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Can VMF1 be improved by the use of new ray-tracing data?

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Troposphere Delay Modeling

$$\Delta L(e) = \Delta L_h^z \cdot mf_h(e) + \Delta L_w^z \cdot mf_w(e)$$

- ΔL_h^z: zenith hydrostatic delay
  from surface measurements, NWM or empirical models (GPT2w)
- ΔL_w^z: zenith wet delay
  from NWM or empirical models (GPT2w)
- mf_h: hydrostatic mapping function
  from discrete (VMF1) or empirical models (GMF, GPT2w,..)
- mf_w: wet mapping function
  from discrete (VMF1) or empirical models (GMF, GPT2w,..)

$\Rightarrow$ **Vienna Mapping Function 1 (VMF1)!**

But: already 10 years old...

VMF1 (*Böhm et al.*, 2006)

$$mf = \frac{1 + \cfrac{a}{1 + \cfrac{b}{1 + c}}}{\sin(el) + \cfrac{a}{\sin(el) + \cfrac{b}{\sin(el) + c}}}$$

- b, c: empirical coefficients
  - determined from 3 years of data
  - c_h: annual and latitude dependence (from a 10°x10° grid)
  - b_h, b_w and c_w: constants
- a: determined discretely from ray-tracing, strictly for el = 3.3° by inversion of above formula

But: Small deficiencies in empirical constants and in tuning for 3.3°!

VMF1 vs. VMF3

VMF1	VMF1_repro	VMF3
b*, *c	***b*, *c***	***b*, *c***
from 3 years of data on a 10°x10° grid	from 3 years of data on a 10°x10° grid	from 10 years of data on a 2.5°x2.0° grid
lat. dep. for c_h	lat. dep. for c_h	lat. and lon. dep. for b_h, b_w, c_h and c_w through spherical harmonics (n=m=12)
annual variation for c_h	annual variation for c_h	annual and semi-annual terms for b_h, b_w, c_h and c_w
a	***a***	***a***
strictly for el = 3.3°	strictly for el = 3.3°	LSM for el = [3°, 5°, 7°, 10°, 15°, 30°, 70°]
simple 1D ray-tracer	2D ray-tracer "RADIATE" (*Hofmeister*, 2016)	2D ray-tracer "RADIATE" (*Hofmeister*, 2016)

VMF1 vs. VMF3

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simple 1D ray-tracer	2D ray-tracer “RADIATE” (*Hofmeister*, 2016)	2D ray-tracer “RADIATE” (*Hofmeister*, 2016)

Input for user

- a_h, a_w, ΔL_h^z, ΔL_w^z: VMF3 text files (6-hourly)
- zd: zenith distance (π/2 – elevation)
- mjd: Modified Julian Date
- φ: Latitude [rad]
- **λ: Longitude [rad]**

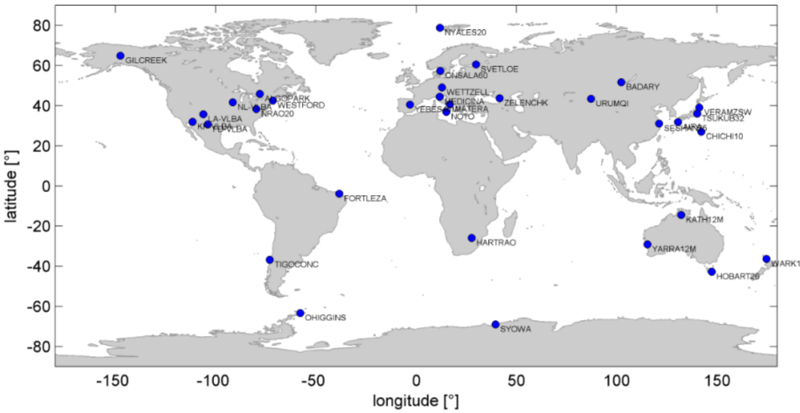
Analysis

Comparisons to assess performance of VMF3 vs. VMF1_repro and VMF1:

1. Delay differences to ray-tracing for specific sites
2. Delay differences to ray-tracing on a grid
3. VLBI analysis → baseline length repeatability (BLR)

Mean absolute differences in slant total delay to ray-tracing [mm]

33 sites around the world
1999 -2014

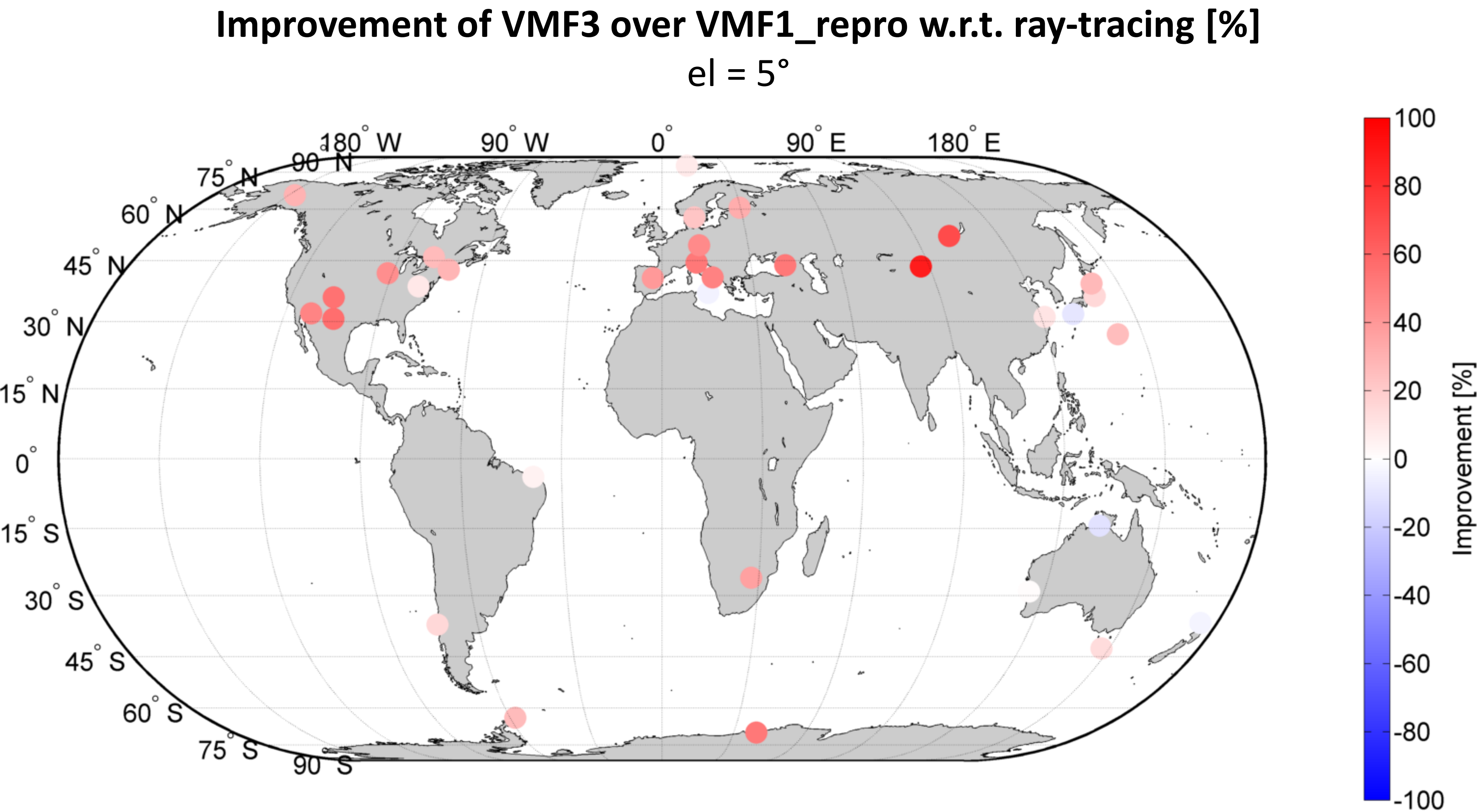


[mm]	3°	5°	7°	10°
VMF1_repro	0.55	3.98	2.54	1.47
VMF3	1.18	2.70	1.71	0.93

⇒ **Improvement over VMF1!**

Analysis

1. Delay differences to ray-tracing for specific sites



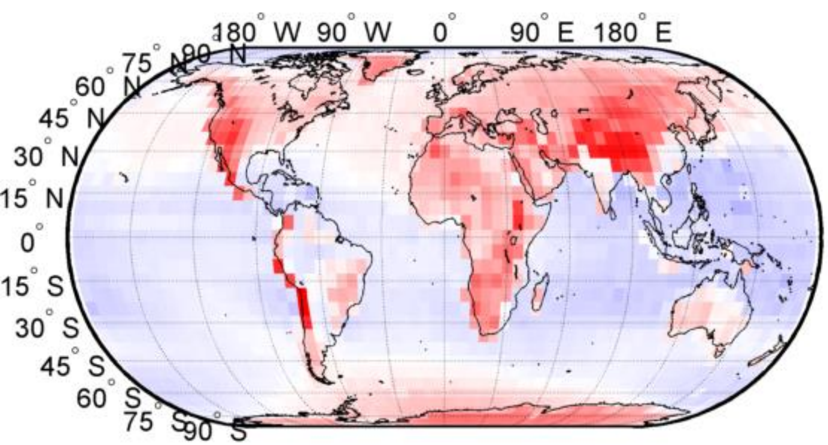
Bias of differences in slant total delay to ray-tracing [mm]

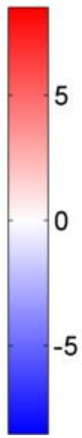
2592 grid points

120 epochs (2001-2010)

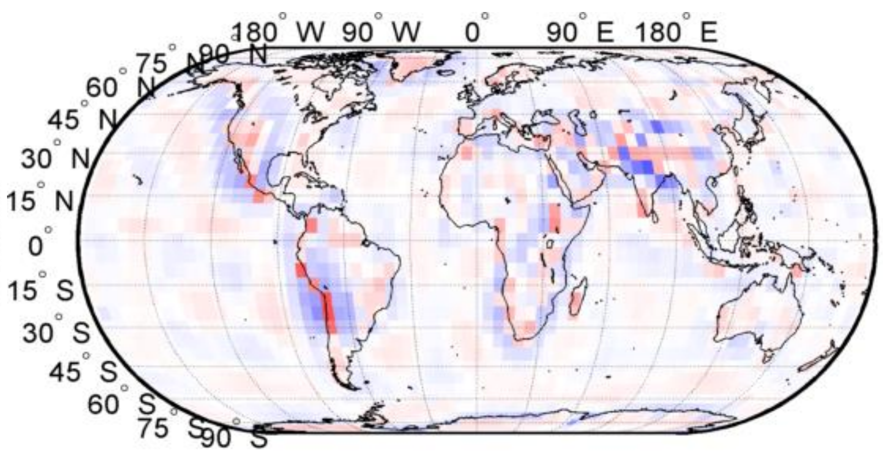
el = 5°

VMF1_repro





VMF3



St. dev. of differences in slant total delay to ray-tracing [mm]

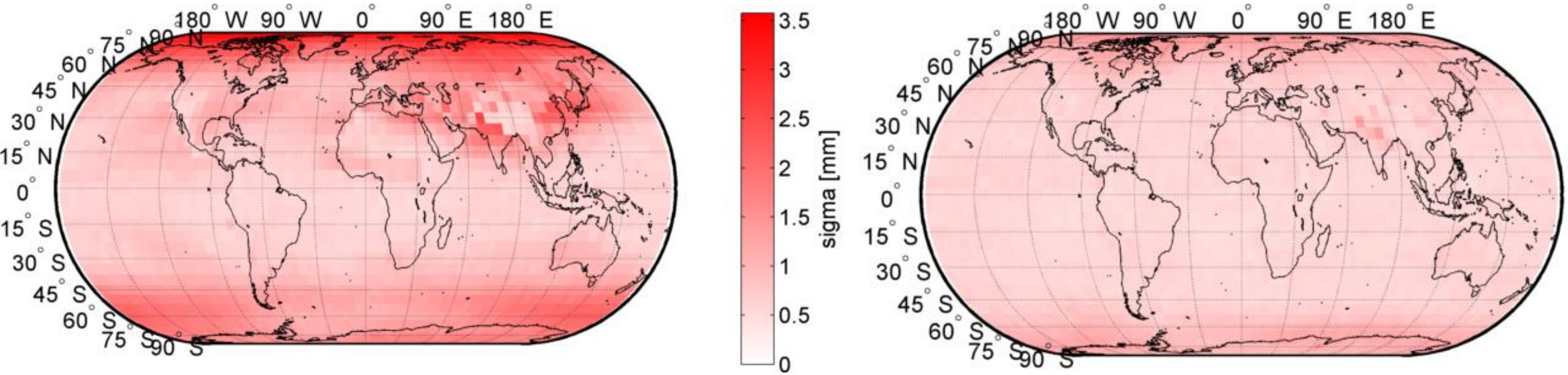
2592 grid points

120 epochs (2001-2010)

el = 5°

VMF1_repro

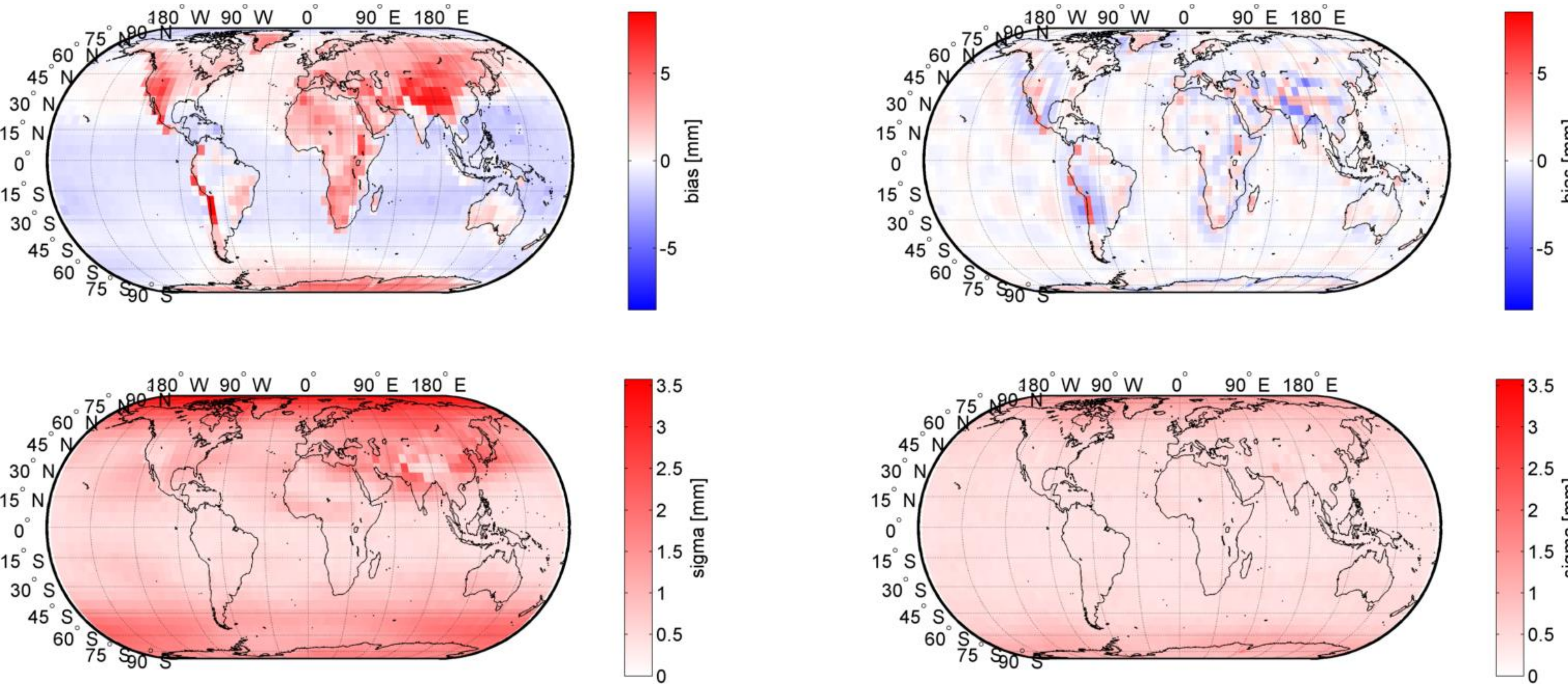
VMF3



Bias and st. dev. of differences in slant hydrostatic delay to ray-tracing [mm]

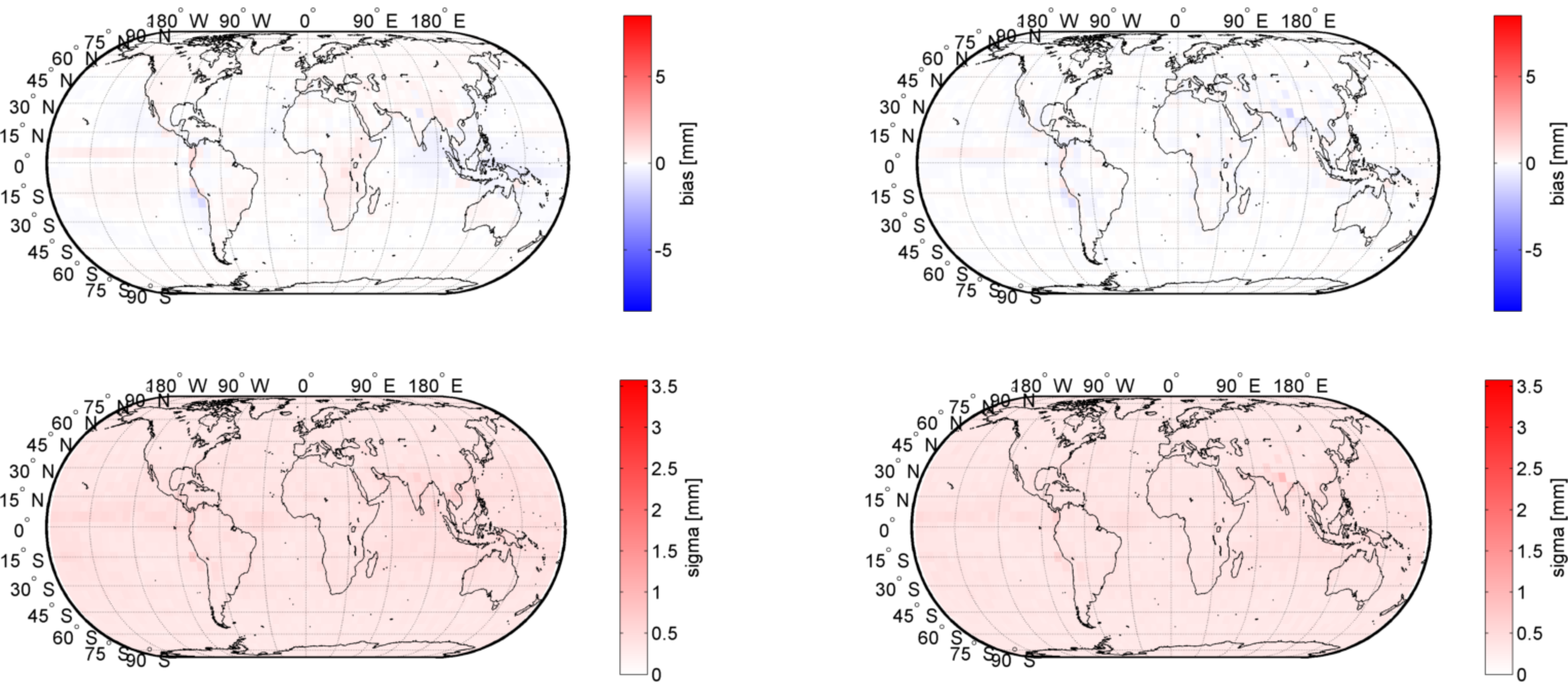
VMF1_repro

VMF3



Bias and st. dev. of differences in slant wet delay to ray-tracing [mm]

VMF1_repro VMF3



Analysis

Mean absolute difference in slant delay to ray-tracing [mm]

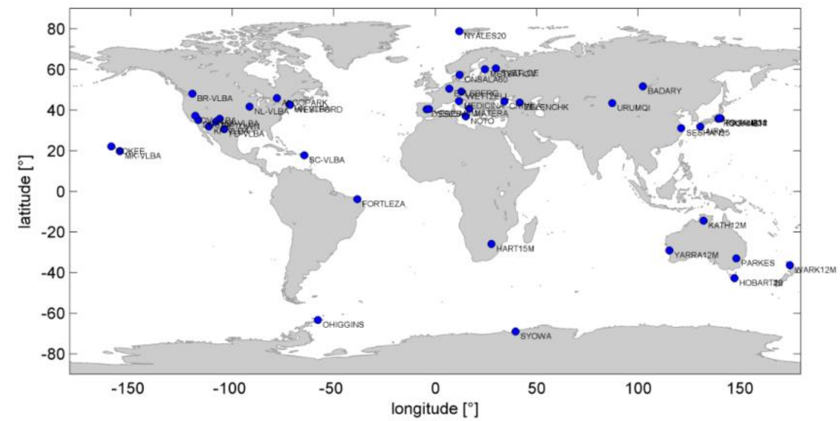
Averaged over all 2592 grid points and 120 epochs from 2001 and 2010
5° elevation

[mm]	VMF1_repro	VMF3
ΔL	**1.86**	**0.83**
ΔL_h	1.80	0.74
ΔL_w	0.31	0.30

$\Rightarrow$ **Improvement over VMF1!**

Comparison of baseline length repeatabilities (BLR)

VLBI analysis using VieVS
real VLBI observations
45 VLBI stations
1338 sessions from 2006-2014
No ΔL_w^z estimated!



[mm]	BLR
VMF1	34.9
VMF1_repro	26.2
VMF3	26.1

⇒ **Improvement over VMF1!**

Conclusions

- New ray-traced delays yield a significant improvement
  - Main improvement comes from zenith delays
  - Re-processed VMF1 more exact than VMF1
- VMF3 model more exact than VMF1 model, especially at low elevations
- VMF3 can be applied just like VMF1

Outlook

- Finalize calculations and provide VMF3 for all
  - IVS stations (VLBI)
  - IGS stations (GNSS)
  - IDS stations (DORIS)
  - on a grid
- Create a new empirical model (GPT3) on the same basis

Thank you very much!

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References:

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Hofmeister, A. (2016): „*Determination of path delays in the atmosphere for geodetic VLBI by means of ray-tracing*". PhD thesis. Department of Geodesy and Geoinformation, TU Wien. http://resolver.obvsg.at/urn:nbn:at:at-ubtuw:1-3444