On the impact of inhomogeneities in meteorological data on VLBI analysis

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Introduction

The explicit purpose of this study is twofold. Initially, we propose a **robust** method for extracting information from Numerical Weather Models (NWMs). We use this algorithm to form reference series of any meteorological parameter (in the broad sense) of interest. Then, we **homogenize** barometric pressure and air temperature observations recorded in the vicinity of very long baseline interferometry (VLBI) telescopes and reprocess **13 years of data**.
Our study is motivated from the potential accuracy limitation the mismodeling of nuisance effects such as:

1. the neutral atmospheric *propagation delay* and
2. the *thermal deformation* of antennas

poses to the VLBI technique due to erroneous meteorological records employed to mitigate them. Hence the quality of meteorological data sets should not be left unquestioned.

Extracting data from NWMs

As it was proven in Heinkelmann et al., 2016, performing the hypsometric adjustment on values extracted from surface fields yields unacceptable results in regions with steep topographic gradients.
We choose to work with **model level** (σ—pressure coordinate system) and not with pressure level data. The reason for this lies mainly in the fact that most NWMs (e.g. ECMWF's products) are generated on model levels and at the surface; the transformation to pressure levels introduces a deterioration in the vertical resolution.
We noticed that in the transformation from ellipsoidal heights to dynamic heights, the **geoid undulation** (N) is currently not considered. This results inescapably in a logarithmically proportional to N bias as large as 5 hPa w.r.t. in situ pressure records. For our investigations, we extract N from EIGEN–6C4*.
With our extraction approach the bias between different models almost vanishes. As far as the temperature is concerned, the reference temperature of each VLBI site is of crucial importance for the thermal deformation correction. Currently these values were extracted from GPT, the finite resolution of which introduces a bias in some cases.

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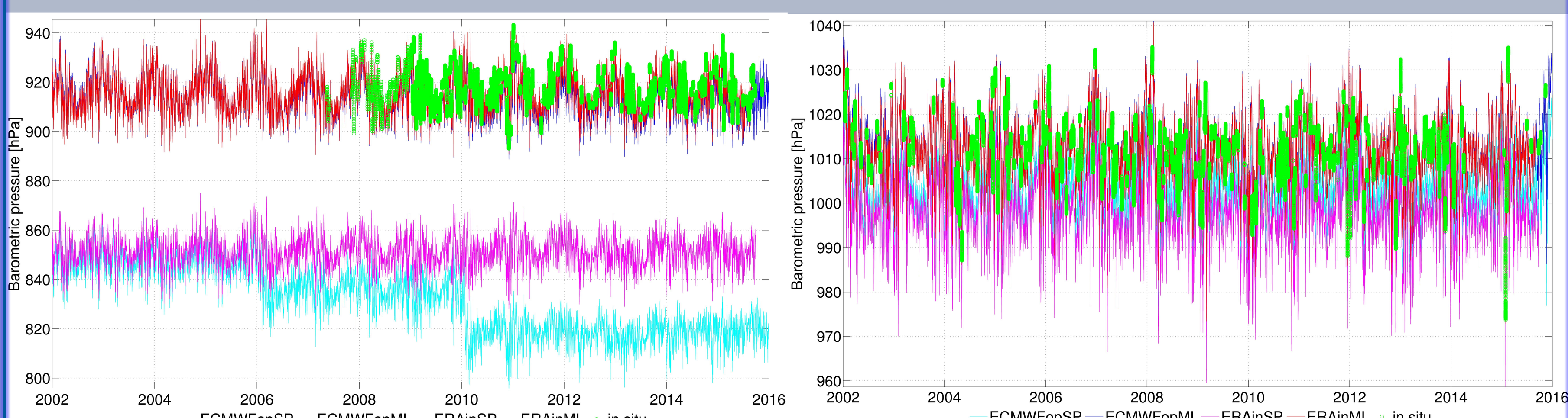

Fig. 1 and 2: Pressure time series at Badary, Russia (left) and Medicina, Italy (right). The suffix "SP" describes data extracted from the surface pressure field, and the suffix "ML" describes data from model levels. Data labeled "in situ" were retrieved from the pressure sensors mounted in the vicinity of the VLBI stations.

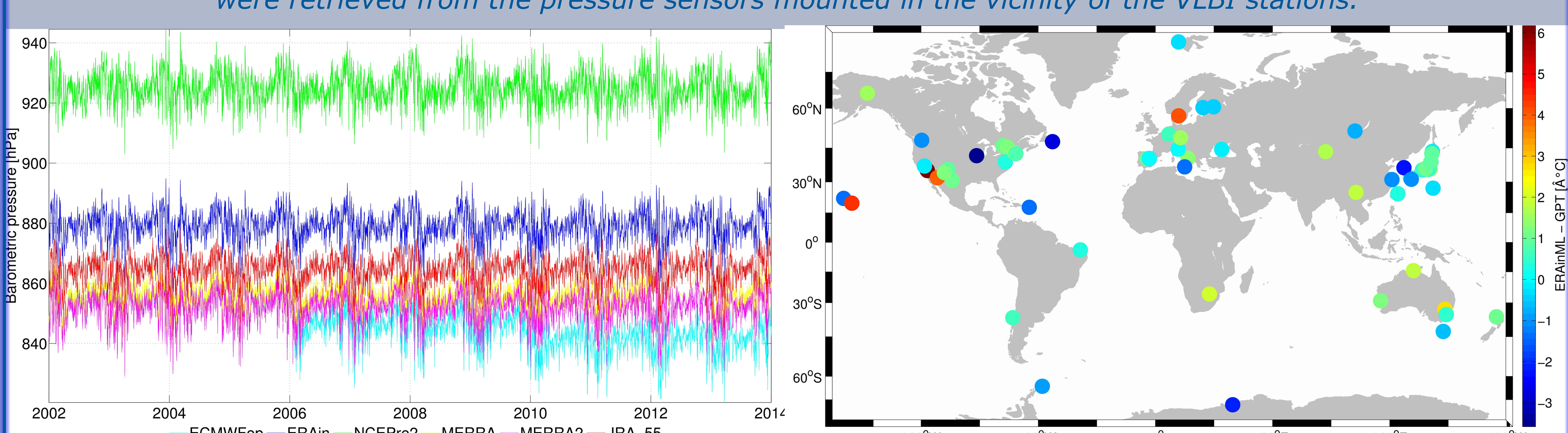

Fig. 3 and 4: Surface pressure time series at Zelenchukskaya, Russia from ECMWF's operational model, ERA interim reanalysis, NCEP-DOE_AMIP-re2, MERRA, MERRA2 and JRA-55 (left) and the bias between the reference temperature currently in use for the thermal deformation calculation and our estimation from ERAinML data (right).

VLBI data analysis

We utilized the least squares adjustment module of the **VieVS@GFZ** VLBI software (Böhm et al., 2012; Nilsson et al., 2015) to analyze interferometric group delay data from the IVS-R1 and IVS-R4 rapid turnaround VLBI experiments (**1326** 24-hr multi-baseline sessions), spanning the period from 2002 until 2015 and featuring in total a 32 station global network.
We produced **5 solutions**, with the meteorological parameters being the only point of difference. These were:

1. in situ data, as recorded at the VLBI sites (when unavailable, GPT2, Lagler et al., 2013, was used),
2. GPT2,
3. MERRA2 surface fields (MERRA2sfc),
4. ECMWF's ERA interim reanalysis model level data (ERAinML) and
5. homogenized in situ data adjusted for the height difference between the meteorological sensor and the VLBI reference point with ERAinML serving as a reference.

In all solutions, we compensated for deformations driven by non-tidal Atmospheric Pressure Loading and Continental Water Storage loading*, in addition to the conventional (IERS2010) displacement models.
Station coordinates and Earth Orientation Parameters (EOPs) were estimated at daily intervals, whereas ZWDs were estimated at hourly and linear horizontal delay gradients at 6-hourly time intervals.

*CWS series were calculated from the Land Surface Discharge Model, forced by the ECMWF operational model, by GFZ, section 1.3. We calculated the APL series consistently, utilizing the ECMWF's operational model, assuming a dynamic ocean response to pressure and wind forcing from the barotropic model MOG2d-G for the high frequencies and the modified inverse barometer response for the low frequencies.

Results

In this block, some of the estimates of the VLBI analysis are presented.

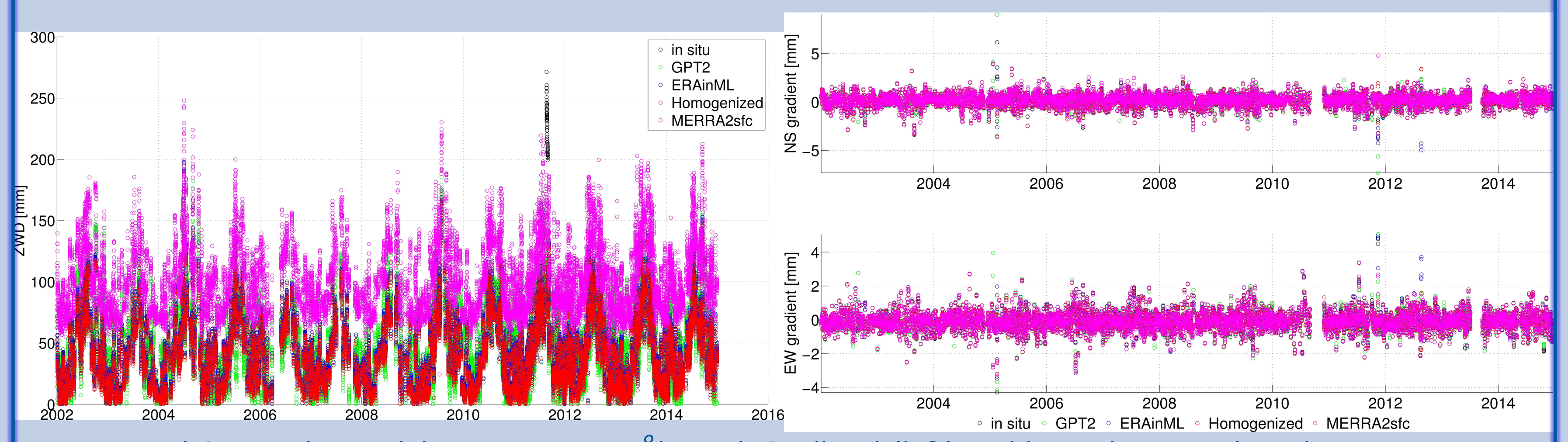

Fig. 5 and 6: Zenith wet delay series at Ny-Ålesund, Svalbard (left) and linear horizontal gradient component series at Wettzell, Germany (right)

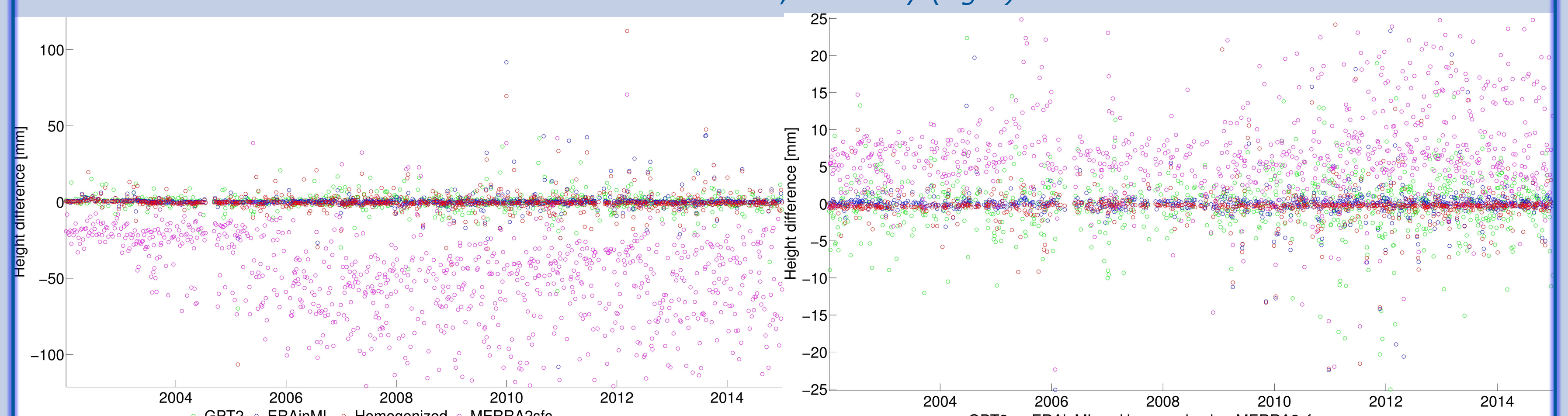

Fig. 7 and 8: Differences between the residual ellipsoidal height estimates at Kokee Park, Kauai (left) and Ny-Ålesund, Svalbard (right), w.r.t. the first solution.

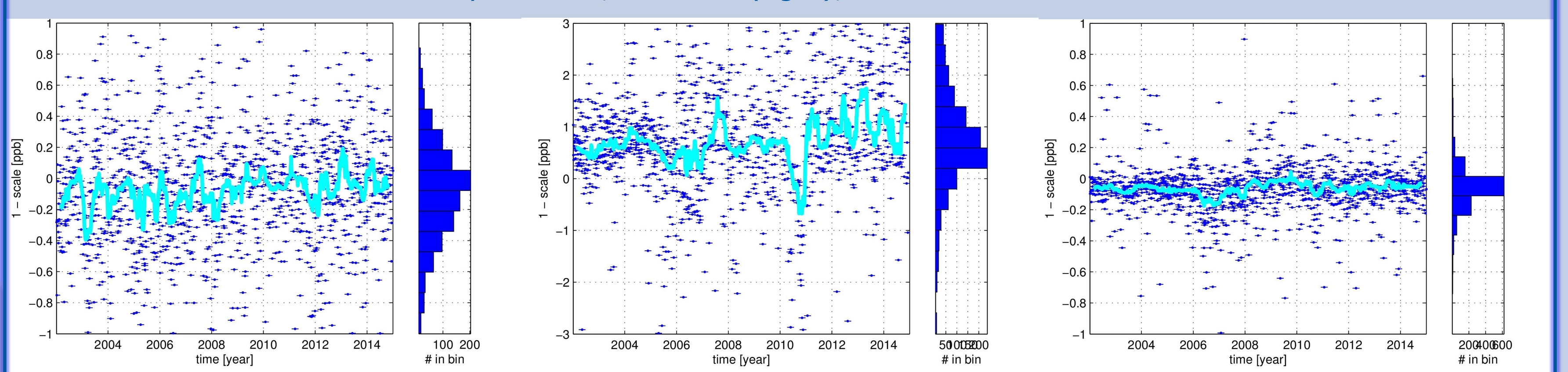

Fig. 9, 10 and 11: The network scale difference, as estimated by the epoch-wise Helmert transformation between the GPT2 solution (left), MERRA2sfc solution (middle) and ERAinML solution (right), w.r.t. the first solution.

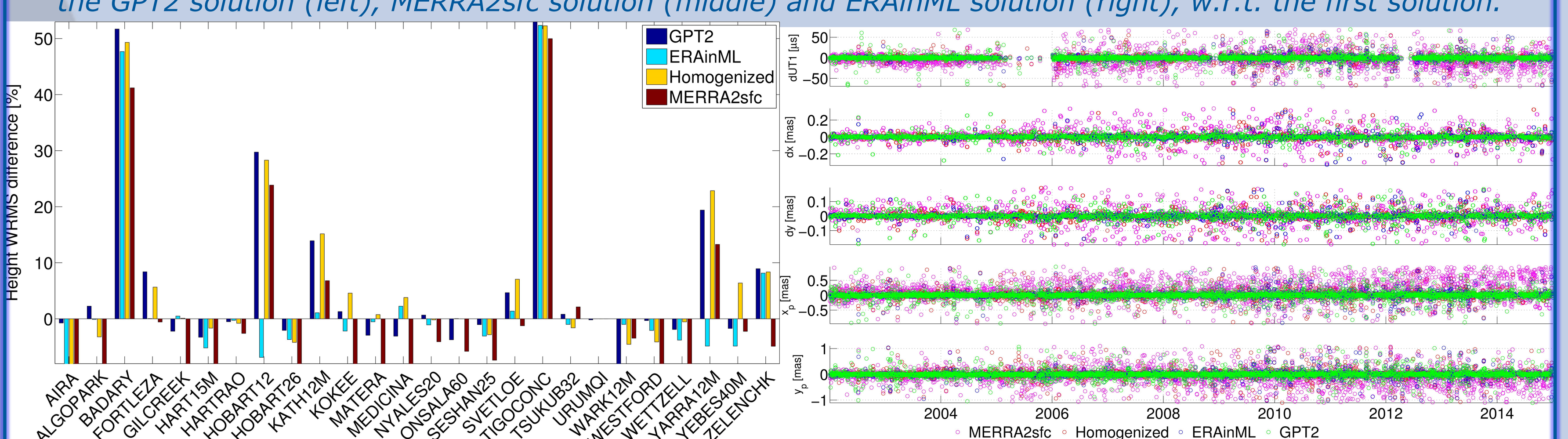

Fig. 12 and 13: Differences in the WRMS of the height time series of all VLBI sites that participated in more than 15 sessions (left) and differences in the full set of EOPs (right). The differences are formed between solutions 2 to 5 w.r.t. the first solution. Positive WRMS differences indicate WRMS reduction.

Conclusions and Outlook

Our results demonstrate that:

1. There is a bias in the **ZWD** series of 5.4 mm, 12.2 mm, 4 mm for solutions 2, 3 and 4, on average, w.r.t. the 1st solution. When the homogenized data set was employed, the average bias was reduced to 1.7 mm.
2. A station **height bias** larger than 2.5 mm is introduced in 22% of the VLBI sites for solutions 2, 4 and 5, and in 77% of the VLBI sites for the 3rd.
3. The **network scale** is considerably distorted for GPT2 and MERRA2sfc solutions, as in addition the scatter increases and a bias is introduced.
4. Employing meteorological data homogenized with ERAinML reduces the **height WRMS** by 6.2% on average.
5. Pressure and temperature values from ERAinML can substitute the raw meteorological records, reducing the height WRMS by 2% on average.
6. The **EOP** series are not affected largely for solutions 2, 4 and 5. Nevertheless, the WRMS of all EOP series deteriorates when data from surface fields are used and a bias of 0.2 mas and −0.1 mas appears in the x and y terrestrial pole coordinates, respectively.

In the near future, we will:

1. reprocess the entire VLBI data archive following the approach adopted here,
2. address inhomogeneities and systematics in mapping functions and
3. relaunch the *IVS Troposphere Combination Centre*.

Acknowledgements

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Selected References

Böhm, J., S. Böhm, T. Nilsson, A. Pany, L. Plank, H. Spicakova, K. Teke and H. Schuh (2012) ***The new Vienna VLBI Software VieVS***, in Proceedings of IAG Scientific Assembly 2009, International Association of Geodesy Symposia Series Vol. 136, edited by S. Kenyon, M. C. Pacino, and U. Marti, pp. 1007-1011, doi: 10.1007/978-3-642-20338-1_126.
Heinkelmann, R., J. Böhm and H. Schuh (2005a) ***Homogenization of surface pressure recordings and its impact on long-term series of VLBI tropospheric parameters.*** In: Vennebusch M, Nothnagel A (eds), Proceedings of the 17th working meeting on European VLBI for geodesy and astrometry, Noto, 22–23 April, pp 74–78
Heinkelmann, R., K. Balidakis, A. Phogat, C. Lu, J. Mora-Diaz, T. Nilsson and H. Schuh (2016) ***Effects of meteorological input data on the VLBI station coordinates, TRF and EOP***, IAG symposia series (*under review*)
Lagler, K., M. Schindelegger, J. Böhm, H. Krásná and T. Nilsson (2013) ***GPT2: Empirical slant delay model for radio space geodetic techniques***, Geophys. Res. Lett., 40, 1069–1073, doi:10.1002/grl.50288.
Nilsson T., B. Soja, M. Karbon, R. Heinkelmann and H. Schuh (2015) ***Application of Kalman filtering in VLBI data analysis***. Earth, Planets and Space 67(136):1 – 9, doi:10.1186/s40623-015-0307-y.
Schuh, H. and D. Behrend (2012) ***VLBI: A fascinating technique for geodesy and astrometry***, Journal of Geodynamics, Vol. 61, pp. 68–80, October 2012. doi:10.1016/j.jog.2012.07.007.