Meteorological data and effects on VLBI estimated geodetic parameters

Karine Le Bail, John Gipson

NVI, Inc./NASA Goddard Space Flight Center, Greenbelt, MD, USA

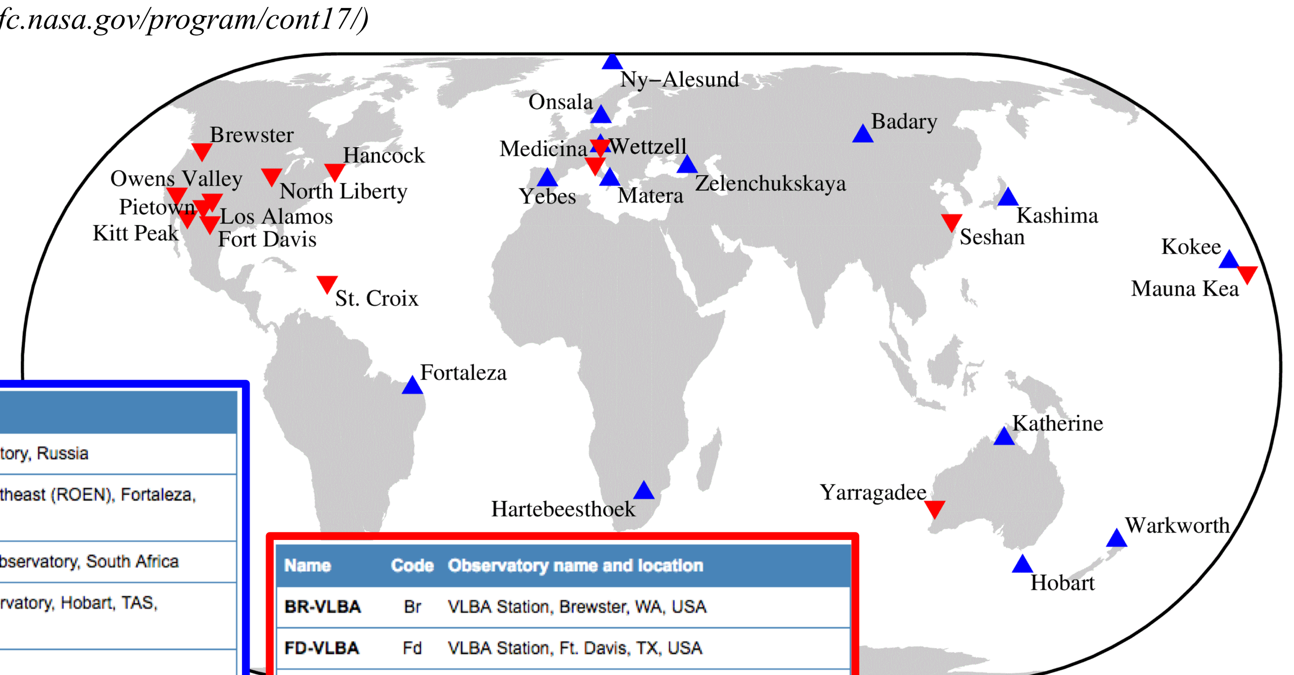
Context

Pressure and temperature impact VLBI processing in two different ways:
1/. The pressure is used to calculate the zenith hydrostatic delay;
2/. The temperature is used to calculate the linear expansion of the telescope components.
These two significant parameters are not systematically measured onsite. The analysts have to use different sources of meteorological data: observations recorded by other met sensors in the neighborhood of the VLBI antenna (GPS network for example) or data from a model. This inhomogeneity in the data cause discontinuities and/or biases in the global time series of meteorological data which alter significantly the VLBI solutions.
In previous studies (Juhl et al. 2012), it has been shown that a bias in pressure of 10mbar for the station Svetloe affects the determination of the vertical component up to 1.2mm. A 9-year period of missing pressure for the station Westford affects the weighted RMS up to 1mm when using a constant default value in the software Calc/Solve.
The VLBI group at Goddard Space Flight Center produces homogeneous time series of pressure and temperature calculated from the ERA Interim data of the European Center for Medium-Range Weather Forecasts (ECMWF). These time series cover the entire VLBI observation period (1979-2018) for all VLBI sites, are updated regularly and are available on the VLBI Temperature and Pressure Service webpage. The grid initially used was a 1.5 x 1.5 degree equal angular grid for the entire Earth. We recently updated our time series using the best available grid which is now 0.125 x 0.125. The objective of this work is to quantify the impact of using a higher resolution.

PART I – Data studied: CONT17 Legacy S/X stations

The results presented pertain to VLBI data collected during the CONT17 campaign.
CONT17 is a campaign of continuous VLBI sessions observed in November and December 2017 (28-NOV-2017 00:00 UT through 12-DEC-2017 24:00 UT).
CONT17 differs from the previous CONT campaigns in that there are three independent networks observed: two legacy networks observed at S/X band, and one VGOS network did broadband observing. In this presentation, we focus on the two legacy networks. The geographical distribution of the two CONT17 legacy S/X networks is shown in the station distribution map: Legacy-1 (in blue) has 14 stations and Legacy-2 (in red) has 14 stations also. In the legacy-2 network, SC-VLBA did not observe because of hurricane damage and SESHAN25 observed only during the first nine days of the campaign.

Source: IVS website (https://ivscc.gsfc.nasa.gov/program/cont17/)



Name	Code	Observatory name and location
BADARY	Bd	Badary Radio Astronomical Observatory, Russia
FORTLEZA	Ft	Space Radio Observatory of the Northeast (ROEN), Fortaleza, Brazil
HART15M	Ht	Hartebeesthoek Radio Astronomy Observatory, South Africa
HOBART26	Ho	Mt. Pleasant Radio Astronomy Observatory, Hobart, TAS, Australia
KASHIM11	K1	Kashima VLBI Station, Japan
KATH12M	Ke	Katherine Observatory, Katherine, NT, Australia
KOKEE	Kk	Kokee Park Geophysical Observatory, Kauai, HI, USA
MATERA	Ma	Centro di Geodesia Spaziale G. Colombo, Matera, Italy
NYALES20	Ny	Ny Ålesund Geodetic Observatory, Spitsbergen, Norway
ONSALA60	On	Onsala Space Observatory, Sweden
WARK12M	Ww	Warkworth VLBI Station, New Zealand
WETTZELL	Wz	Geodetic Observatory Wettzell, Germany
YEBES40M	Ys	Astronomical Center at Yebes, Spain
ZELENCHK	Zc	Radioastronomical Observatory Zelenchukskaya, Russia

Name	Code	Observatory name and location
BR-VLBA	Br	VLBA Station, Brewster, WA, USA
FD-VLBA	Fd	VLBA Station, Ft. Davis, TX, USA
HN-VLBA	Hn	VLBA Station, Hancock, NH, USA
KP-VLBA	Kp	VLBA Station, Kitt Peak, AZ, USA
LA-VLBA	La	VLBA Station, Los Alamos, NM, USA
MK-VLBA	Mk	VLBA Station, Mauna Kea, HI, USA
NL-VLBA	Nl	VLBA Station, North Liberty, IA, USA
OV-VLBA	Ov	VLBA Station, Owens Valley, CA, USA
PIETOWN	Pt	VLBA Station, Pie Town, NM, USA
SC-VLBA	Sc	VLBA Station, St. Croix, VI, USA
MEDICINA	Mc	Medicina Radio Astronomy Station, Italy
SESHAN25	Sh	Shanghai Astronomical Observatory, Seshan, China
WETTZ13N	Wn	Geodetic Observatory Wettzell, Germany
YARRA12M	Ya	Yarragadee Observatory, Yarragadee, WA, Australia

Part II – Motivation to upgrade to higher resolution

Increasing the resolution of our data grid means reducing the topographic discrepancy between the four points used for the interpolation: the distance in between two points on the same longitude corresponds to about 150km for the 1.5°x1.5° grid and 13.8km for the 0.125°x0.125° grid. Figures 1 and 2 show an example for HOBART26: the meteorological data of the four neighboring points of the station on the 1.5°x1.5° grid show maximum differences of 9.5°C in temperature and 59.2mbar in pressure. These differences decrease to 1.5°C in temperature and 6.9mbar in pressure when considering the 0.125°x0.125° grid.

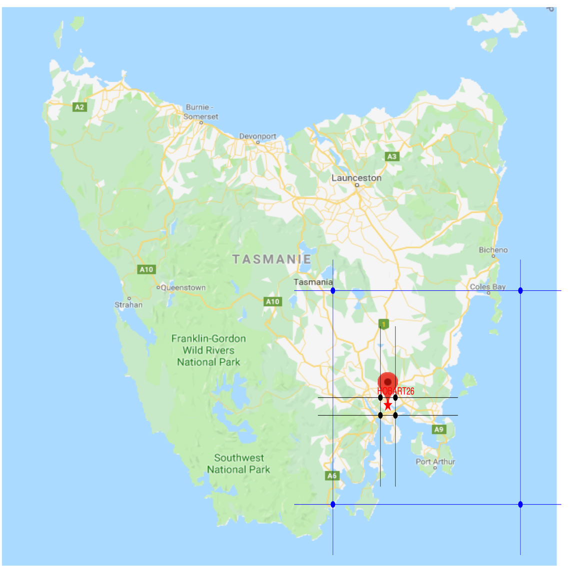


Figure 1: The map was generated on Google Maps (https://www.google.com/maps/). We superimposed lines corresponding to the points on the ERA-Interim grids (1.5x1.5 resolution in blue, 0.125x0.125 resolution in black) and the position of the station HOBART26.

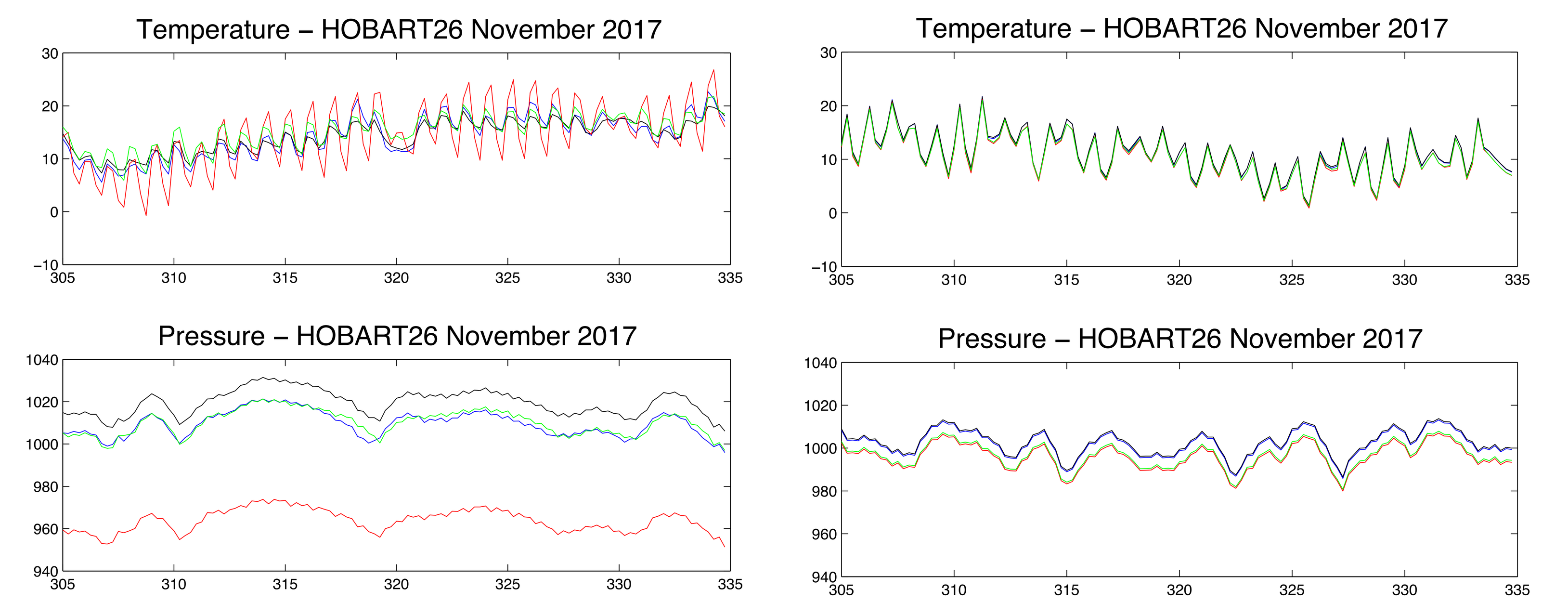


Figure 2: ERA-Interim pressure (in mbar) and temperature (in Celsius degrees) time series for the month of November 2017 (day of the year 305 to day of the year 334). The four time series presented in the plots correspond to the four points of the grid that are the closest to the station HOBART26. Left: 1.5x1.5 grid. Right: 0.125x0.125 grid.

Part III – Time series of Pressure and Temperature

Figure 3 shows the temperature and pressure time series for HOBART26 from day 332 of 2017 (November 28) to day 347 (December 13). The three different sources of met data presented are:

1. ERA-Interim data 0.125x0.125: Pressure and temperature time series calculated from the ERA-Interim reanalysis model (Dee et al. 2011) of the European Center for Medium-Range Weather Forecasts (ECMWF). We used a resolution of 1.5°x1.5° for the grid;
2. ERA-Interim data 0.125x0.125: ECMWF/ERA-Interim data with a 0.125°x0.125° resolution;
3. Values in VLBI database: Pressure and temperature time series from the VLBI databases (meteorological data collected by onsite met sensors or other met sensors in the neighborhood of the VLBI antenna).

For HOBART26, there is no significant differences between the two ERA-Interim pressure time series. The largest difference is 1.1mbar. However, for the temperature, the differences reach up to 5°C. The higher resolution solution seems to capture the daily amplitude of the temperature better than the lower resolution solution.

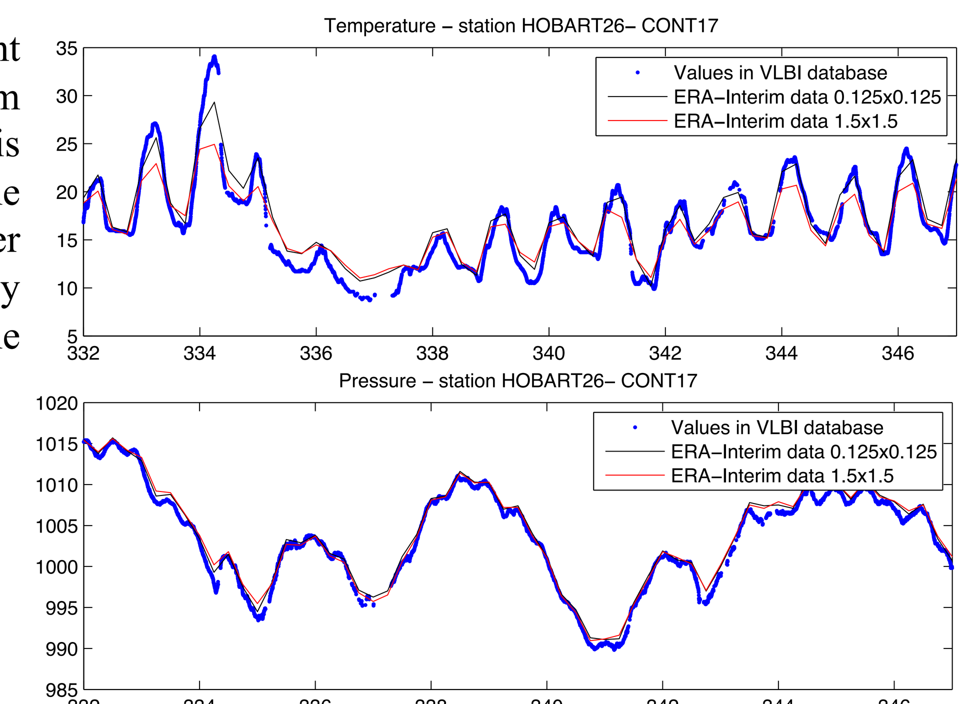


Figure 3: Pressure (in mbar) and temperature (in Celsius degrees) time series for the station HOBART26 during CONT17 from three different sources.

Part IV – Impact on VLBI analysis

To quantify the impact of the two resolutions on the VLBI solutions, we ran solutions using the VLBI processing software Calc/Solve considering the two different sets of temperature and pressure (ERA-Interim 0.125x0.125 and ERA-Interim 1.5x1.5). We compare these solutions with an operational solution which only differs for the tropospheric model (it uses the VMF1 mapping function) and the antenna deformation model (it uses an average temperature from the VLBI database).

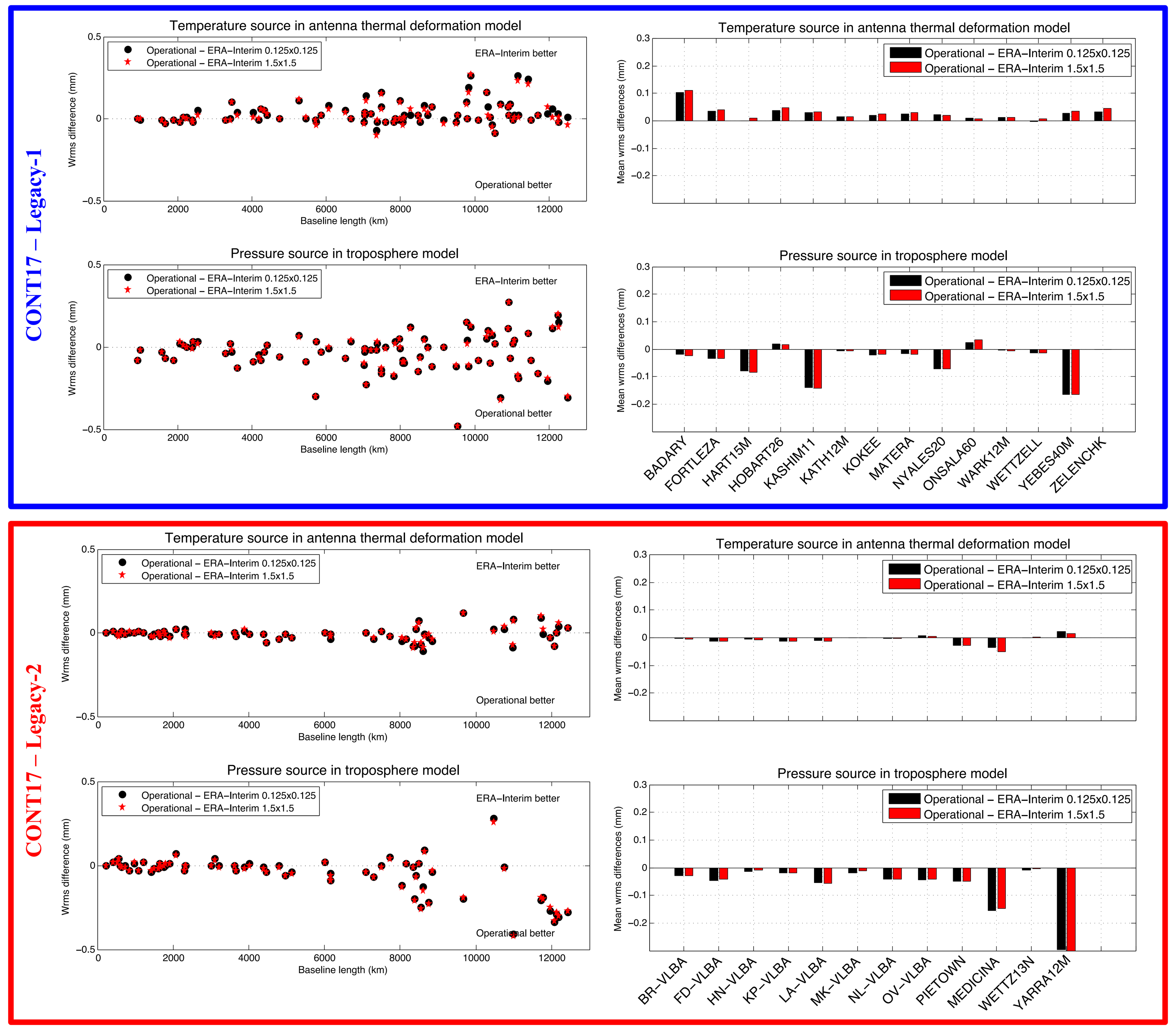


Figure 4: Differences in baseline repeatability (left) and in station repeatability (right) between an operational solution and a solution using the temperature from ERA-Interim in the antenna thermal deformation model (top), and the pressure from ERA-Interim in the troposphere model (bottom). Legacy-1 stations in blue box. Legacy-2 stations in red box.

Comparing the solution using the ERA-Interim 1.5x1.5 and the solution using ERA-Interim 0.125x0.125: there are no significant differences.

Comparing the solutions using the ERA-Interim data with an operational solution:

- Temperature. The WRMS of the solutions using the temperature from the ERA-Interim model are globally lower for all the baselines considered.
- Pressure. The WRMS of the operational solution are significantly lower for some stations. For these stations, there is a bias in the pressure time series of the ERA-Interim interpolation compared to the values in the VLBI database.

Conclusion

- Recommendation on which met data to use:
  - Best case: regularly calibrated onsite met sensors.
  - Unfortunately, it is very rare a VLBI site has a well calibrated onsite met sensor for the entire observation period. Meteorological data from a weather model could be used to calibrate onsite met sensors, or as an alternative to onsite met sensor data when the met sensor does not work.
- Will add NASA/GSFC GMAO data for comparison.
- Met data web service. The machine where the time series were available for download is no longer in service. We are working on an alternative. If interested in these time series, send a request to karine.lebail@nasa.gov.

References:

Juhl, J., Le Bail, K., Gipson, J.M., and MacMillan, D.S., 2012. "Improving VLBI Processing by using Homogeneous Data for Pressure and Temperature." *International VLBI Service for Geodesy and Astrometry, 2012 General Meeting Proceedings* NASA CP/2012-217504: Greenbelt, Maryland, U.S.A.: 241-245

Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., et al. 2011. "The ERA-Interim reanalysis: Configuration and performance of the data assimilation system". *Quarterly Journal of the Royal Meteorological Society*, 137(656), 553–597. https://doi.org/10.1002/qj.828.

E-mail contact: Karine Le Bail (karine.lebail@nasa.gov)