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Impact of a priori gradients on VLBI- and GNSS-derived reference frames

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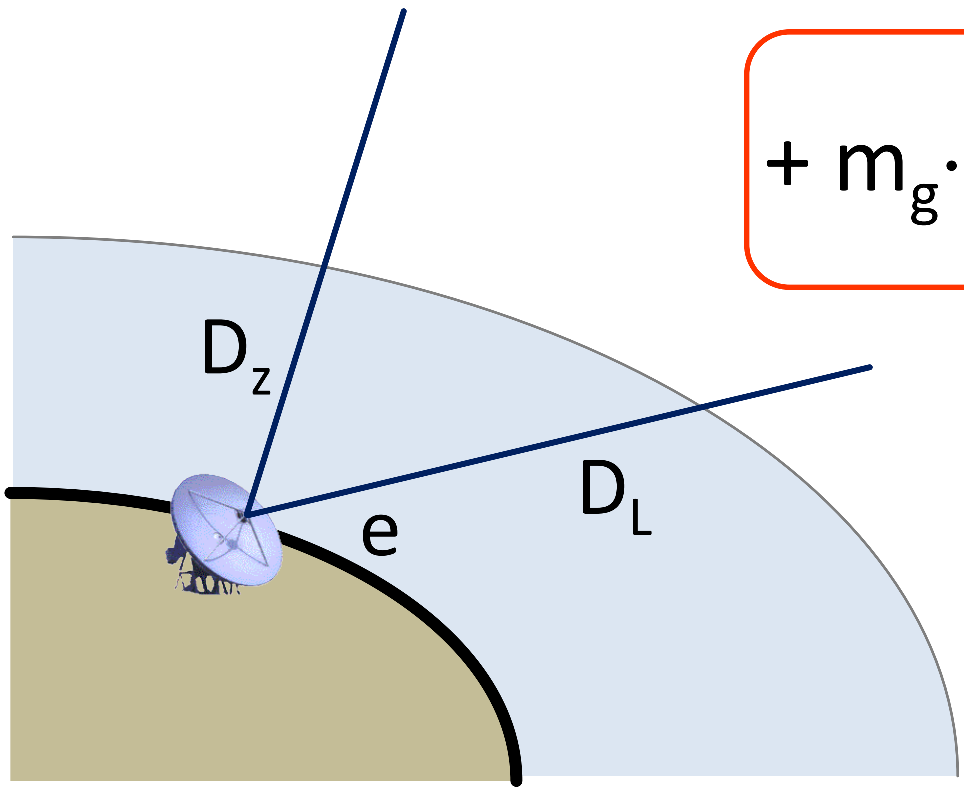
IERS Conventions

$$D_L(e) = D_z \cdot m(e) \quad = D_{zh} \cdot m_h(e) + D_{zw} \cdot m_w(e)$$

$$\boxed{+ m_g \cdot [G_N \cdot \cos(a) + G_E \cdot \sin(a)]}$$

gradients



Gradient mapping function m_g

- MacMillan 1995
  - goes back to Davis et al. 1993 ("wet refractivity")
  - **$\cot(e) \cdot mf_h(e)$** ($\leftarrow$singularity at horizon)

- Chen and Herring 1997
  - **$1/(\tan(e) \cdot \sin(e) + C)$** **$C = 0.0032$**

	hydrostatic	*wet*
C	0.0031	0.0007
H	13 km	3 km

“Conventional” approach

- Comparison with ray-traced delays shows no clear preference of one type
- Impact on station coordinates is small (< 1mm)
- We recommend to use the model by Chen and Herring (1997) with the coefficient C = 0.0032.
  - There is no singularity at the horizon.
  - Easier to implement.
  - Allows the comparability of different solutions.

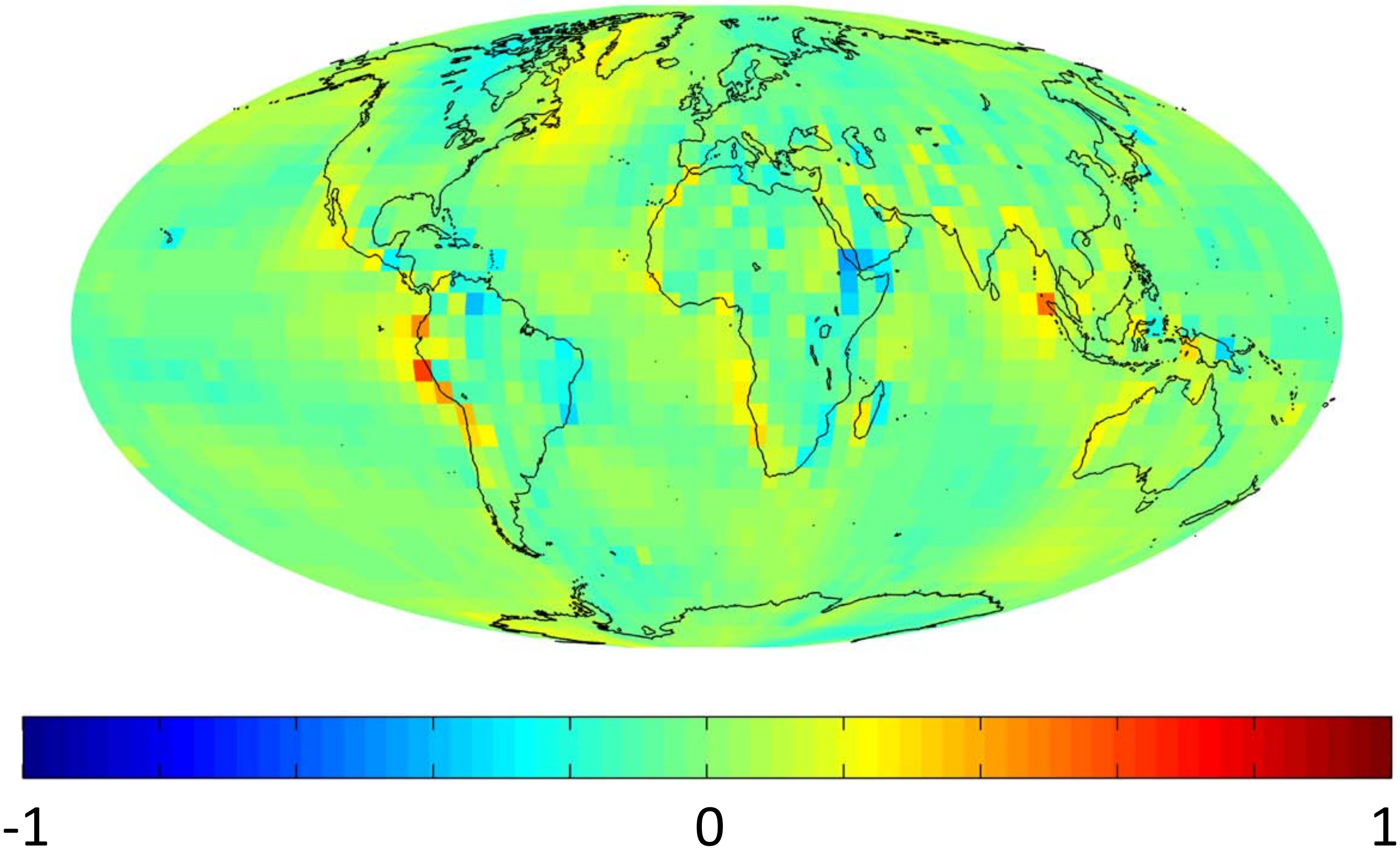
A priori gradients

- VLBI Analysis Centers use mean a priori gradients determined from data of the Goddard Data Assimilation Office (DAO) by integration of vertical refractivity gradients
- DAO gradients are available at VLBI sites
- IGS ACs expressed interest in global model

A Priori Gradient model APG

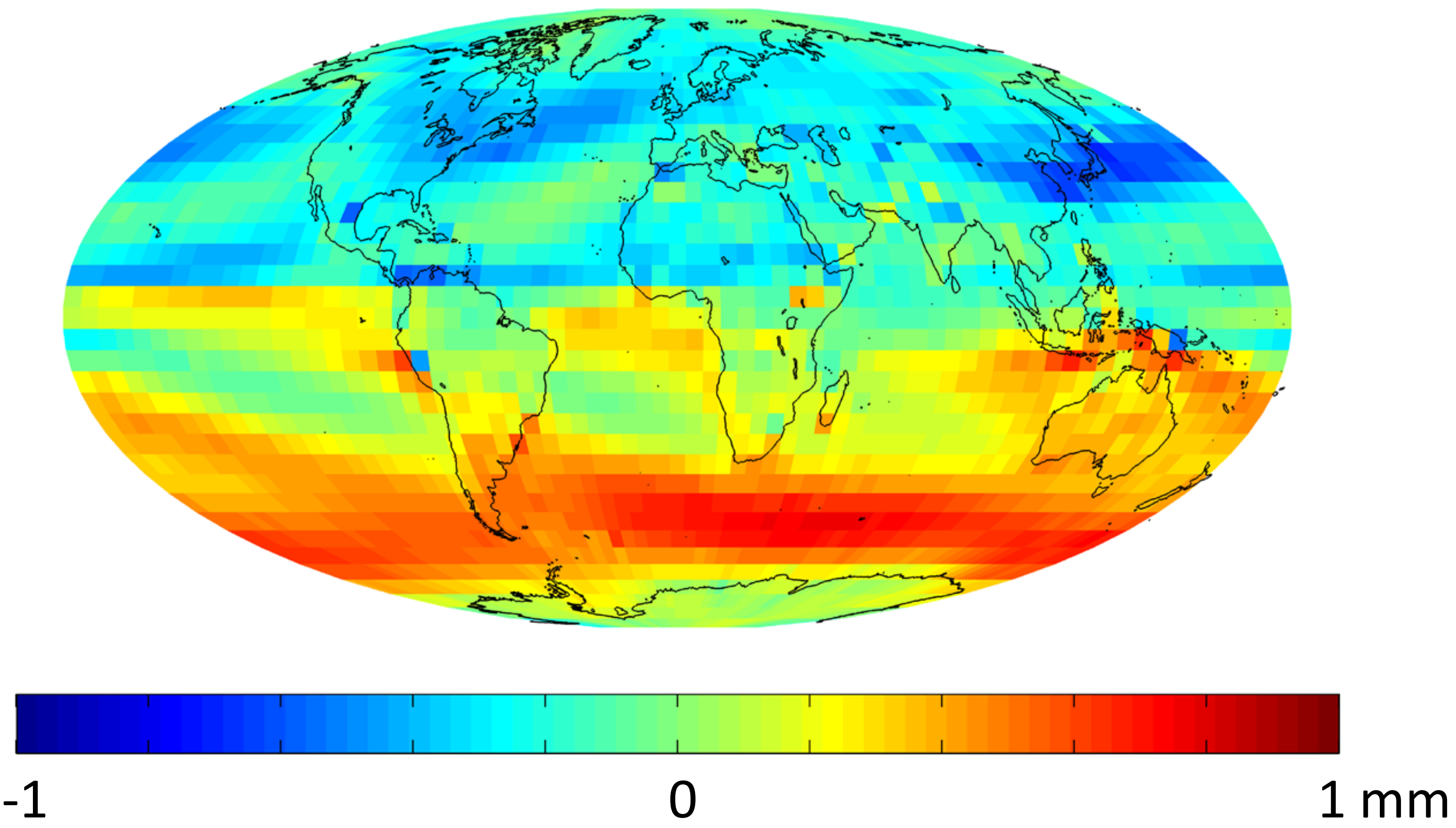
- ECMWF 40 Years Re-Analysis monthly mean pressure level data
  – horizontal resolution of 5°
- Asymmetric delays towards north/east at e=5°
  – determined by ray-tracing
- North and east gradients
  – using Chen and Herring with C = 0.0032
- Average over all 12 months

East gradients from the ECMWF
averaged over 12 months, 5° x 5° resolution



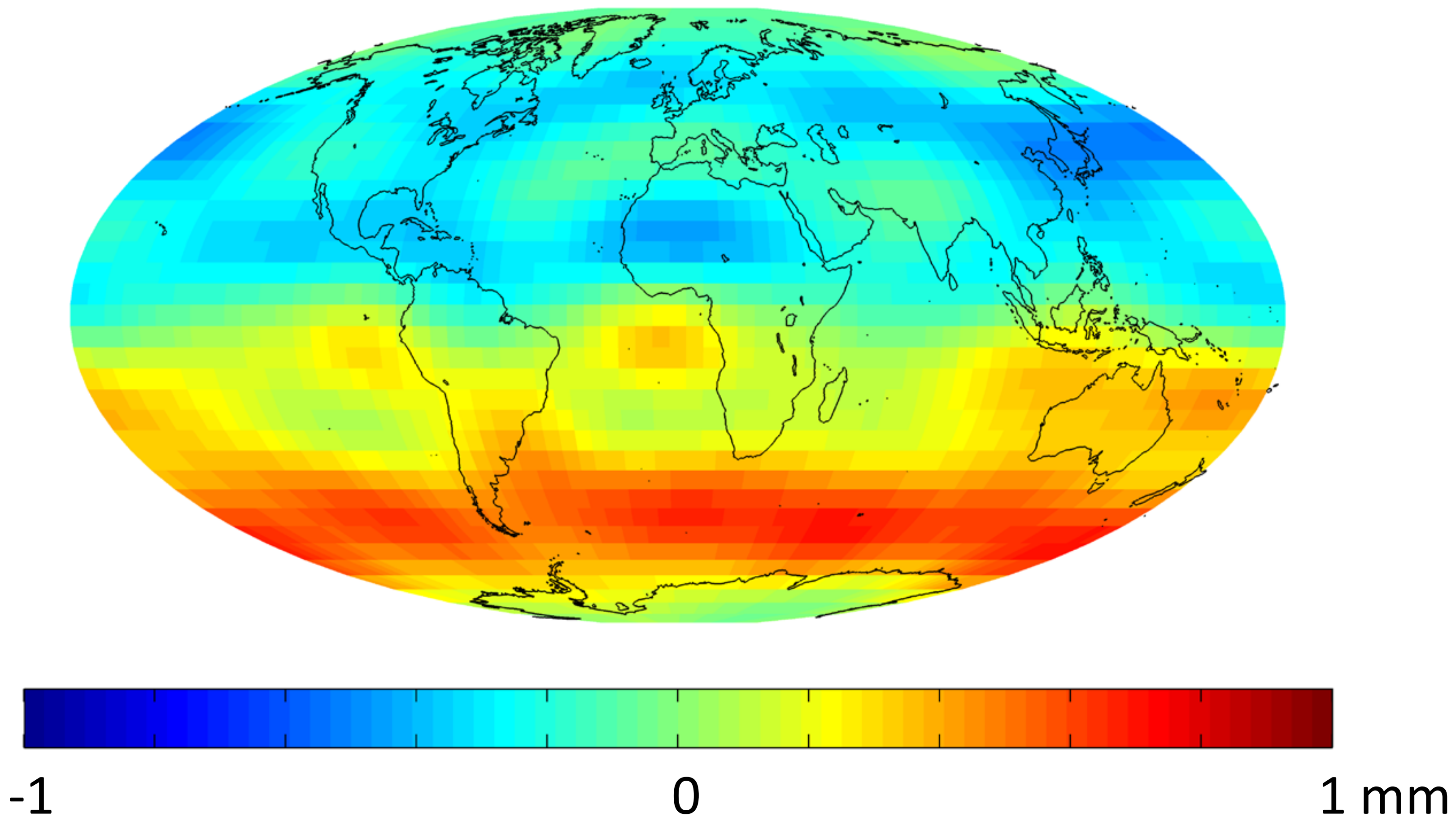
North gradients from the ECMWF

averaged over 12 months , 5° x 5° resolution

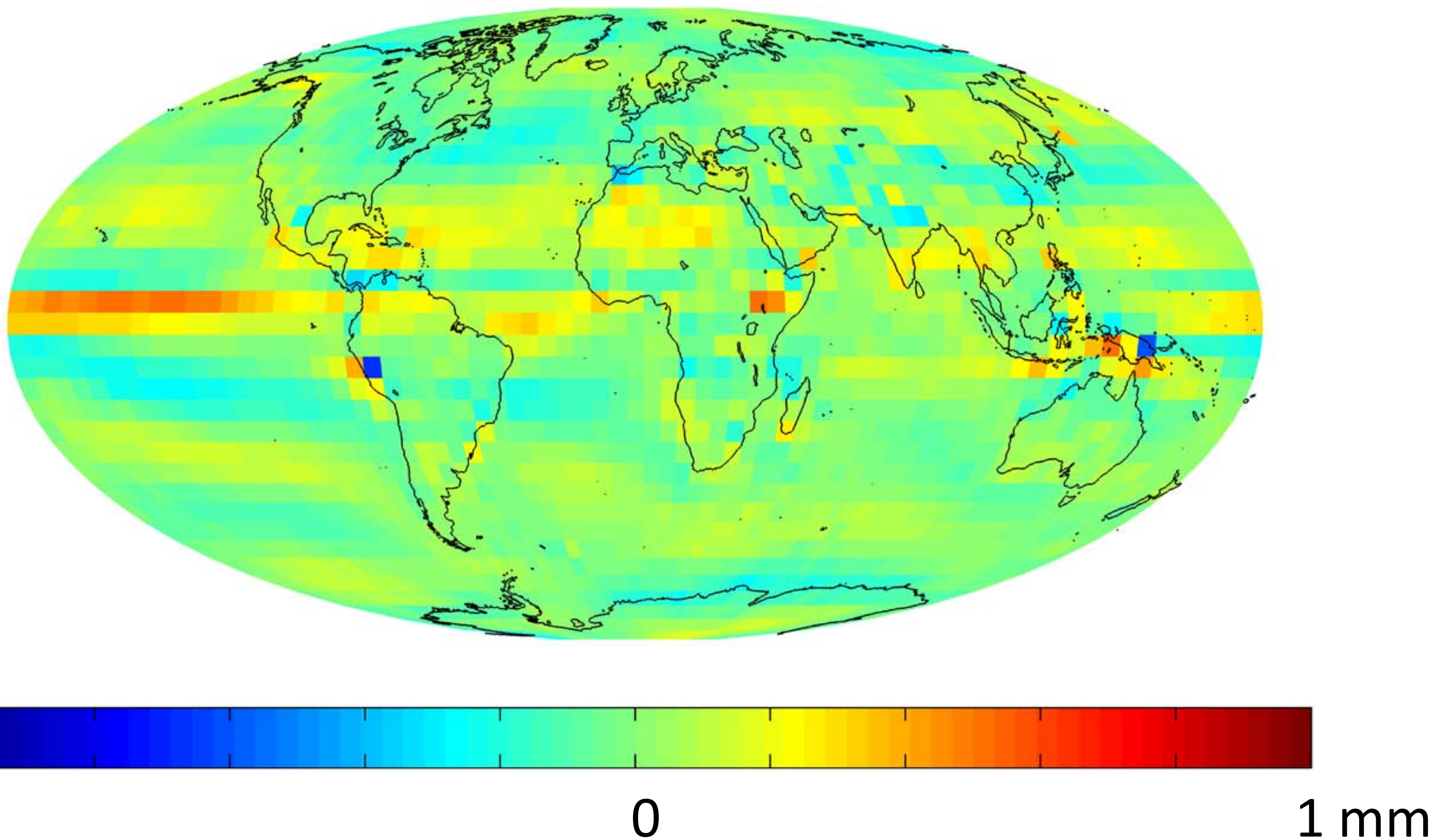


Spherical harmonics expansion

up to degree and order 9



Residual north gradients
ray-traced gradients minus model



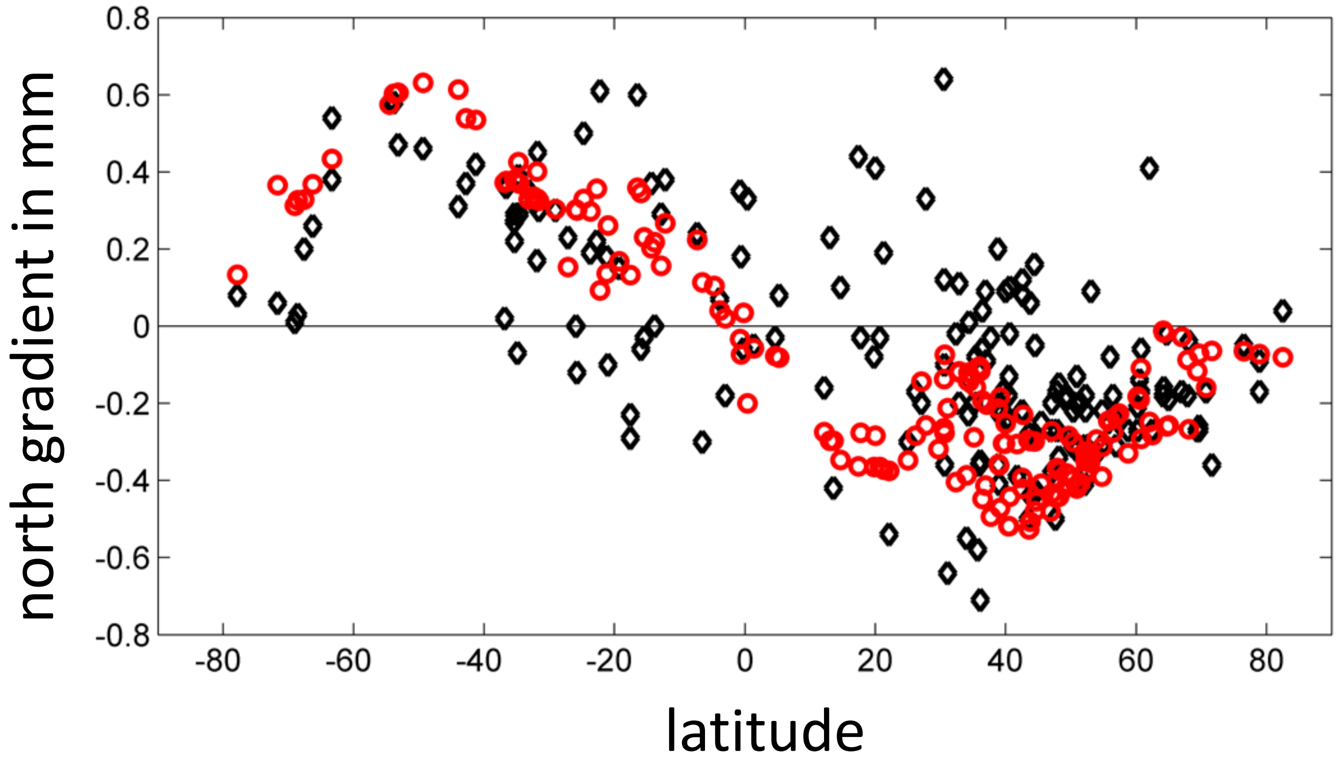
GPS analysis by CODE

- Bernese network solution from 2007 to 2008
- Orbits/EOPs/station coordinates estimated together
- 3° cutoff elevation angle, down-weighting with $\cos^2 z$
- No constraints on 24 h piecewise linear gradients

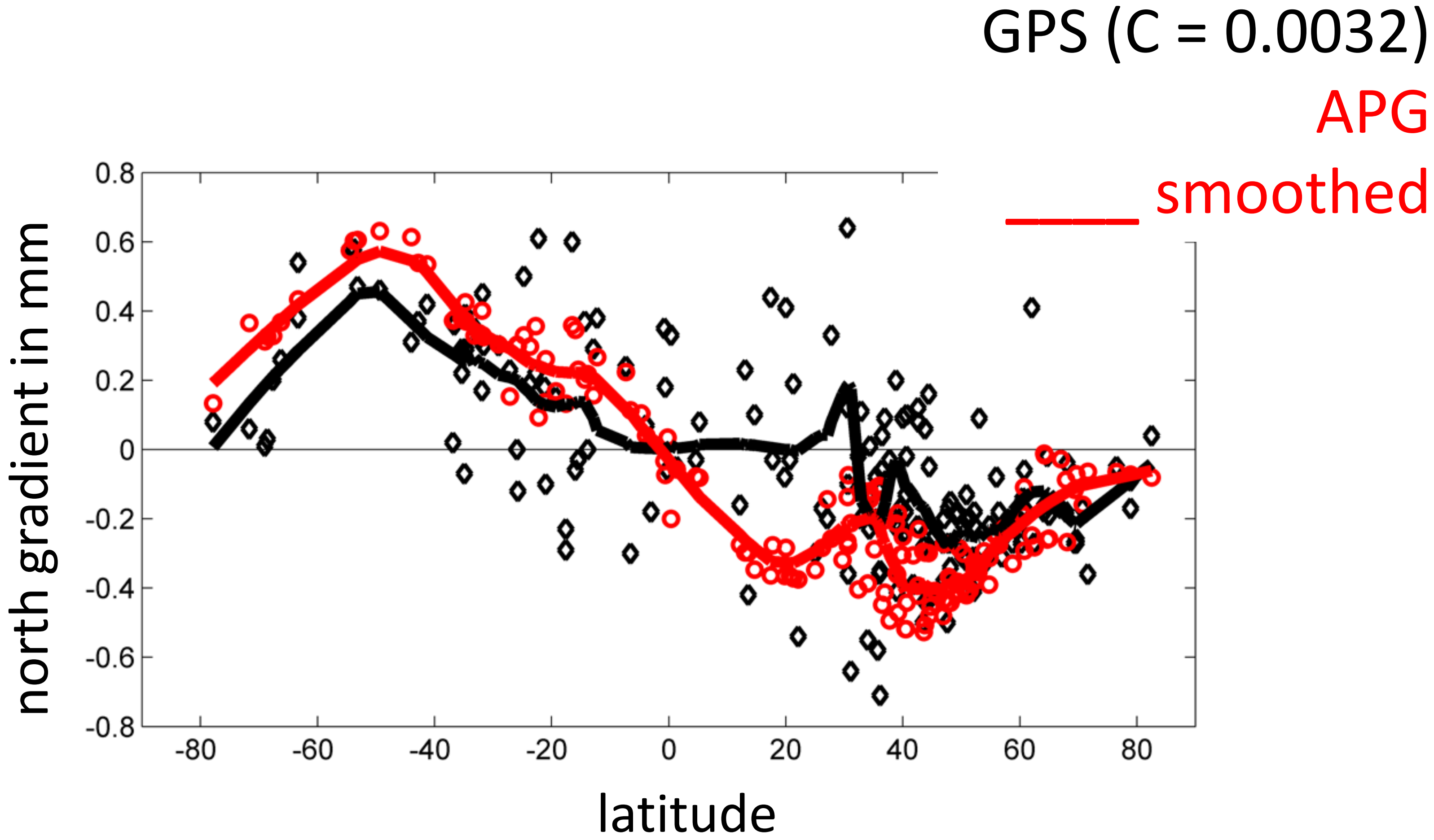
APG versus GPS-derived mean north gradients

GPS (C = 0.0032)

APG



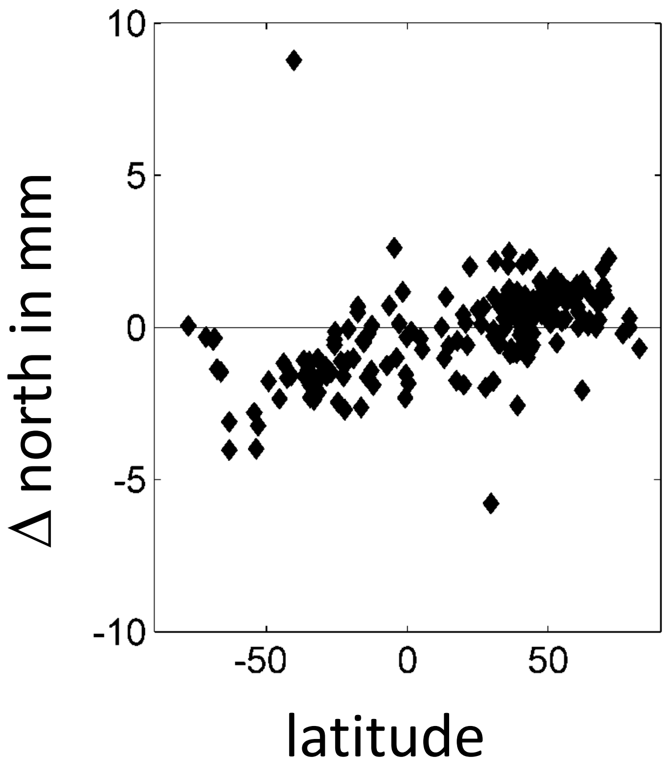
APG versus GPS-derived mean north gradients

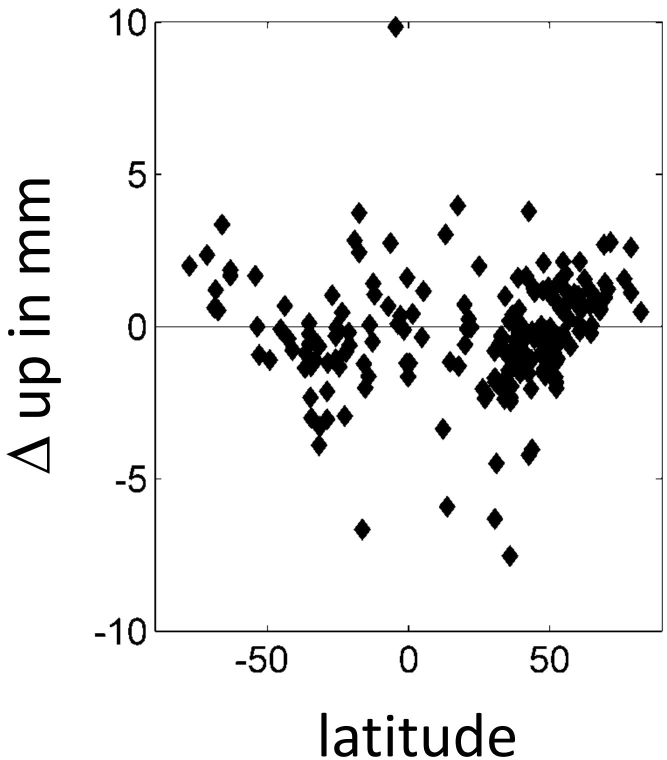


GPS: mean coordinate differences

With / without estimation of gradients

Sol.	A priori gradients	Estimation
I.	no	no
II.	no	Chen&Herring (C = 0.0032)

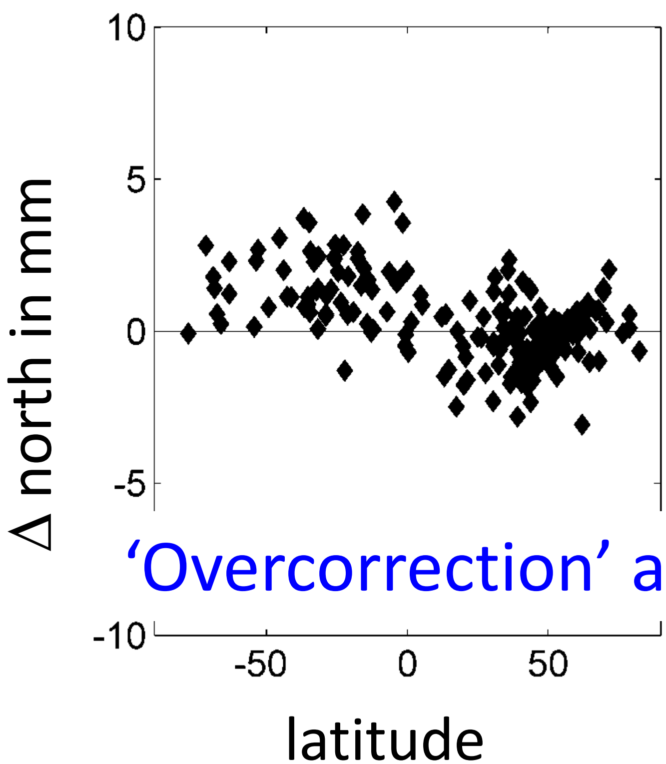


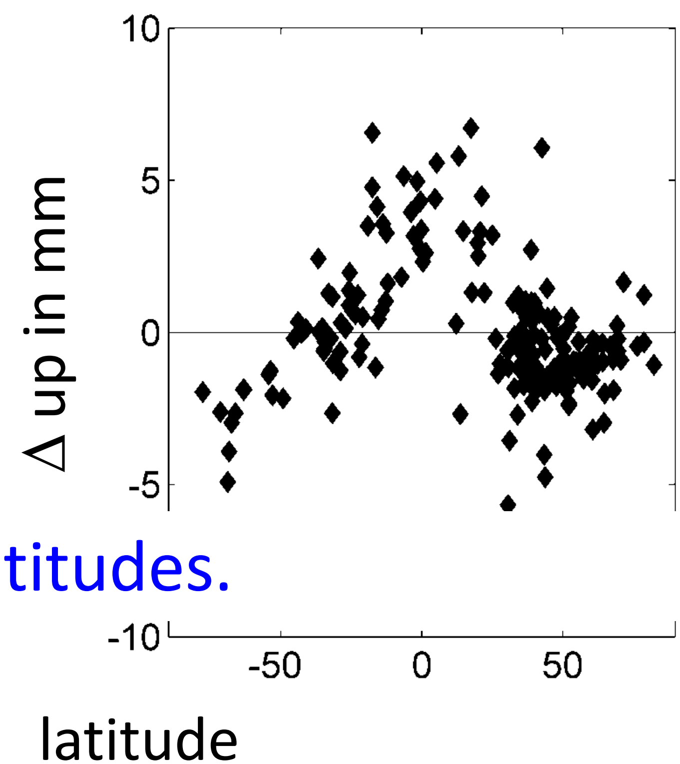


GPS: mean coordinate differences

Does APG help?

	A priori gradients	Estimation
I.	APG	no
II	no	Chen&Herring (C = 0.0032)



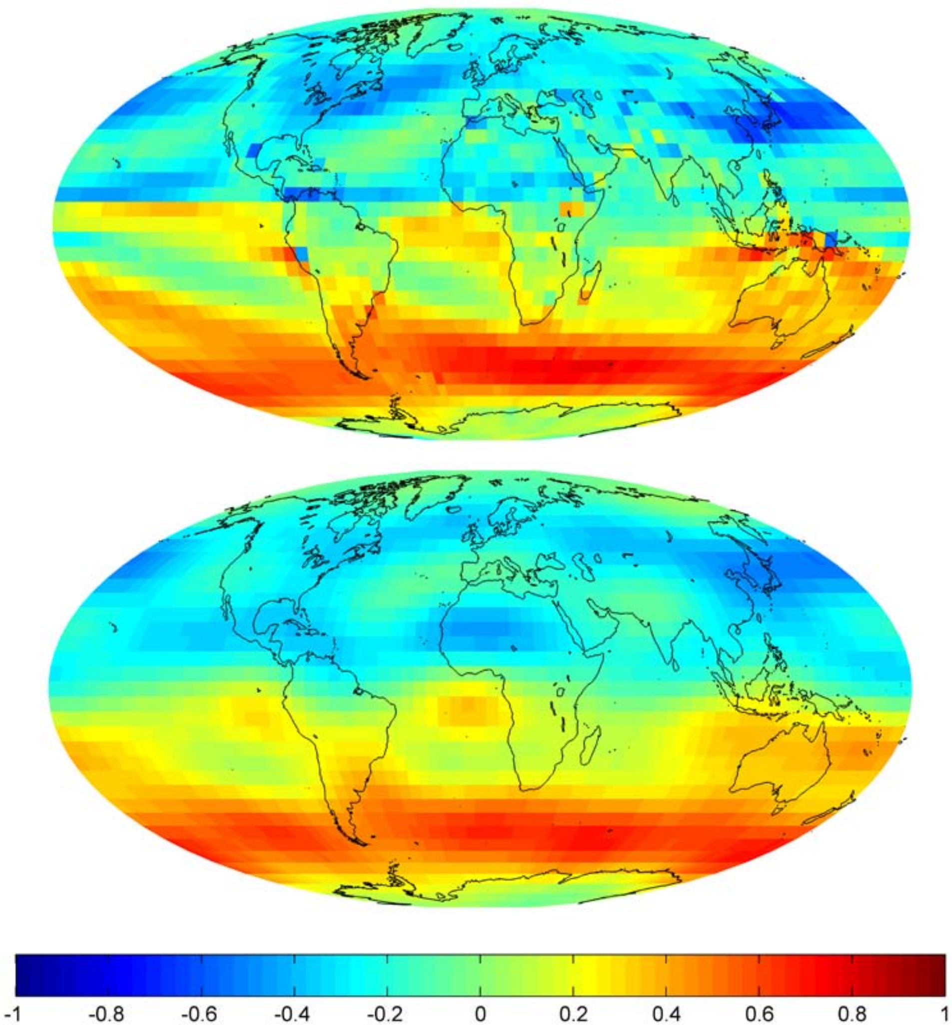


'Overcorrection' at some latitudes.

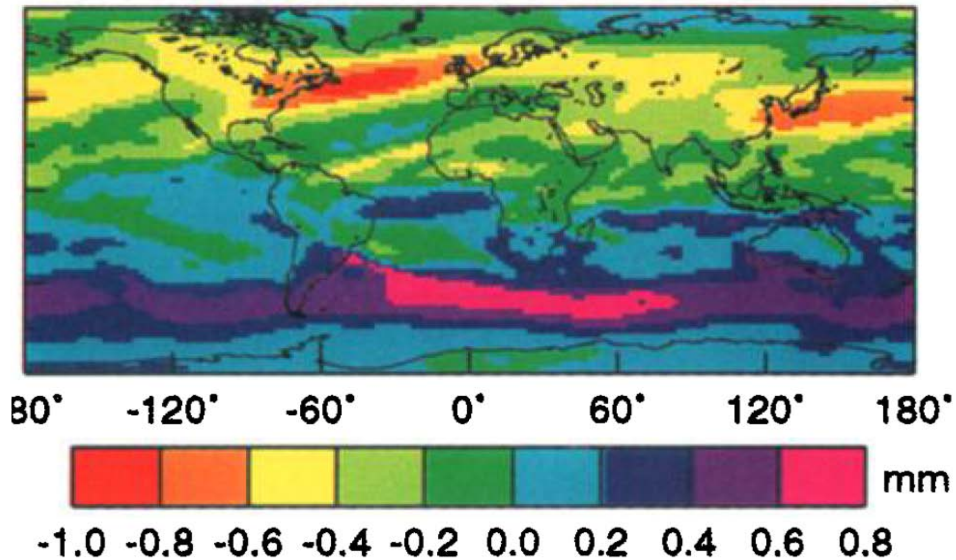
Consequences and questions

- APG are mostly larger than GPS-derived north gradients.
- Possible reasons:
  - C = 0.0032 is too large
    - (0.0007 helps only a bit, makes the gradients more “wet”)
  - Other effects on GPS gradients? Cutoff angle or down-weighting?
  - Error in NWM or ray-tracer?

APG vs. DAO



MacMillan and Ma, 1997



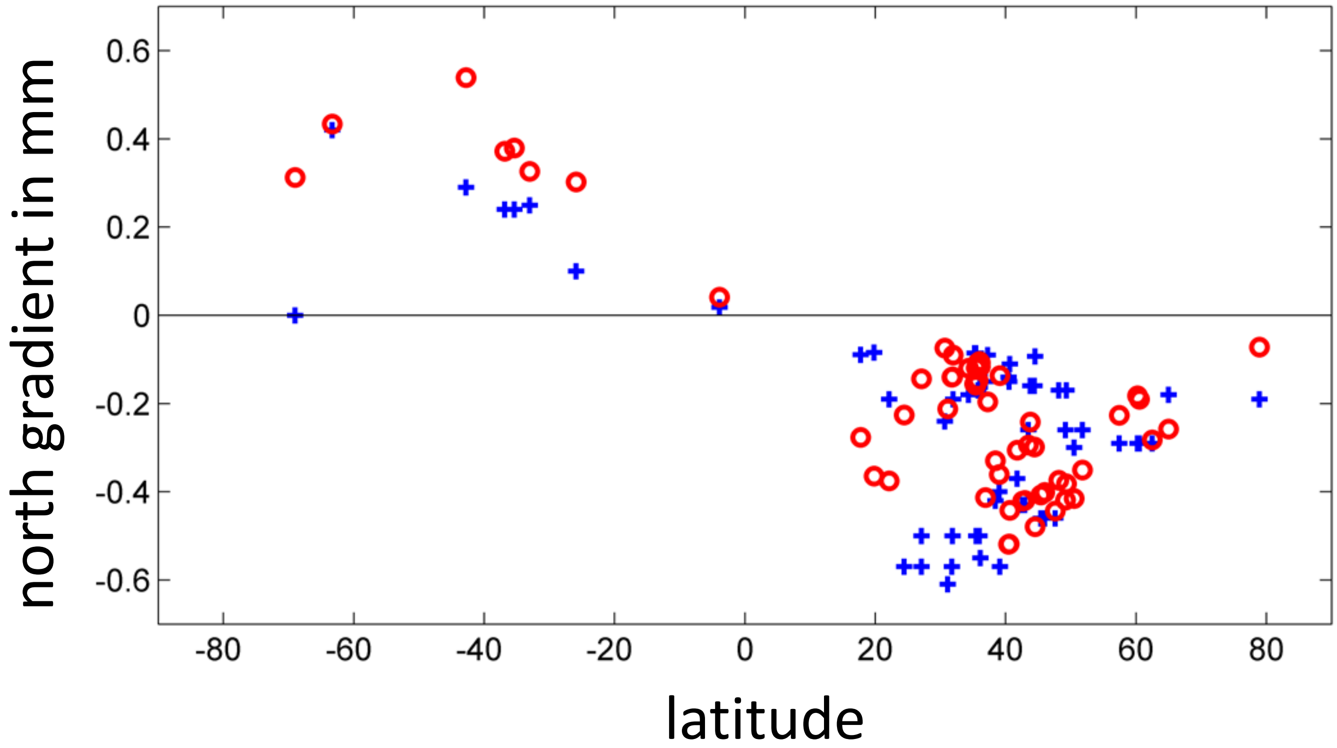
vertical integration of refractivity gradient

ray-trace at 5° elevation and sphericals 9/9

APG versus DAO north gradients

DAO (determined locally from vertical integration)

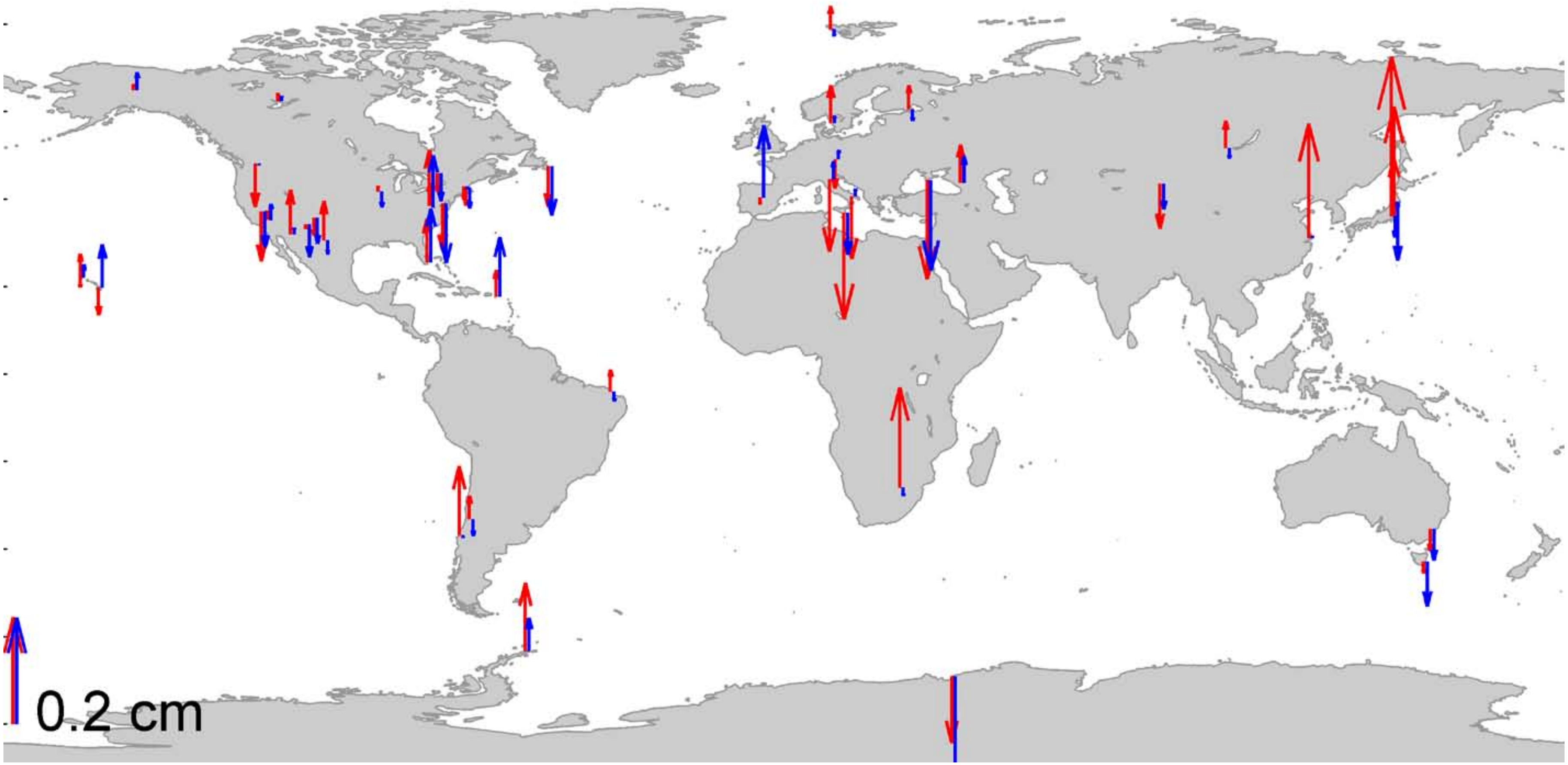
APG (spherical harmonics expansion up to degree 9)



VLBI global solutions with VieVS

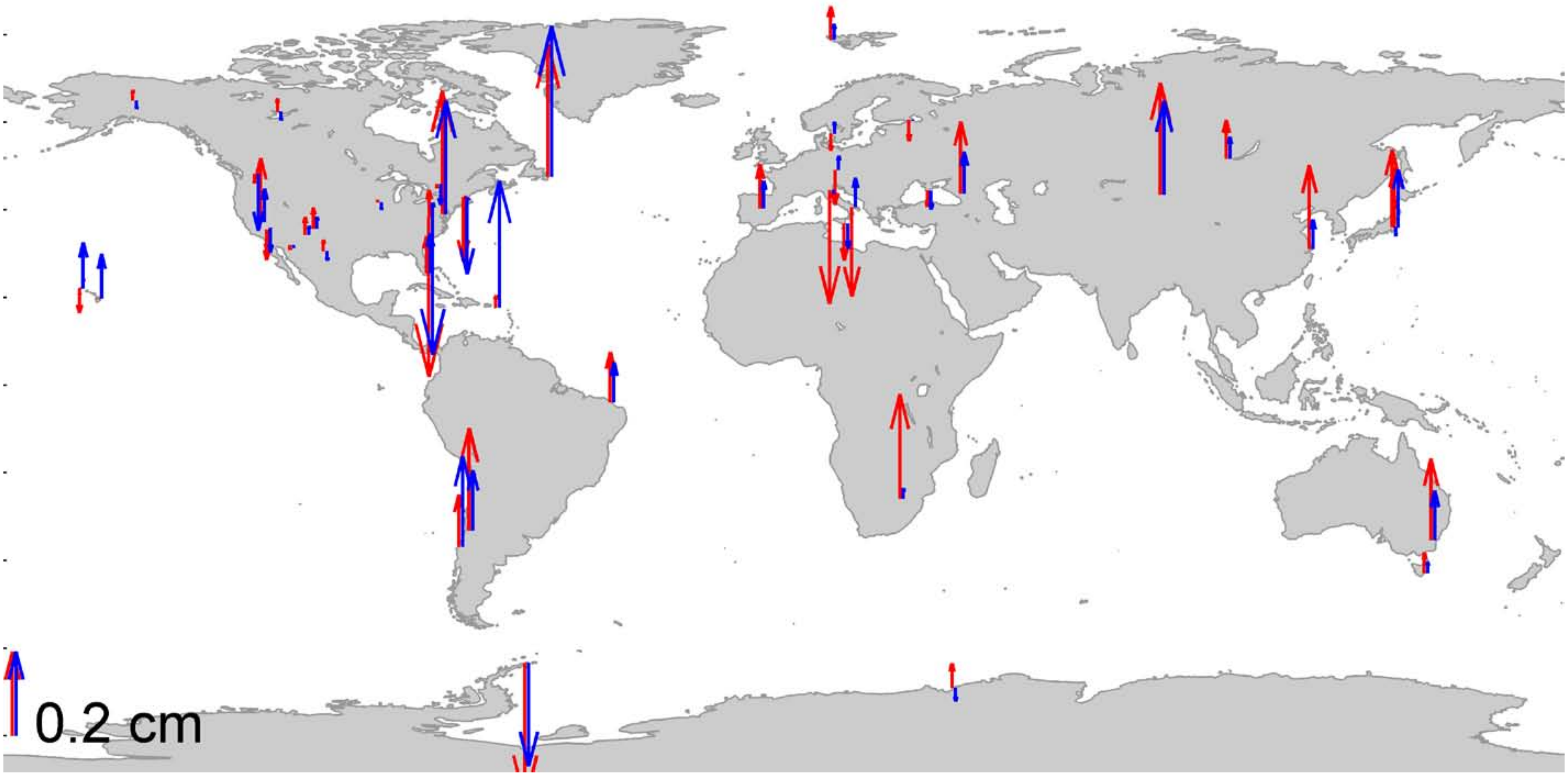
Sol.	a priori	estimated	absolute constraint	relative constraint
Reference	zero	6 hours	no	0.5 mm
APG fix	APG	no	-	-
APG est	APG	6 hours	0.5 mm	0.5 mm
DAO fix	DAO	no	-	-
DAO est	DAO	6 hours	0.5 mm	0.5 mm

North components w.r.t. reference solution



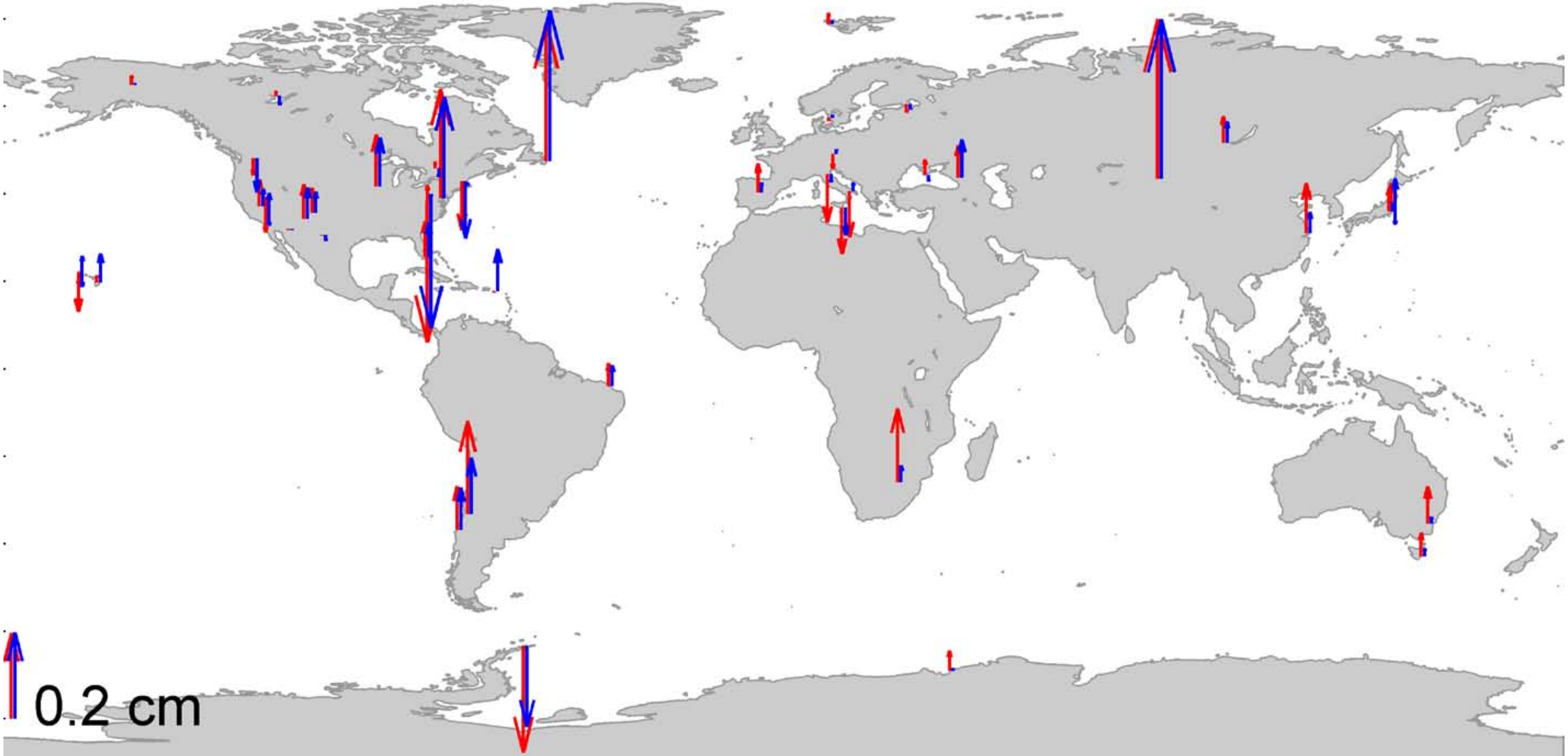
DAO fix APG fix

Up components w.r.t. reference solution



DAO fix APG fix

Up components w.r.t. reference solution



DAO est APG est

Summary

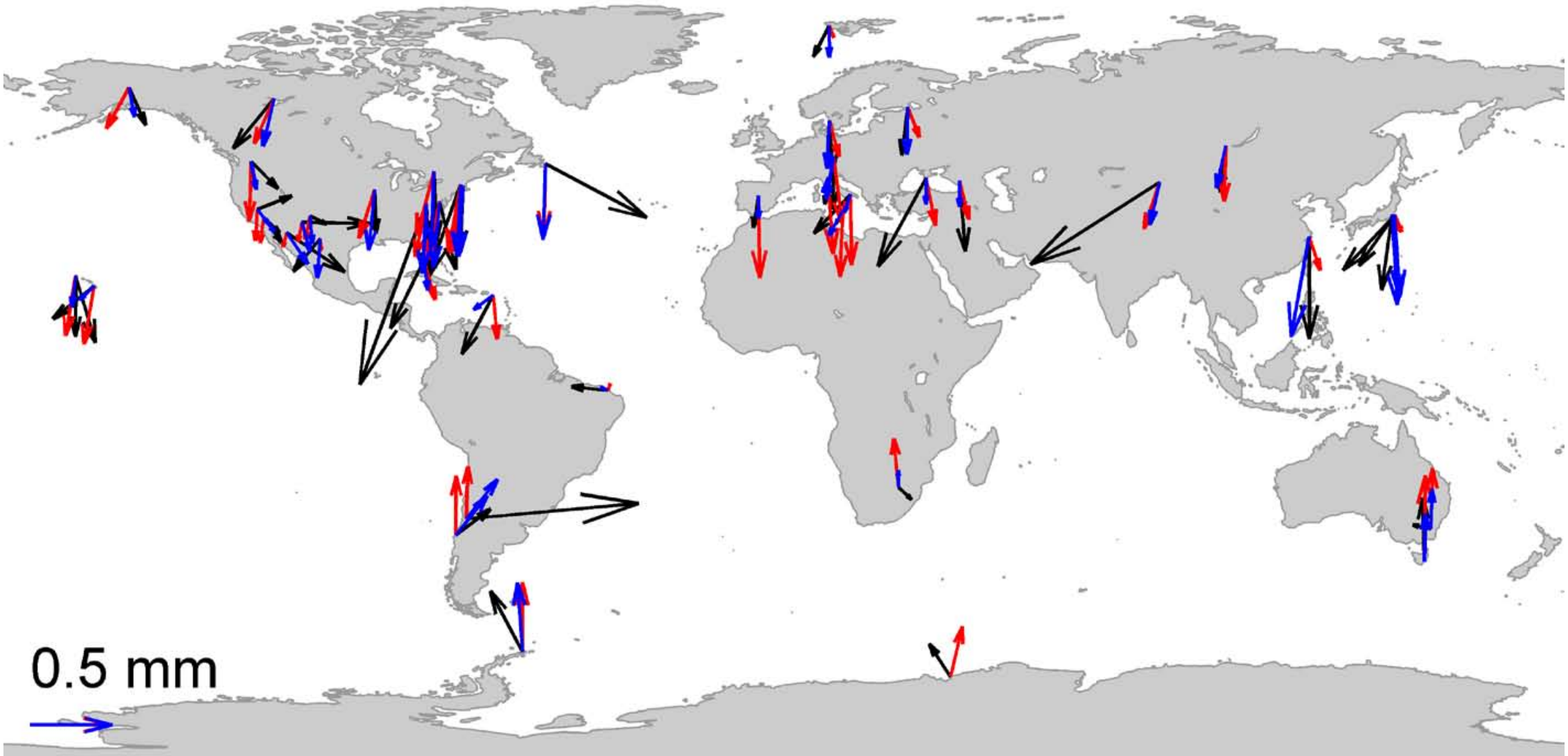
- APG larger than GPS-estimated gradients.
- DAO gradients agree better with VLBI-analysis than APG.
- A priori gradients are only of importance if constraints are applied.

Recommendations

- We recommend to use
  - the gradient mapping function by Chen and Herring with C = 0.0032 (for the sake of consistency)
  - DAO gradients for VLBI analysis

Thanks for your attention.

A priori and estimated gradients
(1990-2010, more than 20 sessions)



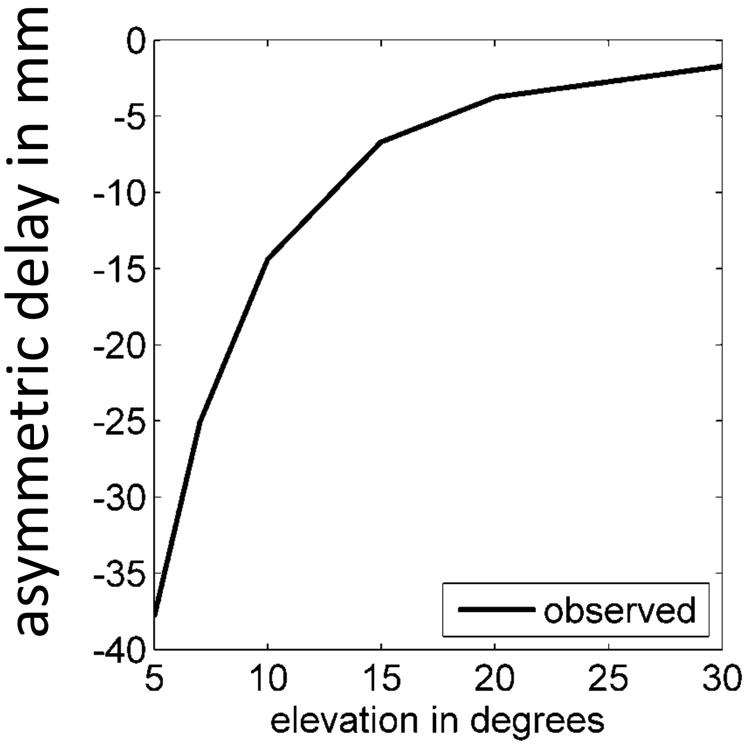
DAO APG estimated

Contents

- Gradient mapping function
- A Priori Gradient model APG
- Comparison with DAO gradients
- Influence on terrestrial reference frame determined with GPS and VLBI
- Conclusions

Examples with ray-traced delays

Wettzell, 1 January 2008
azimuth = 90°



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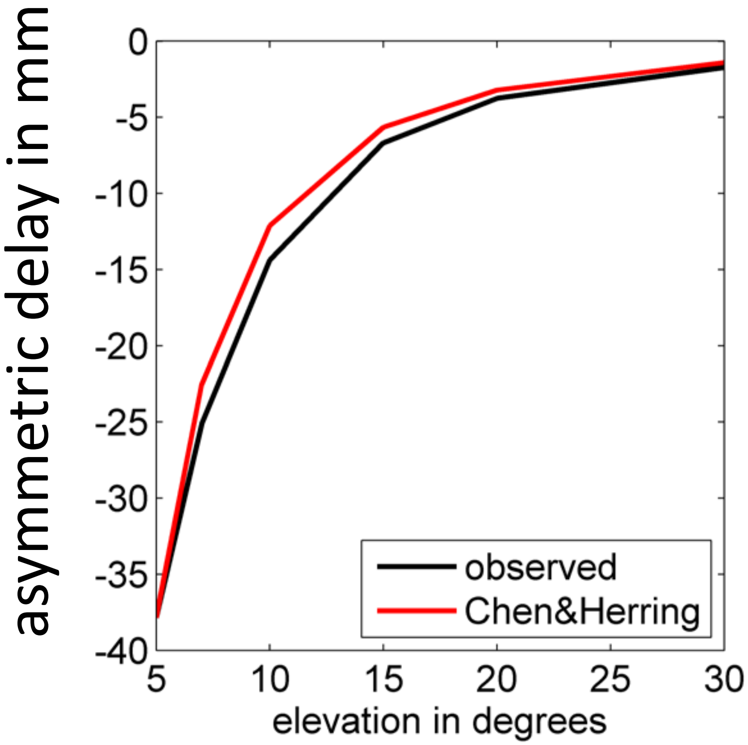

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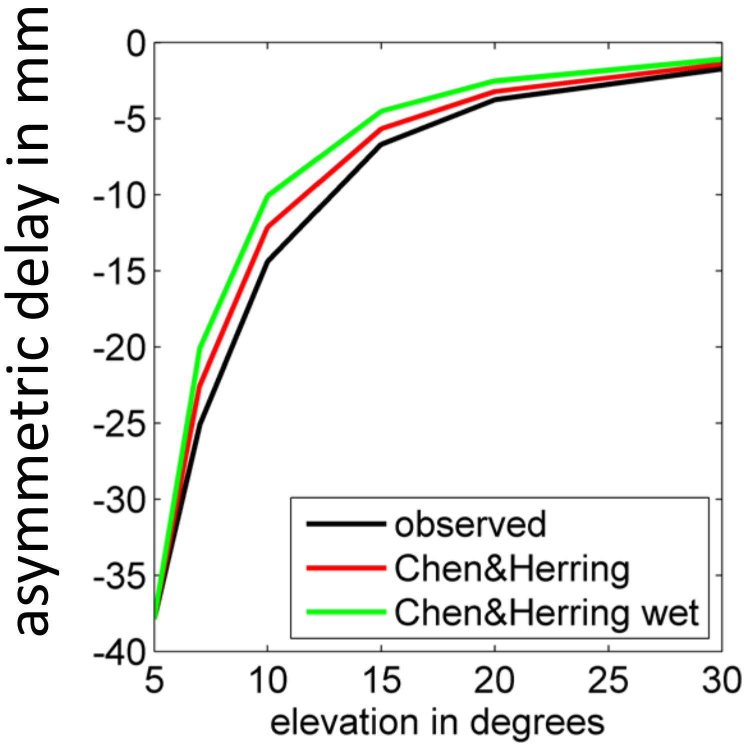

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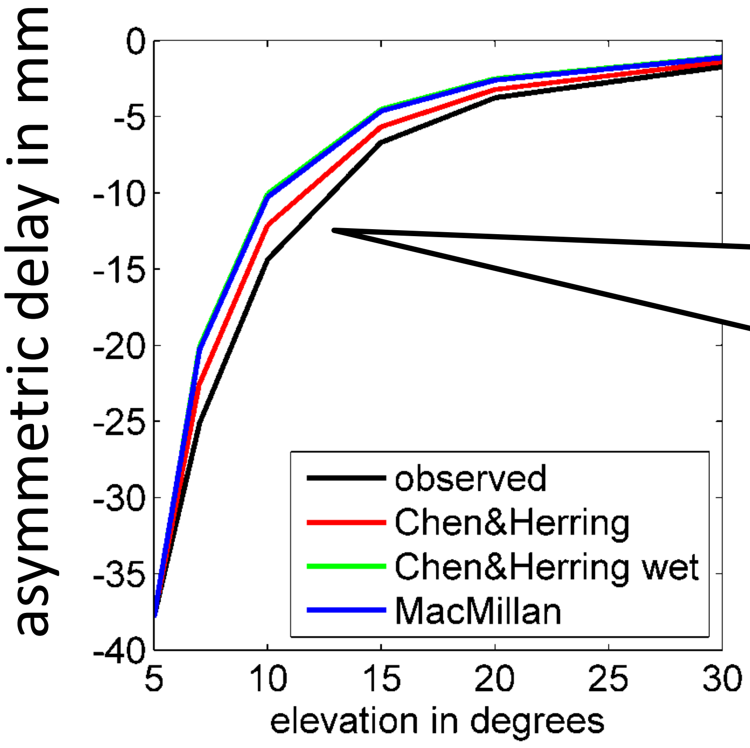

C = 0.0060
to follow the
observations

Examples with ray-traced delays

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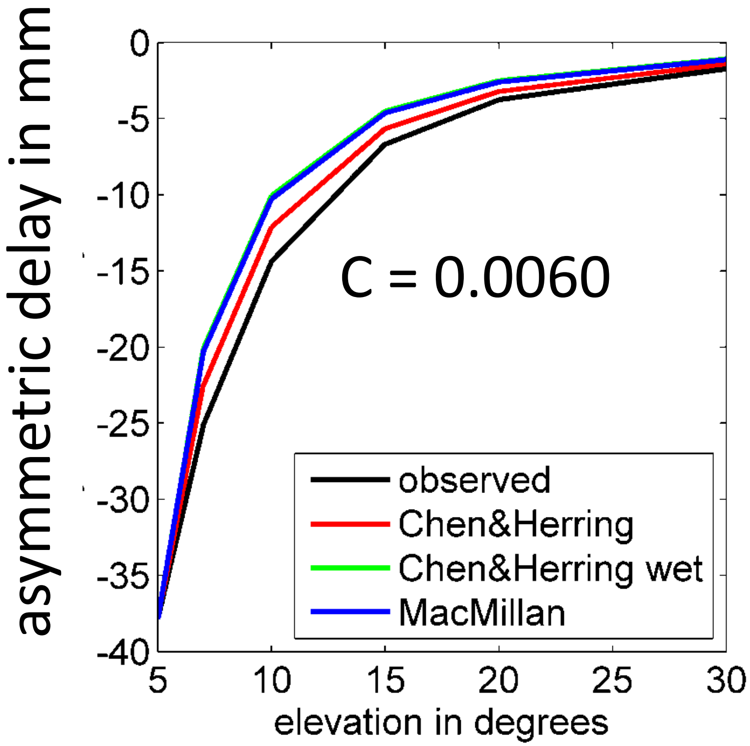
azimuth = 90°



Tsukuba, 12 August 2008
azimuth = 270°