# Optimal time lags to use in the thermal deformation modeling of VLBI Antennas

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## Introduction

Thermal expansion of VLBI antennas has been proven a significant effect changing the height of the VLBI reference point by as much as 20mm. Nothnagel defined a conventional model in his paper "Conventions on thermal expansion modeling of radio telescopes for geodetic and astrometric VLBI" (2009) [4]. This model considers a time delay for the variations in temperature to affect the antenna, depending on the telescope structures and its component: the time lag is of 2-hour for a steel telescope structure and of 6-hour for a concrete one. Those two time lags have been determined 1) for the 2-hour time lag of the reference point in Nothnagel et al. (1995) [3] studying the VLBI station Hartebeesthoek; 2) for the 6-hour time lag of the foundation in Elgered & Carlsson (1995) [1] studying the VLBI station Onsala 20-m.

The thermal expansion model is implemented in *Solve*. In this study, we investigate which time lags are optimal. We compared different solutions and look at the WRMS of the solution per baseline, as well as the average per station to identify systematic effects.

## Studied VLBI solutions

The set of data used is 932 R1 and R4 sessions available from January 2002 to March 2011, for a total of nineteen stations. We run solutions with *Solve* using different options:

1) No thermal deformation model is used, therefore, no temperature is used neither. This solution is called **NoTD**;
2) The thermal deformation model is used with session-based average temperatures from the databases (recorded onsite when available, constant default value otherwise). This solution is called **Average**;
3) The thermal deformation model is used with G-ECM temperatures (homogeneous set of temperature time series derived from the ECMWF ERA-Interim reanalysis model, see Juhl et al. (2012) [2] for details) and different time lags for the antenna ($\Delta t_a$) and the foundation ($\Delta t_f$) ranging from 0 to 9 hour: 99 solutions with time lags different from (0,0) and one solution considered without any time lag (0,0). These solutions are called **GECM{X}{Y}**, where X is $\Delta t_a$ and Y is $\Delta t_f$.

## Using the Thermal Deformation Modeling

We compare the solutions Average, GECM00 and GECM26 with the solution NoTD. The GECM26 corresponds to the conventions in Nothnagel (2009) [4].

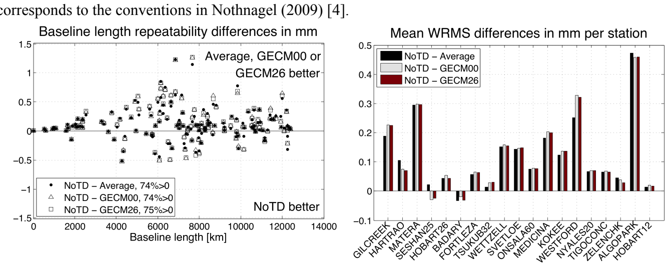


**Figure 1** – Differences in baseline length repeatability between using no thermal deformation model in *Solve* (**NoTD**) and using the thermal deformation model with the **Average** *Solve* option (points), or using the thermal deformation model with G-ECM temperature and no time lags **GECM00** (triangles), or using the thermal deformation model with G-ECM temperature and (2,6) time lags **GECM26** (squares).

| | NoTD - Average | NoTD – GECM00 | NoTD – GECM26 |
|---|---|---|---|
| >0 | 74.3% | 74.3% | 75.0% |
| =0 | 24.3% | 22.2% | 22.9% |
| <0 | 1.4% | 3.5% | 2.1% |
| Max. value | 1.23mm | 1.26mm | 1.27mm |

**Table 1** – Percentage of baselines with improvement and maximum value.

Figure 1 and Table 1 show that using the thermal deformation with session-based average temperatures from the databases (with and without time lags) improves the baseline length repeatability of the solutions up to 1.27mm and for up to 75% of the baselines. The nineteen stations WRMS are also reduced up to 0.47mm (Algopark), except for Seshan25 and Badary. This demonstrates using the thermal deformation modeling improves significantly the VLBI solutions.

## Optimal time lags for $\Delta t_a$ and $\Delta t_f$

In this section, we look at the **GECM{X}{Y}** solutions in detail to determine the optimal time lags for the antenna ($\Delta t_a$) and the foundation ($\Delta t_f$).

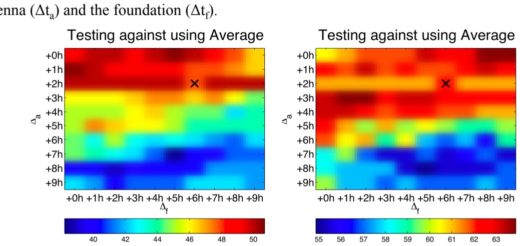


**Figure 2** – Percentage of baselines with WRMS reduction when using G-ECM temperature with or without time lags, against using the Average option in *Solve*. Each box correspond to one solution. Example: the box (0,0) corresponds to GECM00. Left: The differences in WRMS are strictly positive. Right: The differences in WRMS are positive or equal to 0. The cross indicates the value (2,6) which is the conventions value from Nothnagel (2009) [4].

In Figure 2, we compare the percentage of baselines with WRMS reduction when using G-ECM temperature with or without time lags, against using the Average option in *Solve*. The conventions value from Nothnagel (2009) [4] is not the optimal value, but the difference in percentage is relatively low: when considering only the strictly improved baselines, the value for (2,6) is 47.9% while the value for the optimal time lags is 50.7%; and when considering the improved or unchanged baselines, the value for (2,6) is 62.5% while the optimal gives 63.9%. In Figure 3, we look at the impact of varying one time lag when the other is fixed. In both Figures, we see that the time lag for the antenna should not exceed 5-hour, and should preferably be 2-hour or less. When considering a fixed time lag for the antenna (see Figure 3), varying the time lag for the foundation does not modify significantly the percentages.

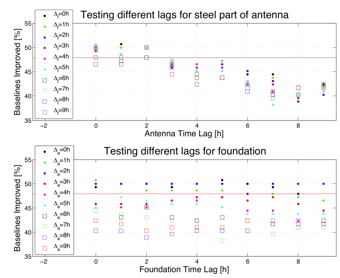


**Figure 3** – Percentage of baselines with improved WRMS when using the thermal deformation modeling with different time lags compared to using the thermal deformation modeling with a session-based Average temperature from the databases. Top: $\Delta t_f$ is fixed, $\Delta t_a$ is varying. Bottom: $\Delta t_a$ is fixed, $\Delta t_f$ is varying.

We look at the different information available for the stations: antenna diameter, height and depth of foundation, length of the fixed axis, length of the axis offset, distance from the movable axis to the antenna vertex, and height of the sub-reflector above the vertex. We notice significant correlations for two of these when comparing with the maximum WRMS improvement per station, that are plotted in Figure 4.

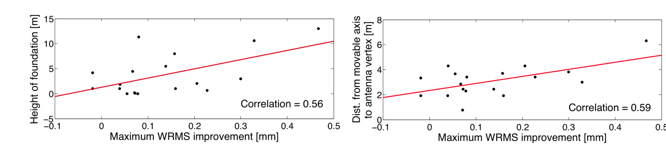


**Figure 4** – Correlation between the WRMS improvement per station and the height of the foundation (left), or the distance from the movable axis to the antenna vertex (right).

The correlation with the height of foundation reaches 0.56, when the correlation with the distance from the movable axis to the antenna vertex reaches 0.59.

When computing the correlation between the optimal time lag for the antenna and the antenna diameter, a correlation of 0.53 is found, suggesting that the bigger the antenna is, the slower it expands.

## References

[1] G. Elgered, and T.R. Carlsson. Temperature Stability of the Onsala 20-m Antenna and Its Impact on Geodetic VLBI. Proceedings of the 10th working meeting on European VLBI for geodesy and astrometry, pages 69-78, 1995.

[2] J. Juhl, K. Le Bail, J. Gipson, D. MacMillan. Improving VLBI processing by using homogeneous data for pressure and temperature. Proceedings of the 7th IVS General Meeting, 2012.

[3] A. Nothnagel, 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, pages 121-133, 1995.

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

[5] J. Wresnik, R. Haas, J. Boehm, and H. Schuh. Modeling thermal deformation of VLBI antennas with a new temperature model. In Journal of Geodesy, vol. 81, pages 423-431, 2007, doi:10.1007/s00190-006-0129-2.

## Conclusions and discussion

Using the thermal deformation modeling improves significantly the VLBI solutions.

In the thermal deformation modeling:

The time lag for the antenna is optimal when equals to 0, 1 or 2 hour;

When studying the time lag for the foundation, the results are insensitive to the time lag used. We believe the reason for this is that the foundation structure is much smaller than the steel part.

Preliminary results show significant correlations between 1) the maximum WRMS improvement and the height of the foundation, 2) the maximum WRMS improvement and the distance from movable axis to antenna vertex, and 3) the optimal time lags determined and the antenna diameter. To confirm these correlations, this study will focus on one station at a time to be rigorous. The authors intend to continue their research in this perspective.



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