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Thermal Deformation of Radio Telescopes Onsala and Wettzell

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Abstract

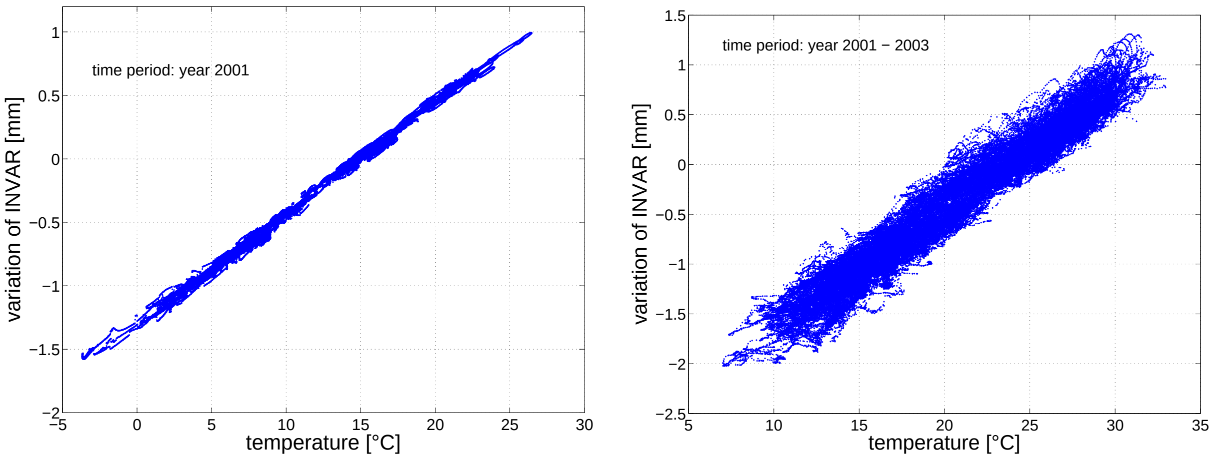
Geodetic VLBI is one of the major space geodetic techniques that contributes to the International Terrestrial Reference Frame (ITRF). Errors due to atmospheric propagation effects, loading phenomena and technical reasons have been minimized during the last years. Today the accuracy of geodetic VLBI results is at the sub-cm level. For further improvements the thermal deformations of the radio telescopes have to be taken into account in the analysis of geodetic VLBI data. Thermal deformation effects typically contain seasonal and daily signatures. The annual amplitudes can reach several millimeters in particular for the vertical position of the antenna reference point. The magnitude depends on the design of the antenna structure, the material, and on environmental influences. Two radio telescopes, Onsala (Sweden) and Wettzell (Germany), are equipped with measurement systems that are based on invar rods or invar wires and provide direct observations of the vertical variation of the telescope reference points. Based on these measurements we developed models that can be used to account for thermal deformations as a function of environmental temperature. Direct observations of thermal deformation of the radio telescopes at Onsala and Wettzell are presented and the corresponding models for thermal deformation are discussed.

1. Measurement Facilities of the Onsala Antenna

The measuring system of the 20 m telescope at Onsala station has been installed in 1996 and was documented under the project title "The Pisa Project" (Johansson et al., 1996 [1]). It is equipped with 16 temperature sensors in the construction of the tower, two temperature sensors recording the air temperature inside the radome and two temperature sensors recording the air temperature inside the tower. The vertical deformation is measured with an invar rod and an inductive position sensor. Figure 1 (left) shows the high correlation (ρ=0.999) between the mean concrete temperature of the telescope tower and the measured vertical deformation.

2. Measurement Facilities of the Wettzell Antenna

In Wettzell, temperature is recorded at three locations inside the telescope tower. One of the sensors gives the concrete temperature, and an invar wire measurement system provides the vertical deformation. The invar measurement system uses an invar wire that is attached to a 1 kg weight. The weight of the anchor was doubled on February 28, 2000. The sampling rate for recording the data is 15 minutes (Zernecke, 1999 [4]). Figure 1 (right) shows the correlation (ρ=0.973) between the measured temperature of the antenna tower and the measured vertical deformation which is almost as high as for Onsala.



ONSALA

Measured vertical height changes of the tower of the Onsala 20 m telescope versus mean temperature of all 16 temperature sensors in the antenna tower for 2001.

WETTZELL

Measured vertical height changes of the Wettzell 20 m telescope versus temperature values of the sensor T2 for the period 2001 to 2003.

Figure 1. Correlation between measured mean antenna tower temperature and hight deformation for Onsala (left) and Wettzell (right).

3. Model for Correction

Figure 1 shows a very high correlation between the temperature of the antenna structure and its vertical deformation. Thus, if we know the temperature of the construction we can easily compute a correction, *corr* [mm], due to vertical thermal deformation by taking the expansion coefficient of the material and the dimensions of the antenna (Equation 1), where γ_f and γ_a are the expansion coefficients of concrete ($1.0{\cdot}10^{-5}$ 1/°C) and steel ($1.2{\cdot}10^{-5}$ 1/°C), h_f [m] is the height of tower, h_p [m] the height of the antenna part, T_i [°C] the tower temperature, and T_0 [°C] the reference temperature.

$$corr = [\gamma_f \cdot (T_i - T_0) \cdot h_f + \gamma_a \cdot (T_i - T_0) \cdot h_p] \cdot 1000 \tag{1}$$

Since at most VLBI stations there are no temperature data available for the antenna structures, but sensors exist that record the air temperature, the idea of modeling the antenna temperatures as a function of the air temperatures is rather obvious. The model must take into account that the deformation caused by variation of the air temperature has a time lag, and that the antenna material stores temperature for a certain period of time. The time lag amounts to about 6 hours with concrete and to about 2 hours with steel constructions (Nothnagel et al., 1995 [2]). The model should contain annual and diurnal temperature variations.

The model for the Onsala antenna was realized by a digital filter technique. The model temperature T_m at a time i is calculated as weighted sum of the recent air temperatures, with temperatures from earlier time periods getting lower weights than temperatures close to time epoch i. This weighting is done exponentially. The sum is normalized by dividing it by the sum of the weights. This is done for a short and a long period term. To get the very short period temperature variation, too, the short period term uses a temperature interval of 12 hours and the long period term uses an interval of three days before epoch i. The weighting factors q which are different for short and long period effects are adjusted empirically. The factors f and the *offset* are calculated by least-squares adjustment.

$$T_{mi} = f_{short} \cdot \frac{\sum_{j=i-z_{short}}^{i} T_{Aj} \cdot q_{short}^{(z_{short} - (i-j) \cdot d)}}{\sum_{j=i-z_{short}}^{i} q_{short}^{(z_{short} - (i-j) \cdot d)}} + f_{long} \cdot \frac{\sum_{j=i-z_{long}}^{i} T_{Aj} \cdot q_{long}^{(z_{long} - (i-j) \cdot d)}}{\sum_{j=i-z_{long}}^{i} q_{long}^{(z_{long} - (i-j) \cdot d)}} + offset \qquad (2)$$

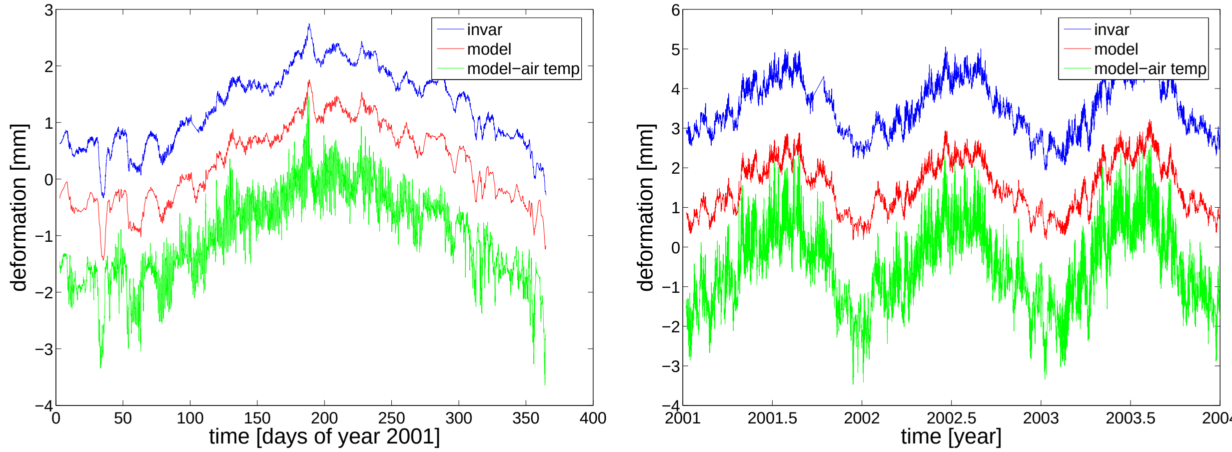
The parameters of the model are T_{mi}, and T_{Aj} which represent the modeled telescope temperature at epoch i and the observed air temperature at epoch j, the sampling rate d (e.g. 5 min), the coefficients q_{short} and q_{long} for long period and short period variations of the outside temperature, the weight factors f_{short} and f_{long} for the short and long period terms, and finally z_{short} and z_{long} which express memory effect for 12 hours and 3 days, respectively (Equation 2). The parameters of this model were determined for the Onsala telescope by least-squares adjustment based on the time series of outside air temperature and temperature of the telescope structure. All details of this modeling approach are described in Wresnik et al. (2005)[3].

Table 1. Parameters for the filter model and standard deviations

Parameter	Onsala	Wettzell
q_{short}	0.999	0.99999
q_{long}	0.99999999	0.9999999
f_{short}	0.19316	0.28161
f_{long}	0.72798	0.44132
$offset$	4.42°C	13.62°C
rms temperature	0.82°C	1.42°C
rms deformation	0.10 mm	0.13 mm

4. Conclusions

The use of highly precise terrestrial measurement facilities for the vertical deformation (invar rod or invar wire) shows a very high correlation between the measured temperature of the antenna structure and the vertical deformation. Thus, the vertical thermal deformation of the VLBI antenna can be modeled very well if the antenna temperature is precisely known and added to the logfile. The presented model contains the tower temperature which can be approximated by the air temperature that is available at most VLBI stations. For the Onsala antenna we are able to model the tower temperature with an rms of 0.82°C and for the calculated vertical deformation we achieve an rms of 0.10 mm. The same strategy was used to design a model for the Wettzell antenna. The results for this antenna during the years 2001 to 2003 give an rms of 1.42°C for the



ONSALA WETTZELL

Figure 2. Measured vertical deformation (upper curve) and the calculated antenna deformation using the modeled temperature (central curve) and finally using the measured air temperature (lower curve), which is stored in the VLBI logfiles (left for the Onsala antenna and right for the Wettzell antenna). The curves are plotted with an offset of 1 mm for Onsala and 2 mm for Wettzell for better illustration.

temperature and an rms of 0.13 mm for the vertical deformation.

References

[1] Johansson, L.A., F. Stodne and S. Wolf, The Pisa Project, Variations in the height of the foundation of the 20 meter radio telescope, Research Report No 178, 1996.

[2] Nothnagel, A., M. Pilhatsch and R. Haas, Investigations of Thermal Height Changes of Geodetic VLBI Radio Telescopes, Proceedings of the 10th Working Meeting on European VLBI for Geodesy and Astrometry, 121-133, edited by R. Lanotte and G. Bianco, Matera, 1995.

[3] Wresnik, J., R. Haas, J. Boehm and H. Schuh, Thermal deformation of VLBI antennas, Proceedings of the 17th Working Meeting on European VLBI for Geodesy and Astrometry, 45-50, edited by M. Vennebusch and A. Nothnagel, April 21-23, Noto, 2005.

[4] Zernecke, R., Seasonal Variations in Height demonstrated at the Radiotelescope Reference Point, 13th Working Meeting on European VLBI for Geodesy and Astronomy, 15-18, edited by W. Schlueter and H. Hase, Viechtach, 1999.