Generation and Assessment of VMF1-Type Grids Using North-American Numerical Weather Models

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Overview

- Use of Numerical Weather Models (NWM) for geodetic purposes
- IERS Conventions
  - Vienna Mapping Functions 1
- Comparison of VMF1 and zenith delays
  - ECMWF, NCEP, CMC-GEM
- Tests using VLBI CONT08
- Conclusions and Future Work

Numerical Weather Models for Geodesy

- NWM are being used for modeling troposphere delay, atmospheric pressure loading, gravity effects, ...

- Generally, a lack of consistency. Progress being made: http://ggosatm.hg.tuwien.ac.at/

- Redundancy concerns

Troposphere Delay Modelling

According to IERS Conventions (2010):

Hydrostatic / Non-hydrostatic

$$\Delta L = \underbrace{\Delta L_h^z \cdot mf_h(e)}_{\text{Hydrostatic}} + \underbrace{\Delta L_w^z \cdot mf_w(e)}_{\text{Non-hydrostatic}}$$
$$+ \underbrace{mf_G(e) \cdot [G_N \cdot \cos(\alpha) + G_E \cdot \sin(\alpha)]}_{\text{Gradient Model}}$$

Gradient Model

Vienna Mapping Functions 1

- Derived from ECMWF (6 hour basis):

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

a -- Ray-tracing at fixed elevation angle of 3.3 degrees

b, c -- from empirical functions, latitude and day-of-year dependent

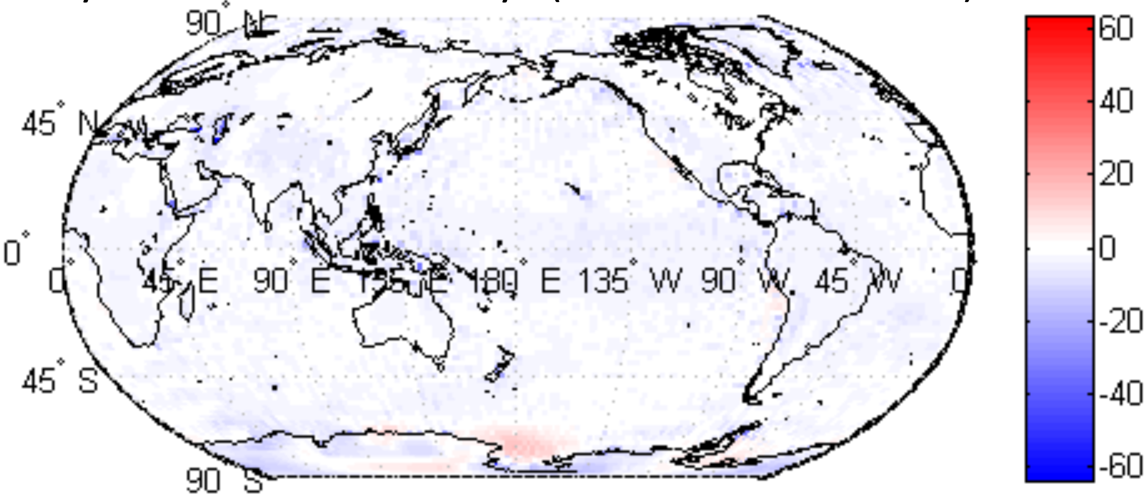
UNB Realizations of VMF1

- UNB implementation (UNB-VMF1):
  - NOAA-NCEP Reanalysis (also CMC-GEM)
  - Available on 6 hour basis
  - Only use gridded format (2.0 x 2.5 lat. – long. grid)
    - See http://ggosatm.hg.tuwien.ac.at/DELAY/readme.txt

- Independent ray-tracing algorithms
  - Nievinski (2009)

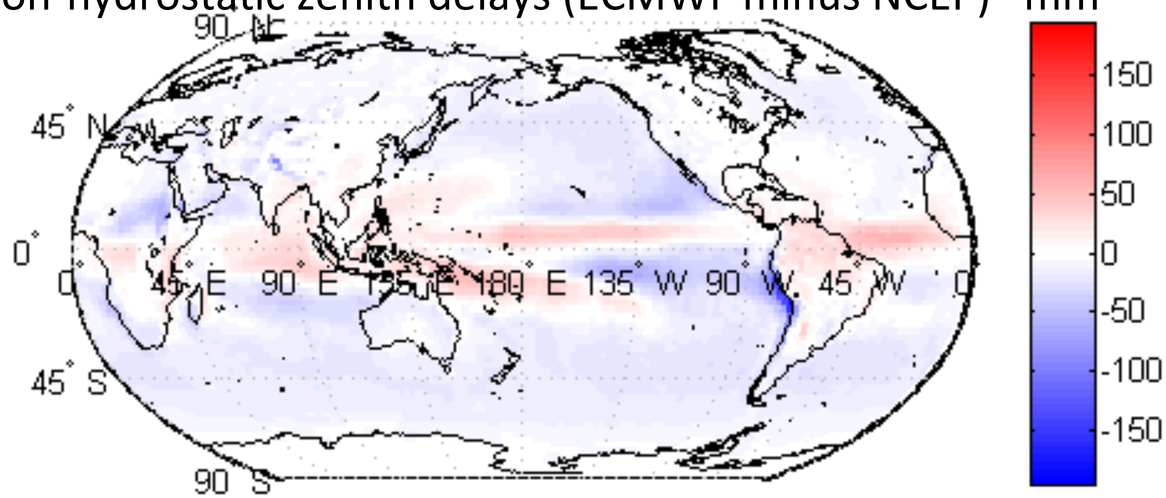
Zenith Delay Comparison (2010)

Hydrostatic zenith delays (ECMWF minus NCEP) mm



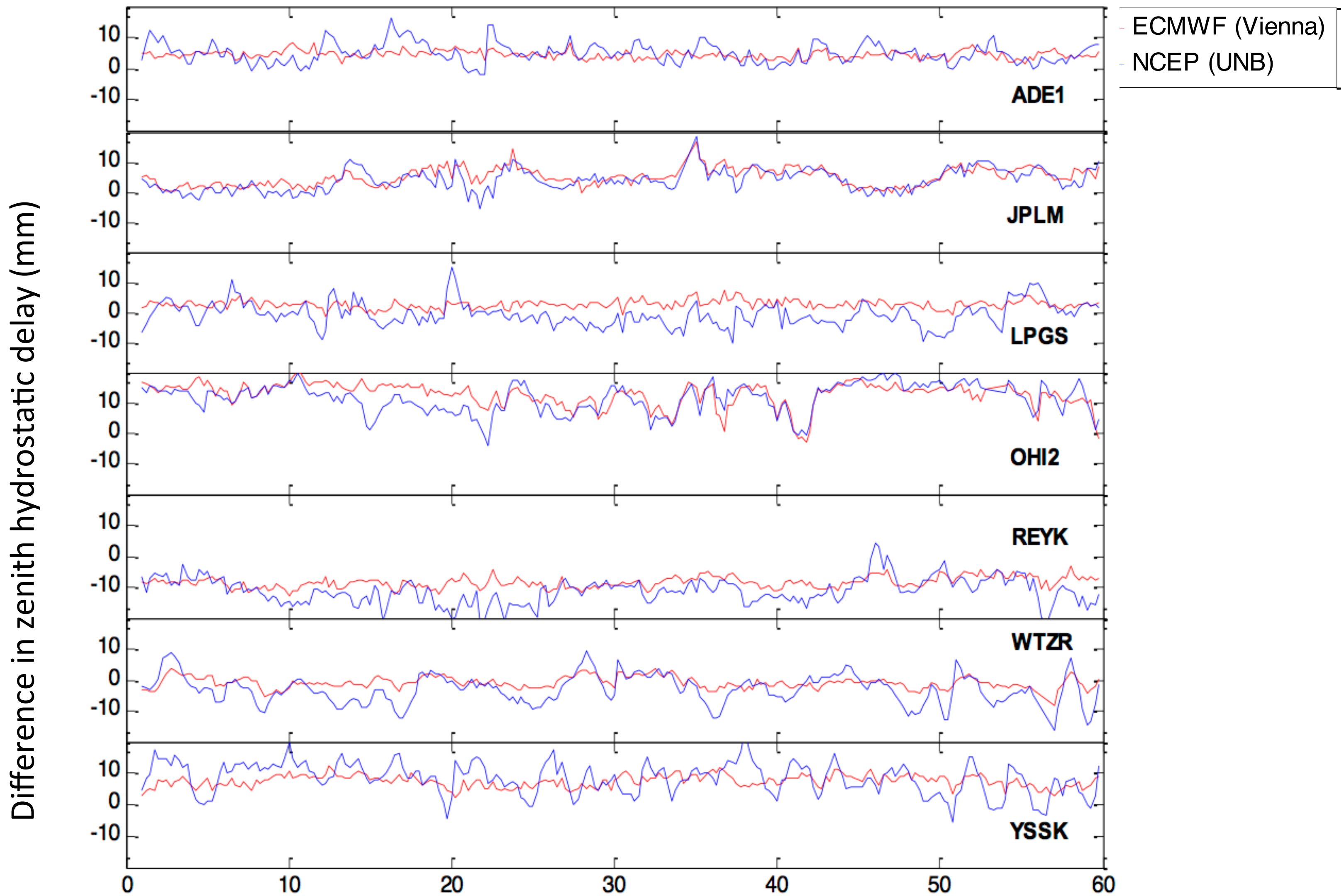
Overall: -2.4 ± 3.8 mm

Non-hydrostatic zenith delays (ECMWF minus NCEP) mm

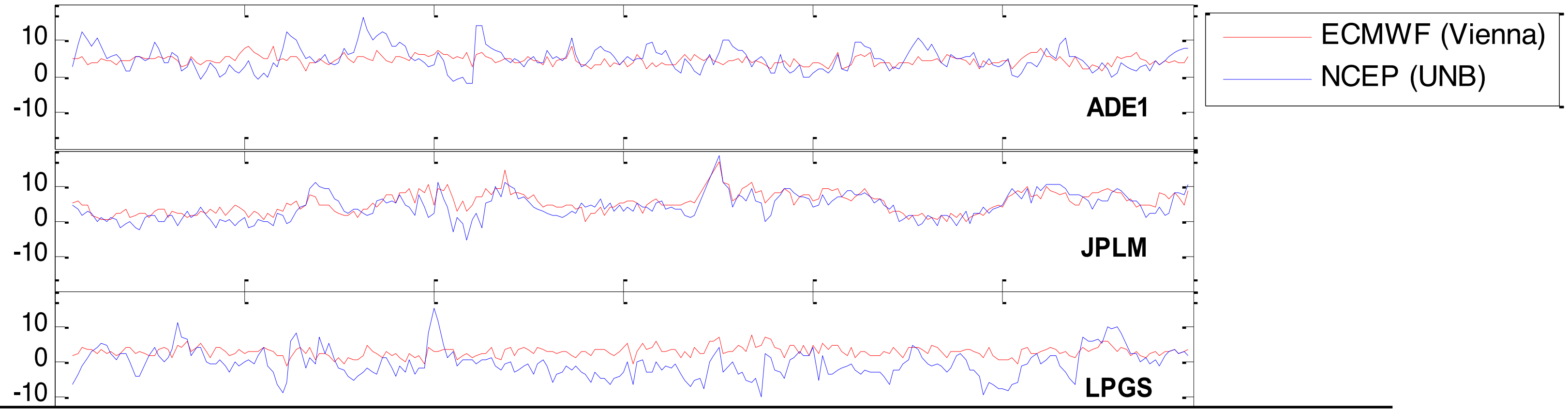


Overall: -6.3 ± 14.7 mm

Comparison w.r.t. Saastamoinen Delays



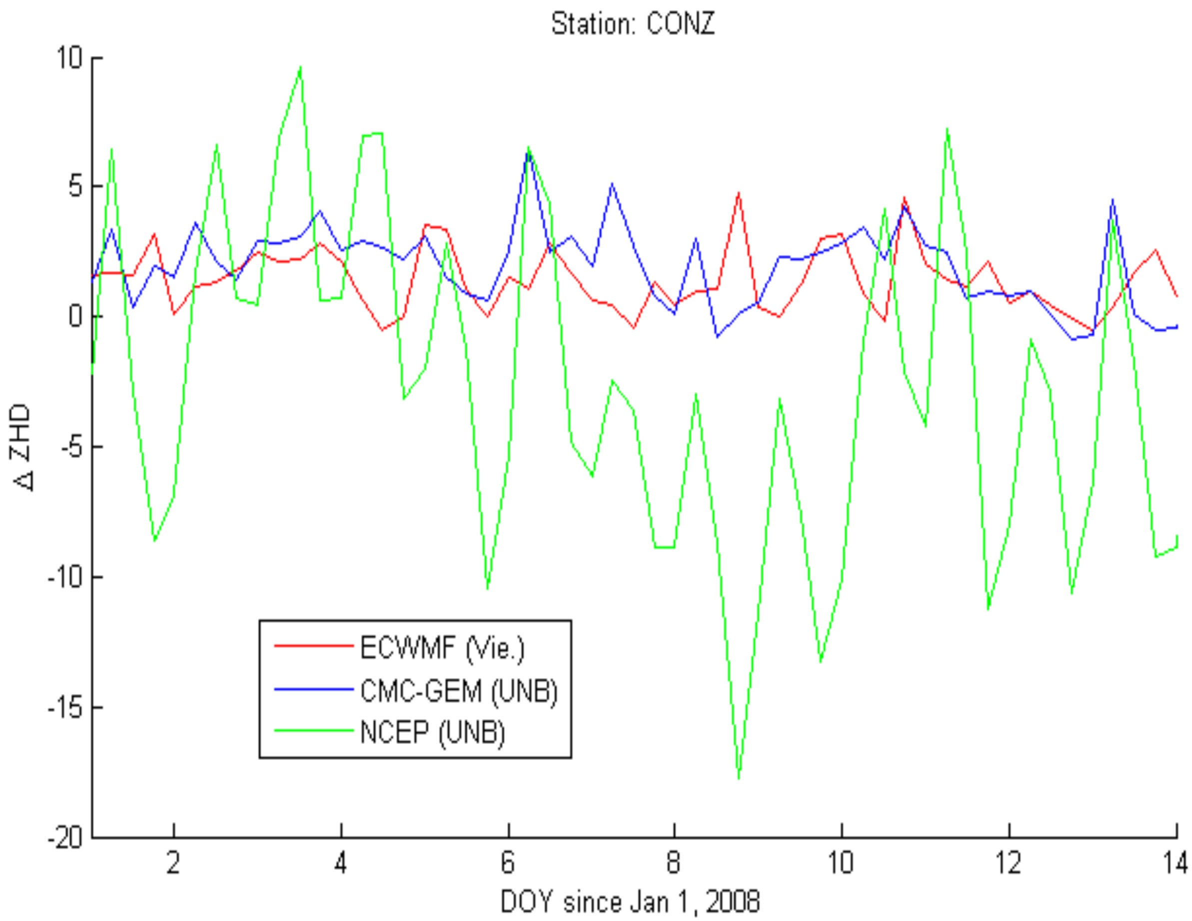
Comparison w.r.t. Saastamoinen Delays



Average statistics over all stations

Zenith Hydrostatic Delays	Bias	Std. Dev.
ECMWF (Vienna)	3.27 mm	2.18 mm
NCEP (UNB)	1.95 mm	4.22 mm

Comparison w.r.t Saastamoinen Delays



NCEP ZHD much noisier. Believed to be implementation issue in treatment of NCEP data in our algorithms

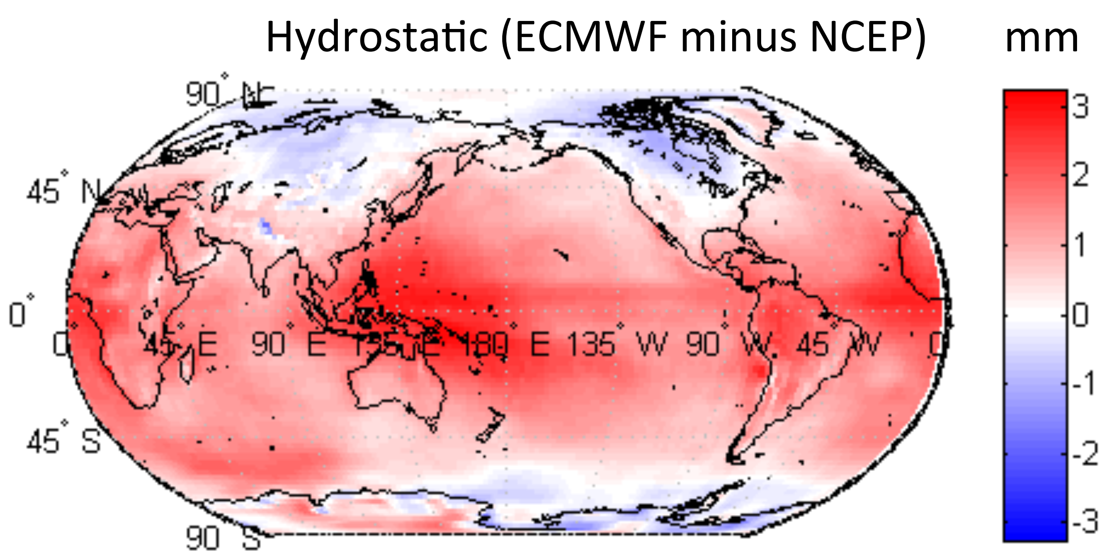
Comparison of Mapping Function Errors

- Use rule of thumb (MacMillan and Ma, 1994; Boehm et al., 2008):

Bias in station height is approximately equal to 1/5 bias in slant delay at 5 degrees elevation angle

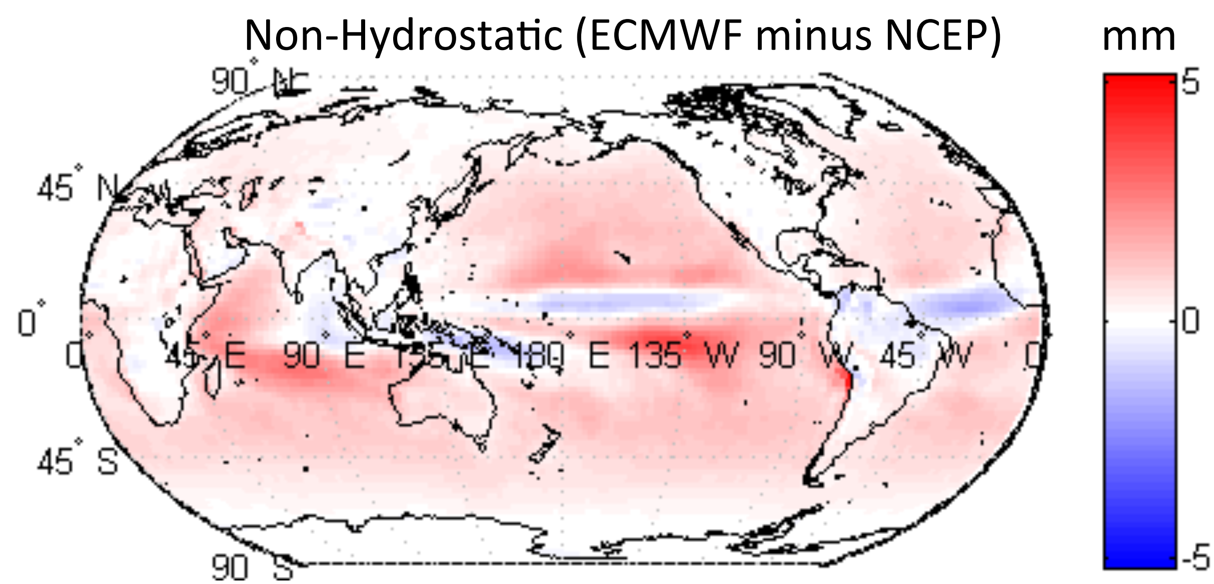
Difference in Station Height due to Mapping Functions

Hydrostatic (ECMWF minus NCEP)



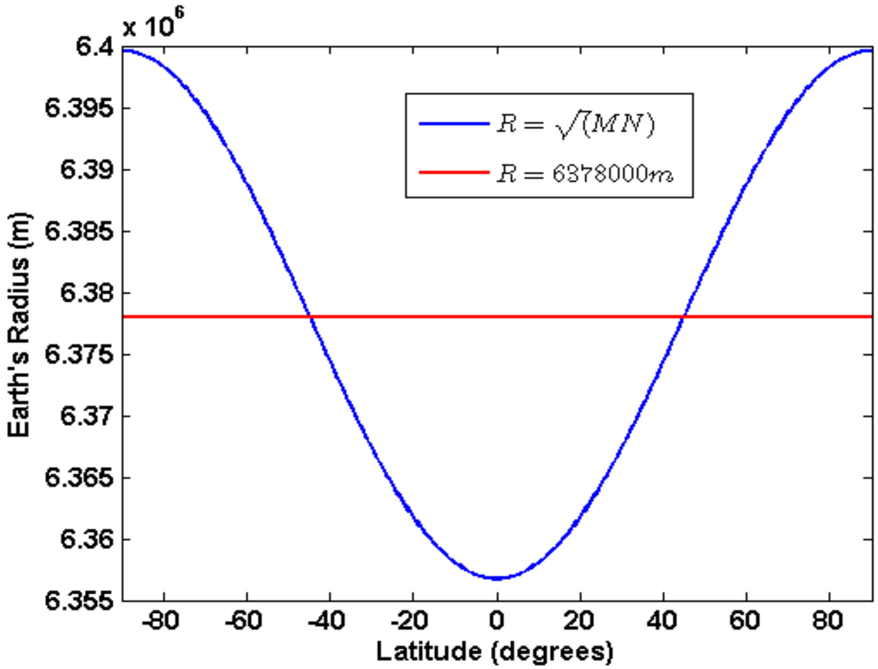
Overall: 0.79 ± 0. 89 mm

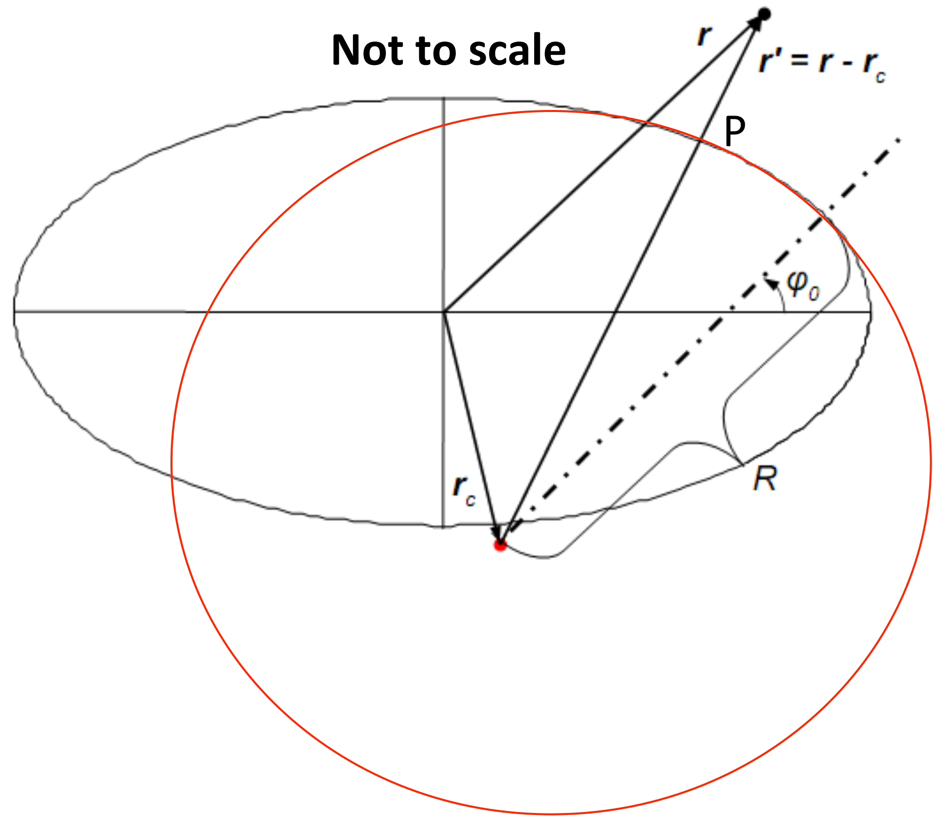
Non-Hydrostatic (ECMWF minus NCEP)



Overall: 0.4 ± 0.58 mm

Effect of Earth's Radius on Slant Hyd. Delay

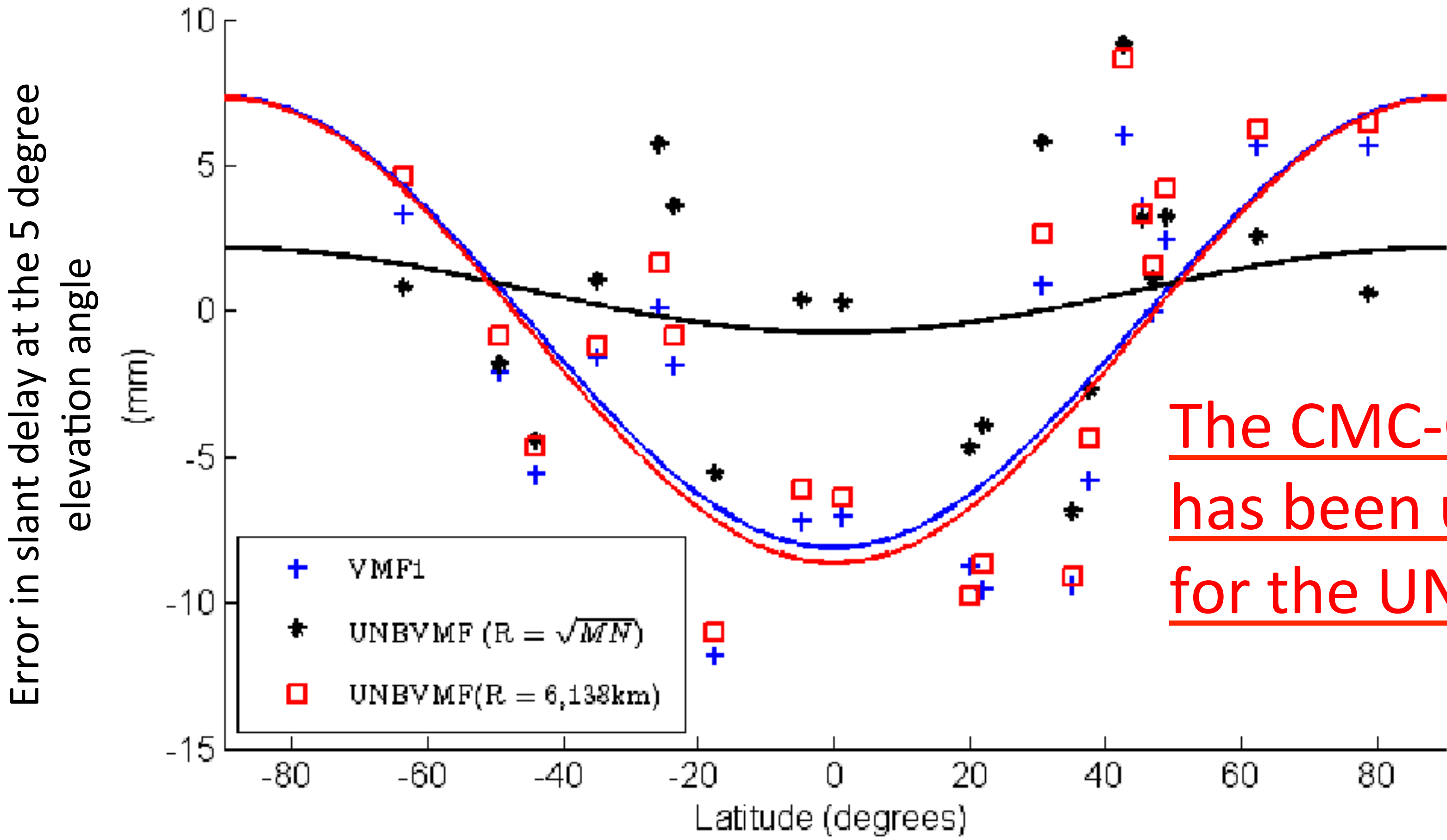




Spherical Atmosphere always locally normal (to ellipsoid), never geocentric

Comparison to 3D ray-tracing

Three dimensional ray-tracing uses ellipsoidal coordinates



The CMC-GEM has been used for the UNBVMF

Systematic effect of ± 2mm error in station height

VLBI Results – CONT08

CONT08 ...
see JOGE
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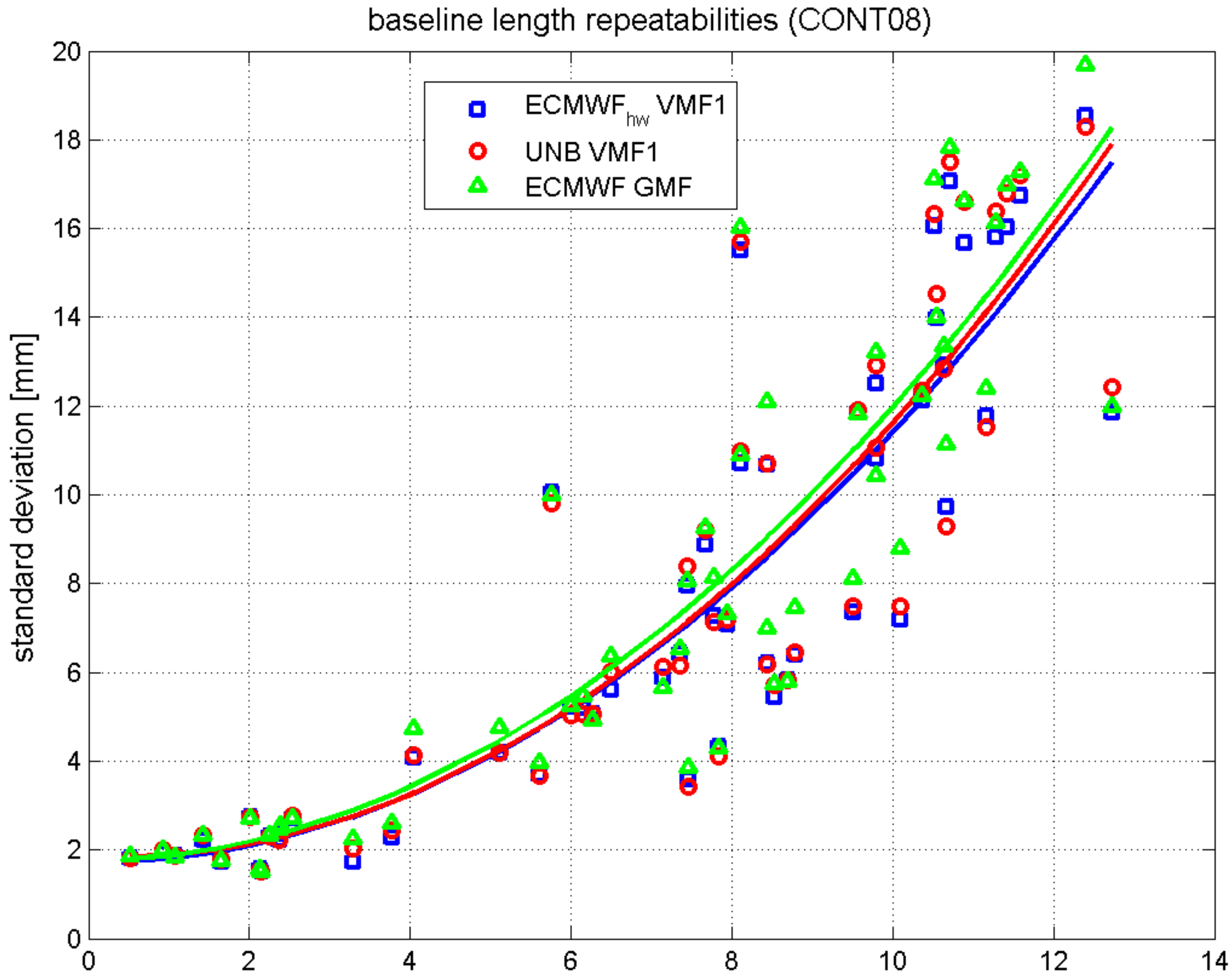

Baseline length (in thousand of km)

Side Note

- Importance to consider impact of different NWM.
  - ✓ Specially for asymmetric delay

➔NWM Benchmarking comparisons

See Poster #4967 "Benchmarking Campaign for Ray-traced Tropospheric delays"

(full paper accepted for publications in IEEE Trans. Geo. Sci...., 2011)

Conclusion

1. NWM will continue to improve. As they do, they will become more useful for geodetic purposes.
2. We have been generating VMF1-type grids using NCEP and GEM models at UNB.
3. Addresses consistency and redundancy issues.
4. Test results:
    1. Zenith delays (ECMWF – NCEP):
        - Hydrostatic: -2.4 ± 3.8 mm
        - Non-hydrostatic: -6.3 ± 14.7 mm
    2. Comparison to Saatamoinen:
        - NCEP: 2 mm (bias); 4 mm (st. Dev.)
        - NCEP "noisier" than GEM

Conclusion

5. Test results (cont.):
   3. Difference in Station Height (ECMWF – NCEP):
      - Hydrostatic: 0.8 ± 0.9 mm
      - Non-hydrostatic: -0.4 ± 0.6 mm
   4. Different radius of curvature:
      1. ± 2 mm difference
   5. Impact on baseline repeatability (VLBI CONT08):
      1. VMF1 and UNB-VMF1 closer together than GMF
      2. GMF → higher values

Future Work

- Tests ... More tests!
- Comparisons in the position domain
  - GPS campaigns, effect on mean station position
- Provision of UNB-VMF1 to public
  - Similar to current service
  - Act as a backup or alternative for users.

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