Technische Universität Berlin

On the impact of tropospheric modeling on the results of VLBI analysis

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Motivation

- Troposphere is the main ***random*** and ***systematic error*** source contributor in microwave-based space geodetic techniques such as GNSS and VLBI.
- Numerical Weather Models (NWMs) can augment geodetic analysis (e.g., background information) further upon.

In this presentation . . .

- we investigate the impact of different ***modeling*** and ***parameterization*** of the tropospheric delay on VLBI data analysis.

. . . setting the stage

$$\tau_{trop}(\varepsilon,\alpha) = mf_h d_h^z + mf_w d_w^z + mf_g [G_{NS}\cos(\alpha) + G_{\mathrm{EW}}\sin(\alpha) + G_{\mathrm{NN}}\cos^2(\alpha) + G_{\mathrm{NE}}\cos(\alpha)\, sin(\alpha) + G_{EE}\, sin^2(\alpha)]$$

ε: elevation

α: azimuth

$mf_{h,w,g}$: hydrostatic, non-hydrostatic and gradient mapping factor resp.

$d_{h,w}^z$: zenith hydrostatic and non-hydrostatic delay resp.

$G_{NS,EW}$: total linear (1st order) horizontal delay gradient components

$G_{NN,NE,EE}$: total 2nd order horizontal delay gradient components

Some mapping functions

$$mf_i(\varepsilon) = \begin{cases} \dfrac{1 + \dfrac{a_i}{1 + \dfrac{b_i}{1 + c_i}}}{\sin(\varepsilon) + \dfrac{a_i}{\sin(\varepsilon) + \dfrac{b_i}{\sin(\varepsilon) + c_i}}}, i = h \vee w \\ \dfrac{1}{\sin(\varepsilon)\tan(\varepsilon) + 0.0032}, i = g \end{cases}$$

Marini, 1972
Herring, 1992

Chen & Herring, 1997

- VMF1 and UNB_VMF1 (e.g., Böhm et al., 2006)
  - a_i estimated,, b_i and c_i from climatology
- GMF, GPT2, GPT2w (e.g., Böhm et al., 2015)
  - a_i annual + semi-annual terms,, b_i and c_i from climatology
- PMF (e.g., Zus et al., 2014, Douša et al., 2016; Balidakis et al., 2016a)
  - a_i, b_i and c_i estimated

Impact of mapping functions on VLBI analysis

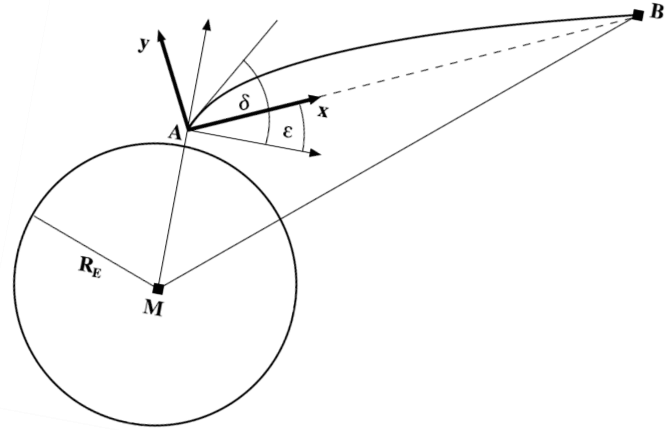
Here we focus on:

- ❑ A priori slant hydrostatic delay $$d_h^{\varepsilon} = mf_h \cdot d_h^z$$
- ❑ A posteriori zenith non-hydrostatic delay $$\frac{\partial \tau}{\partial d_w^z} = mf_w$$

PMF: Potsdam mapping functions

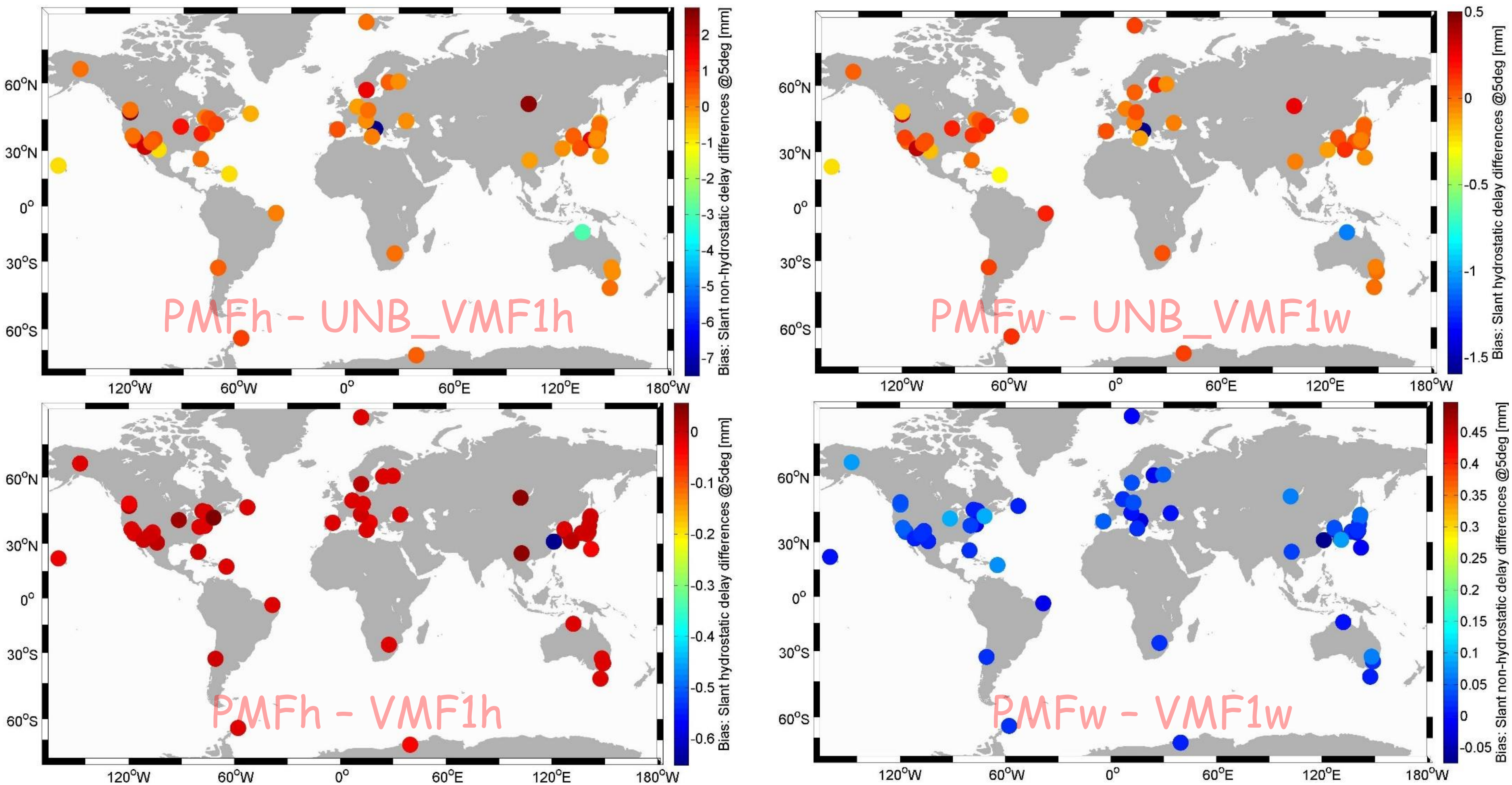
- ❑ Ray-trajectory solution with an **implicit finite difference scheme.**
- ❑ Structured non-linear system of equations solution with the **Newton-Raphson method**
- ❑ We estimate gradient components of 1st and 2nd order
- ❑ Ultra-rapid computation
  - ❑ using Intel 10.0.23 FORTRAN compiler e.g., given 90 stations and an ordinary PC (Core2QuadIntel processor, 2.5 GHz and 2 GB RAM) it takes ~1 sec for 10,800 station-quasar links

$$\varepsilon = \begin{bmatrix} 3 \\ 5 \\ 7 \\ 10 \\ 15 \\ 20 \\ 30 \\ 50 \\ 70 \\ 90 \end{bmatrix} \quad \alpha = \begin{bmatrix} 0 \\ 30 \\ 60 \\ 90 \\ 120 \\ 150 \\ 180 \\ 210 \\ 240 \\ 270 \\ 300 \\ 330 \end{bmatrix}$$



. . . comparisons

$\delta d_i^{5^\circ}, i = h \vee w$

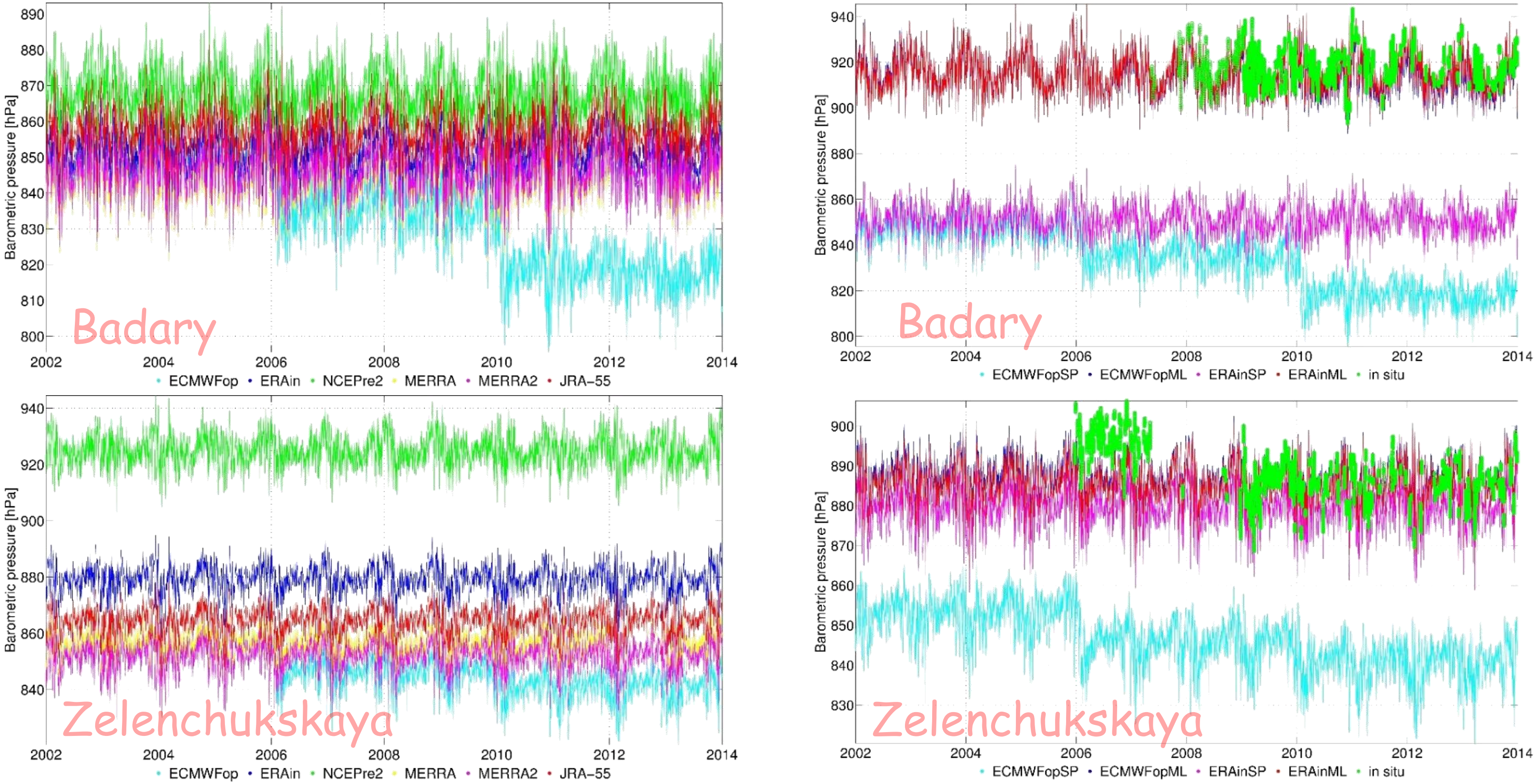


VLBI data analysis

- Vienna VLBI Software, VieVS@GFZ (Gauß-Markov model)
- Group delay data from IVS-R1 and IVS-R4 from 2002 until 2015 (1326 sessions) featuring a 32 station network
- We produced 3 solutions:
  - **VMF1** (Böhm et al., 2006b)
  - **GPT2w** (Böhm et al., 2015)
  - **PMF** (Douša et al., 2016)

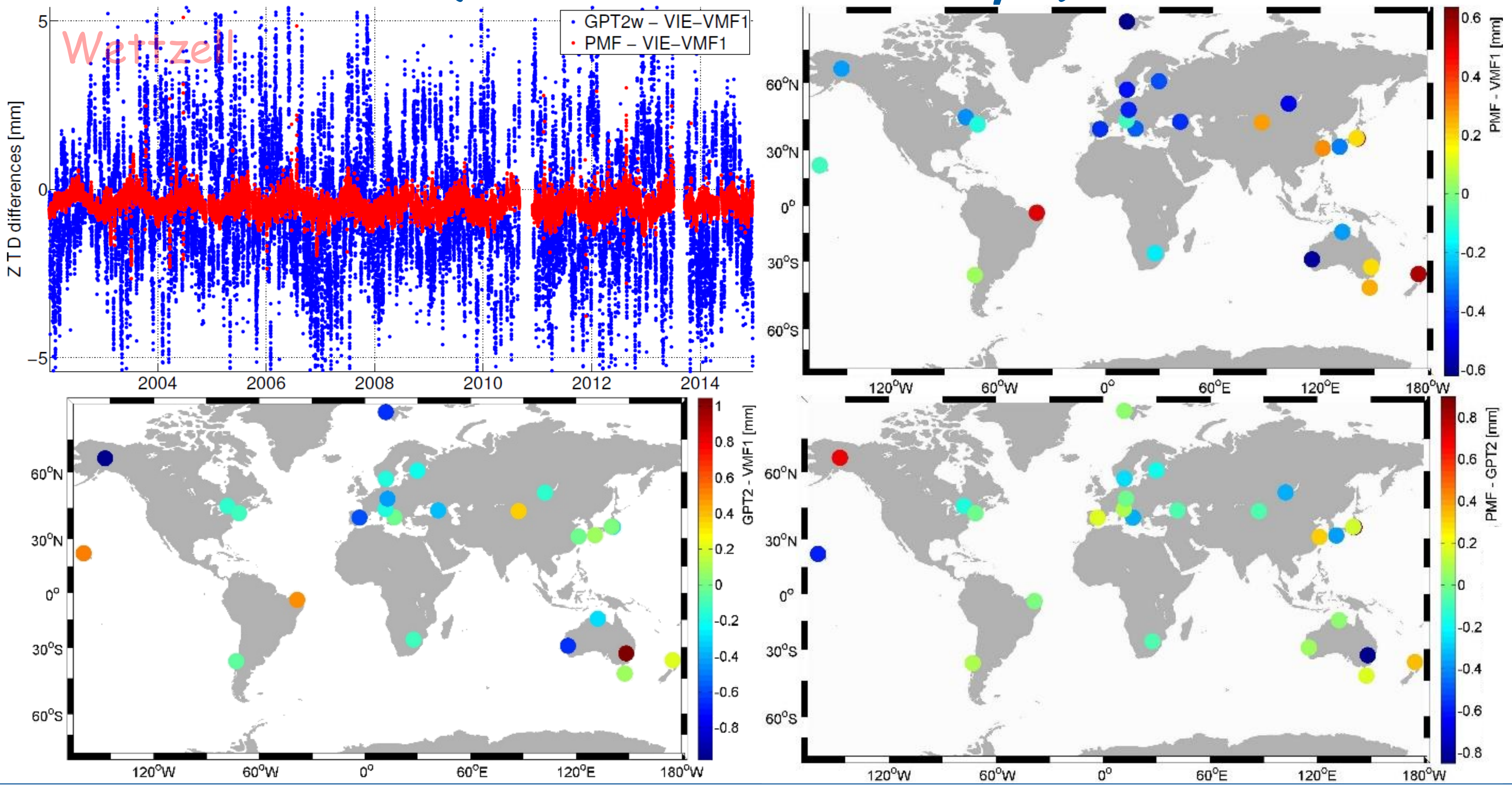
- All solutions determined w.r.t. ITRF2008 and USNO Finals EOP series, using the homogenized meteorological dataset and accounting for geophysical loading at the observation level.
- Daily estimates of station positions and EOPs, hourly ZWDs, 6-hourly gradients, ...

. . . concerning meteorological data

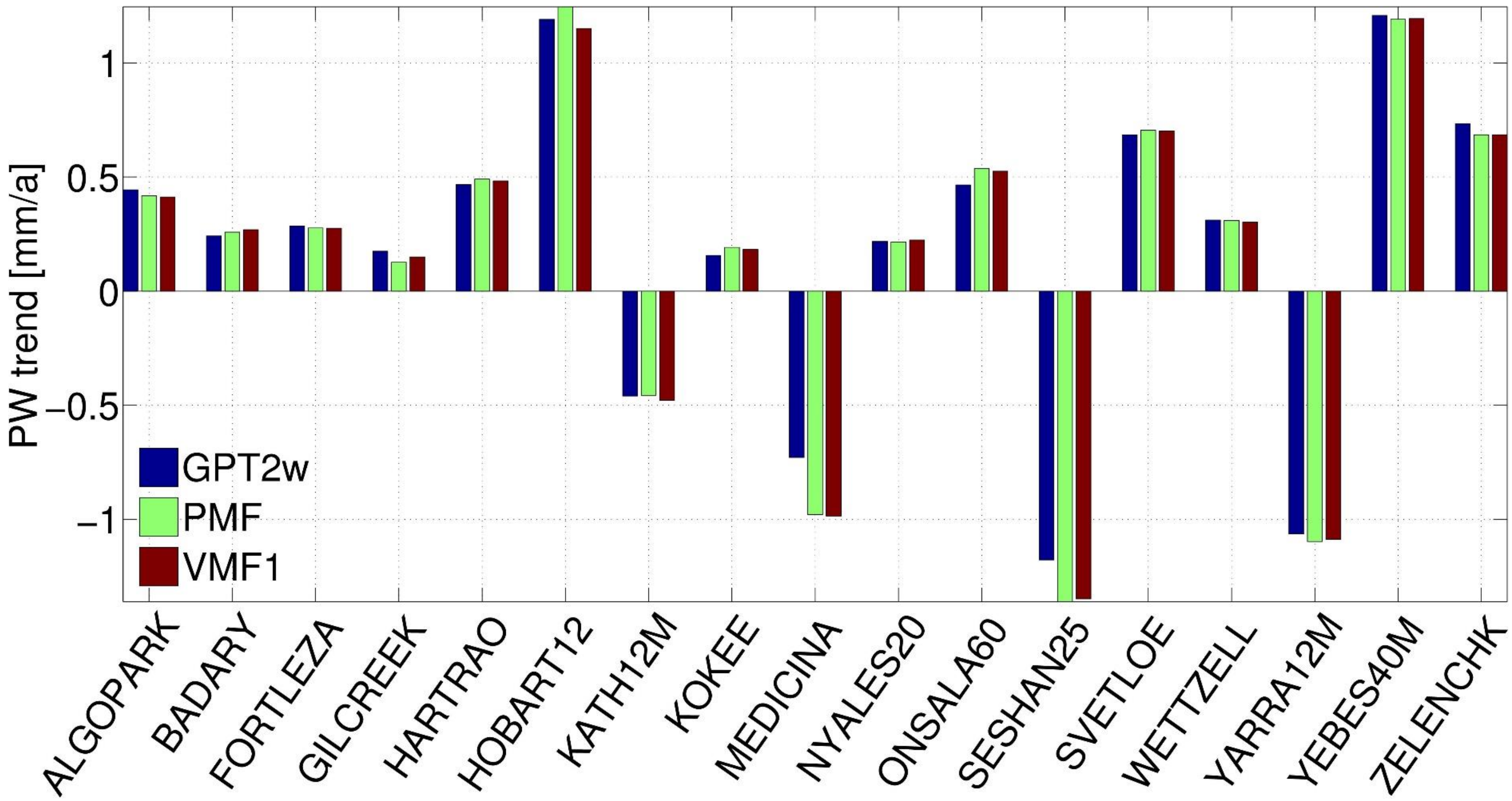


Balidakis et al., 2016b

VLBI analysis
(zenith total delays)

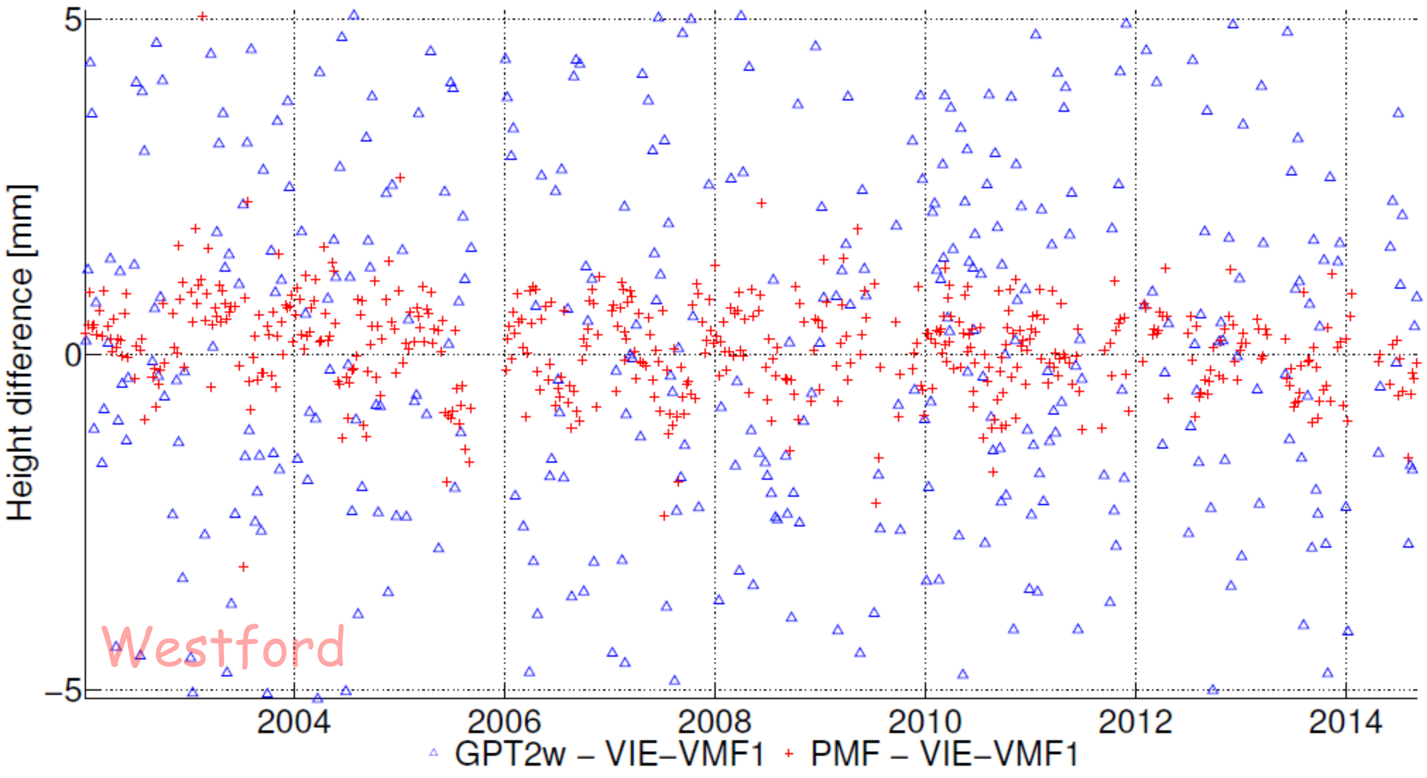


VLBI analysis (precipitable water vapor trends)

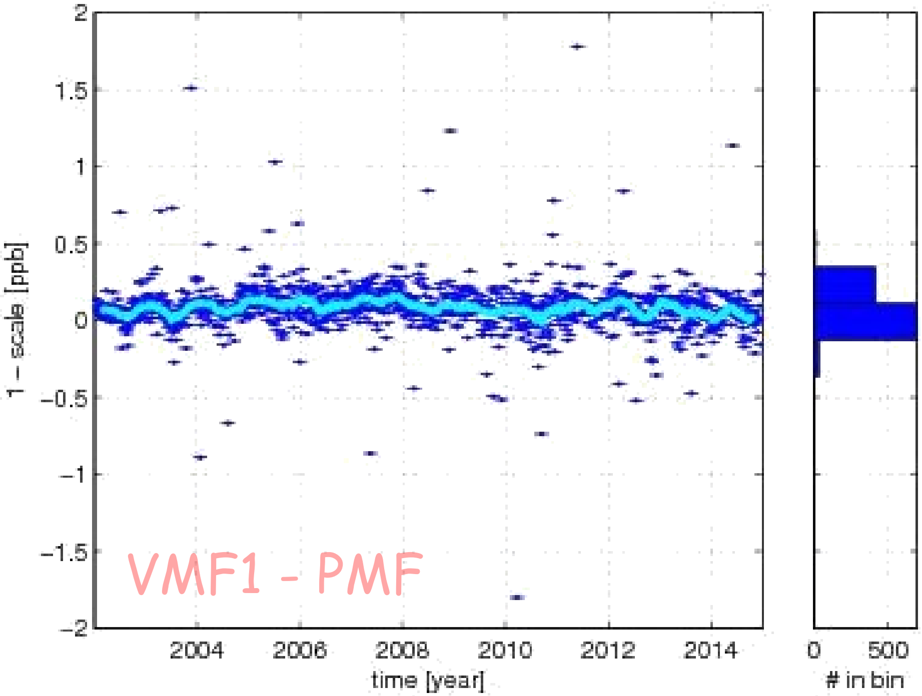


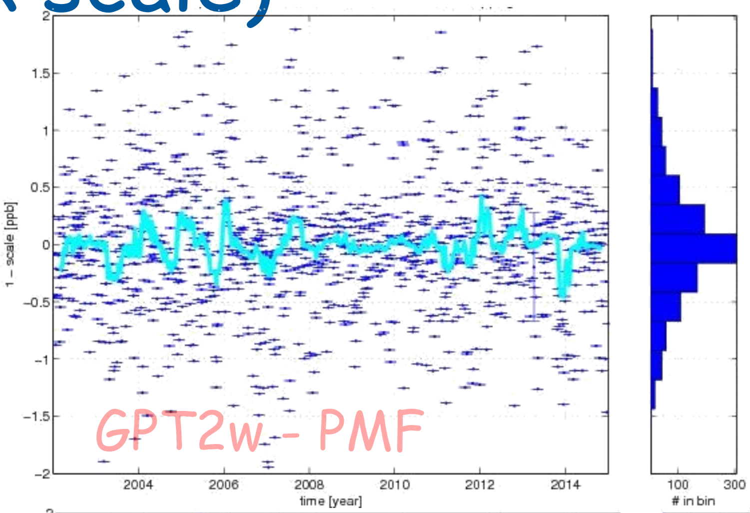
Balidakis et al., 2016c

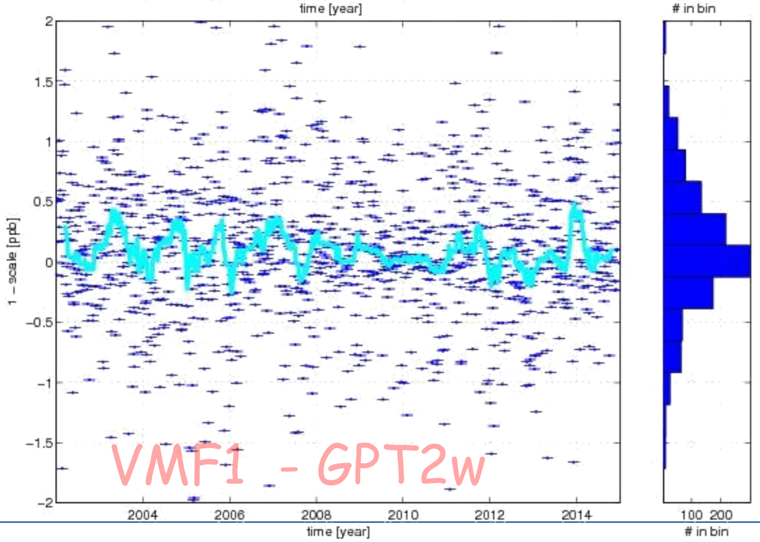
VLBI analysis (station ellipsoidal heights)



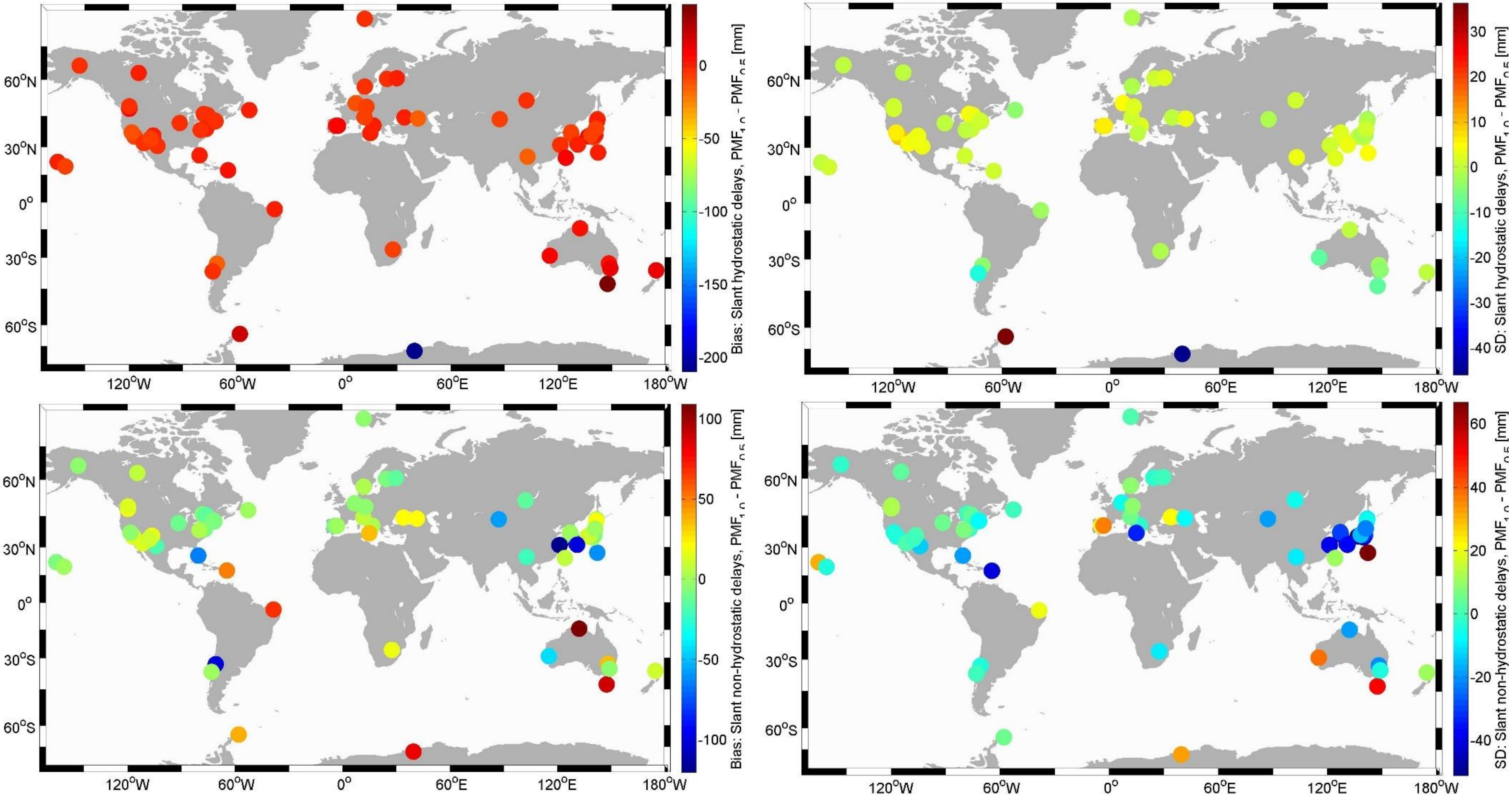
VLBI analysis
(network scale)







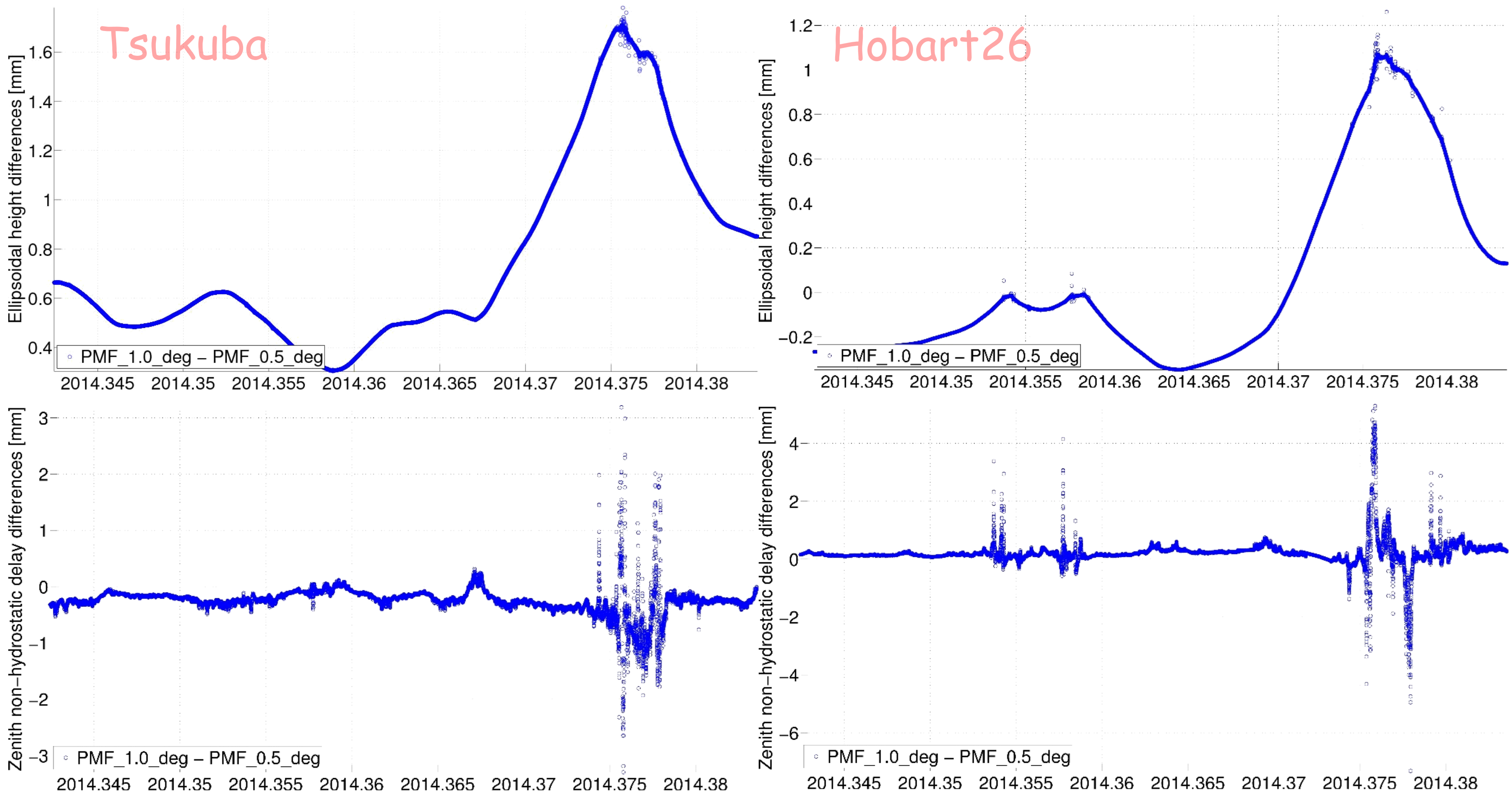
PMF
Spatial resolution of NWM: 1.0^0 vs 0.5^0



VLBI data analysis with Kalman Filtering

- Vienna VLBI Software, VieVS@GFZ, VIE_KAL (Nilsson et al., 2015)
- Group delay data from CONT14 featuring a 17 station network
- We produced 2 solutions:
  - **PMF 1.0^0 spatial resolution**
  - **PMF 0.5^0 spatial resolution**
- Both solutions determined w.r.t. ITRF2008 and USNO Finals EOP series, using the homogenized meteorological dataset and accounting for geophysical loading at the observation level.
- Scan-wise estimates of station positions and EOPs, ZWDs, gradient components, . . .

Some results



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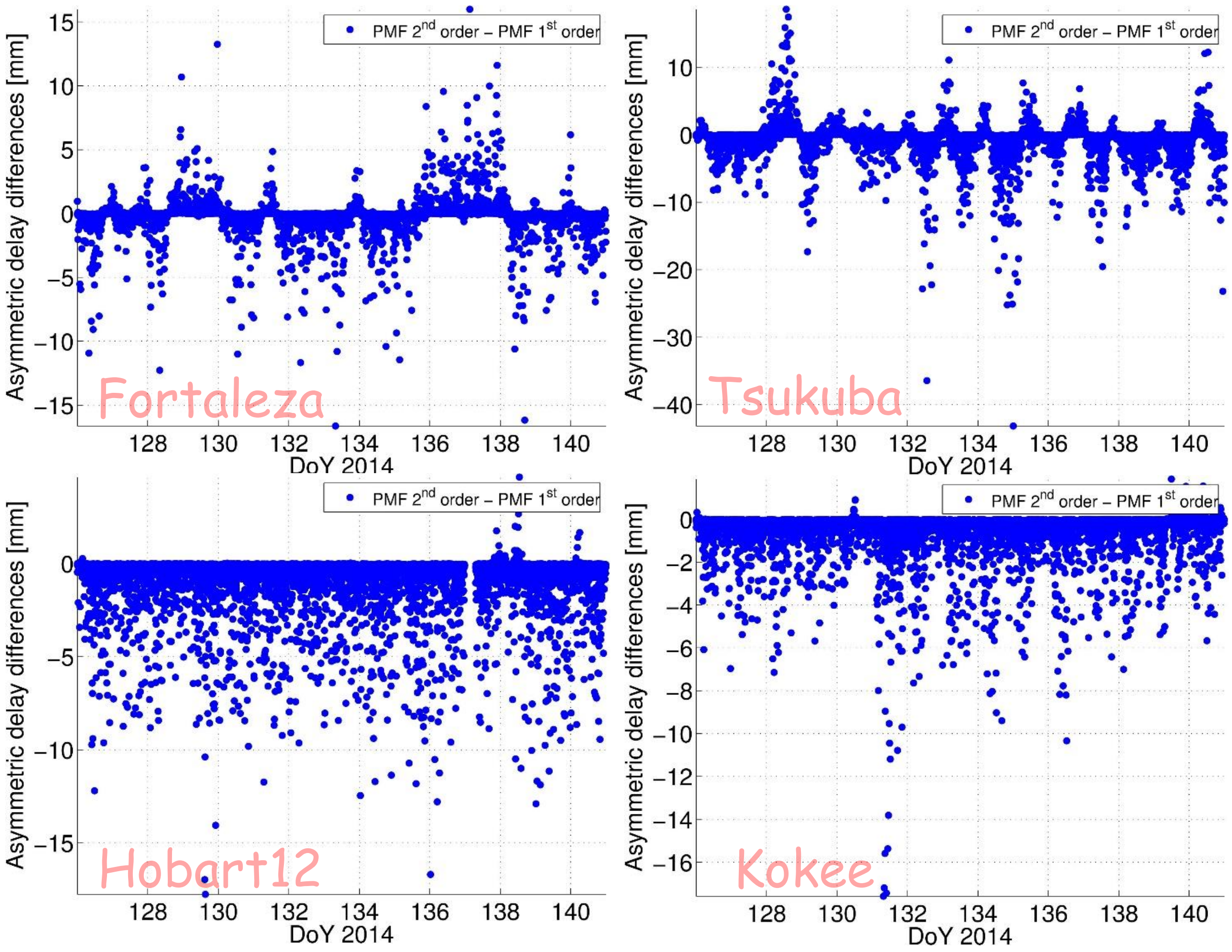
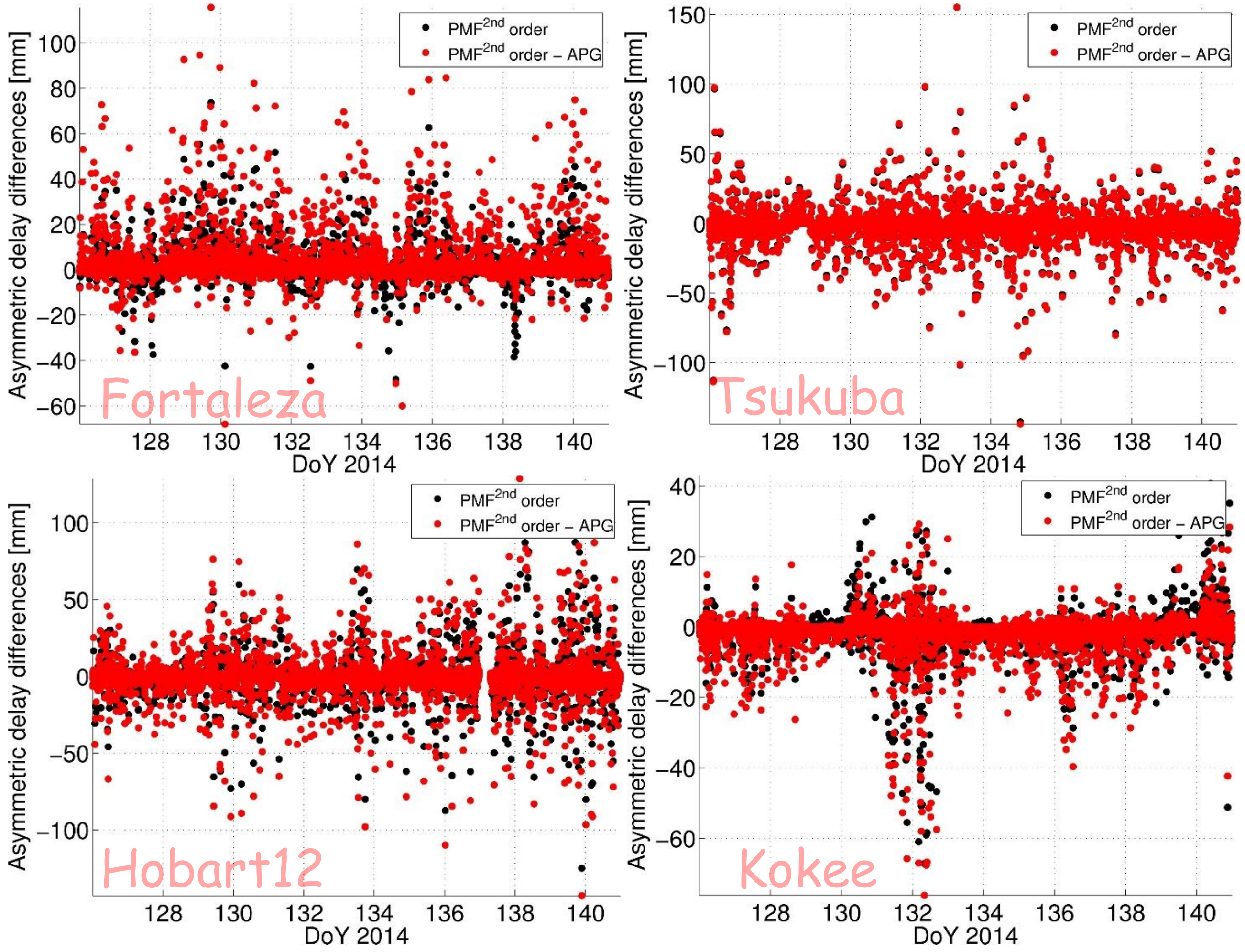
Impact of a priori gradients (I)



Impact of a priori gradients (II)



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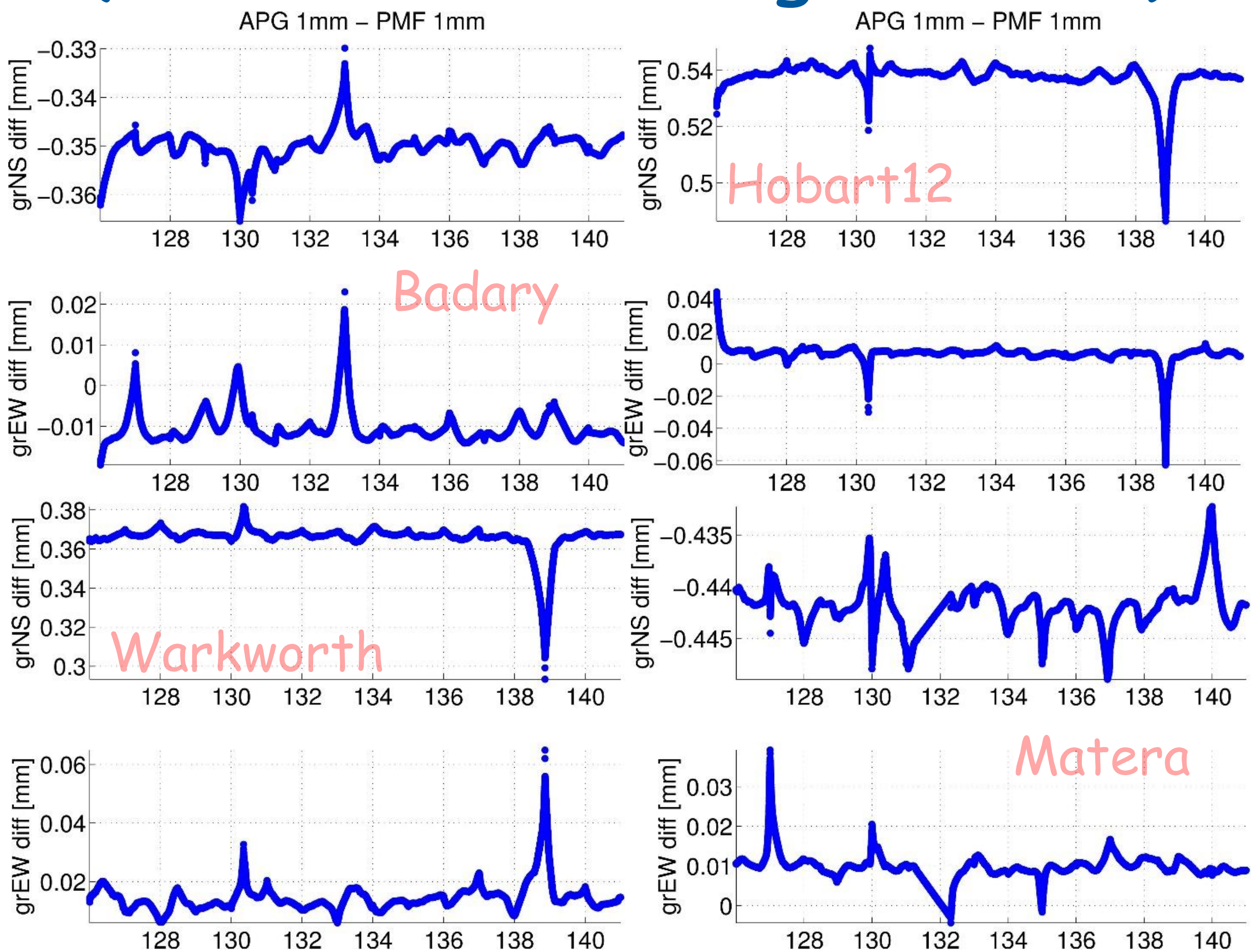
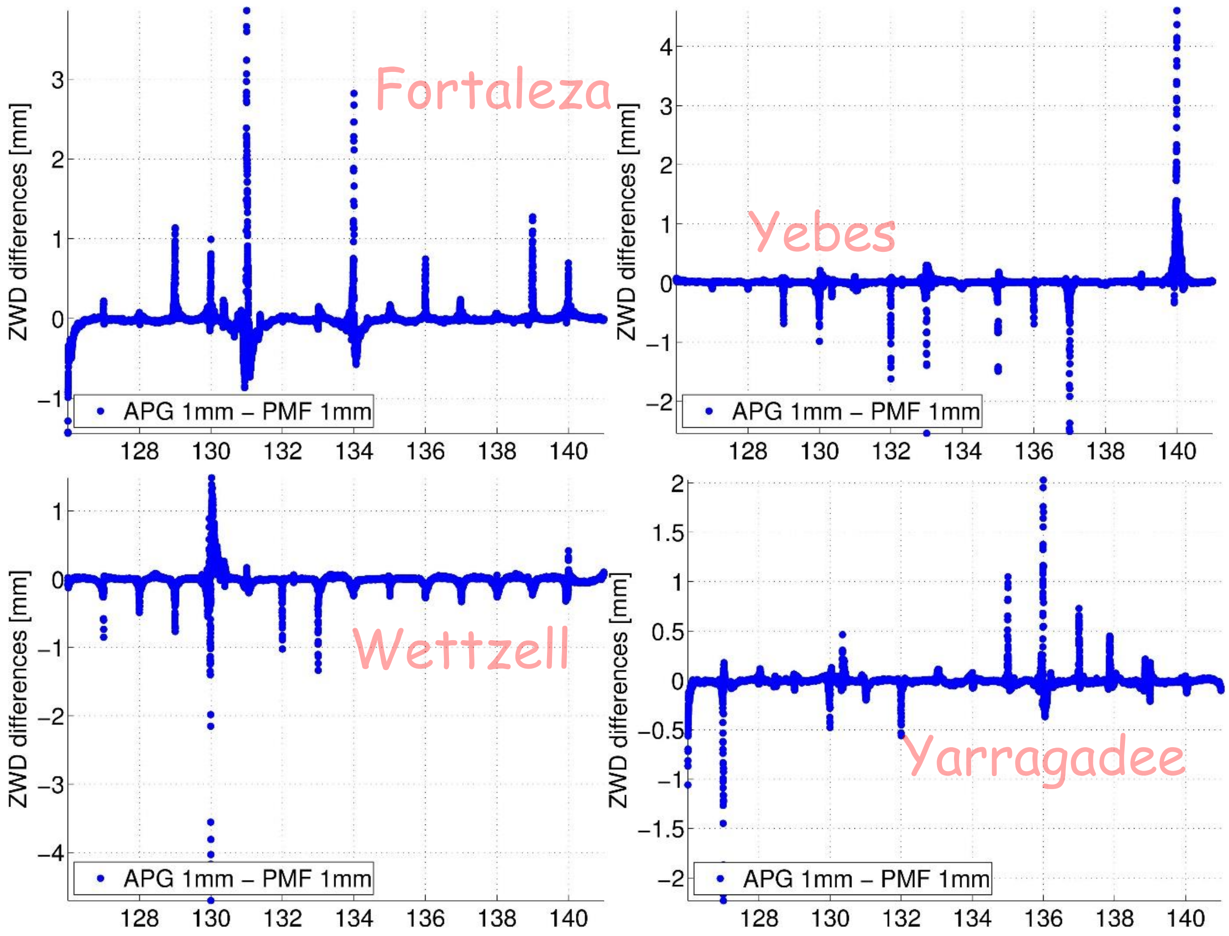
VLBI data analysis with Kalman Filtering

- Vienna VLBI Software, VieVS@GFZ, VIE_KAL (Nilsson et al., 2015)
- Group delay data from CONT14 featuring a 17 station network
- We produced 2 solutions:
  - ***APG gradients***
  - ***PMF (2nd order) gradients***
- Both solutions determined w.r.t. ITRF2014 and USNO Finals EOP series, using the homogenized meteorological dataset and accounting for geophysical loading at the observation level.
- Scan-wise estimates of station positions and EOPs, ZWDs, gradient components, . . .

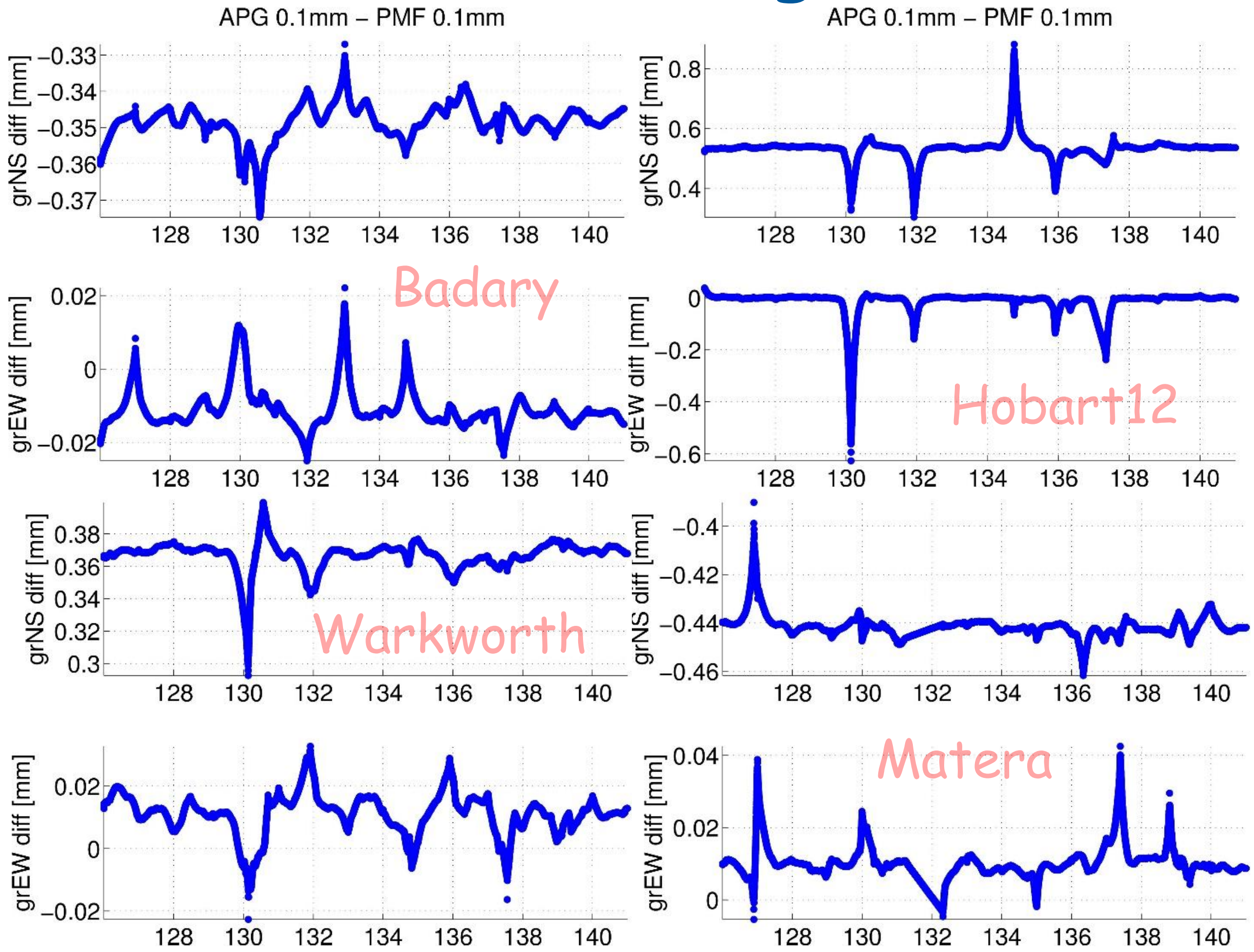
VLBI analysis (linear horizontal gradients)



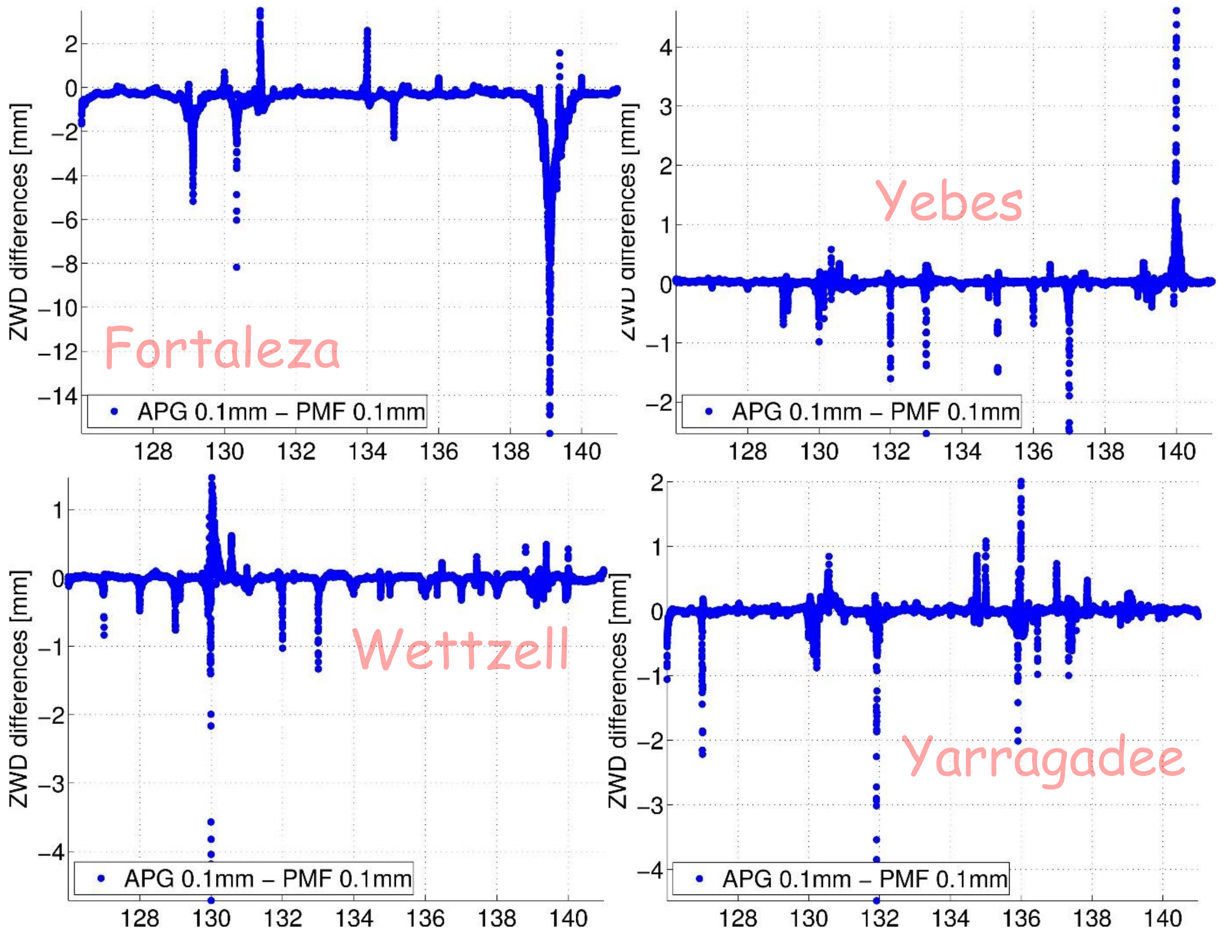
VLBI analysis (zenith wet delays)



VLBI analysis (linear horizontal gradients)



VLBI analysis (zenith wet delays)



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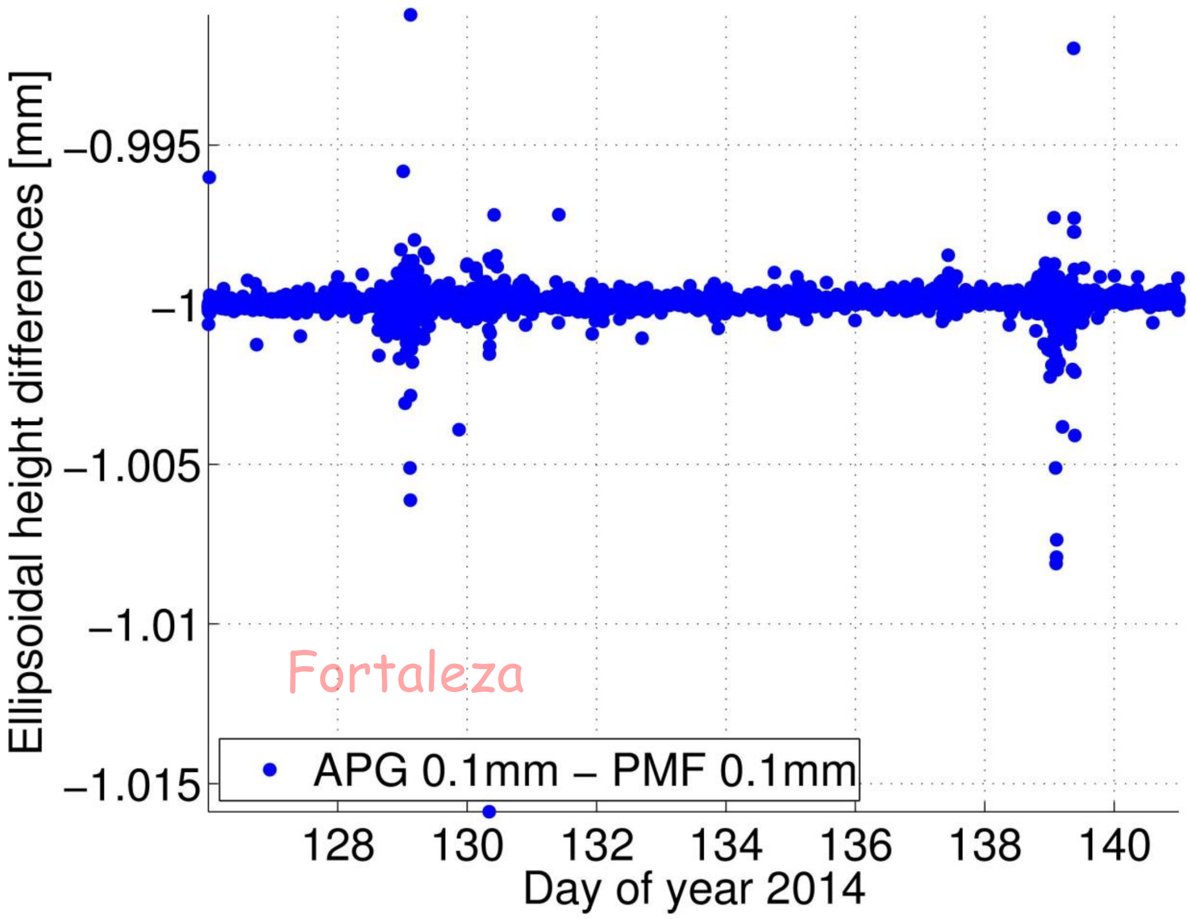
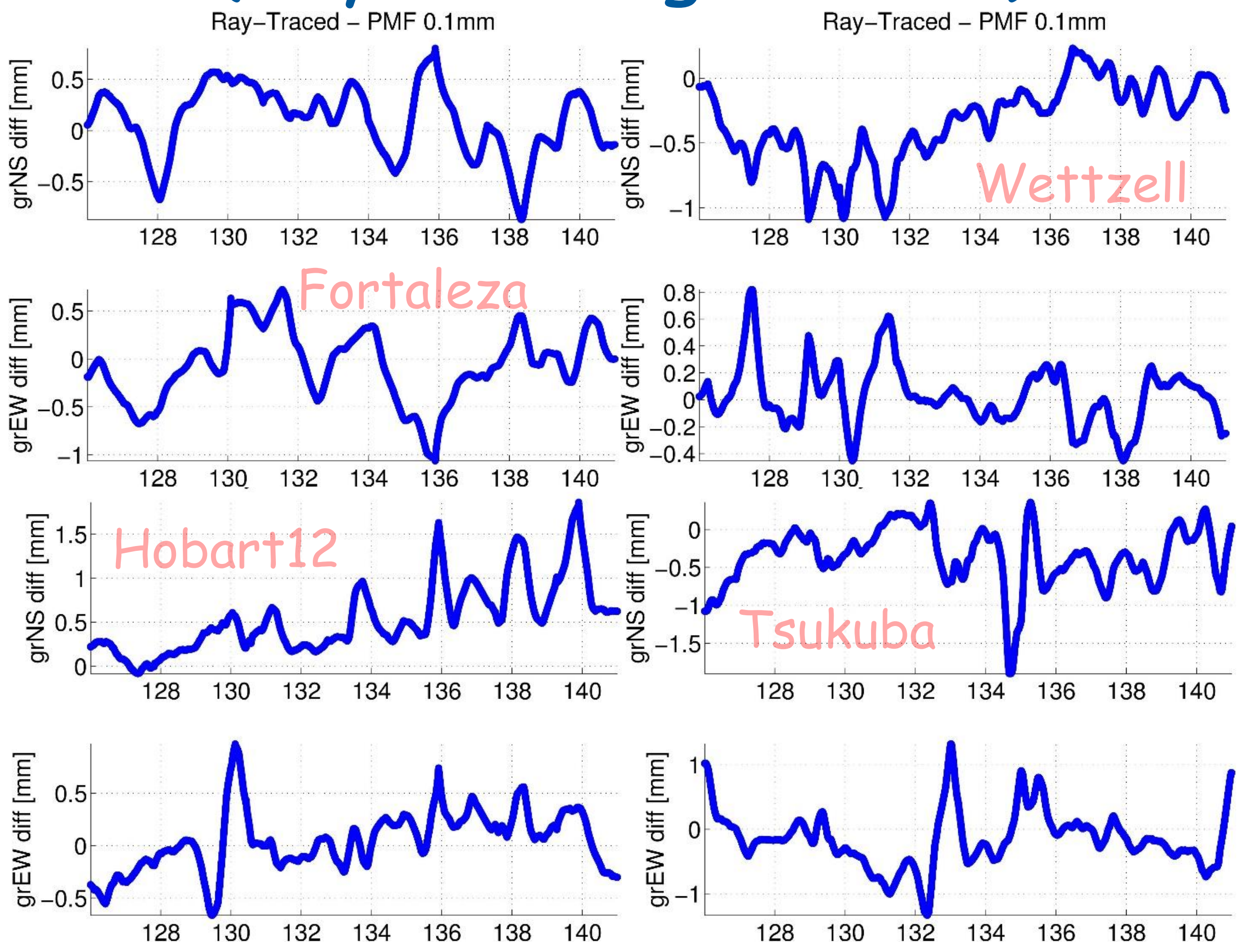
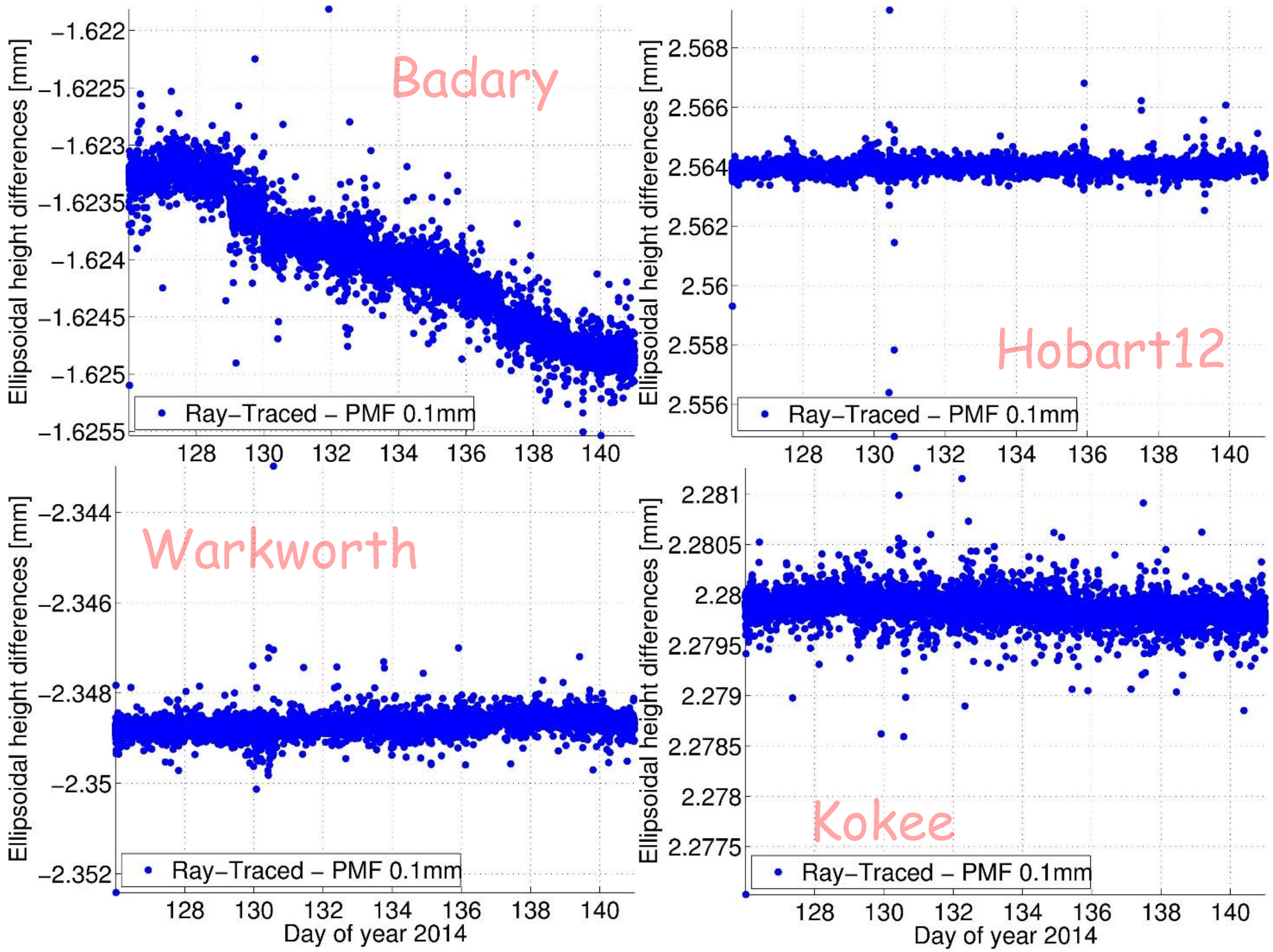
VLBI analysis (station ellipsoidal heights)



Bonus slide I: VLBI analysis (Ray-Tracing vs PMF)



Bonus slide II: VLBI analysis (Ray-Tracing vs PMF)



Recapitulation

- Estimating b_i and c_i in addition to a_i does not affect the estimated parameters appreciably, given the grid spacing. E.g., the height difference rarely exceeds 1 mm and PW trends are not affected.
- Utilizing a finer resolution of the same NWM and the same ray-tracing algorithm, results in an offset at the mm level in the height time series during severe weather events.
- Loosely constrained a priori gradients have no impact on VLBI estimates from modern sessions.

In the future . . .

- Both VMF1 and PMF suffer from systematics, so we should replace the parametrized mapping approach by the rapid direct mapping concept (e.g. Eriksson et al., 2014; Zus et al., 2015).
- Implement ultra-rapid direct mapping in VieVS@GFZ as the default option (done!).

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Thank you for your attention!

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