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Uncertainties in models for glacial isostatic adjustment

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Uncertainties in models for glacial isostatic adjustment

Wouter van der Wal & Valentina Barletta
GGFC Workshop
Vienna, April 20, 2012

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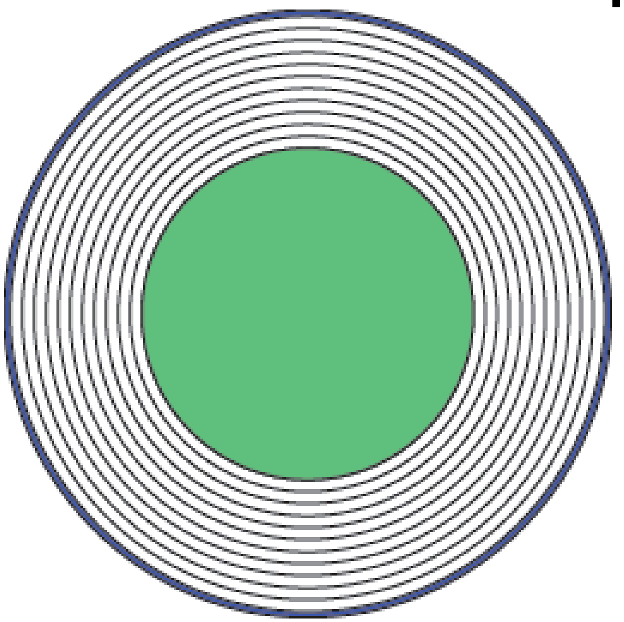
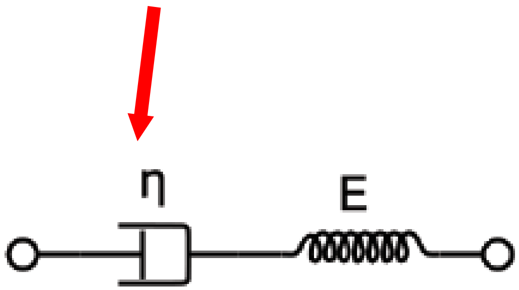
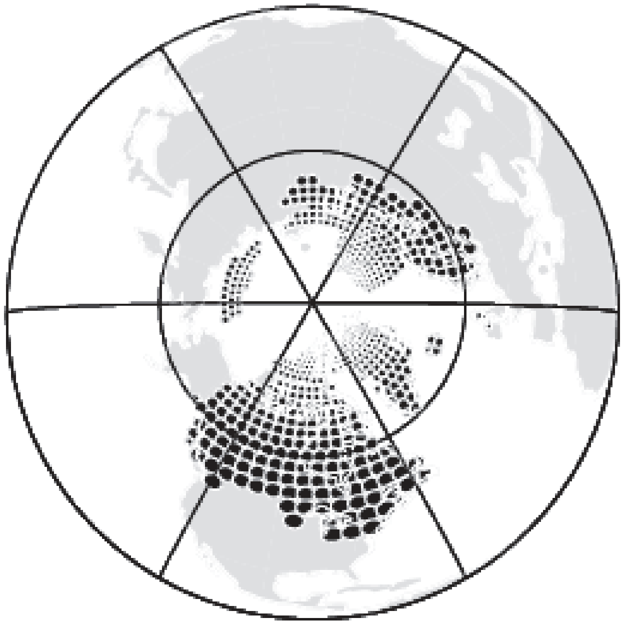
Standard GIA model

Free parameter



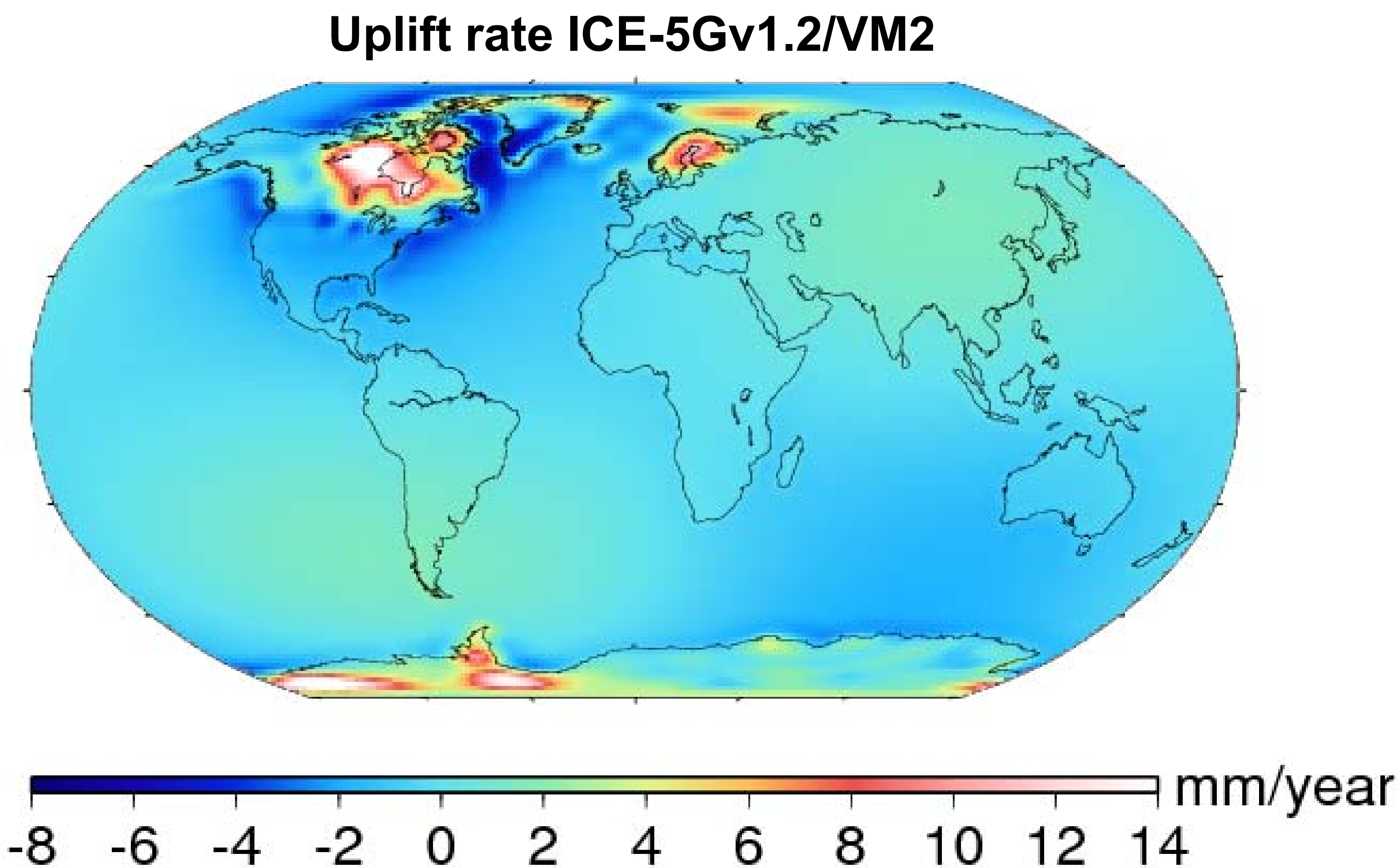




From: Paolo Stocchi, IMAU Utrecht

STANDARD MODEL

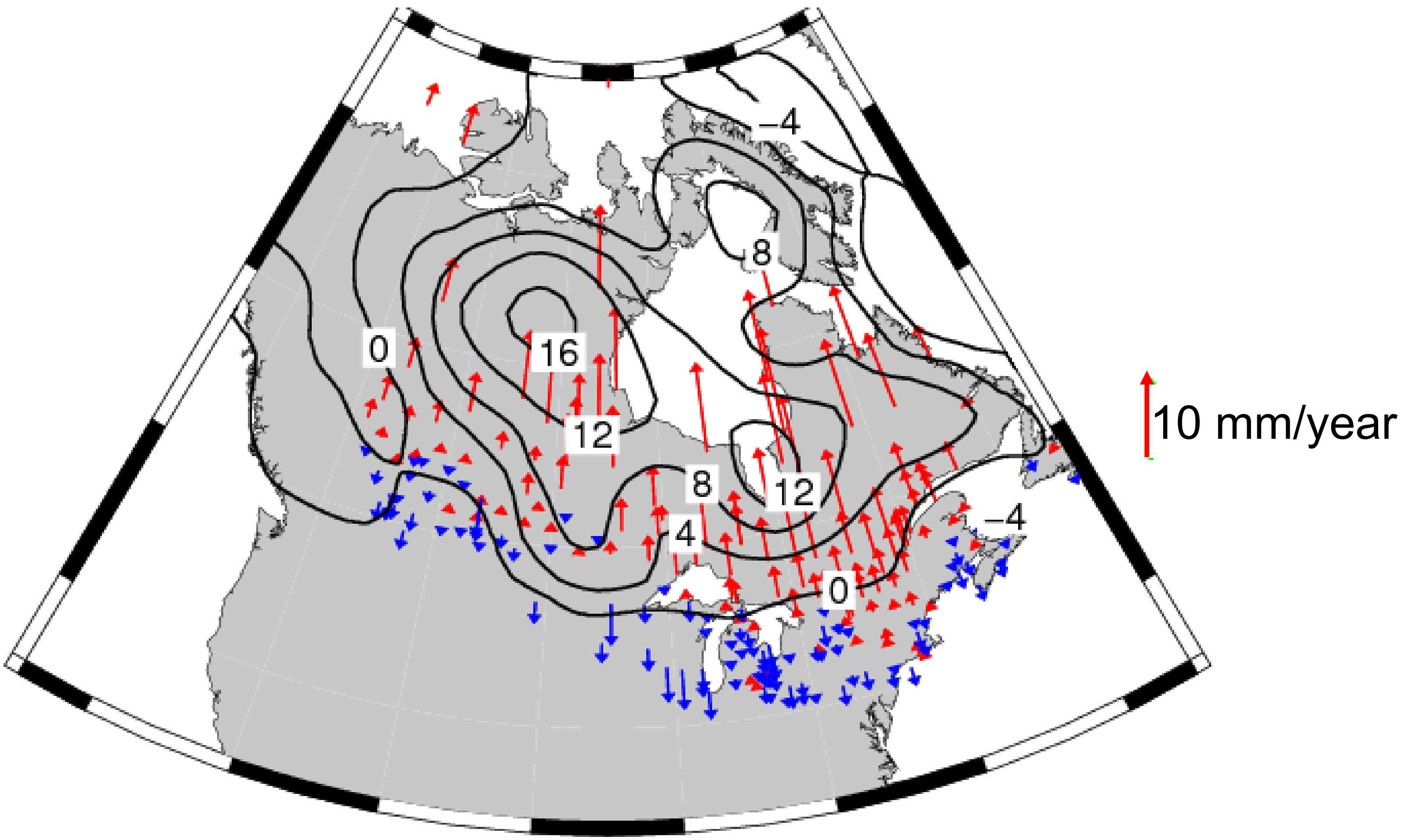
Standard GIA model



Uplift rate from Peltier submission to Special Bureau for Loading website

Standard GIA model

Contours: ICE-5G/VM2 **Arrows**: GPS uplift rates Sella et al. (2007)



van der Wal et al. (Canadian Journal of Earth Sciences 2009)

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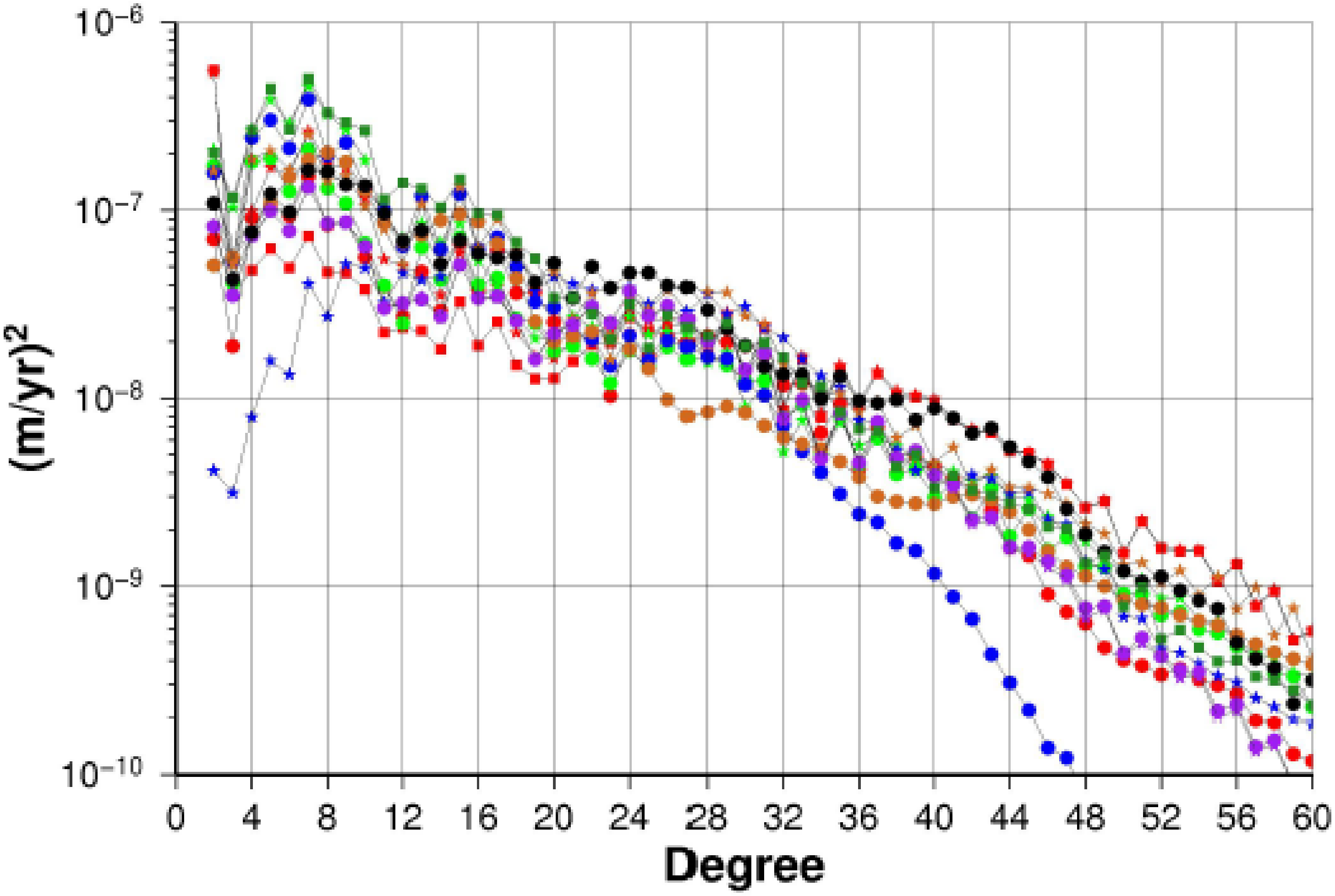
Uplift Rate Spectrum



Guo et al, J. Geodyn. (2012)

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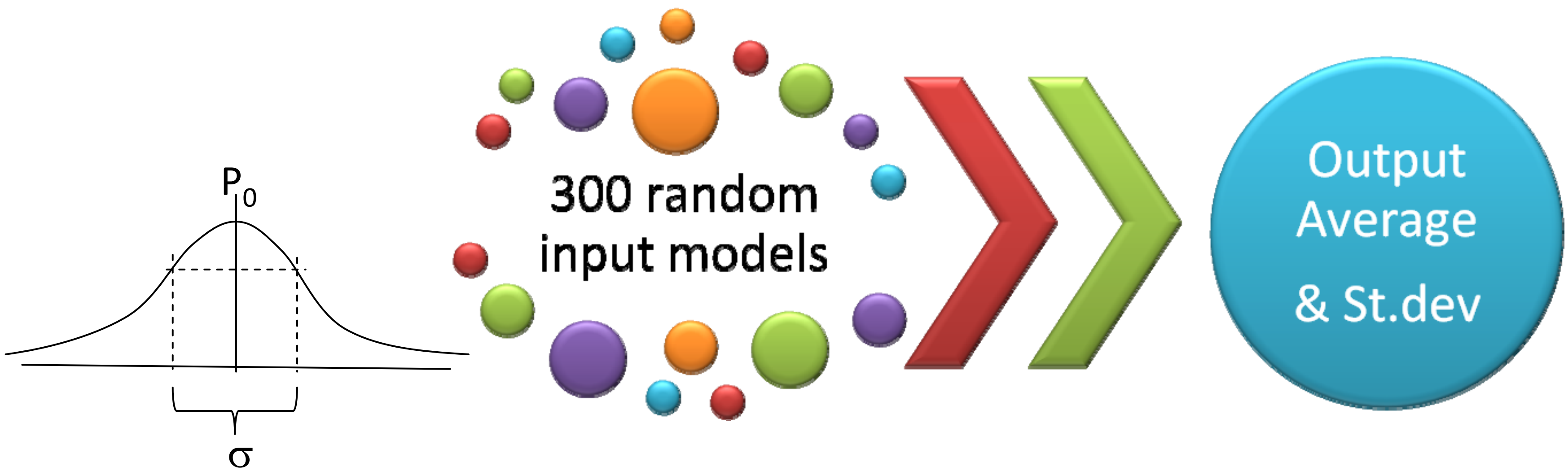
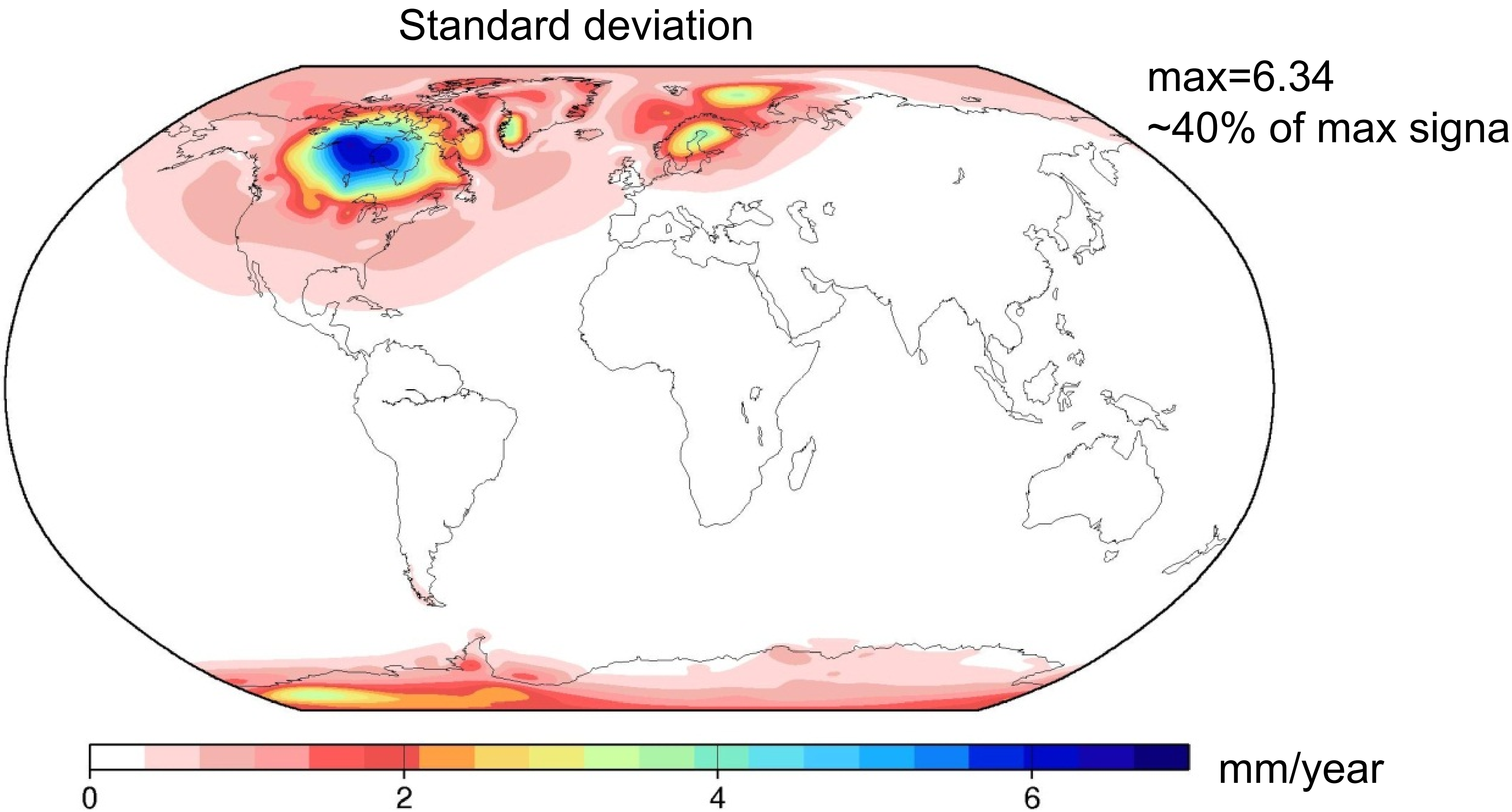
Method for uncertainty propagation

Monte Carlo Method:
hundreds of randomly generated input models with a Gaussian distribution with selected sigma around the input reference model P_0



Reference model:
Ice and Earth model: ICE5G (incompressible - 5Layer - VM2 – L90)

Uncertainty propagation: viscosity



Variation of the viscosity by ± 0.3 in Log10 scale, i.e. by $\mathbf{10^{\pm 0.3}}$

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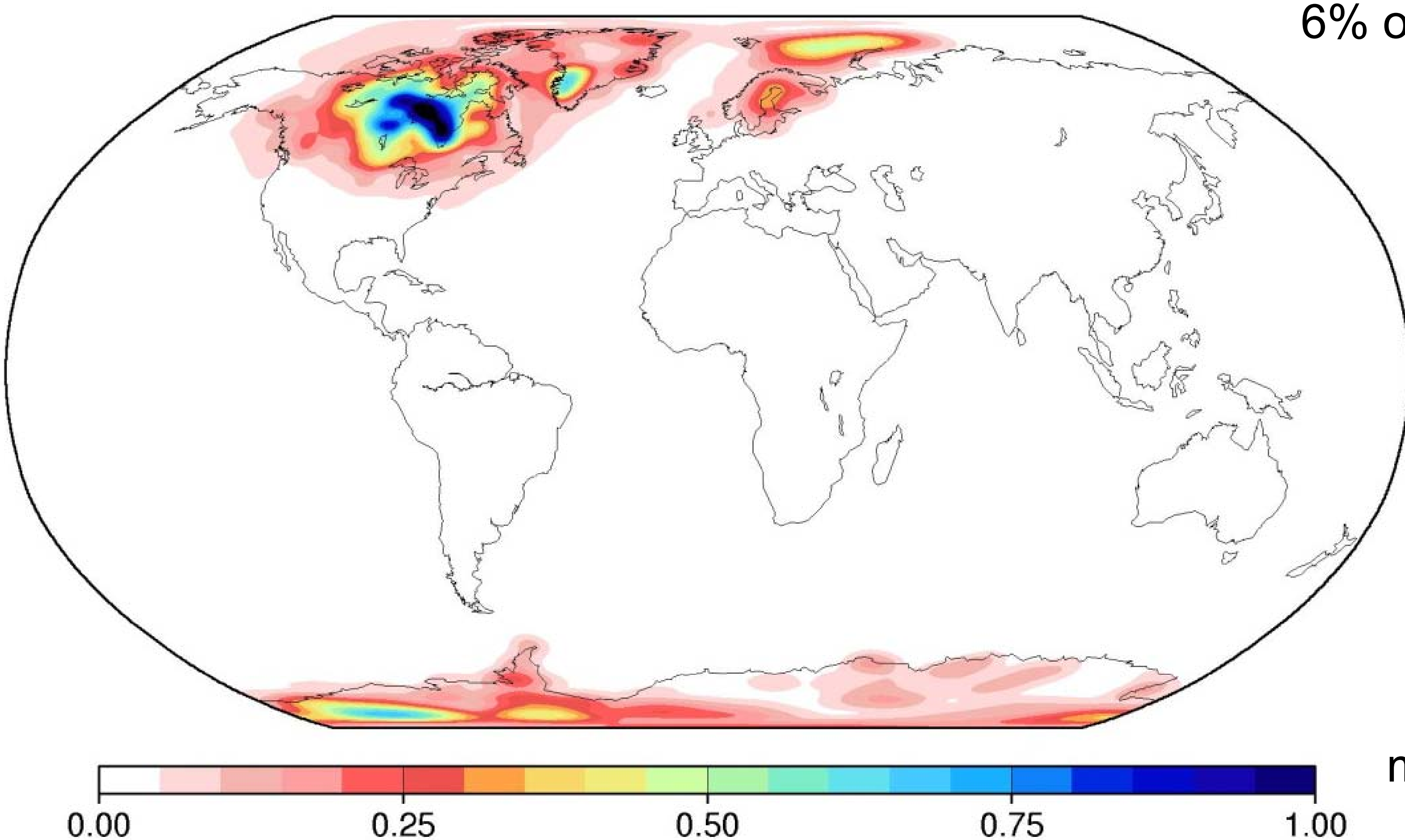
Uncertainty propagation: ice height

Standard deviation

Max = 1.1
6% of the signal

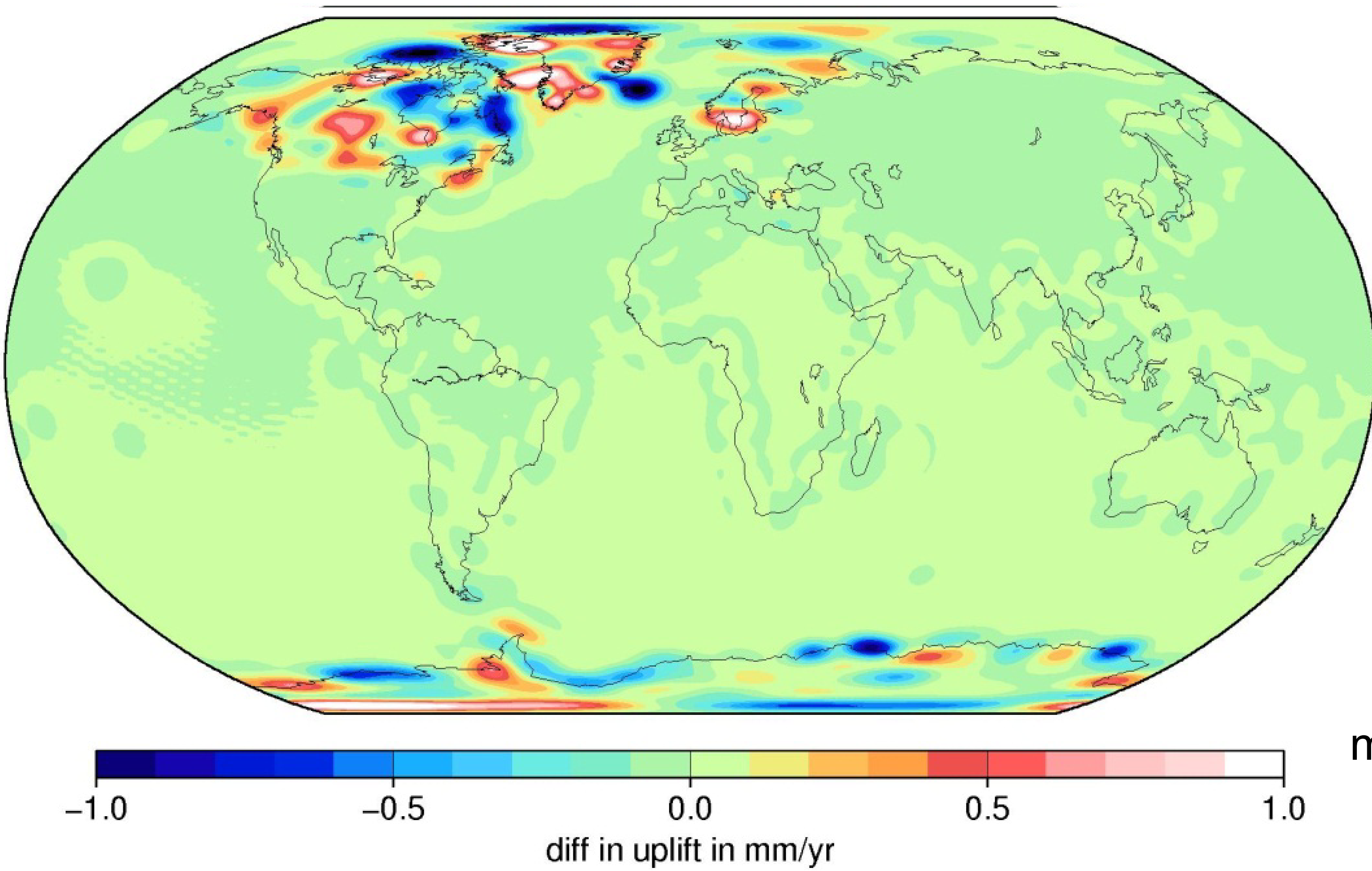


mm/year

I10: Variation of ± 30% of the Ice thickness for each time and location. Where *I*(t, w) is the same as today, we assumed a ± 10% variation for the ice< 800m.

Uncertainty: implementation

Difference in uplift rate



mm/year

Same Ice model ICE5G, Same Earth model VM2
Difference in initial sampling of the ice model and the ocean function

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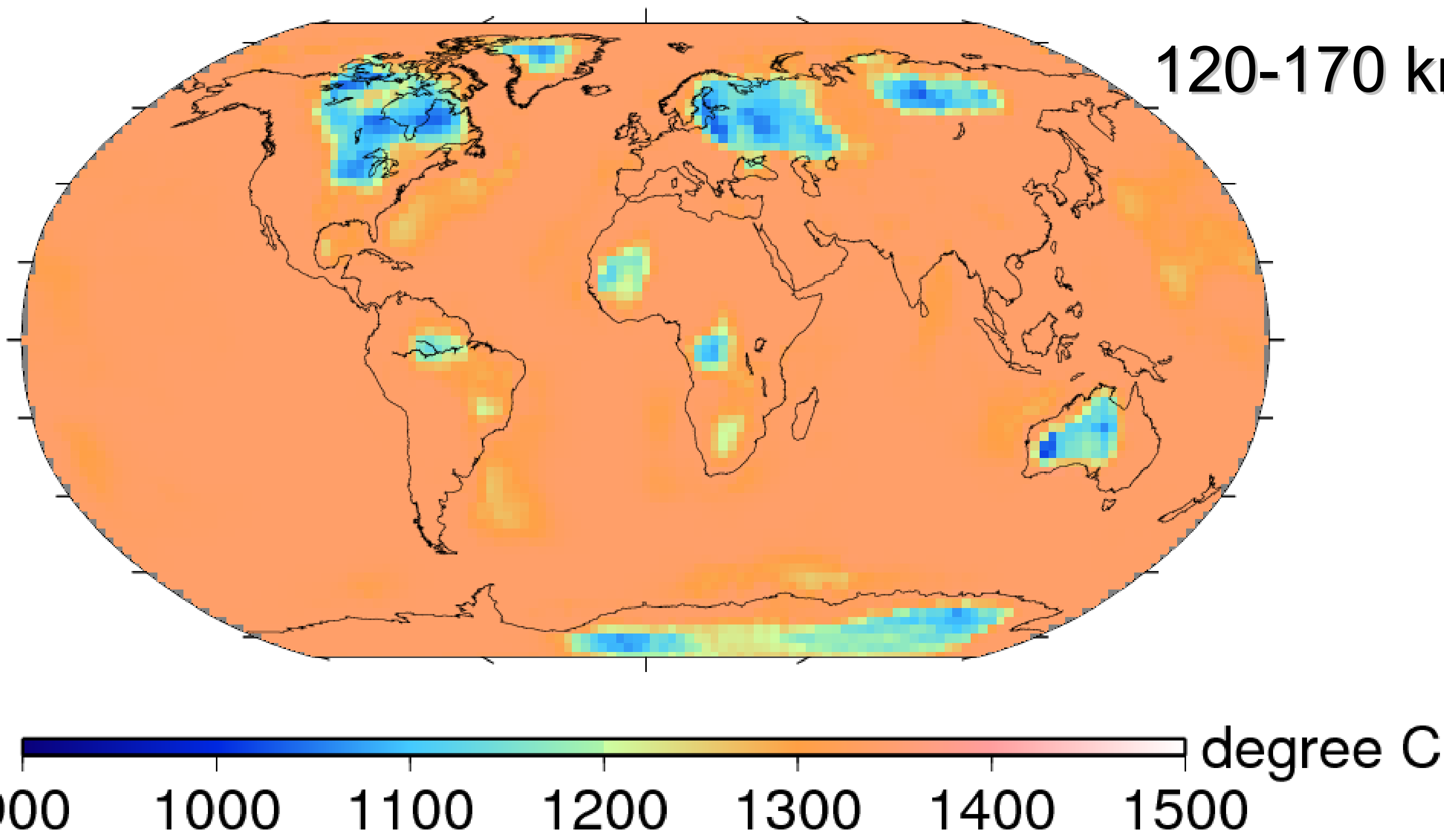
FINITE-ELEMENT MODEL

Uncertainty: lateral variation

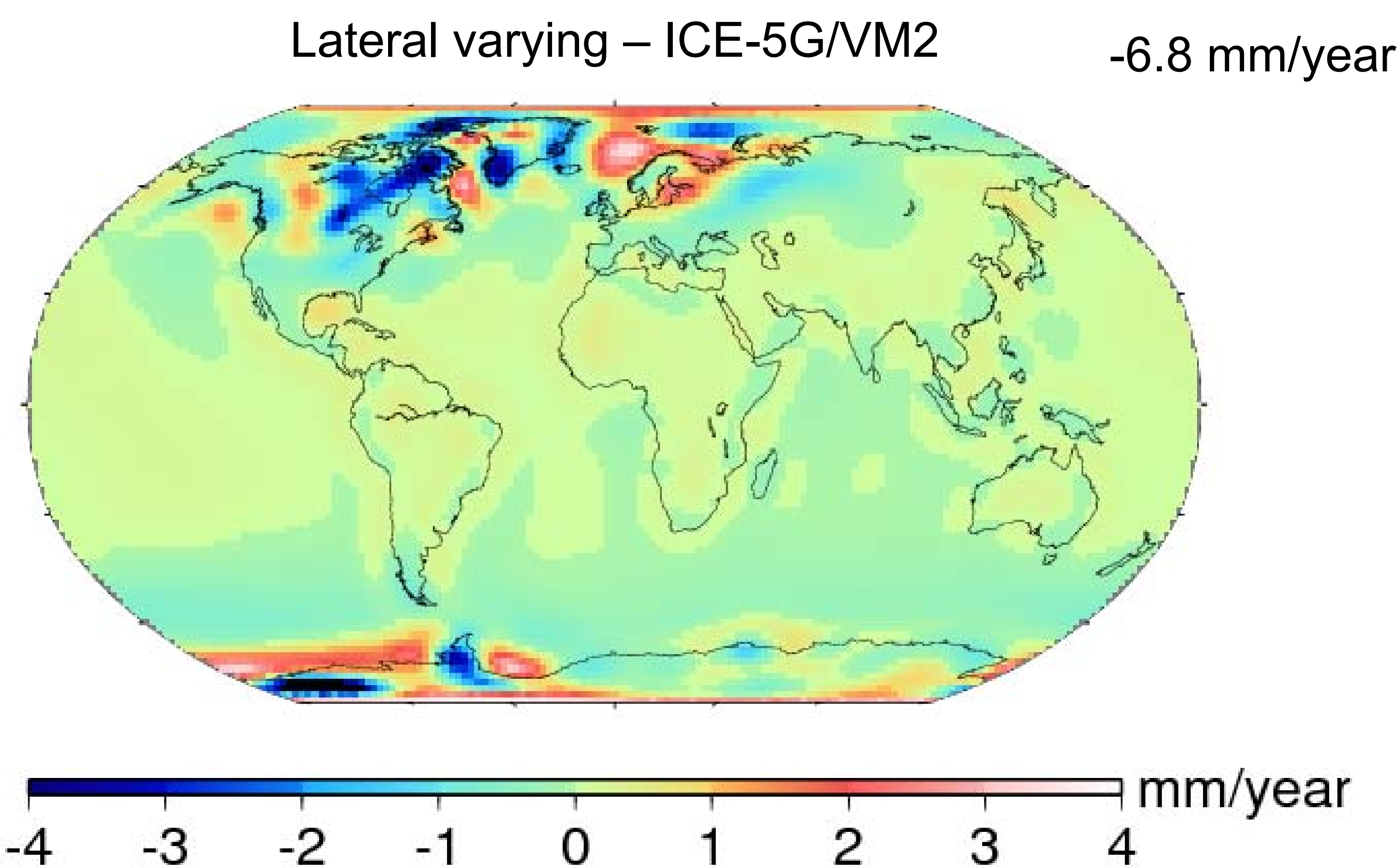


120-170 km depth

- Heatflow measurements extrapolated by a global seismic model (Shapiro & Ritzwoller 2004)+ heat diffusion equation

van der Wal et al., (in prep.)

Uncertainty: lateral variation



van der Wal et al., (in prep.)

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Uncertainty: mantle deformation

Mantle rocks in the laboratory

$$\dot{\tilde{\varepsilon}}_{ij} = \left(\frac{3A_{n=1}}{2} + \frac{3}{2} A \tilde{q}^{n-1} \right) S_{ij}$$

S_{ij} *deviatoric stress tensor*

$\tilde{q}$ *von Mises equivalent stress*

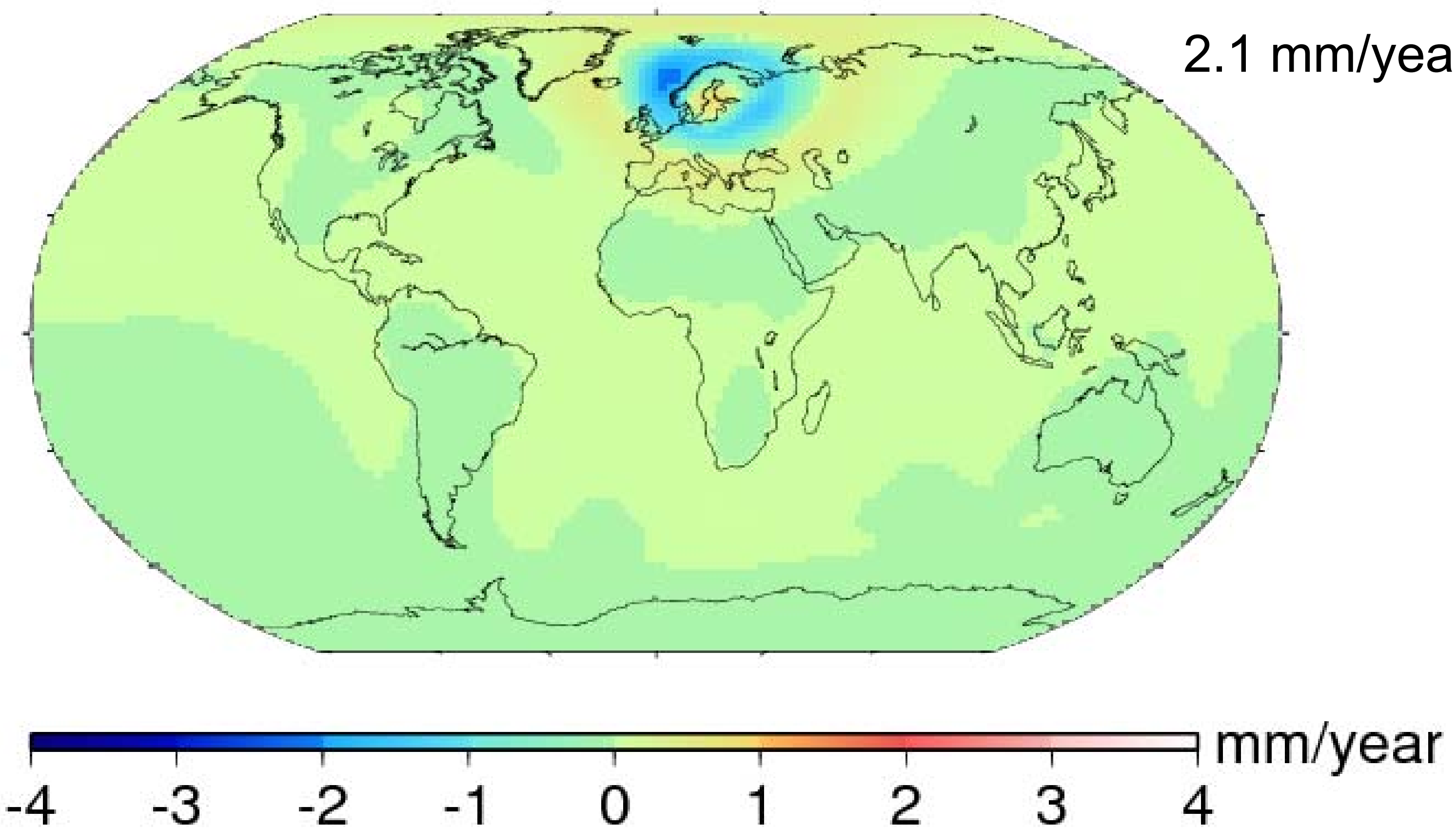
n *stress exponent (3.5)*

From: Martyn Drury, Utrecht Univ.

van der Wal et al., (in prep.)

Uncertainty: mantle deformation

Stress-dependent flow law



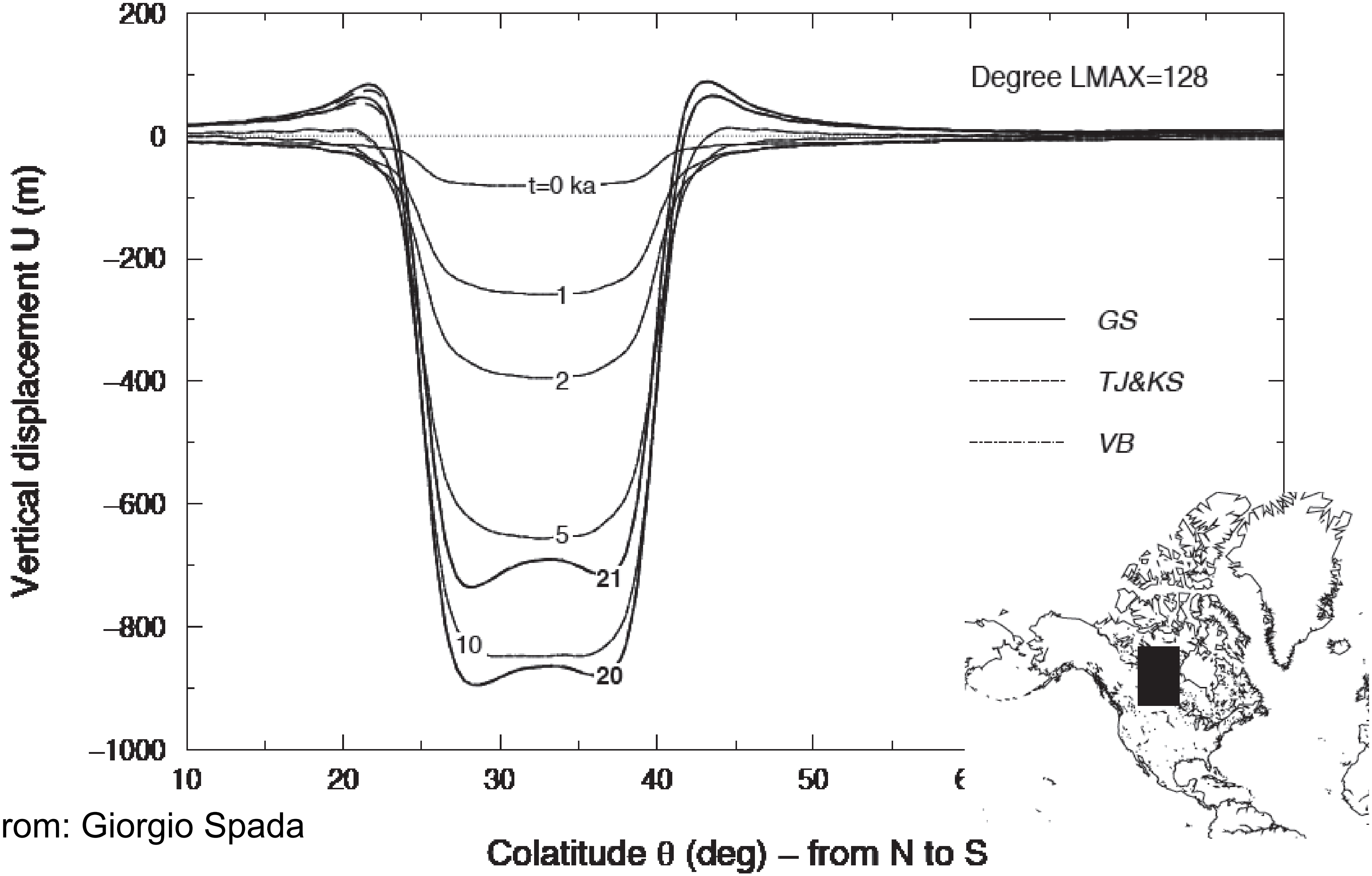
Max.

2.1 mm/year

van der Wal et al., (in prep.)

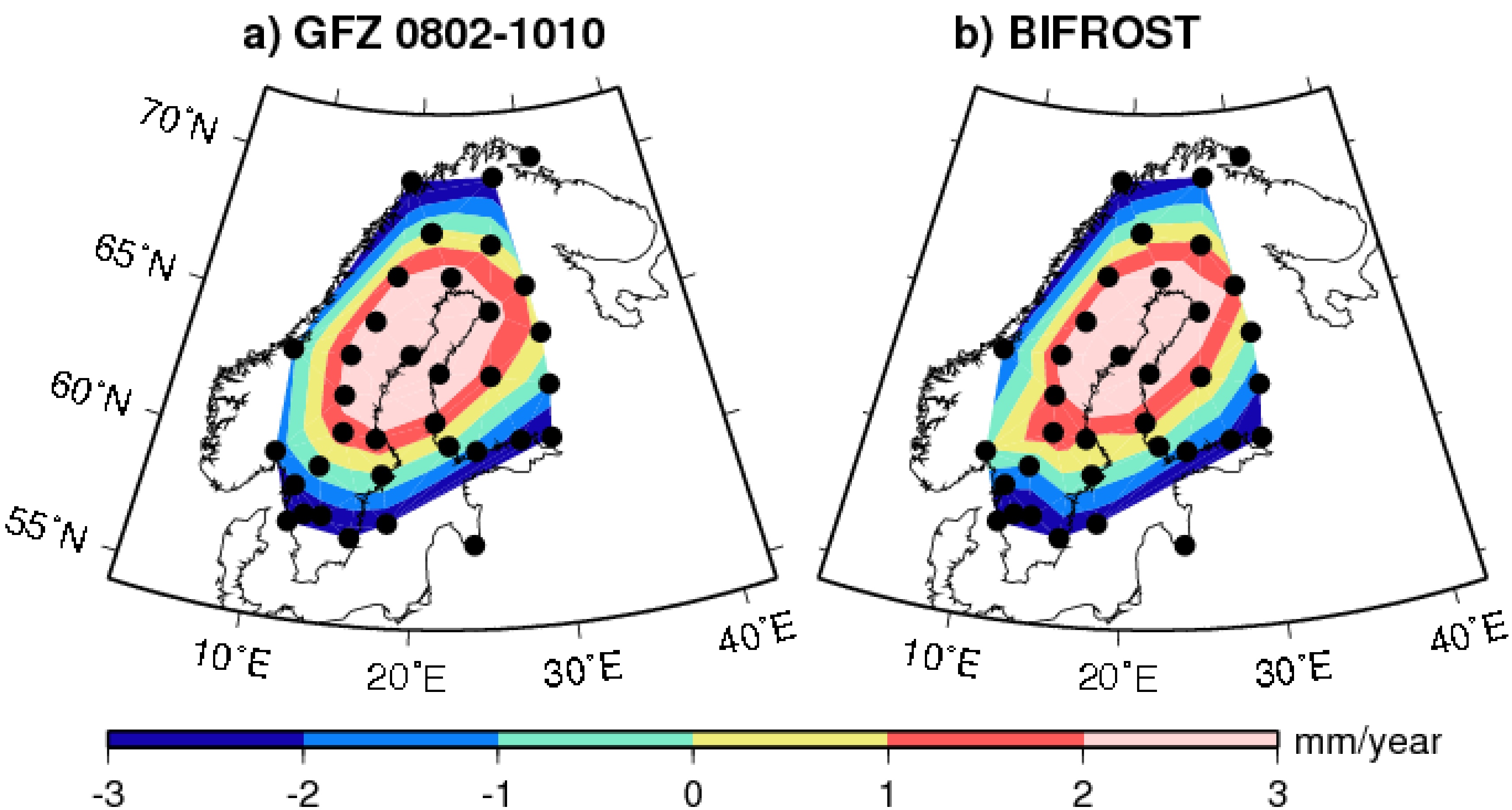
SOLUTIONS?

Solutions: Benchmark



From: Giorgio Spada

Solutions: Data



Van der Wal et al. (GJI 2011)

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Summary

Standard model: Viscosity - 6.3 mm/a, other Earth model – 1.9 mm/a, ice height - 1.1 mm/a, rotational feedback ??

3D: 6.8 mm/a, **Flow law**: 2.1 mm/a

Solutions:

- Use uncertainty estimate
- Benchmark
- Use other measurements
- Constrain the model for the region of interest
- Constrain the model with information from other Earth sciences

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Acknowledgements

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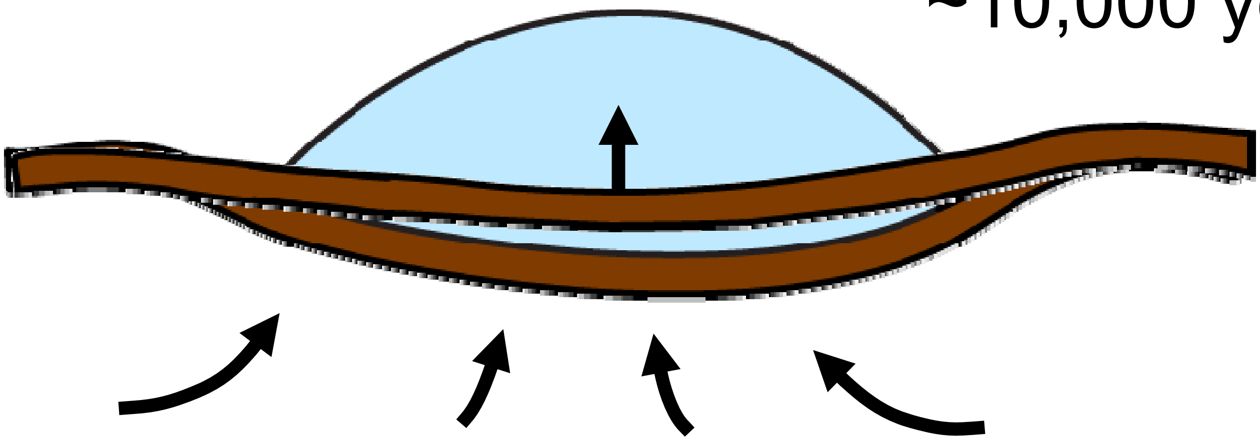
BACKUP SLIDES

Glacial Isostatic Adjustment (GIA)

rising

~10,000 years



Flow in the mantle determined by viscosity

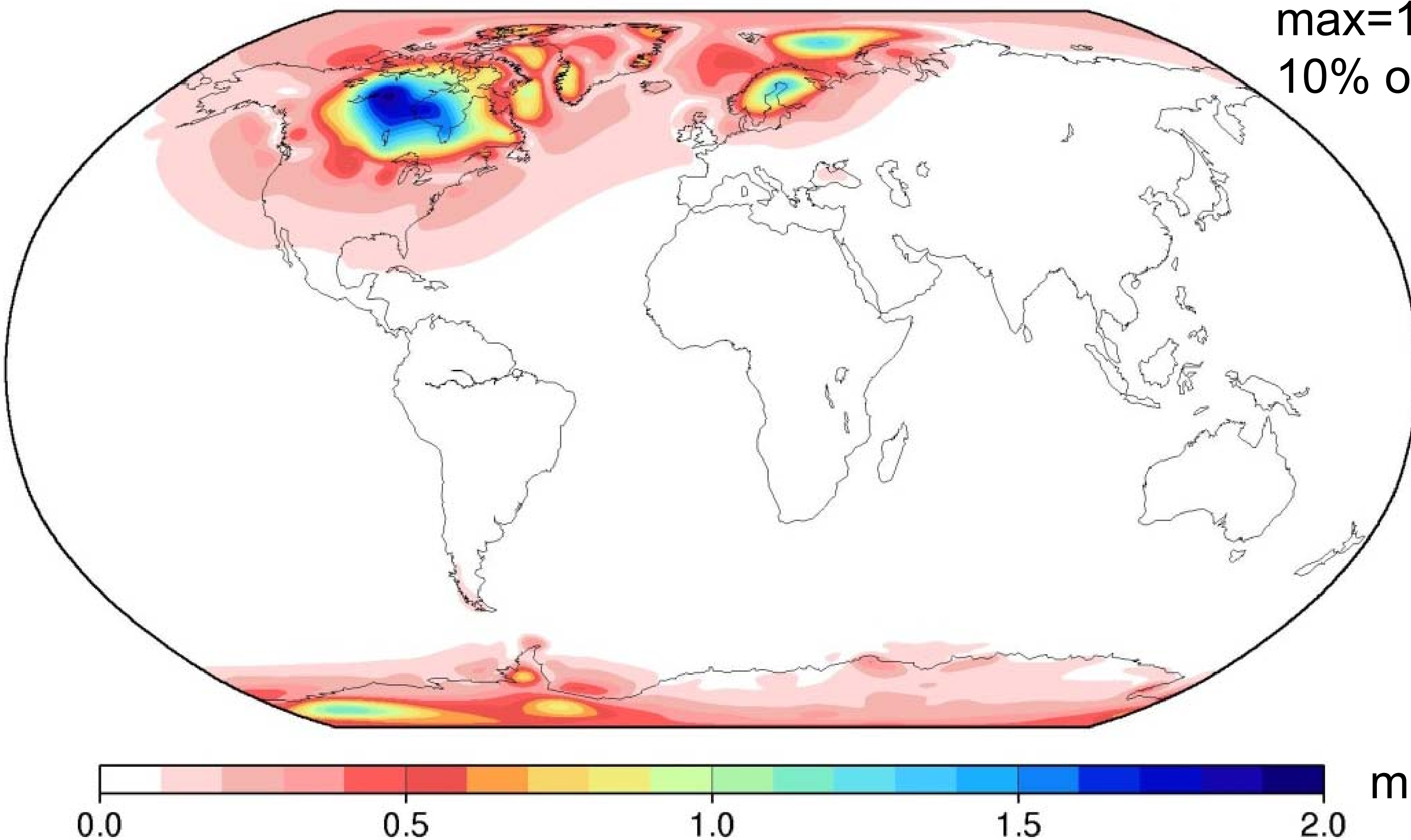
Results: best fitting mantle viscosities

	η_{UM} [10^{20} Pas]	η_{LM} [10^{20} Pas]
Tushingham & Peltier (1991)	10	20
Mitrovica & Forte (2002	4	80
Kaufmann & Lambeck (2002)	7	200
Wolf et al. (2006)	3.2	160
Paulson et al. (2007)	5.3	23
GPS (ICE-4G)	8	32
GRACE (ICE-4G)	64	256
Historic sea level (ICE-4G)	16	32
Historic sea level (ICE-5G)	16	256

Van der Wal et al (GJI 2011)

Uncertainty propagation: Earth model

Standard deviation



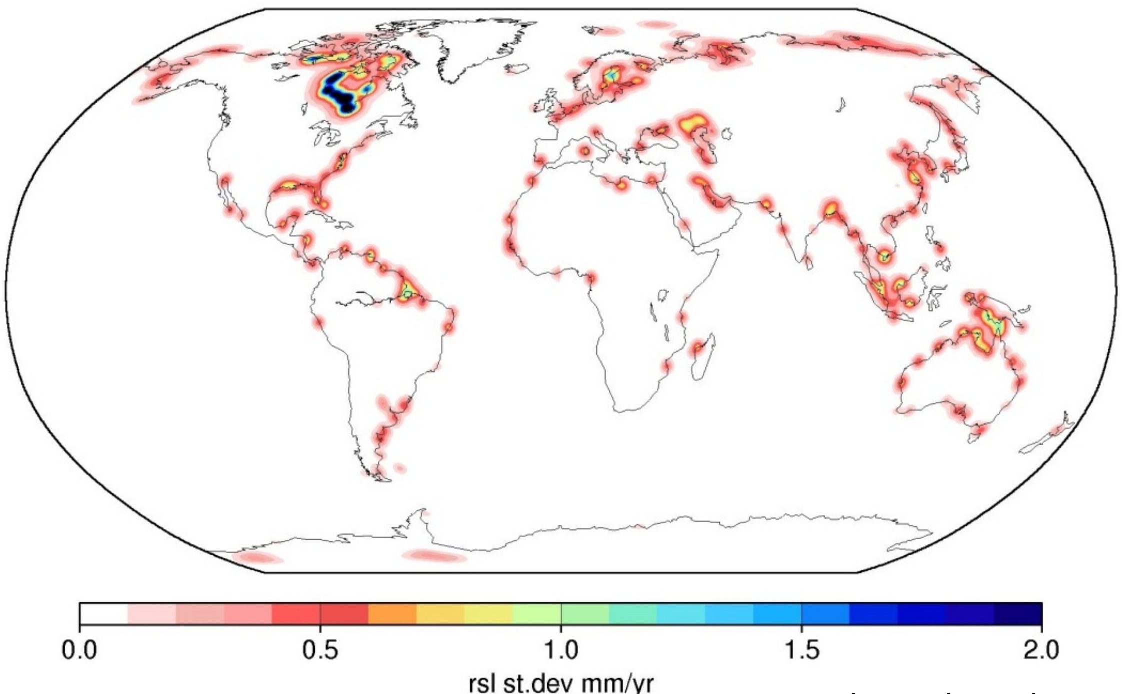
max=1.93,
10% of the signal

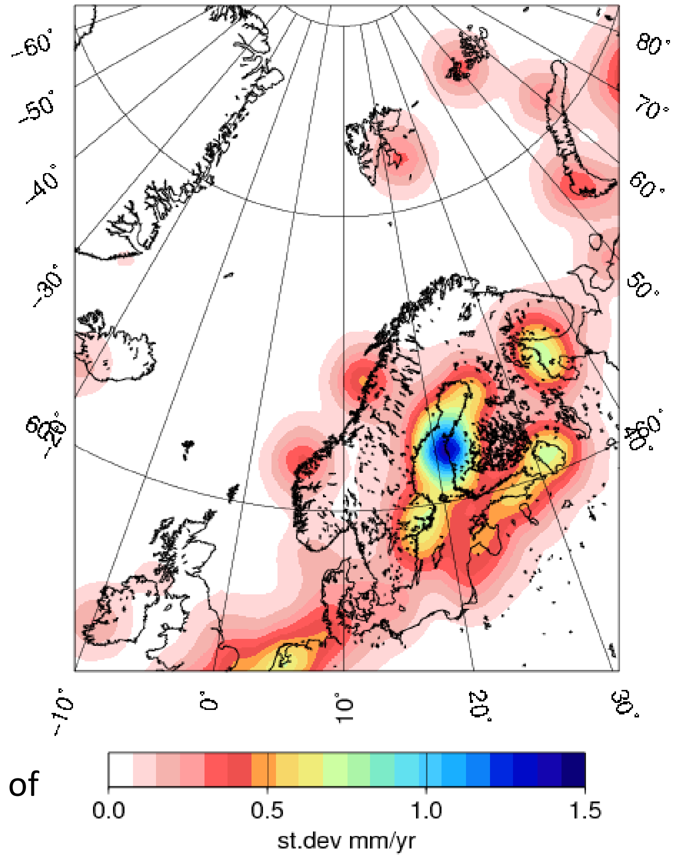
mm/year

Variation of Lithospheric thickness ± 5 km, Density ± 5%, V_S ± 5%, and viscosity by ± 0.05 in Log10 scale

Propagation of Ocean Function uncertainties

St. Dev for RSL (GPS and tide-gauges)

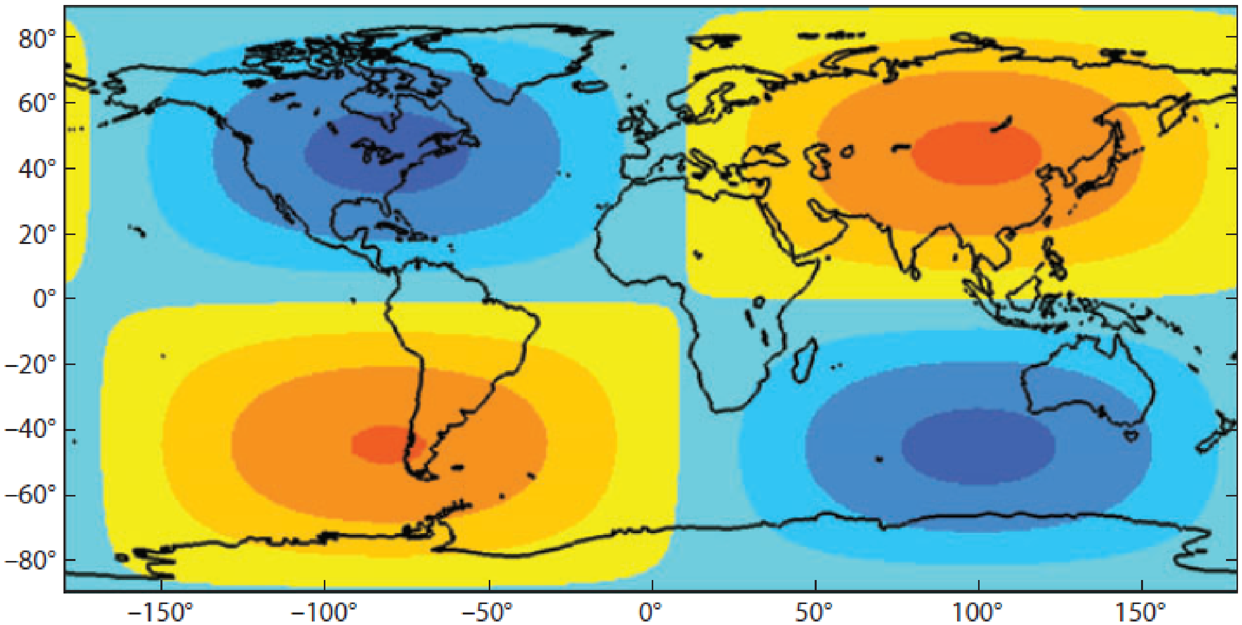




The scale is about 15% of the whole signal.

O2: Variation of ± 10% of the paleotopography *T*(t, ω) for each time t and only in locations (ω) within a belt following the shorelines. From the paleotopography then we compute the ocean function *FO*(t) by setting *FO* = 1 where the paleotopography is negative, and FO = 0 otherwise.

Uncertainty propagation: rotational feedback



Mitrovica & Wahr, Ann. Rev. Earth Planet. Sci. (2011)

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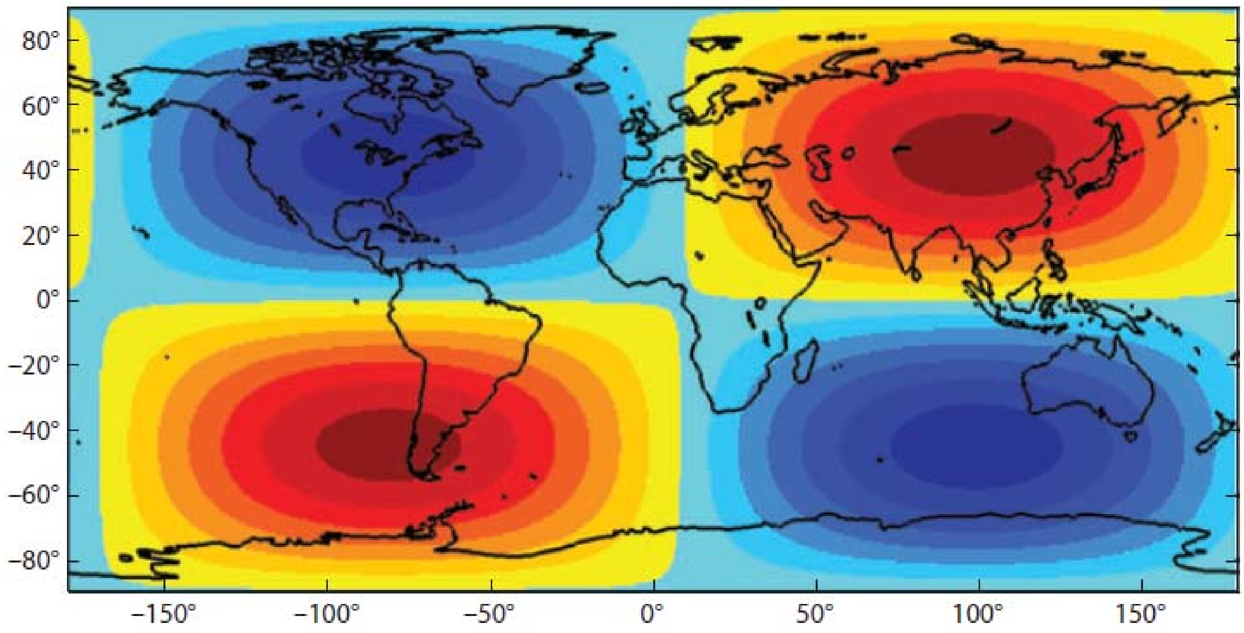
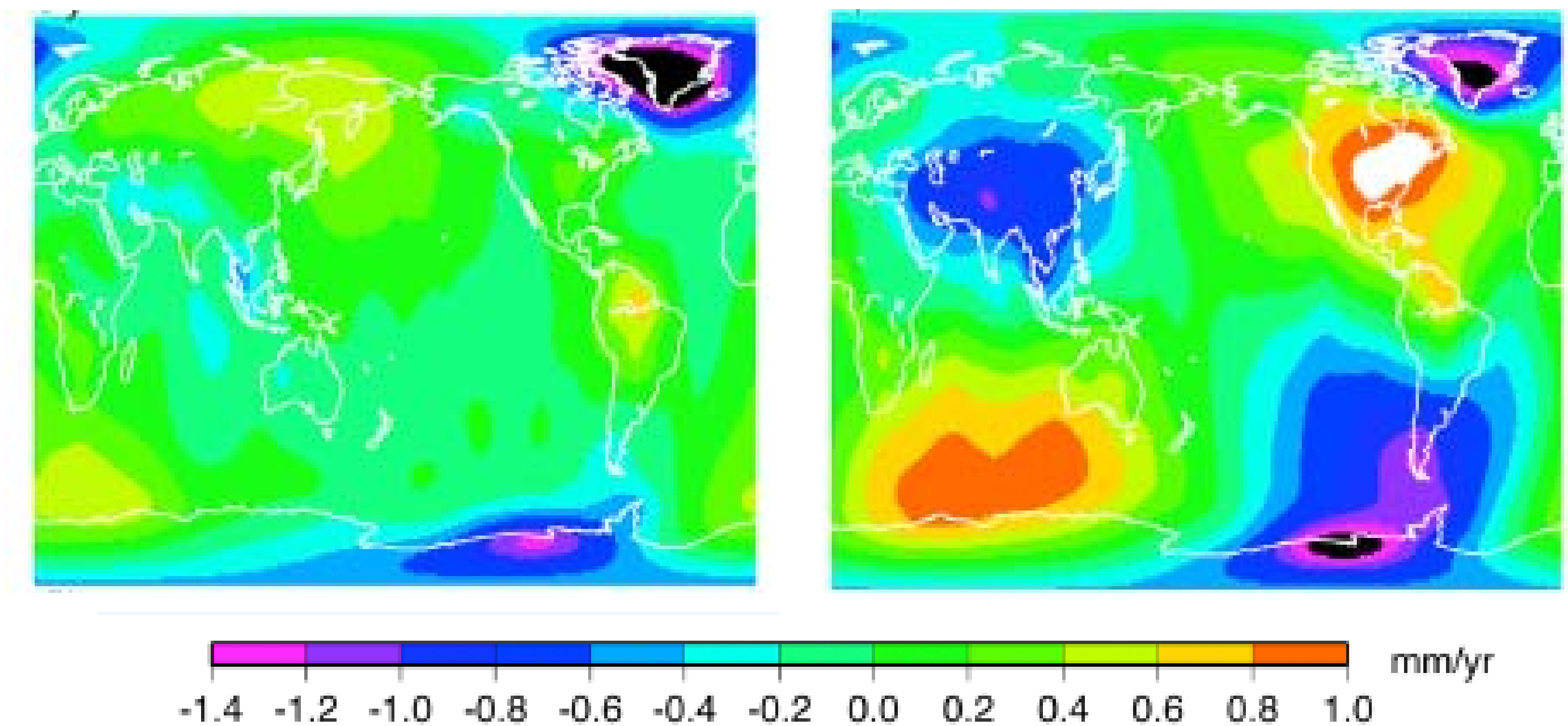
Uncertainty propagation: rotational feedback



Uncertainty: rotational feedback

GRACE – Paulson et al (2007)

GRACE – Peltier (2004)



Chambers et al., JGR (2010)

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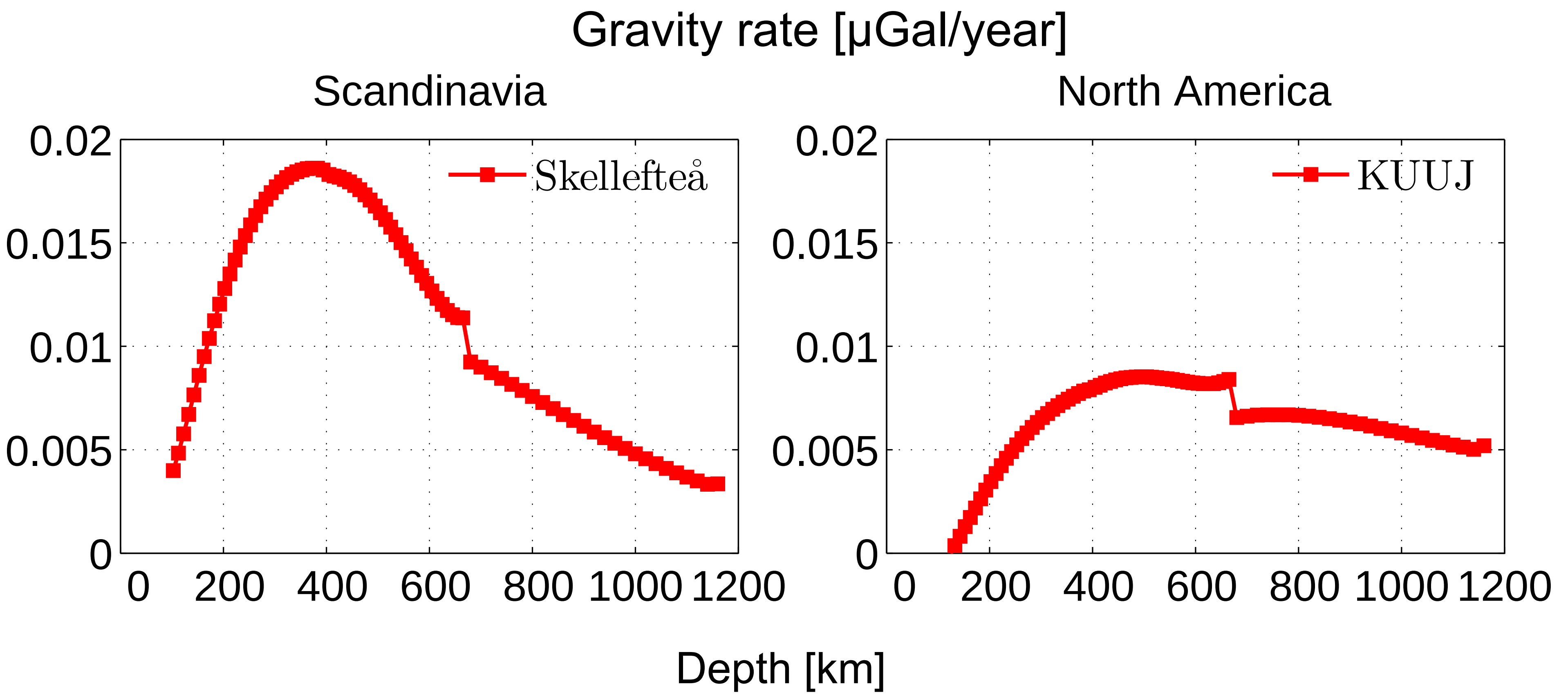
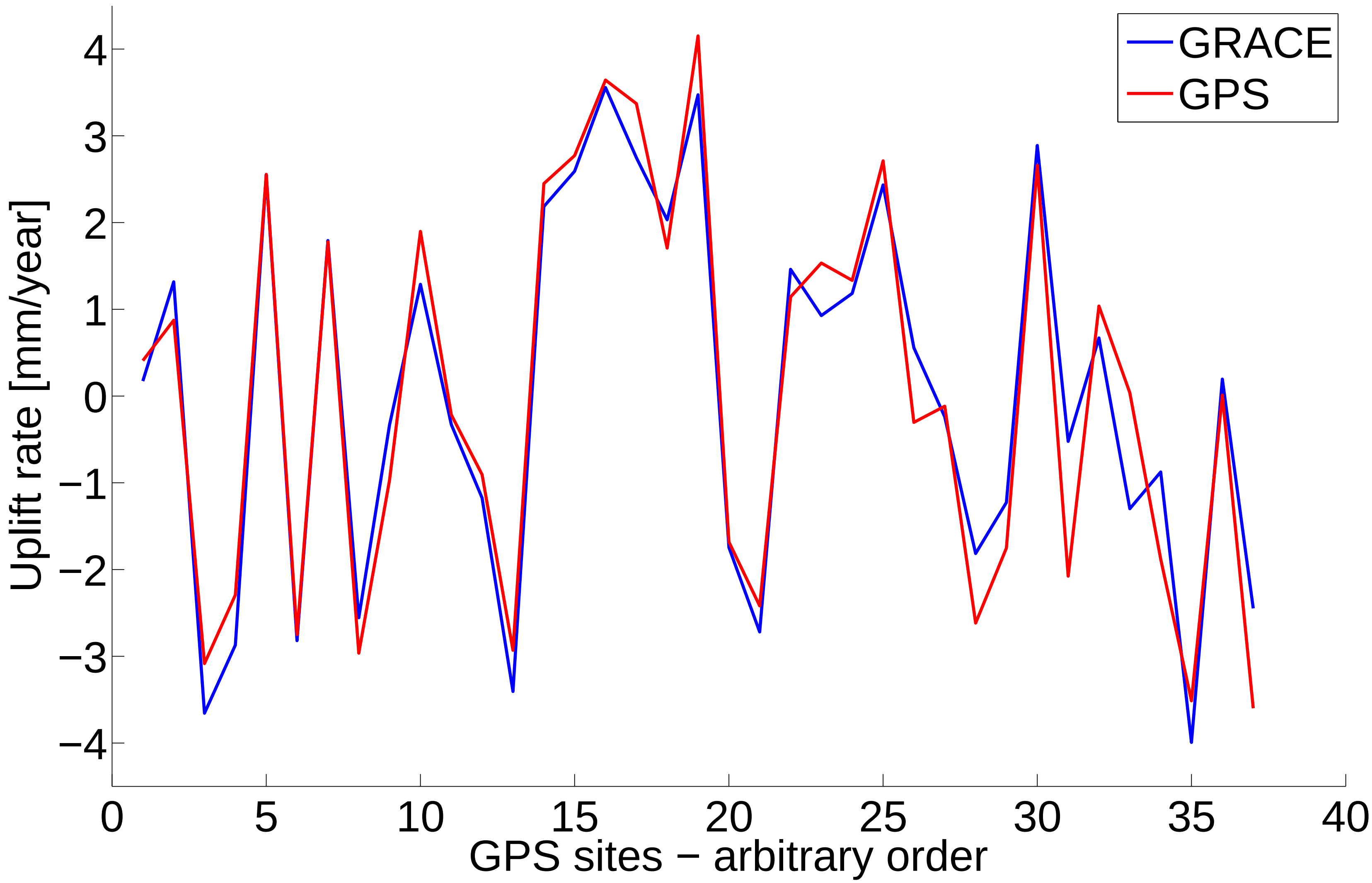
Sensitivity kernels



Gravity rate (uplift rate) in North America is more sensitive to the lower mantle viscosity

Van der Wal et al. (GJI 2011)

After scaling



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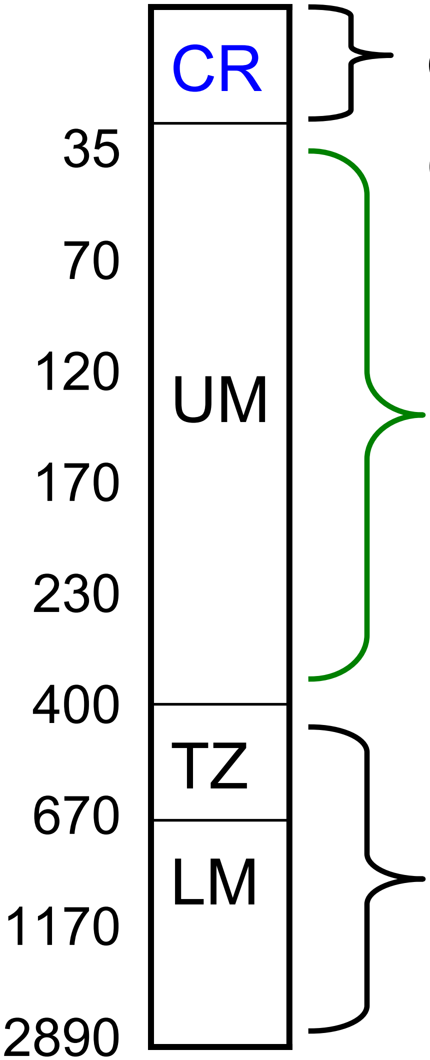
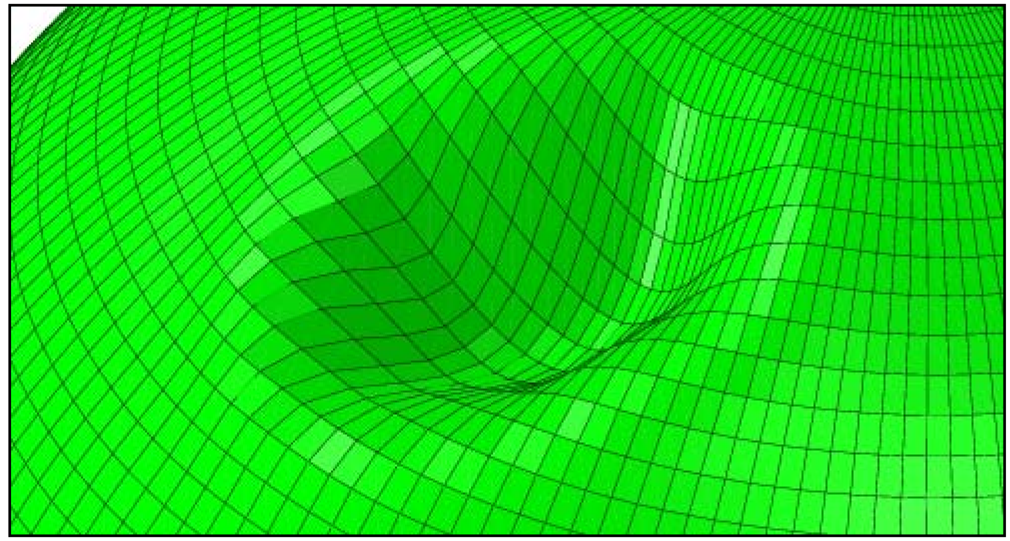
Model



Crust

(fully elastic)

Temperature



Best fitting composite rheology parameters of van der Wal et al. (2010)

Model

Hirth & Kohlstedt (2003)

$$\dot{\varepsilon} = A_D \sigma^n d^{-p} fH_2O^r \exp(\alpha\phi) \exp\left(-\frac{E+pV}{RT}\right)$$

A_D pre-exponent factor

n stress exponent (3.5)

d grain size (0.5–4 mm) Kukkonen&Peltonen (1999)

fH_2O water fugacity

Φ melt factor (0)

E activation energy

P pressure

V activation volume

T temperature

R gas constant

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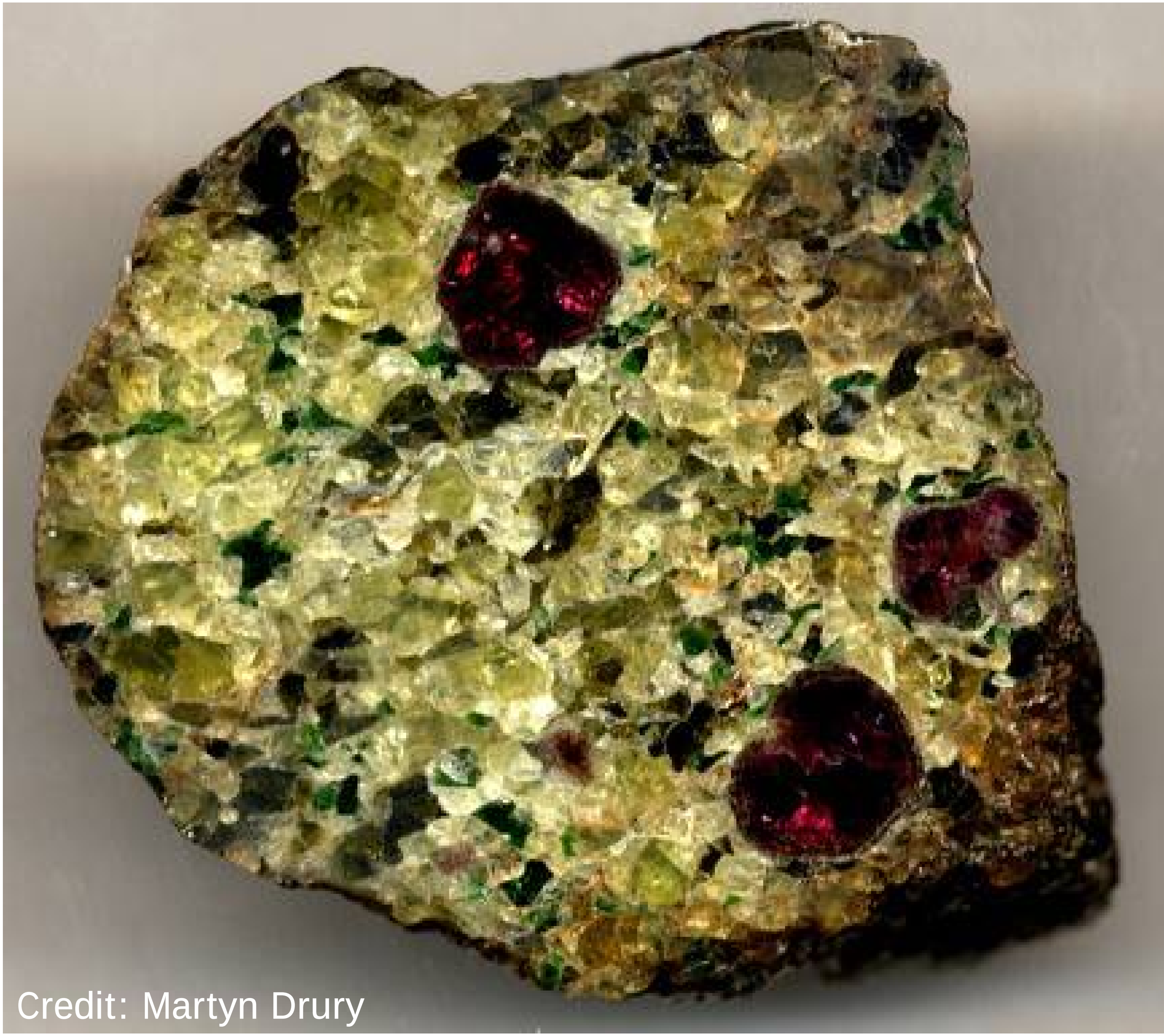

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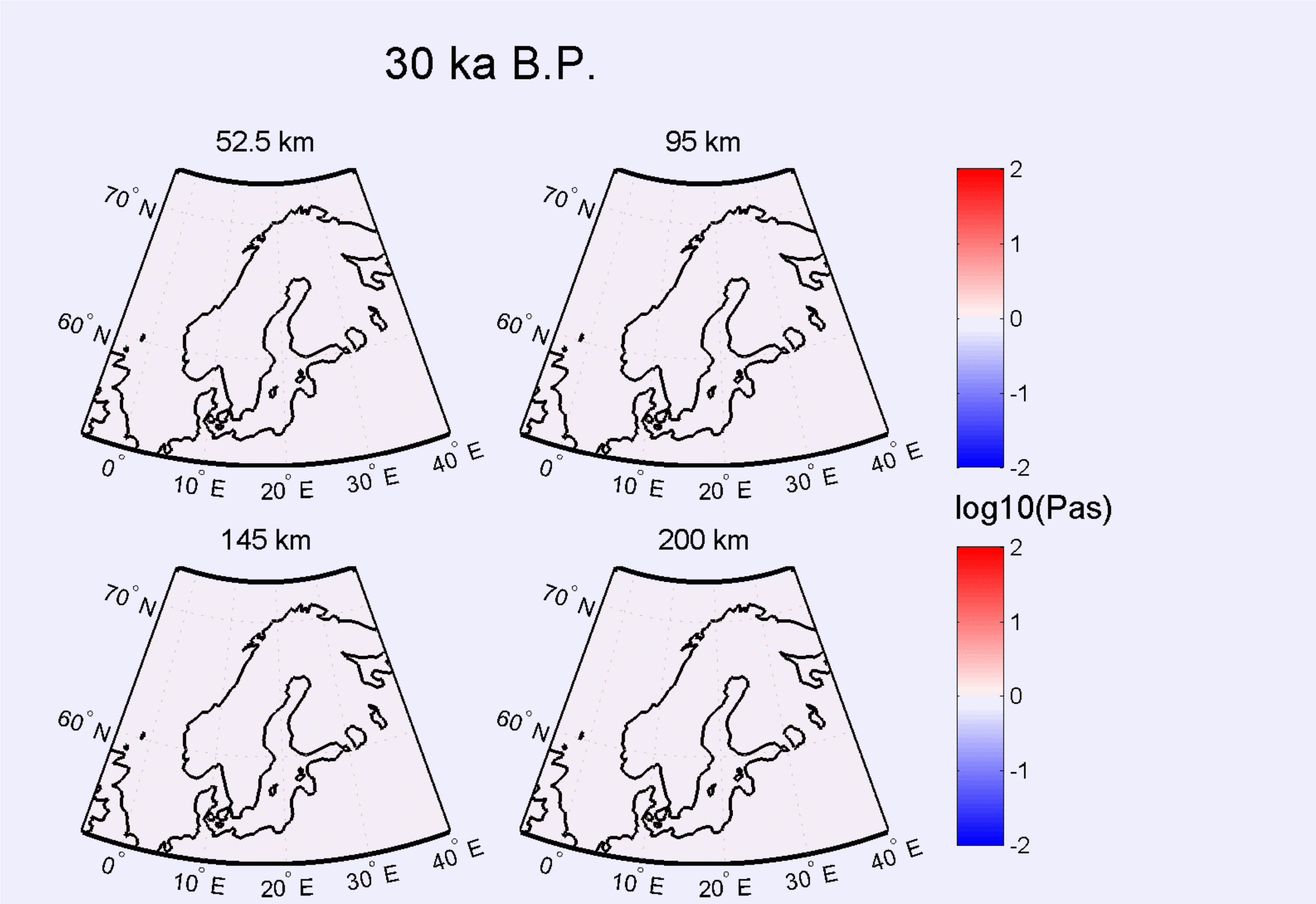


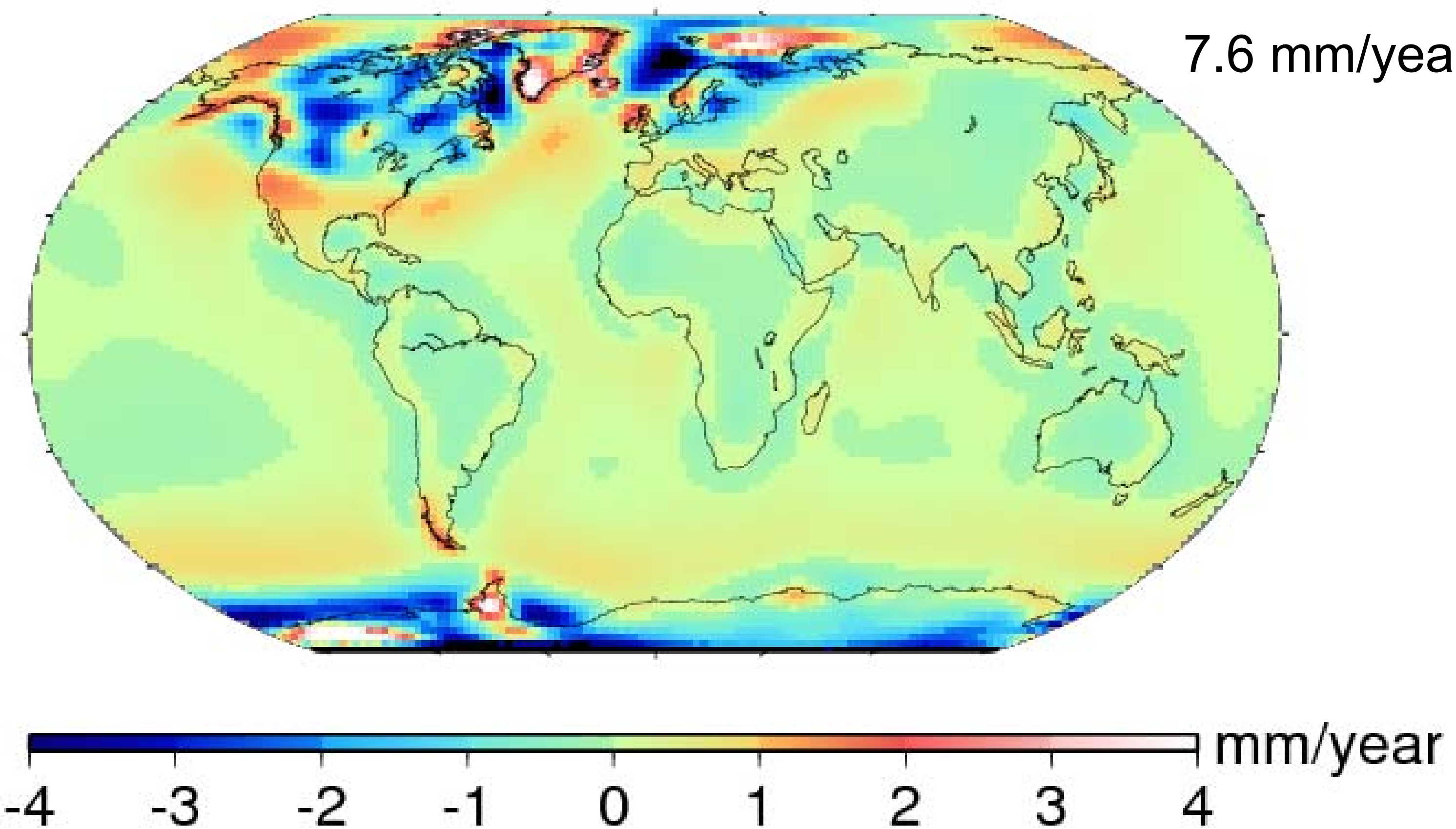
Barnhoorn, van der Wal, Drury, Vermeersen (G-cubed 2011)

Uncertainty: 3D temperature

Temperature II – Temperature I

Max.

7.6 mm/year



van der Wal et al., (in prep.)