSTACK	12.0	8.6	3.4
ROBLED32	16.0	12.4	3.6
HN-VLBA	11.0	7.1	3.9
OVRO_130	14.0	10.0	4.0
KP-VLBA	15.0	10.2	4.8
MOJAVE12	18.0	13.1	4.9
OV-VLBA	15.0	10.1	4.9
SANTIA12	17.0	11.8	5.2
ALGOPARK	10.0	4.7	5.3
GILCREEK	2.0	-3.3	5.3
MK-VLBA	6.4	0.6	5.8
TIDBIN64	20.0	14.0	6.0
MARPOINT	21.0	14.3	6.7
SEST	16.0	3.5	12.5
YELLOWKN	12.0	-0.5	12.5

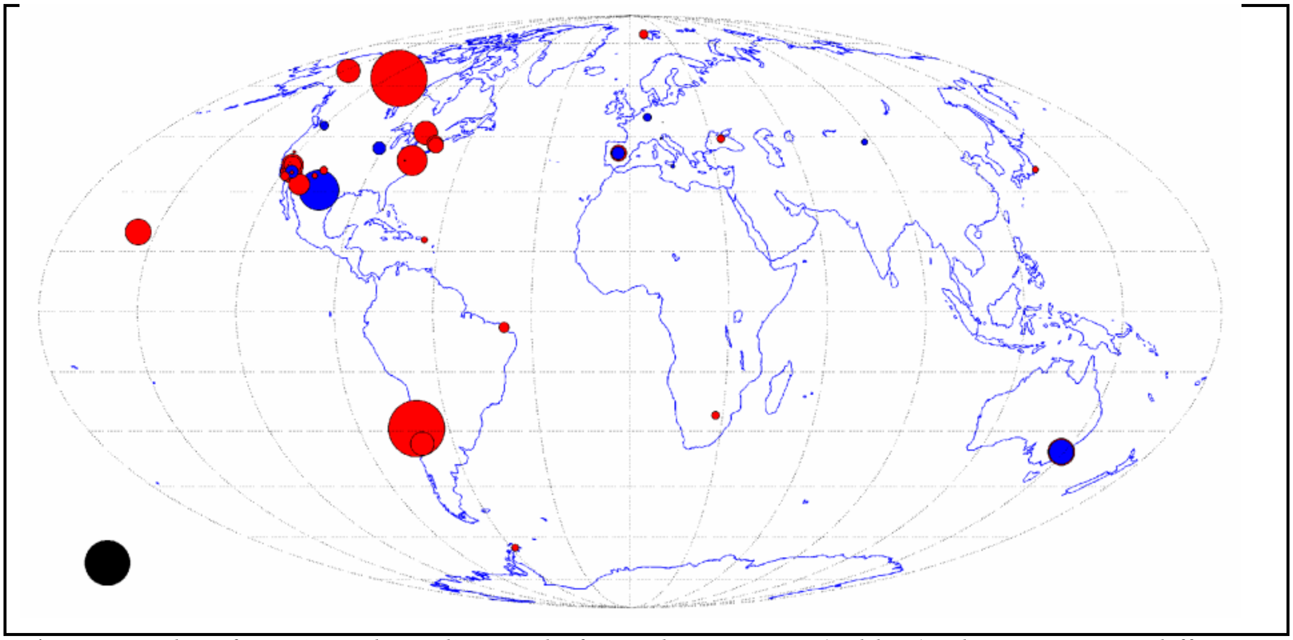

Figure 2. *Values from A. Nothnagel's Email of 12 February 2008 (Table 2). The temperature differences scale with the radii of the circles, and the black circle at the lower left side of the plot corresponds to a temperature difference of 10 degrees. Blue circles correspond to negative temperature differences, red circles to positive temperature differences in the sense log files minus GPT.*

3. Summary

Table 3. Overview of potential sources for the determination of the reference temperature.

	ECMWF grids	Log files	GPT
rough estimate of the accuracy of the reference temperature	used as reference in this study	±2° C (but outliers possible)	±2° C
empirical	no	no	yes
easily calculable	no	no	yes
referred to same epoch	yes	no	yes
applicable for new stations	yes	no	yes
global coverage	yes	no	yes

Table 3 summarizes the advantages and disadvantages of the various reference temperatures. Although the accuracy of the temperature sensors at the stations - if properly calibrated - would be superior to the other methods, there are several disadvantages with this option. ECMWF grids are very accurate but they do not implicitly include height-dependent temperature corrections or interpolation routines, which are both realized with GPT.

Heinkelmann et al. (2008) applied reference temperatures from GPT in global VLBI solutions and they found insignificant scale changes compared to the use of reference temperatures derived from the log files.

References

Boehm, J., R. Heinkelmann, and H. Schuh (2007). Short note: A global model of pressure and temperature for geodetic applications. Journal of Geodesy, Vol. 81, No. 10, pp. 679-683.

Heinkelmann, R., J. Boehm, H. Schuh (2008). The influence of meteorological input data on the VLBI reference frames. In: International IAG/FIG Symposium Geodetic Reference Frames GRF2006, IAG Symposium Series, Springer Verlag, in press.