Improving VLBI processing by using homogeneous data for Pressure and Temperature

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- State-of-the-art: Pressure and Temperature.
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  - What is in the databases?
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- *Calc/Solve* developments:
  - Choice of using external sources for meteorological data;
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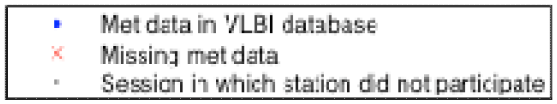
Meteorological data used in Calc/Solve

- **Pressure**: it is used to calculate the zenith hydrostatic delay.
- **Temperature**: a temperature mean is used to calculate the linear expansion of the telescope components as VLBI telescopes are deformed by time-dependent temperature effects.

$\Rightarrow$ The meteorological data affects the results of *Calc/Solve*.

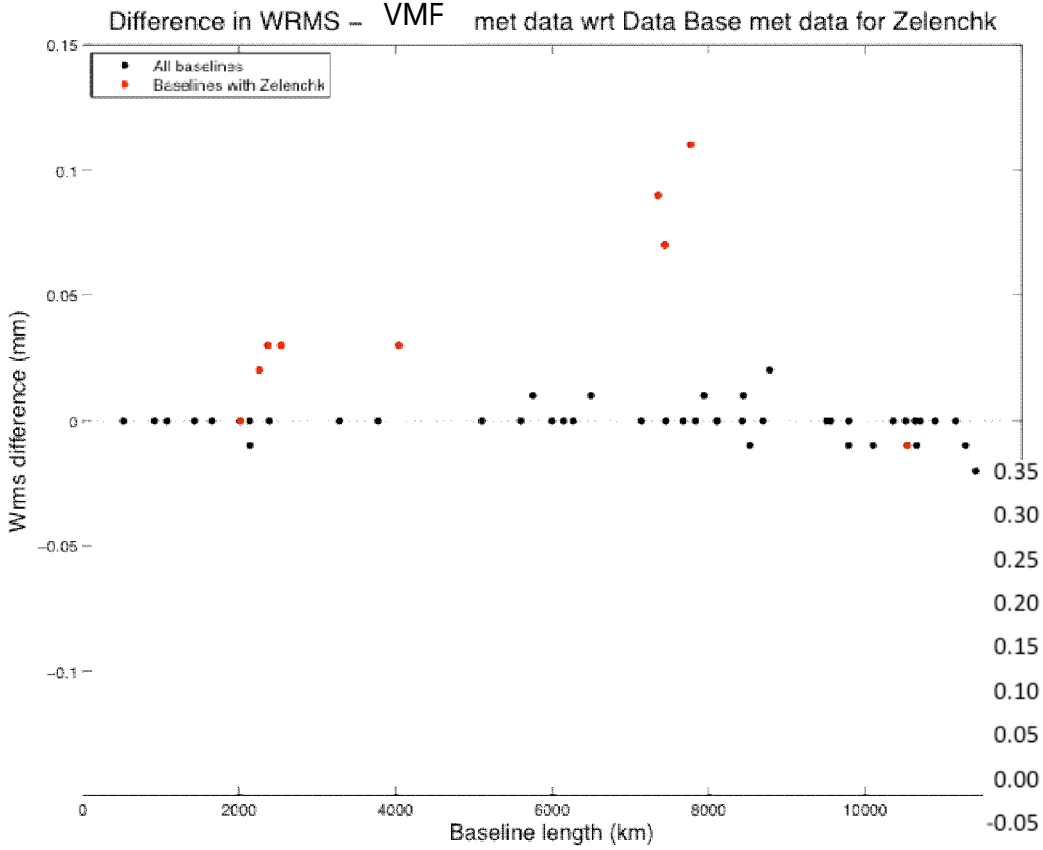
- *Calc/Solve* uses meteorological data from databases. The data in these databases is coming from different sources: observations done onsite by a met sensor (ideal case), observations recorded by another met sensor in the neighborhood of the VLBI antenna (GPS network for example) or data from a model.

Pressure and Temperature: What is in the databases?

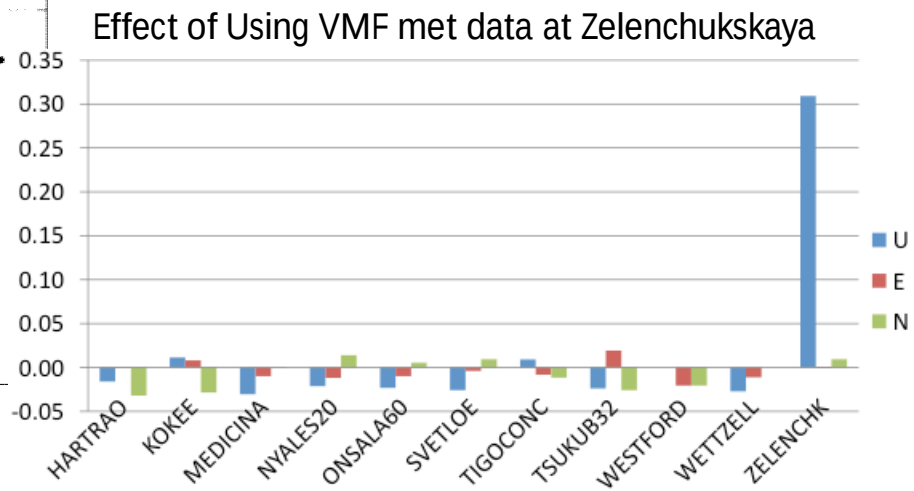


2008 VLBI sessions (167)

Pressure and Temperature: Missing data strategy of Calc/Solve

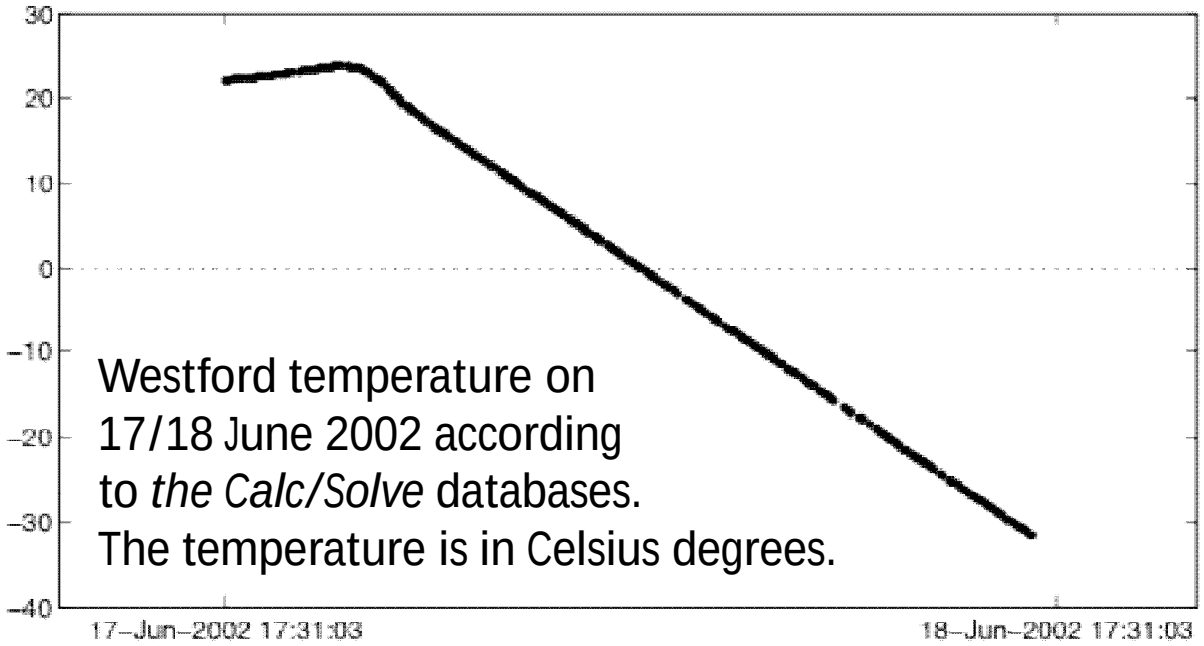


- Use of a default value computed from the position of the station (constant if no a priori position change).
- Comparison with using « VMF met data »: pressure and temperature found in the VMF files.



Pressure and Temperature: Abnormal behavior

Quality of the meteorological data in the databases?



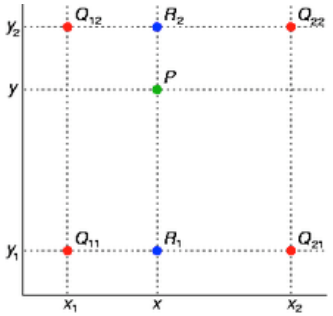
Westford temperature on 17/18 June 2002 according to *the Calc/Solve* databases. The temperature is in Celsius degrees.

Pressure and Temperature: Intermediate conclusions

- The data base is not homogeneous in terms of meteorological data. It contains missing, biased and inaccurate data.
- That impacts directly the quality of the VLBI processing, as shown in previous studies:
  - The WRMS is affected (for example, by using *CALC/SOLVE* default value: 0.12mm for 2 weeks in the case of Zelenchukskaya and 1mm for 9.5 years in the case of Westford);
  - The determination of the Up component varies within a significant level (8.9mbar/mm for Svetloe).
- Using a constant default value to replace missing data is not a satisfying solution.
- It is necessary to have a homogeneous data base for the meteorological data:
  - Homogeneous meteorological sensors in the global network (VLBI2010 specification);
  - **Meteorological data time series derived from a model.**

A homogeneous set of meteorological data

- Data in netCDF format downloaded from the European Center for Medium-Range Weather Forecasts (ECMWF) website: www.ecmwf.int. The data is given on a 1.5x1.5 degree equal angular grid every six hours from 1979 to 2012.
- **First step:** determination of the four points around the VLBI station P. We obtain four time series of pressure and temperature at geopotential height (Q points).
- **Second step:** extrapolation of the pressure and temperature time series of those four points from the grid height to the height of the station:
  - Temperature: After calculating the geometric height difference, we use the lapse rate of 0.006499° K/m to height adjust the temperature series.
  - Pressure: We use the barometric height formula (*Zdunkowski and Bott, 2004*):

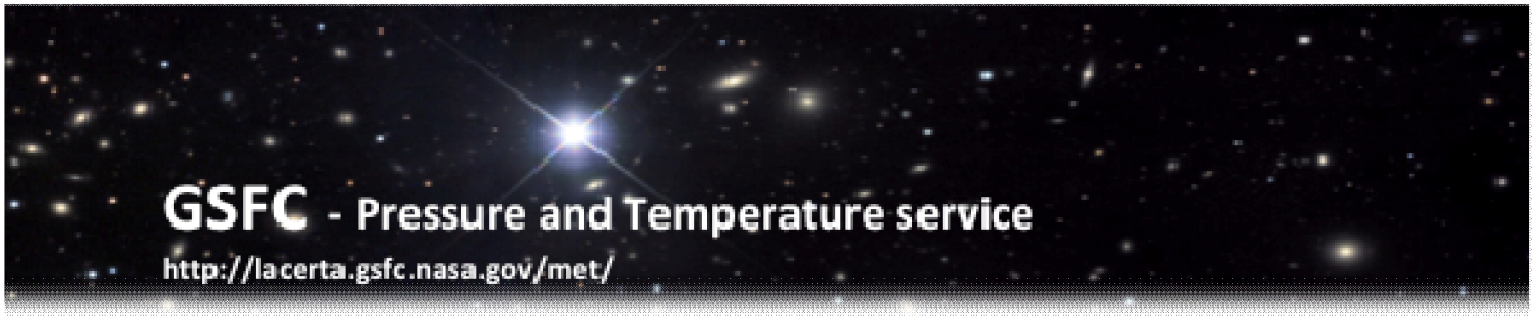


$$p(z) = p_0\left(\frac{T_0 - \Gamma\Delta z}{T_0}\right)^{\frac{g}{R\Gamma}}$$

p_0 – reference pressure
T_0 – reference temperature
Γ – lapse rate
g – acceleration due to gravity
R – gas constant
Δz – difference in geopotential height

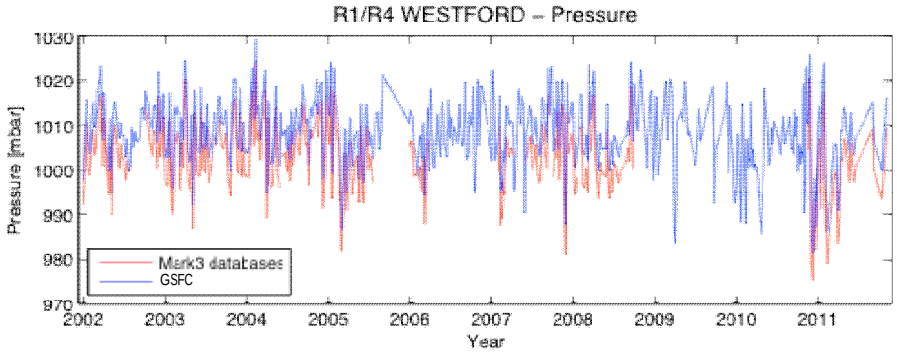
- **Third step:** bilinear interpolation of the four sets of pressure and temperature time series – linear interpolation in the x-direction first and then, in the y-direction.

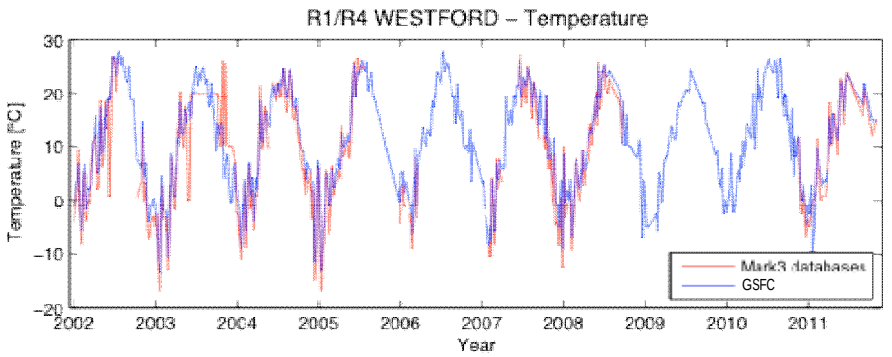
A homogeneous set of meteorological data

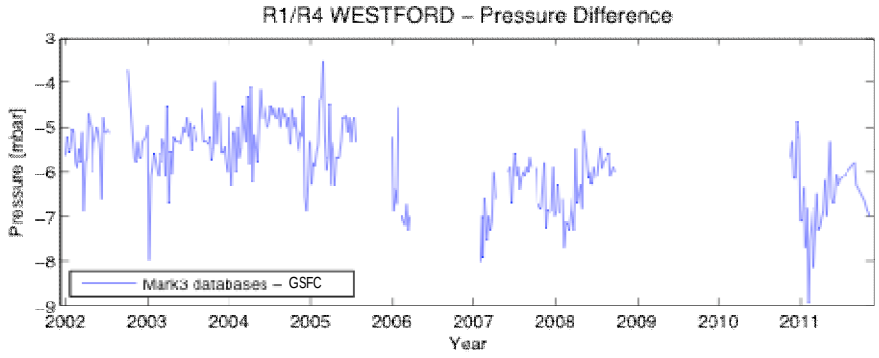


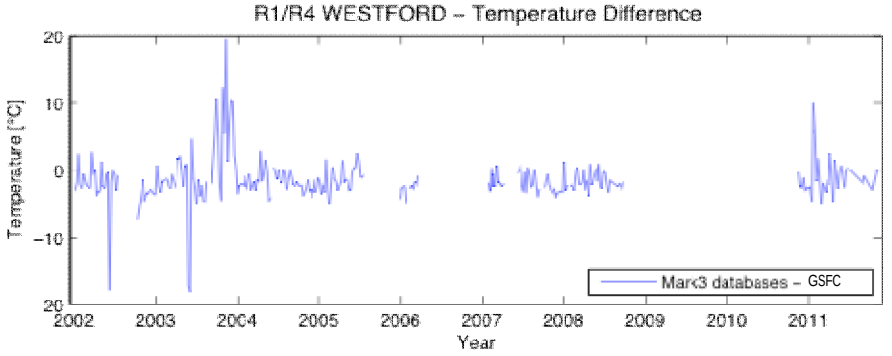
The webpage provides links to files relevant to the service of the pressure and temperature provided by the VLBI group at NASA Goddard Space Flight Center. The service provides interpolated and extrapolated temperature and pressure time series every 6th hour from 1979 to 2011 for all VLBI sites. These time series are updated every month when new temperature and pressure data is released by the European Center for Medium-Range Weather Forecasts (ECMWF).

A homogeneous set of meteorological data









Recent developments in Calc/Solve

- Choice in using **external sources for meteorological data**:
  - Databases data (default);
  - GSFC service meteorological data.
- **Thermal deformation model**:
  - Time lags: 2 hours for steel (Nothnagel et al. 1995) and 6 hours for concrete telescope structures (Elgered and Carlsson 1995) or values defined by user;
  - Temperature used: either from the databases or from external sources.
- Those new options will be available in the next release of *Calc/Solve*.
- Tests done with those new options:
  - Using GSFC-ECMWF derived time series instead of the meteorological data of the databases:

    1/ impact of the improvement in homogeneity of the Pressure time series;

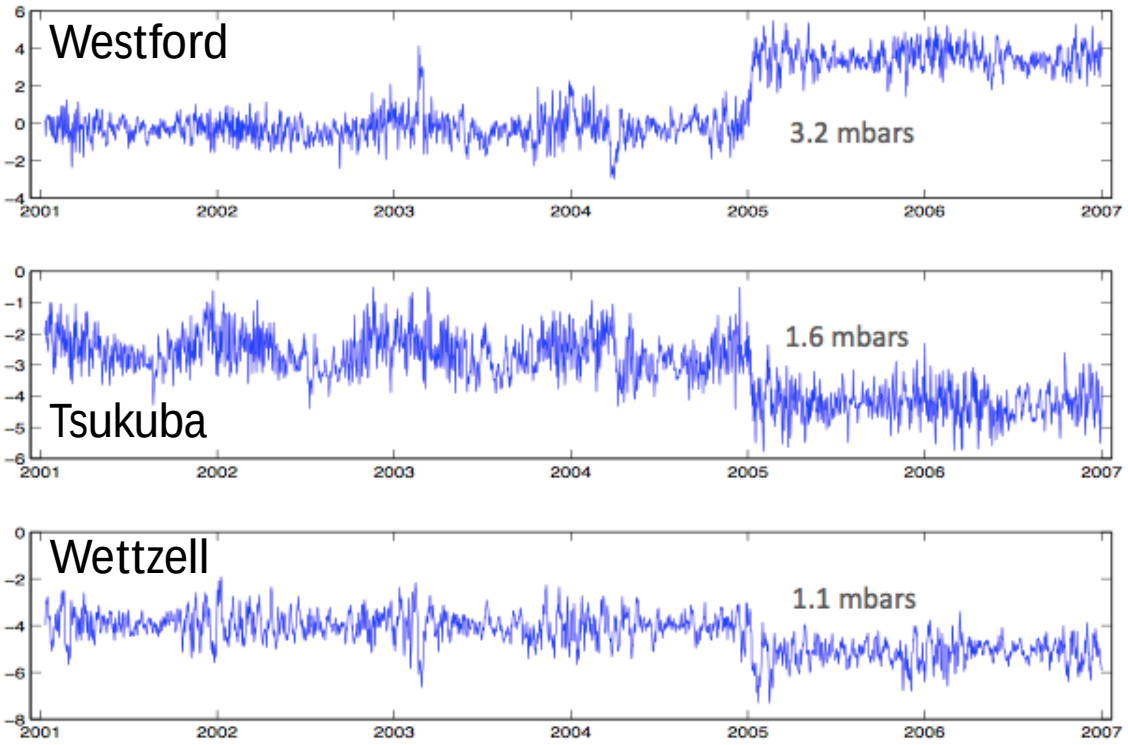
    2/ impact of the improvement in homogeneity of the Temperature time series;

    3/ impact of using the time lag option with 2 hours for steel, 6 for concrete.

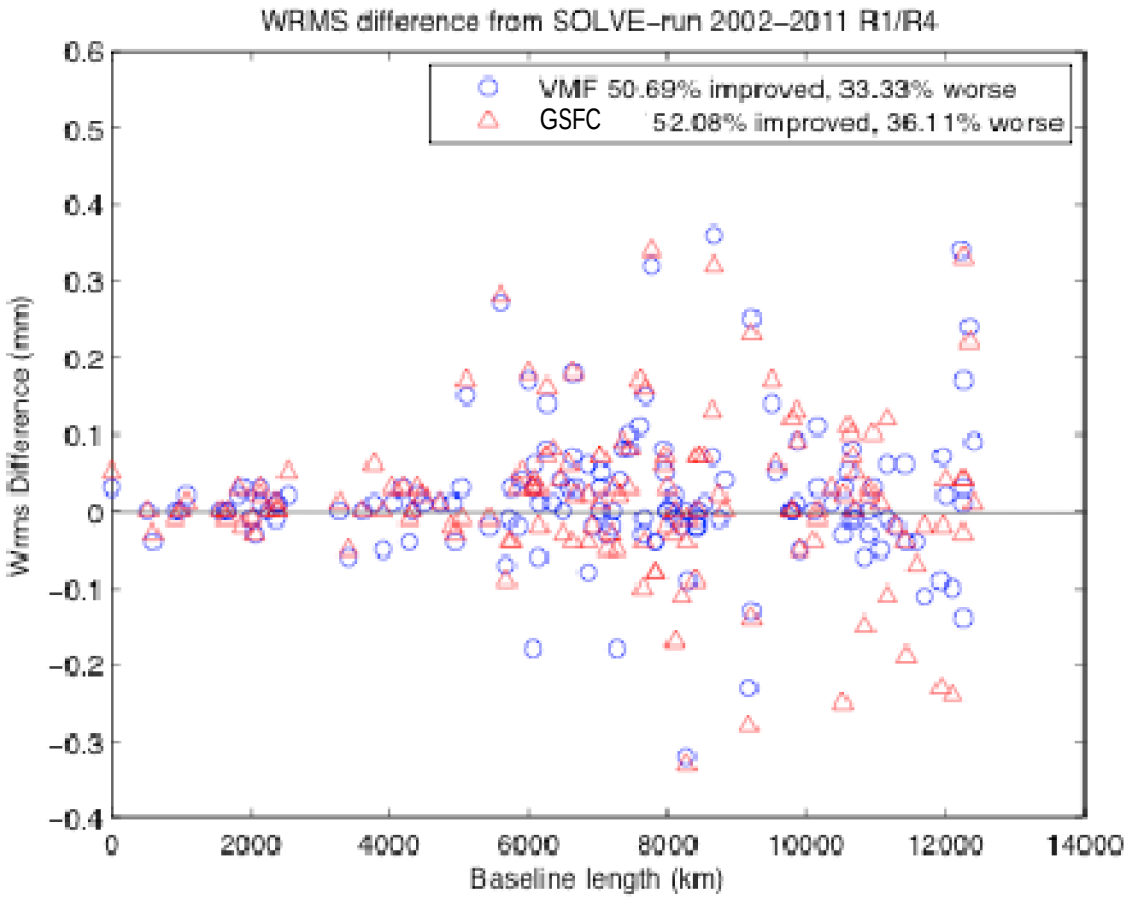
Comparison with VMF-ECMWF Pressure and Temperature

- VMF-ECMWF: meteorological data from the ECMWF model interpolated to the VLBI station positions (*J. Boehm*). Grid resolution: 0.25º x 0.25º.
- A jump between the data in the databases and VMF-ECMWF is identified at the end of 2004. This jump can be seen with different magnitudes in other stations pressure time series (*Kouba, 2007*). This is partly explained (cf. *J. Boehm*) by the modification of the analysis strategy (geoid model).
- Problem of homogeneity in the VMF-ECMWF time series.

Pressure differences - moving average in mbar

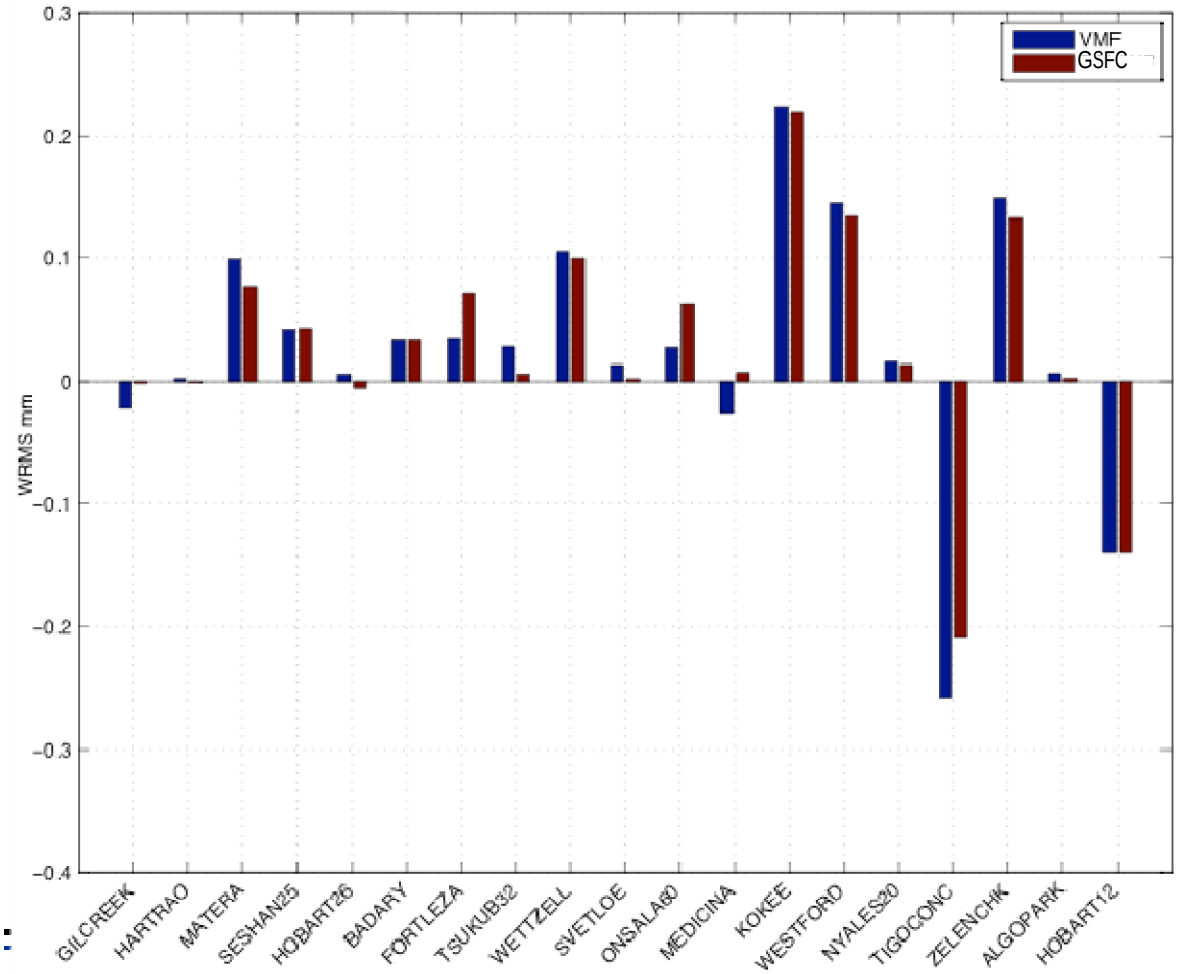


Impact of the improvement in homogeneity of the Pressure time series



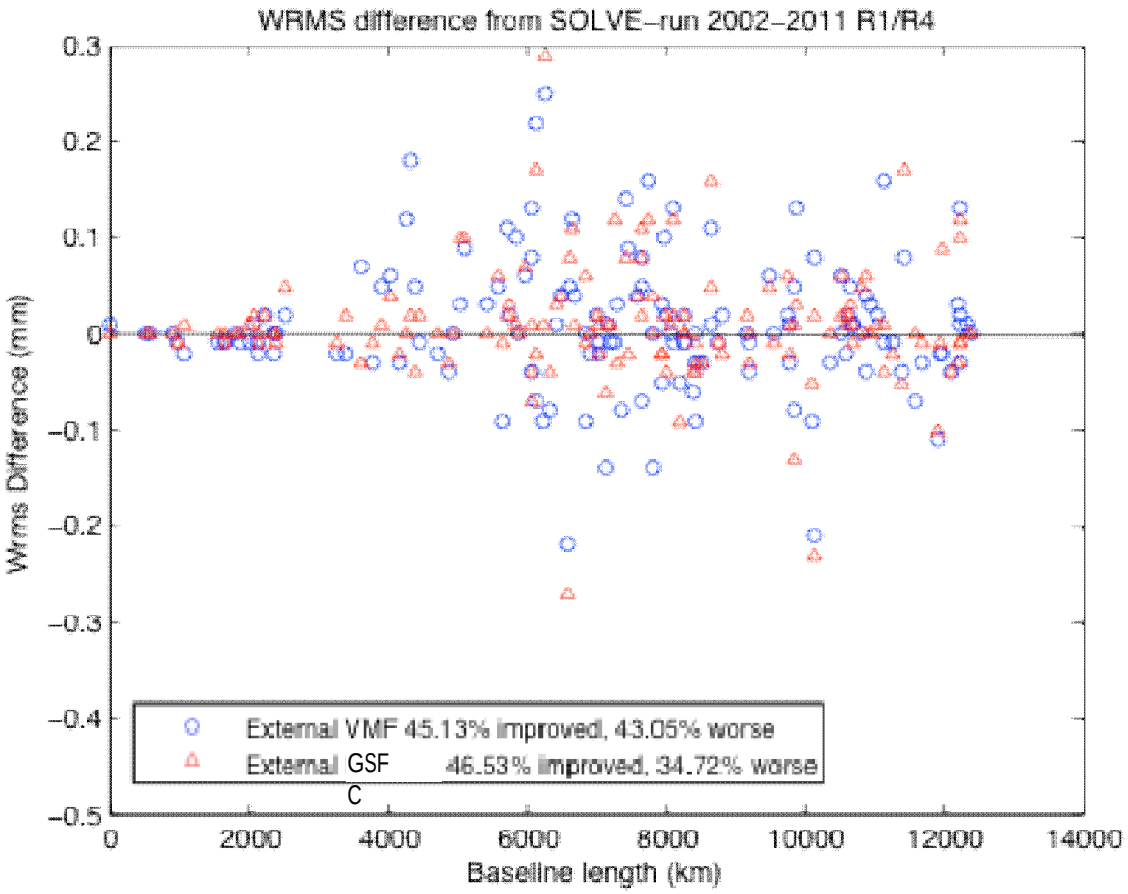
- All R1 and R4 sessions from 2002 to 2011;
- Using the **Pressure** from either GSFC-ECMWF or VMF-ECMWF compared with using the Pressure from the databases:
  - Using GSFC-ECMWF instead of the databases improves 52.08% of the baselines considered (11.81% unchanged);
  - Using VMF-ECMWF instead of the databases improves 50.69% of the baselines considered (15.98% unchanged).

Impact of the improvement in homogeneity of the Pressure time series



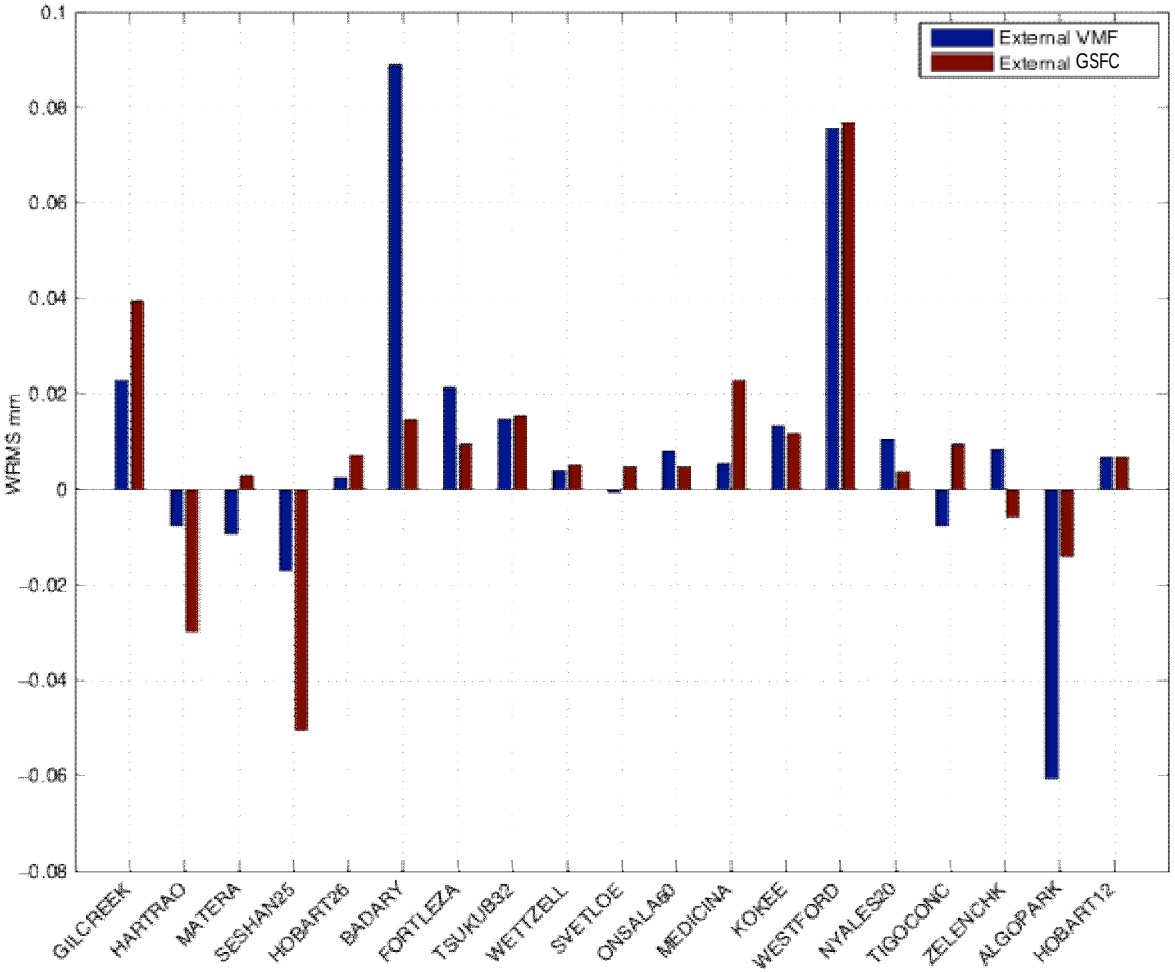
- All R1 and R4 sessions from 2002 to 2011;
- Using the **Pressure** from either GSFC-ECMWF or VMF-ECMWF compared with using the Pressure from the databases;
- **Baseline length repeatability per station.**

Impact of the improvement in homogeneity of the Temperature time series



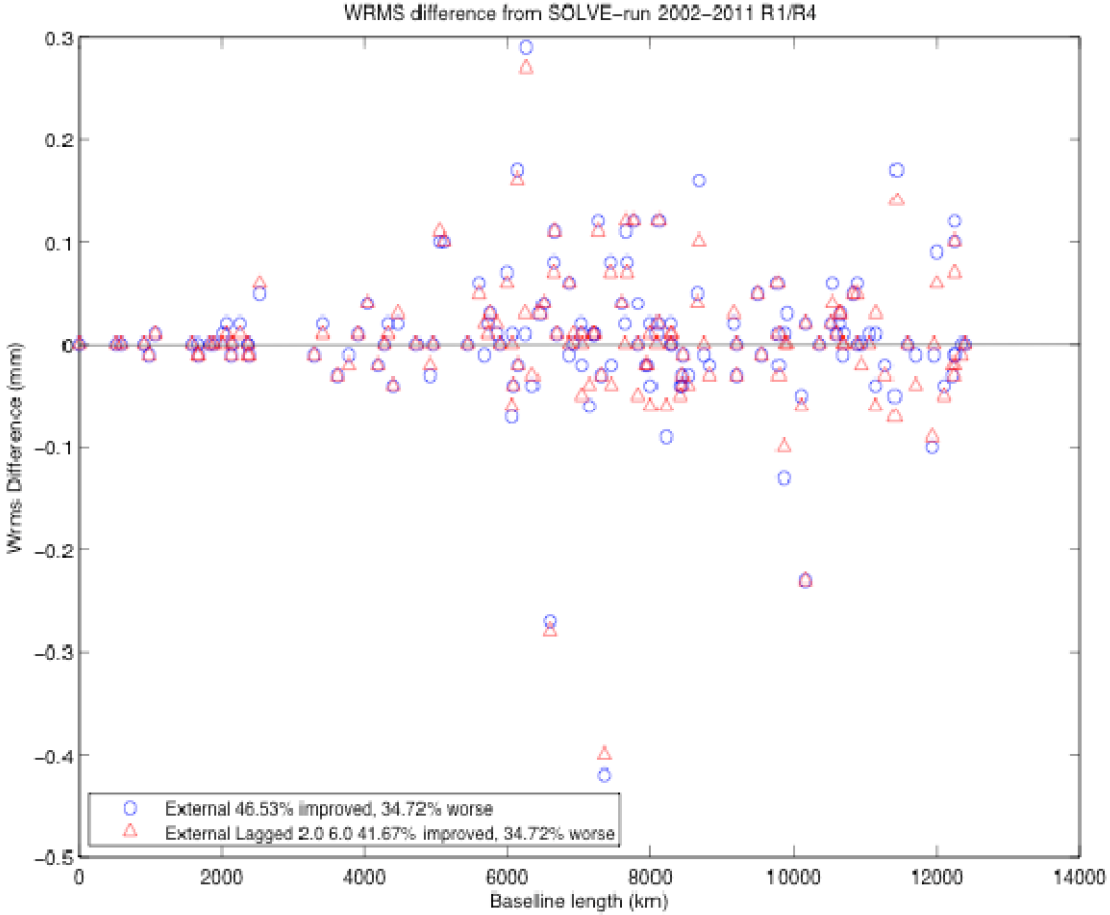
- All R1 and R4 sessions from 2002 to 2011;
- Using the **Temperature** from either GSFC-ECMWF or VMF-ECMWF compared with using the Temperature from the databases:
  - Using GSFC-ECMWF instead of the databases improves 46.53% of the baselines considered (18.75 % unchanged);
  - Using VMF-ECMWF instead of the databases improves 45.13% of the baselines considered (11.82 % unchanged).

Impact of the improvement in homogeneity of the Temperature time series



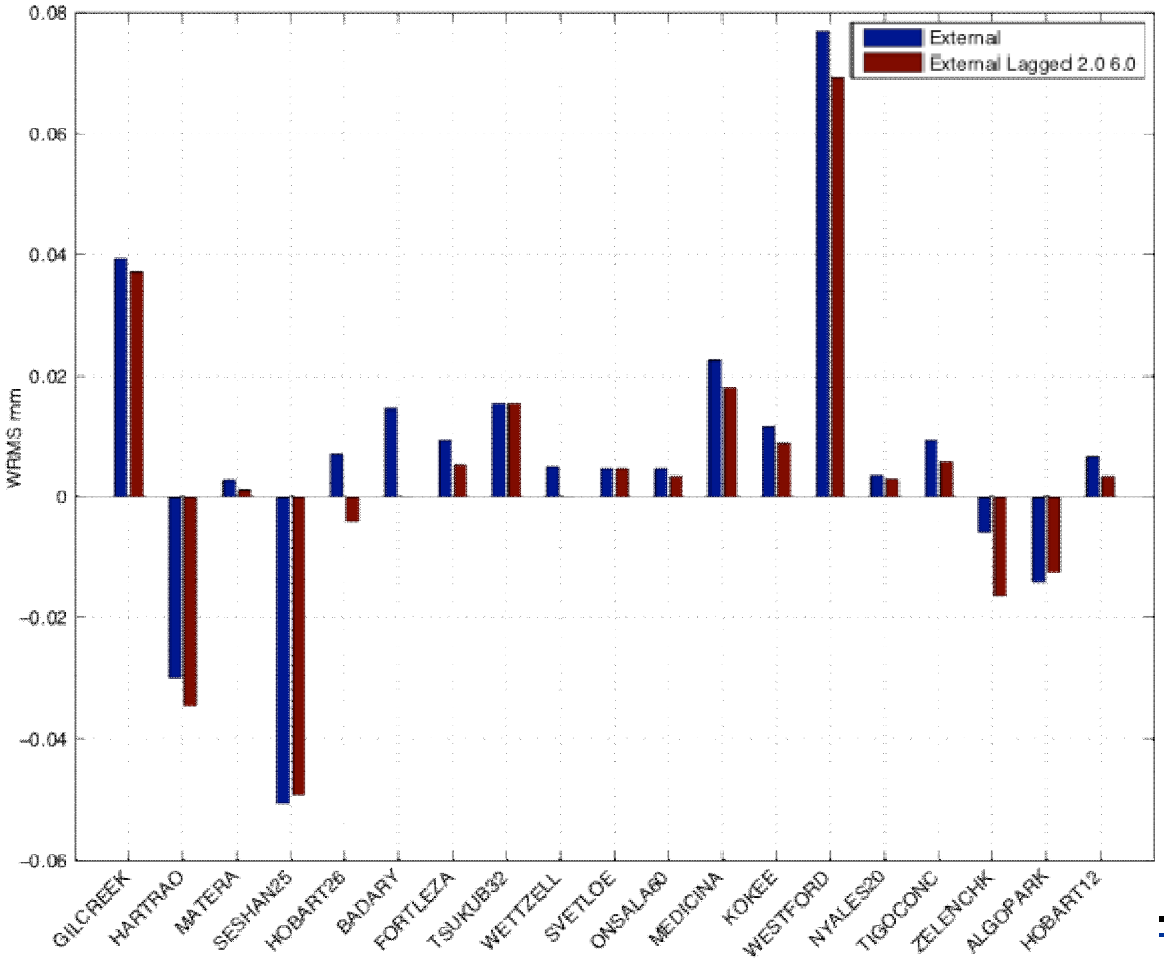
- All R1 and R4 sessions from 2002 to 2011;
- Using the **Temperature** from either GSFC-ECMWF or VMF-ECMWF compared with using the Temperature from the databases;
- **Baseline length repeatability per station.**

Impact of the improvement in homogeneity of the Temperature time series and using a (2,6) time lag for the thermal deformation model



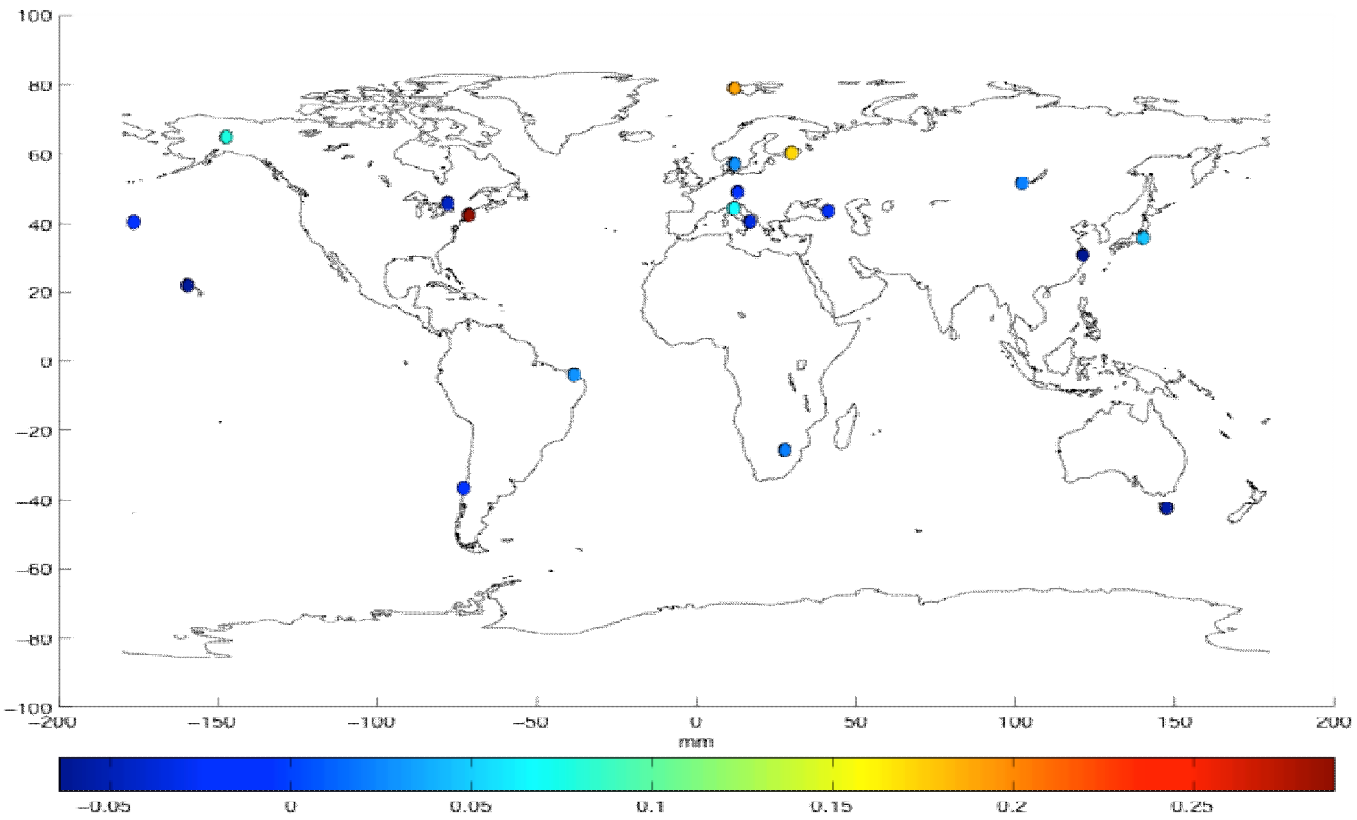
- All R1 and R4 sessions from 2002 to 2011;
- Using the **Temperature** from GSFC-ECMWF with or without **time lags** compared with using the Temperature from the databases:
  - Using GSFC-ECMWF instead of the databases improves 46.53% of the baselines considered (18.75 % unchanged);
  - Using VMF-ECMWF and a (2,6) time lag instead of the databases improves 41.67% of the baselines considered (23.61 % unchanged).

Impact of the improvement in homogeneity of the Temperature time series and using a (2,6) time lag for the thermal deformation model



- All R1 and R4 sessions from 2002 to 2011;
- Using the **Temperature** from GSFC-ECMWF with or without **time lags** compared with using the Temperature from the databases;
- **Baseline length repeatability per station.**

Impact of the improvement in homogeneity of the Temperature time series and using a (2,6) time lag for the thermal deformation model



- All R1 and R4 sessions from 2002 to 2011;
- Using the **Temperature** from GSFC-ECMWF with or without **time lags** compared with using the Temperature from the databases;
- **Seasonal change in annual amplitude for the Up component.**

Conclusions and perspectives

- The databases used to process VLBI data with *Calc/Solve* contains missing and inaccurate data that affects the quality of the *Calc/Solve* solutions;

- GSFC has developed a homogeneous set of Temperature and Pressure time series derived from ECMWF data. This set is available online: http://lacerta.gsfc.nasa.gov/met/ . It can be extended to any stations, given its position. GSFC has the tools to easily compute Pressure and Temperature time series for new stations or stations of other techniques.

- Using the GSFC ECMWF-derived Temperature and Pressure time series improves considerably the VLBI WRMS of the solutions and decreases the annual amplitude of the vertical components.

- New options in *Calc/Solve* allow the user to use these time series. The next release of *Calc/Solve* will contain those options.

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