

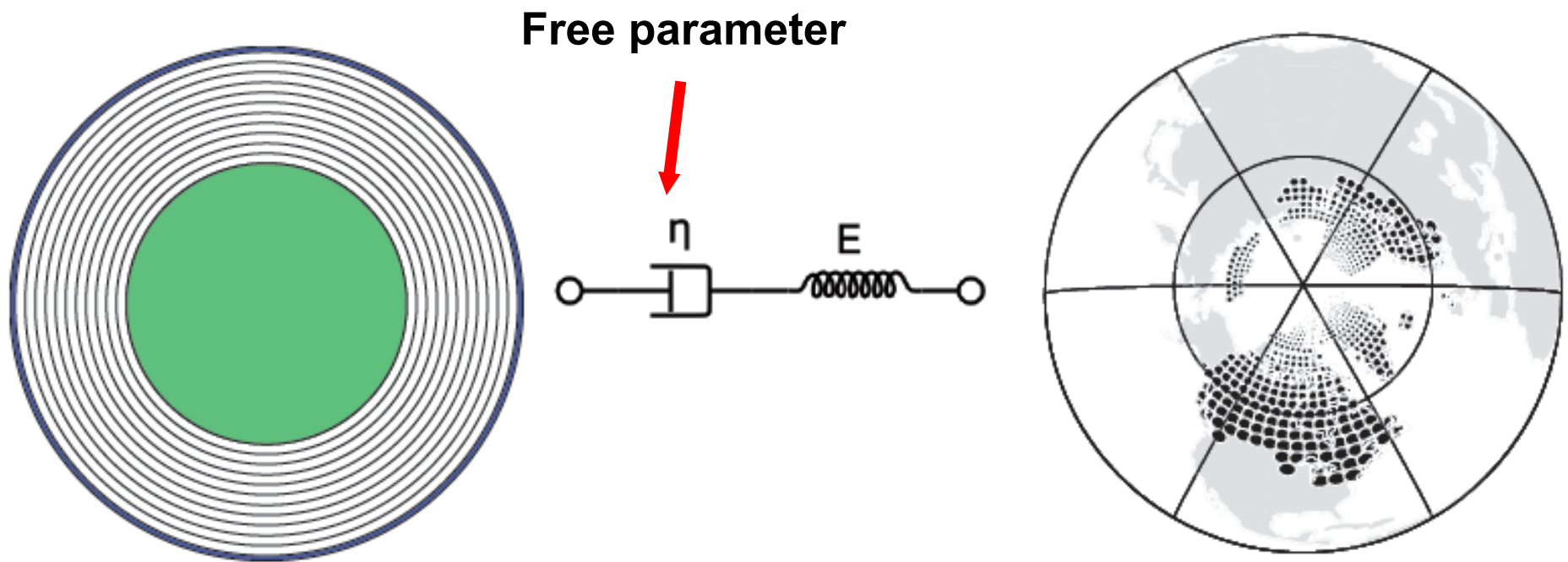
Uncertainties in models for glacial isostatic adjustment

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

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- Standard GIA Model
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 - Earth model parameters
 - Ice thickness
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- Summary

Standard GIA model

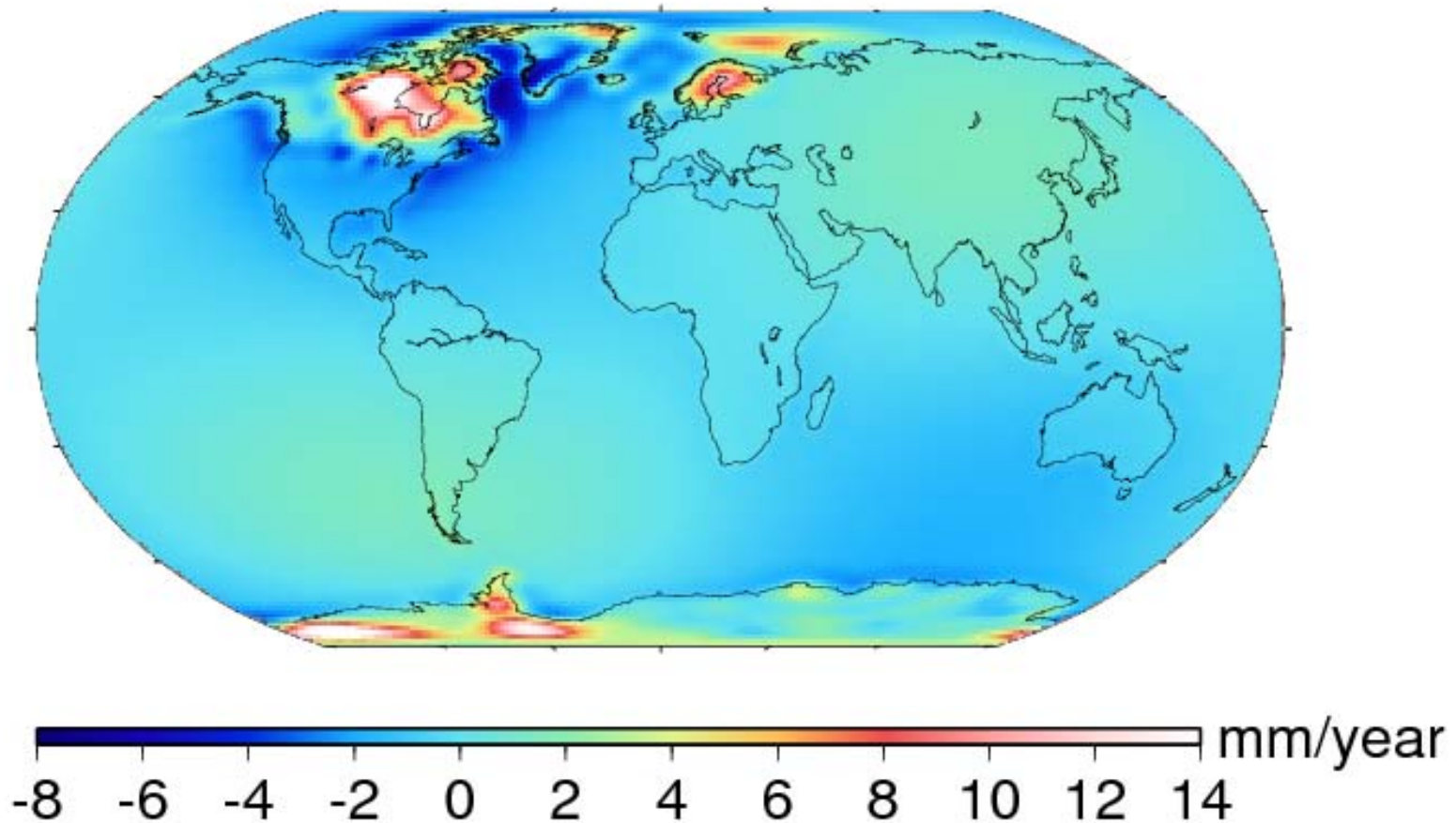


From: Paolo Stocchi, IMAU Utrecht

STANDARD MODEL

Standard GIA model

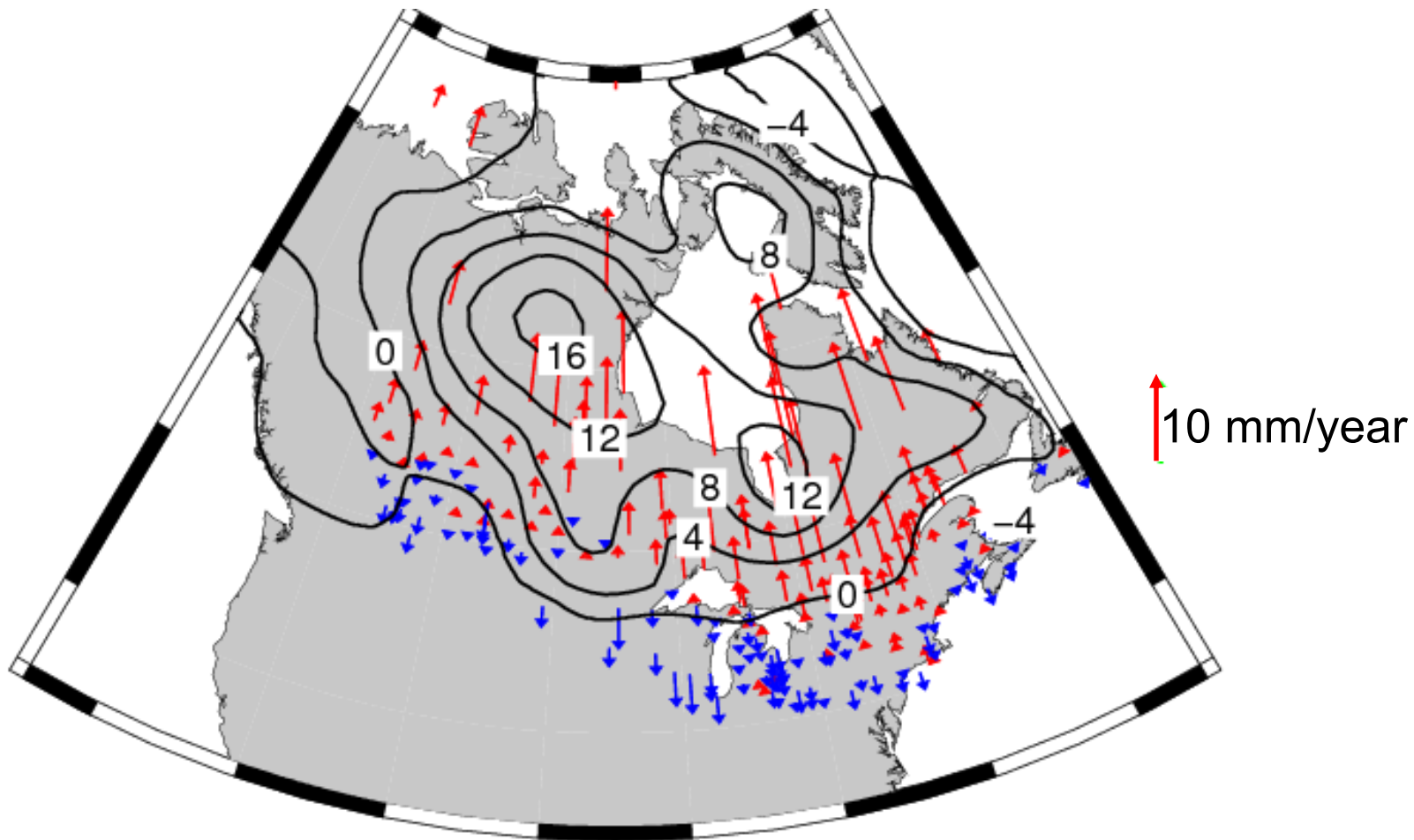
Uplift rate ICE-5Gv1.2/VM2



Uplift rate from Peltier submission to Special Bureau for Loading website

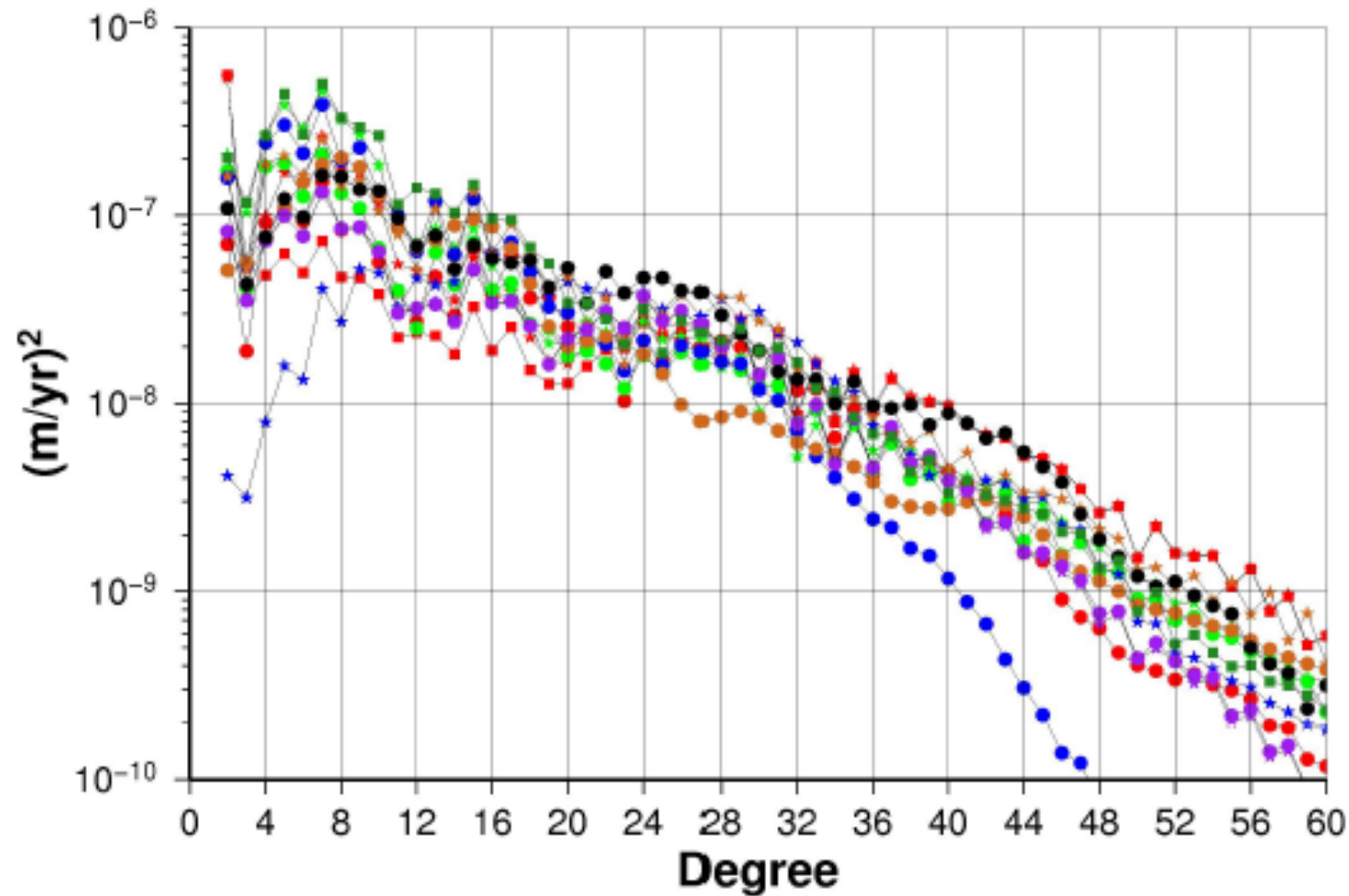
Standard GIA model

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



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

Uplift Rate Spectrum

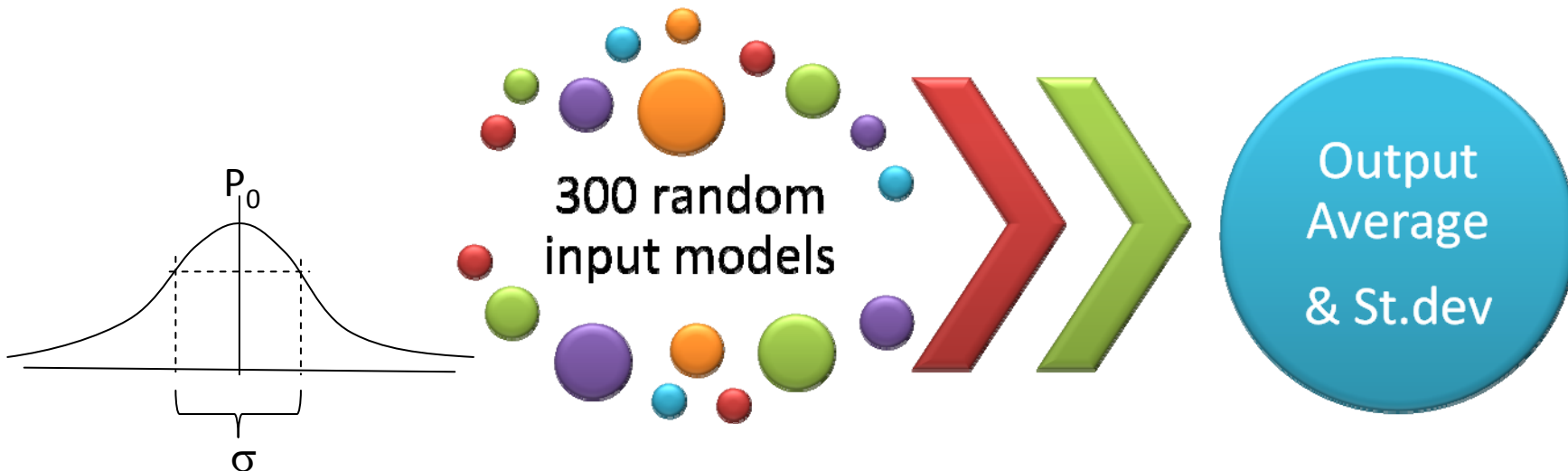


Guo et al, J. Geodyn. (2012)

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

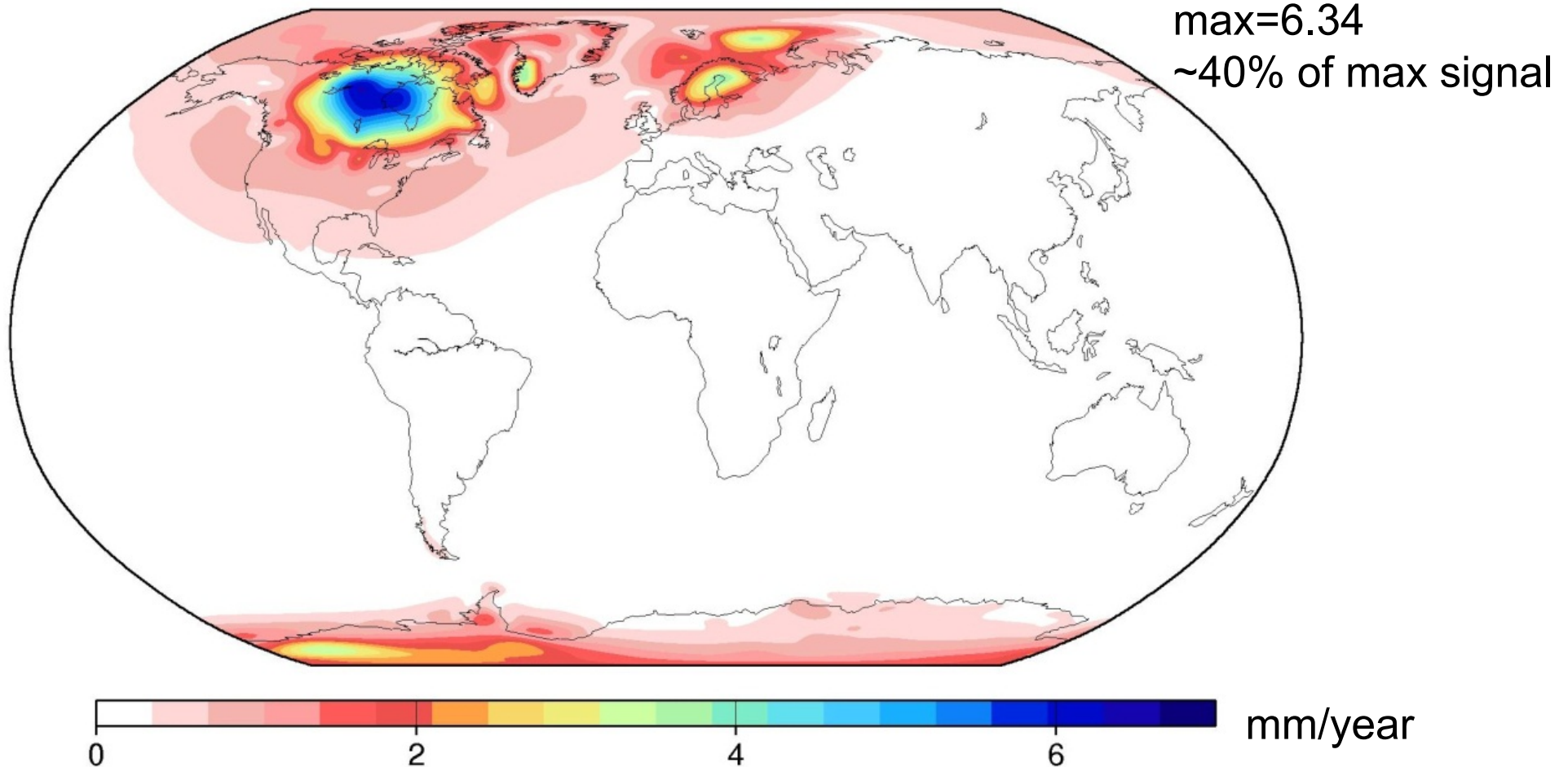


Reference model:

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

Uncertainty propagation: viscosity

Standard deviation



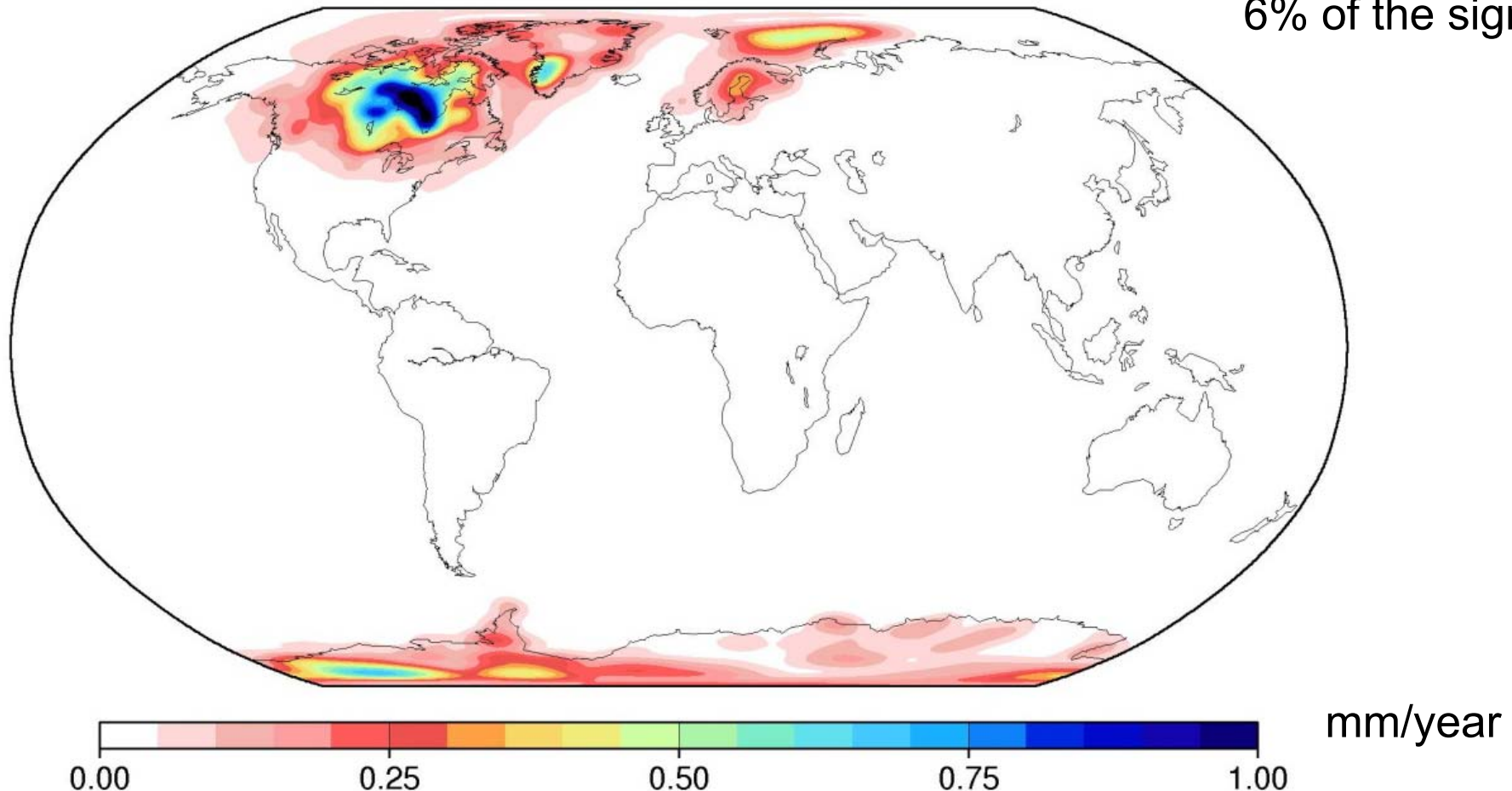
Variation of the viscosity by ± 0.3 in Log10 scale, i.e. by $10^{\pm 0.3}$

Uncertainty propagation: ice height

Standard deviation

Max = 1.1

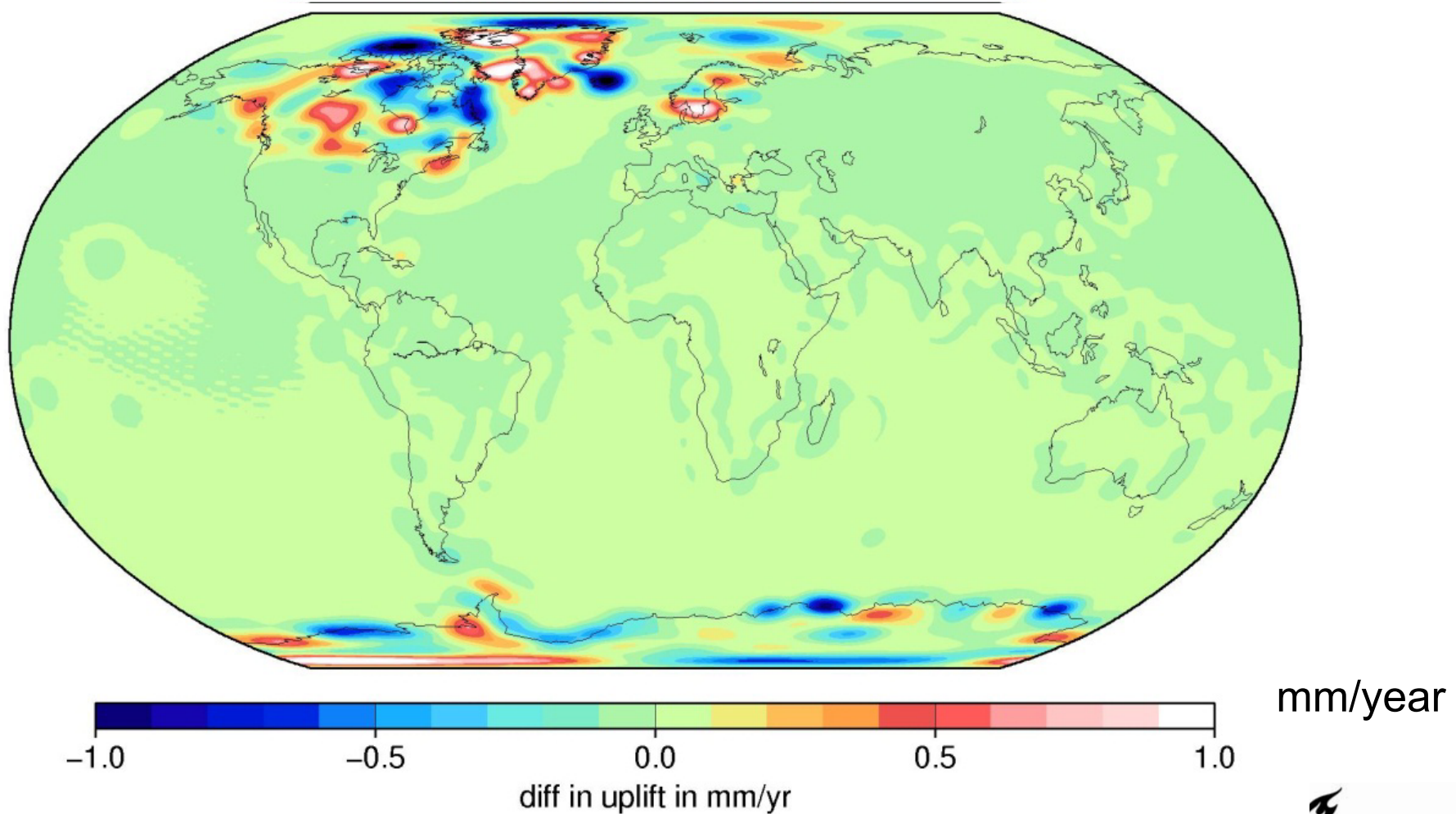
6% of the signal



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

Uncertainty: implementation

Difference in uplift rate

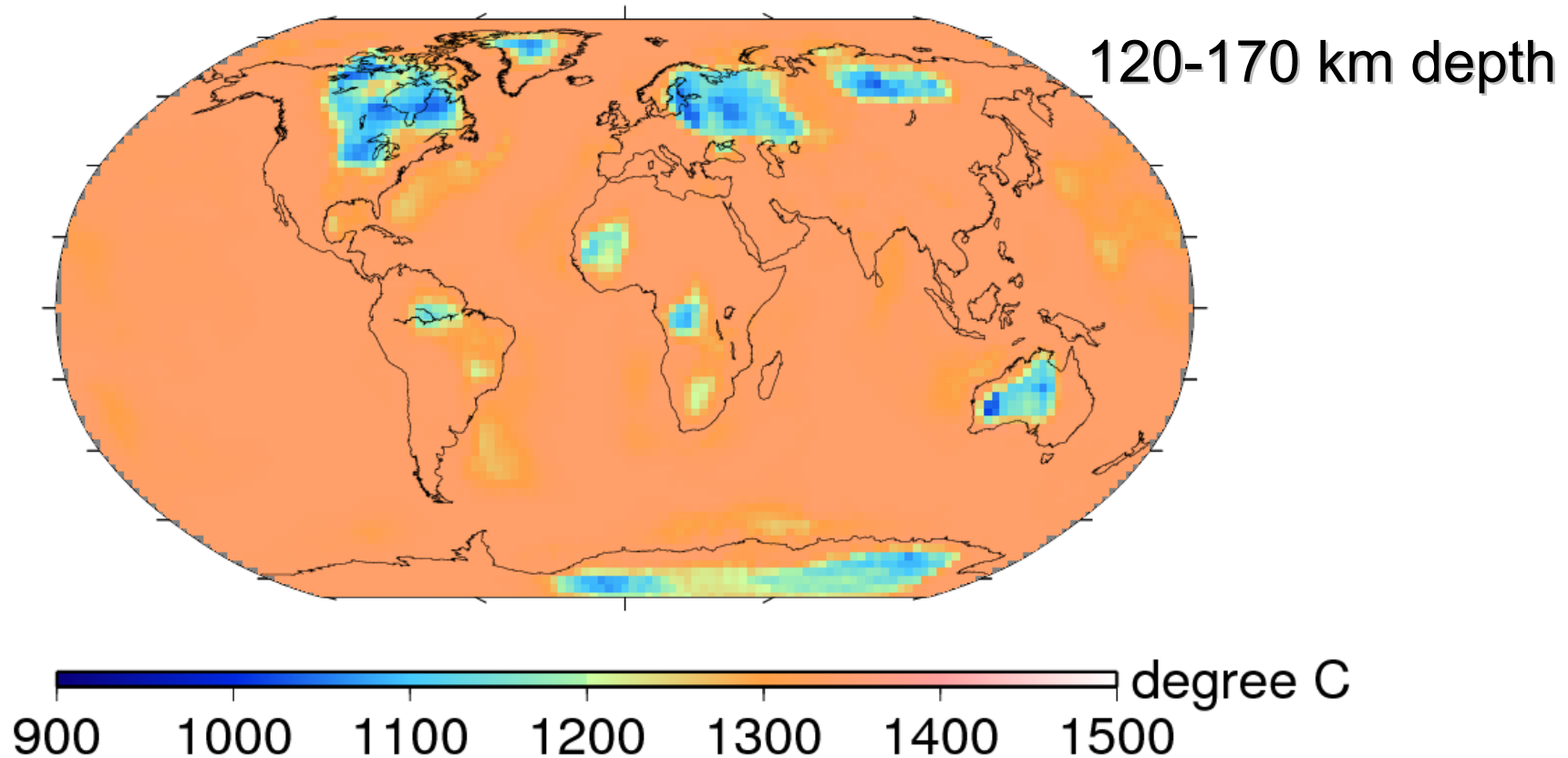


Same Ice model ICE5G, Same Earth model VM2

Difference in initial sampling of the ice model and the ocean function

FINITE-ELEMENT MODEL

Uncertainty: lateral variation



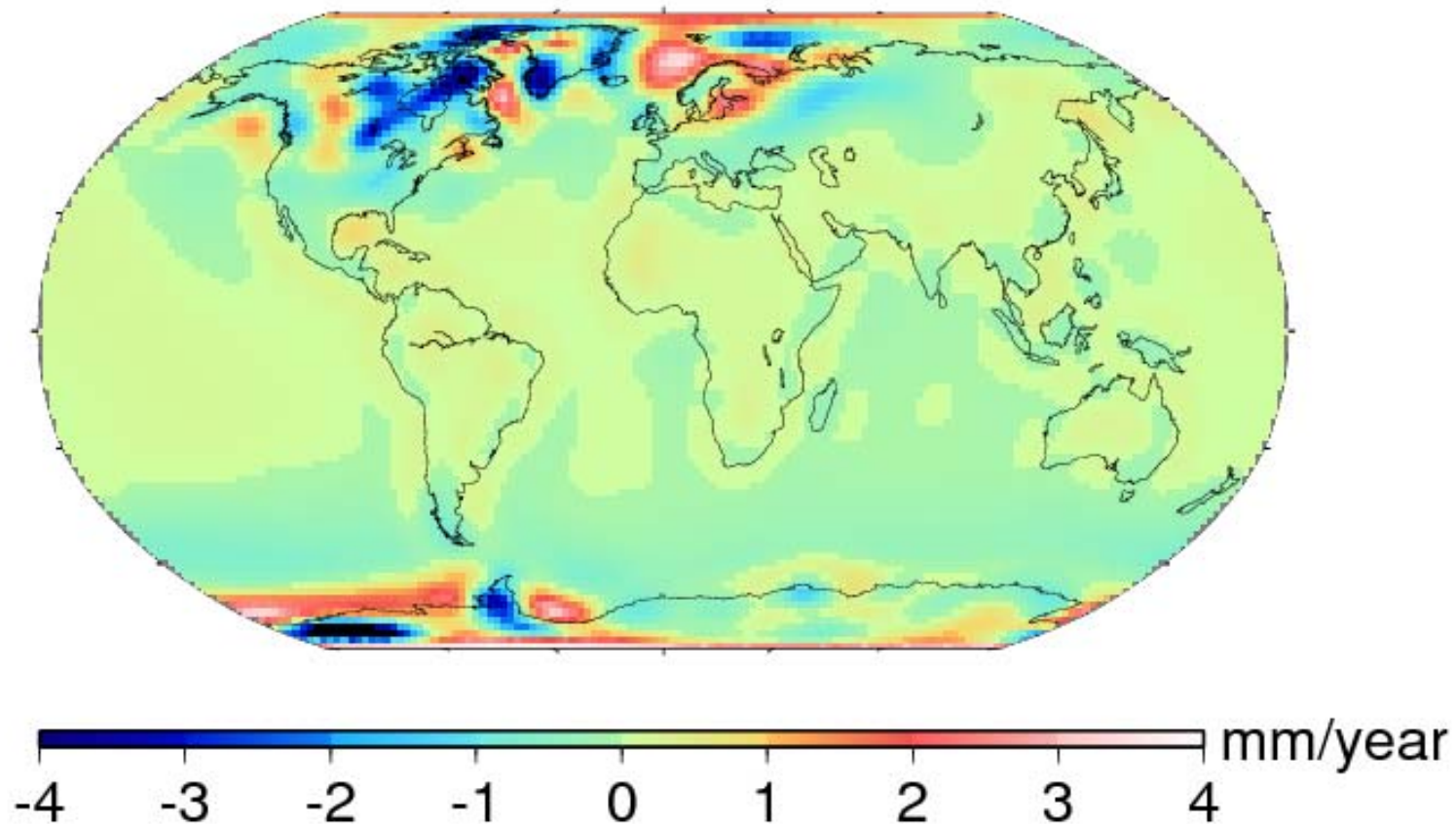
- Heatflow measurements extrapolated by a global seismic model
(Shapiro & Ritzwoller 2004)+ heat diffusion equation

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

Uncertainty: lateral variation

Lateral varying – ICE-5G/VM2

-6.8 mm/year



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

Uncertainty: mantle deformation

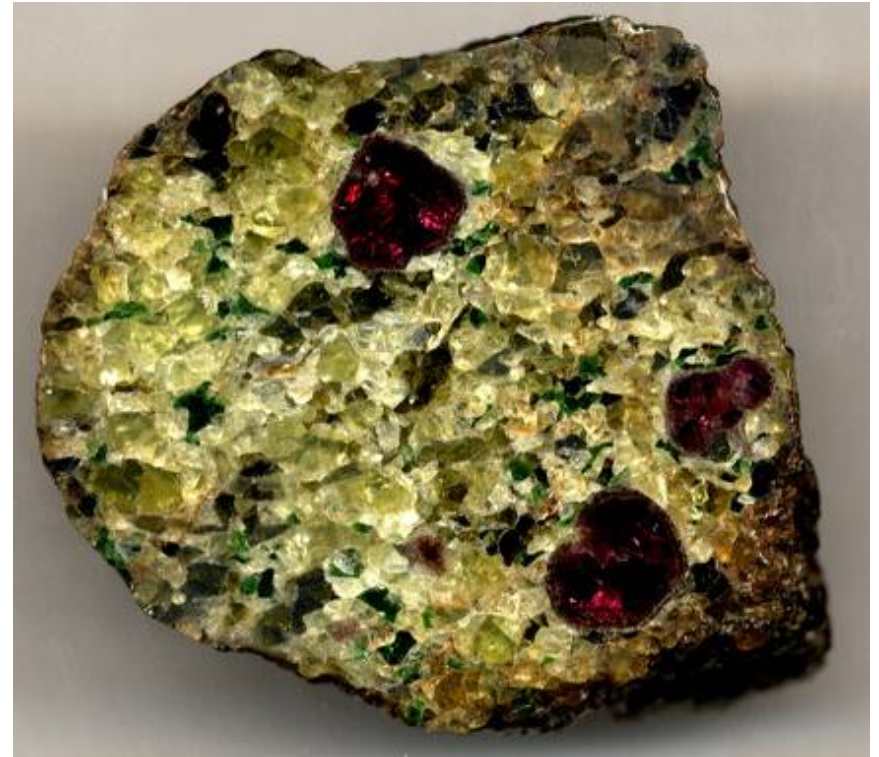
Mantle rocks in the laboratory

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

S_{ij} deviatoric stress tensor

$\tilde{q}$ von Mises equivalent stress

n stress exponent (3.5)



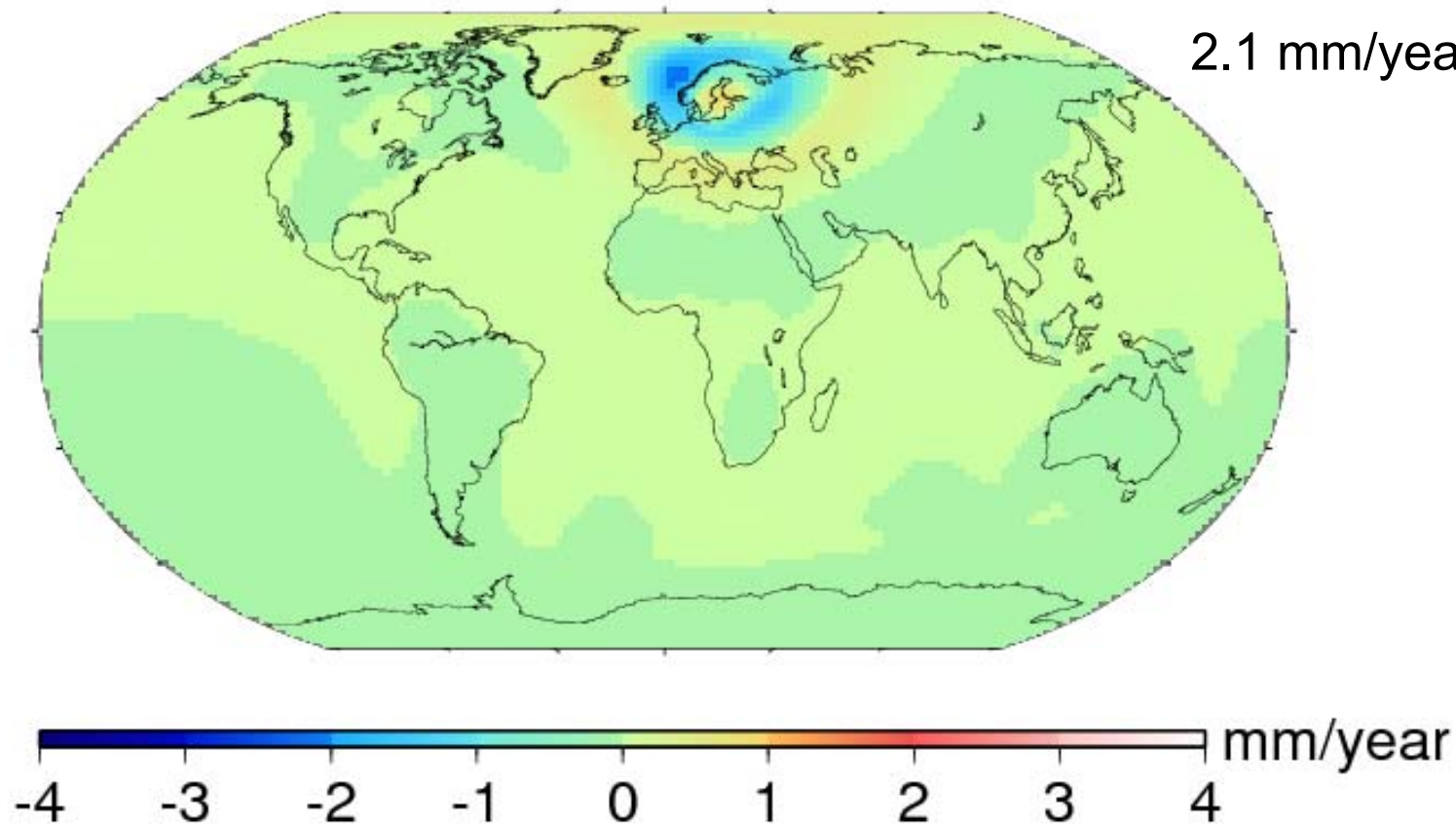
From: Martyn Drury, Utrecht Univ.

Uncertainty: mantle deformation

Stress-dependent flow law

Max.

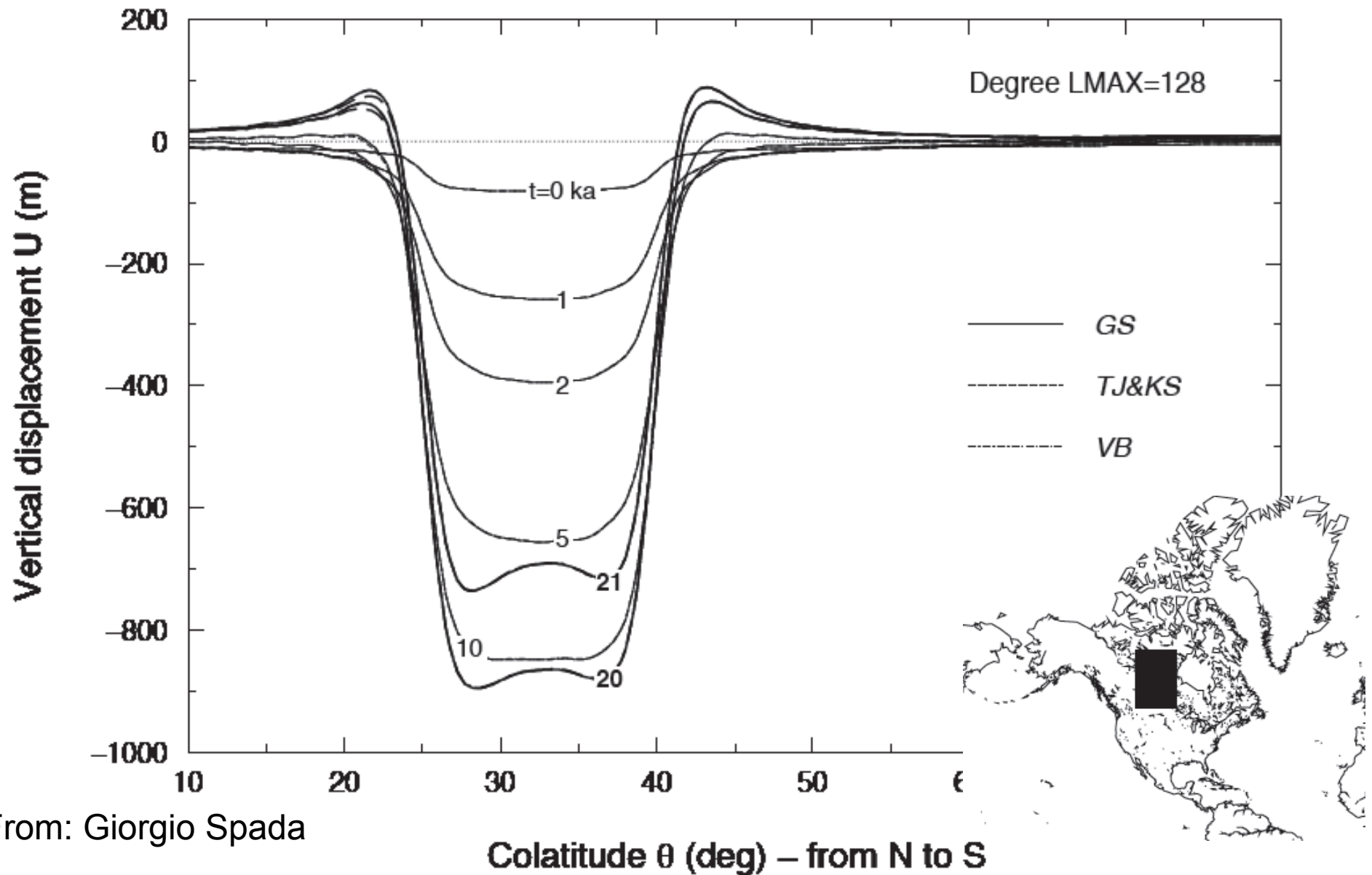
2.1 mm/year



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

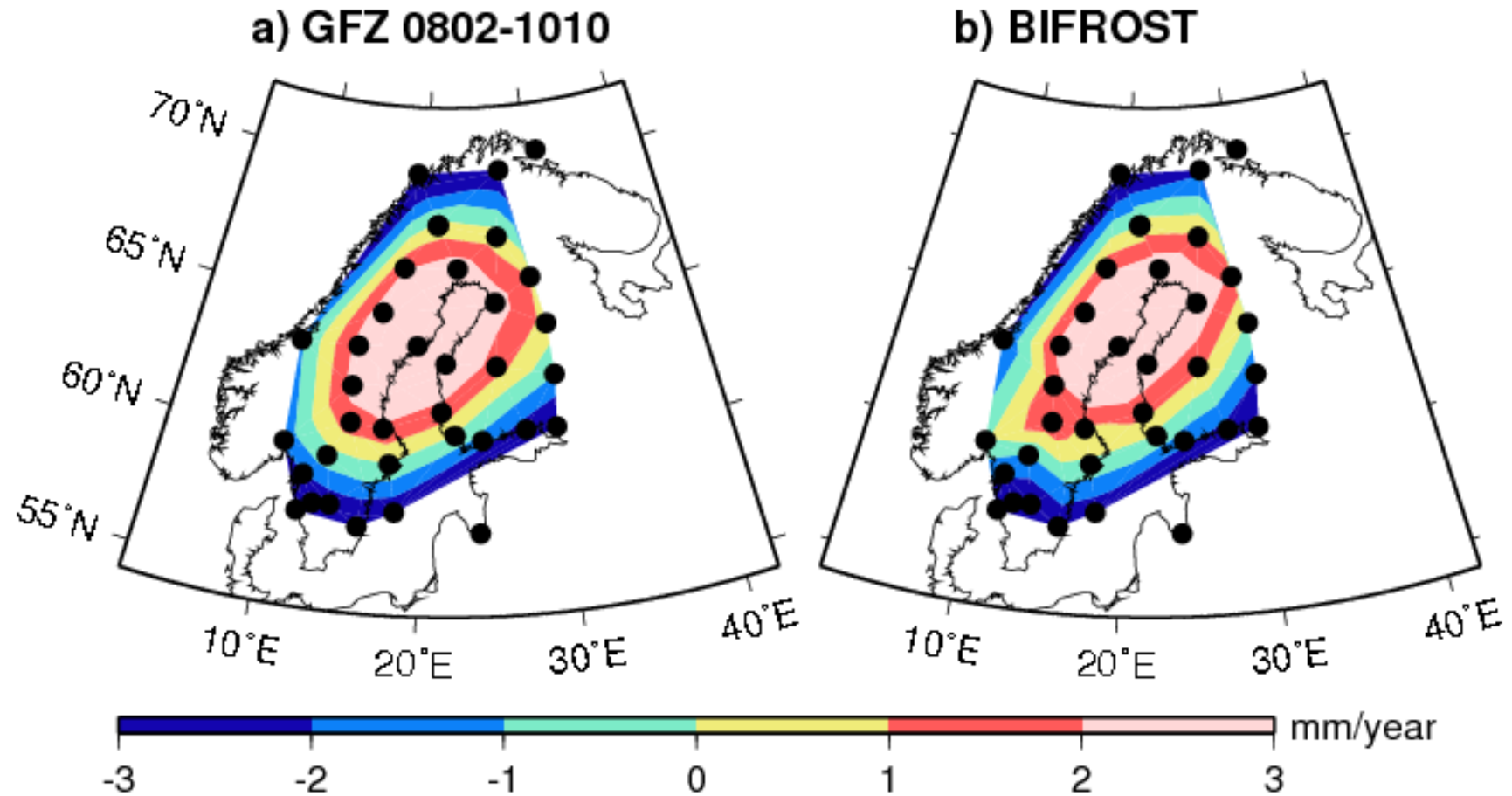
SOLUTIONS?

Solutions: Benchmark



From: Giorgio Spada

Solutions: Data



Van der Wal et al. (GJI 2011)

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

Funded by TOPO-EUROPE, a EUROCORES project from
the European Science Foundation

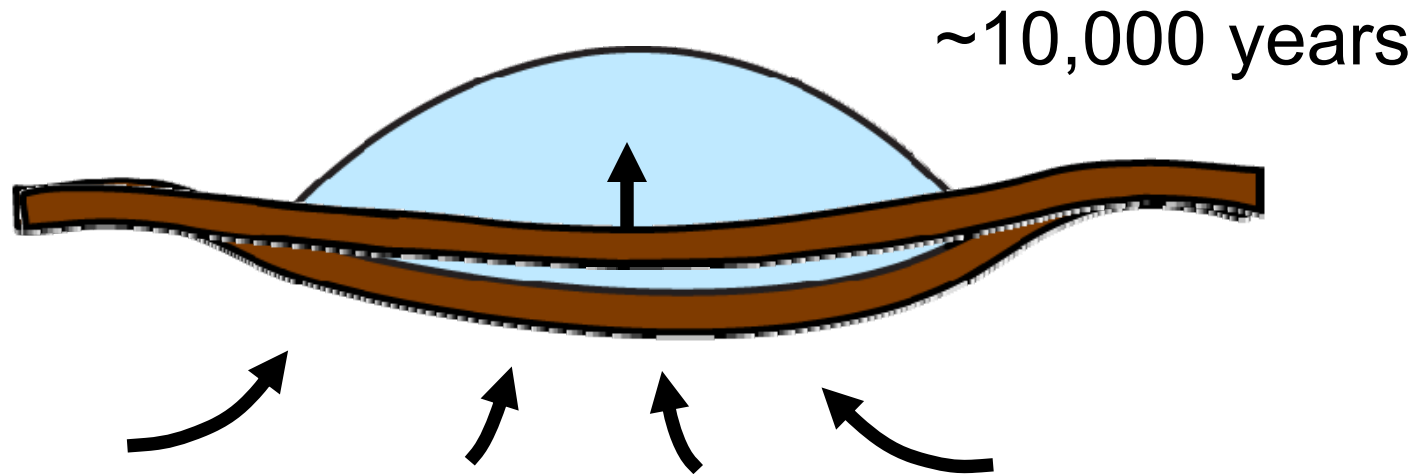
With support by COST Action ES0701 "Improved constraints
on models of Glacial Isostatic Adjustment"



BACKUP SLIDES

Glacial Isostatic Adjustment (GIA)

rising



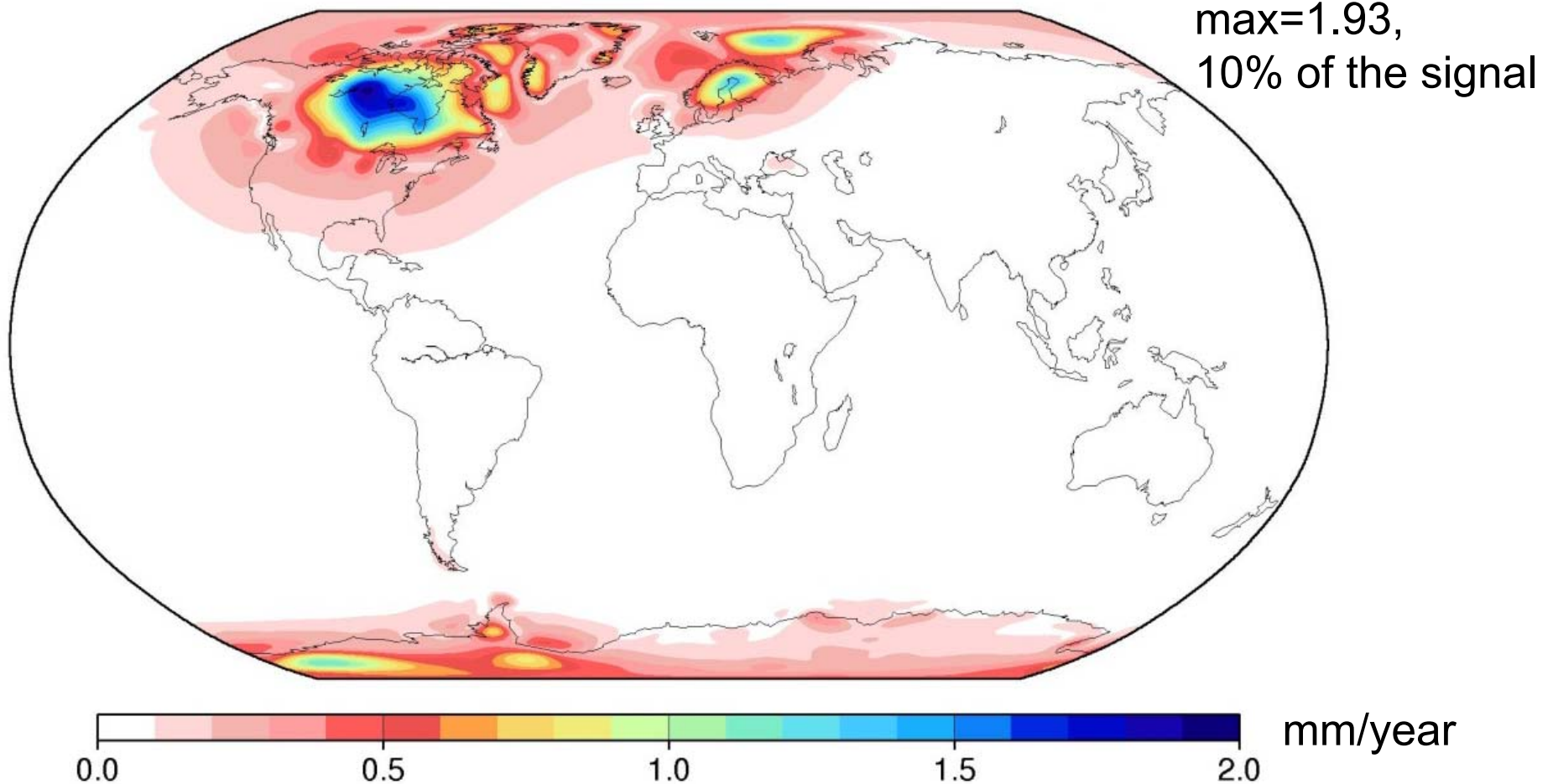
Flow in the mantle determined by viscosity

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

Uncertainty propagation: Earth model

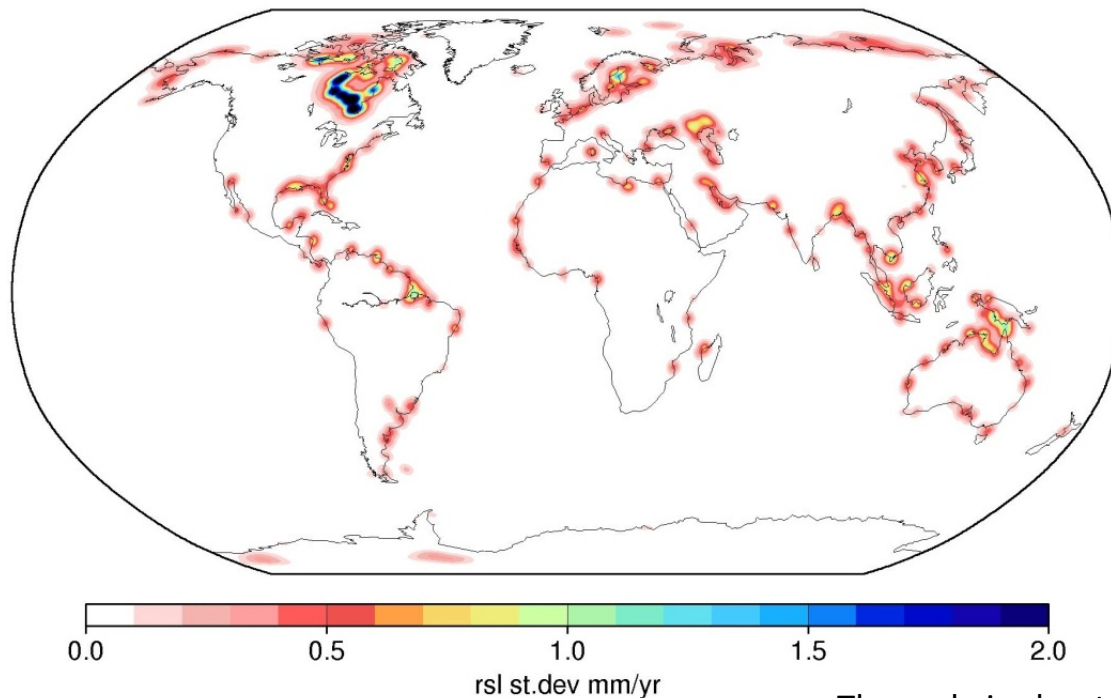
Standard deviation



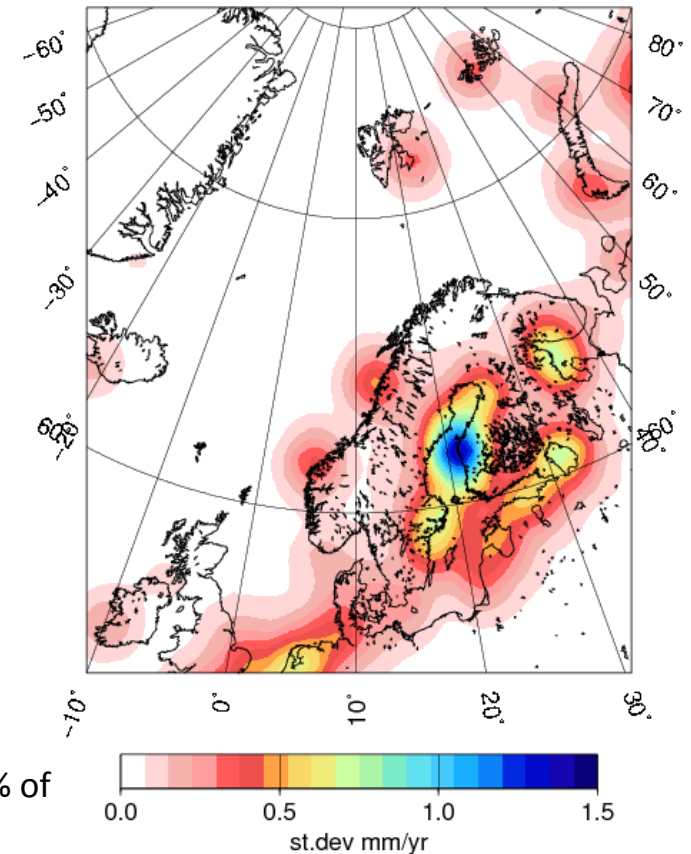
Variation of Lithospheric thickness ± 5 km, Density $\pm 5\%$, $V_s \pm 5\%$, and viscosity by ± 0.05 in Log10 scale

Propagation of Ocean Function uncertainties

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

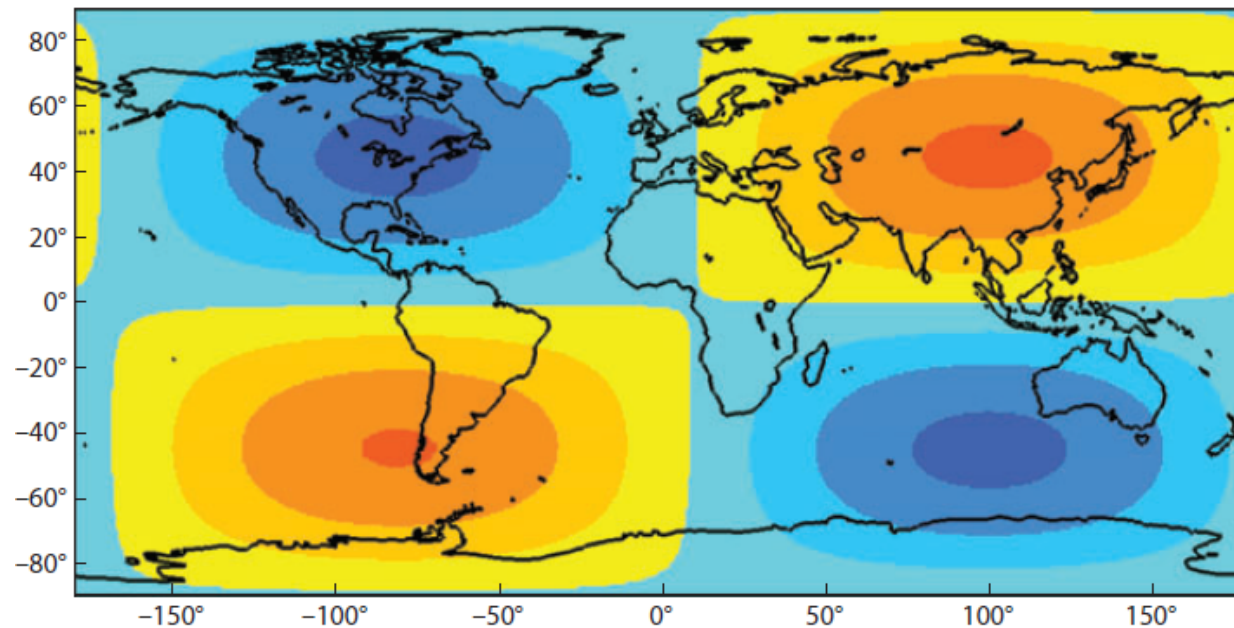


The scale is about 15% of the whole signal.



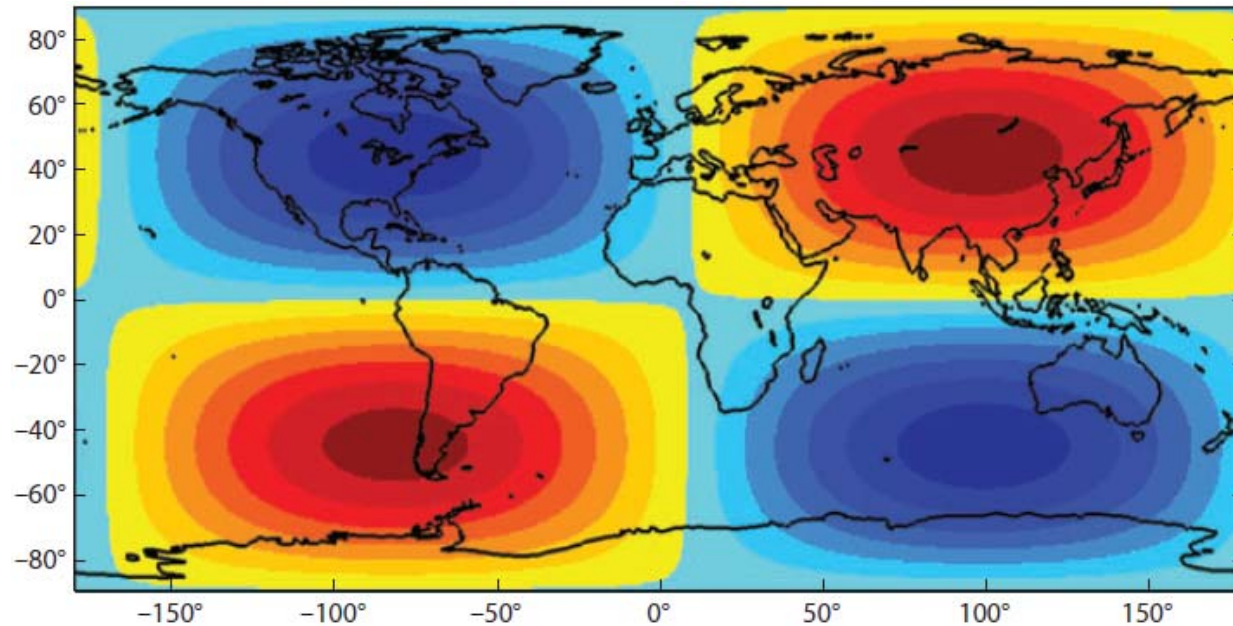
O2: Variation of $\pm 10\%$ of the paleotopography $T(t, \omega)$ for each time t and only in locations (ω) within a belt following the shorelines. From the paleotopography then we compute the ocean function $FO(t)$ by setting $FO = 1$ where the paleotopography is negative, and $FO = 0$ otherwise.

Uncertainty propagation: rotational feedback



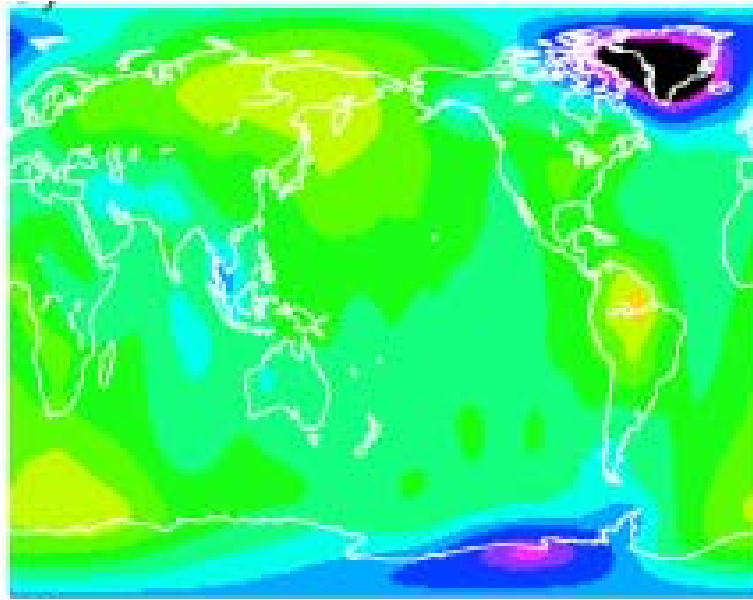
Mitrovica & Wahr, Ann. Rev. Earth Planet. Sci. (2011)

Uncertainty propagation: rotational feedback

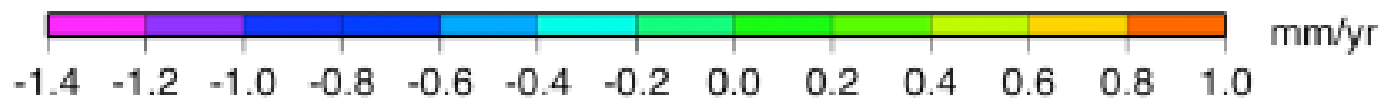
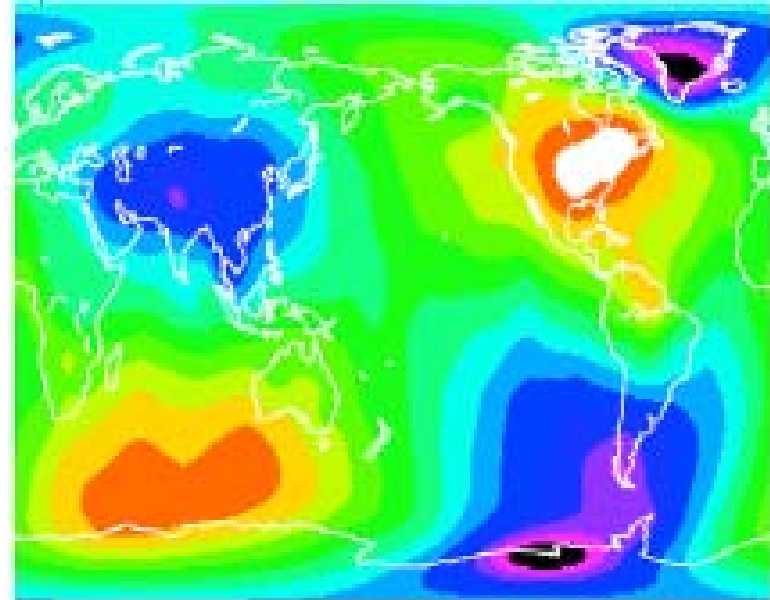


Uncertainty: rotational feedback

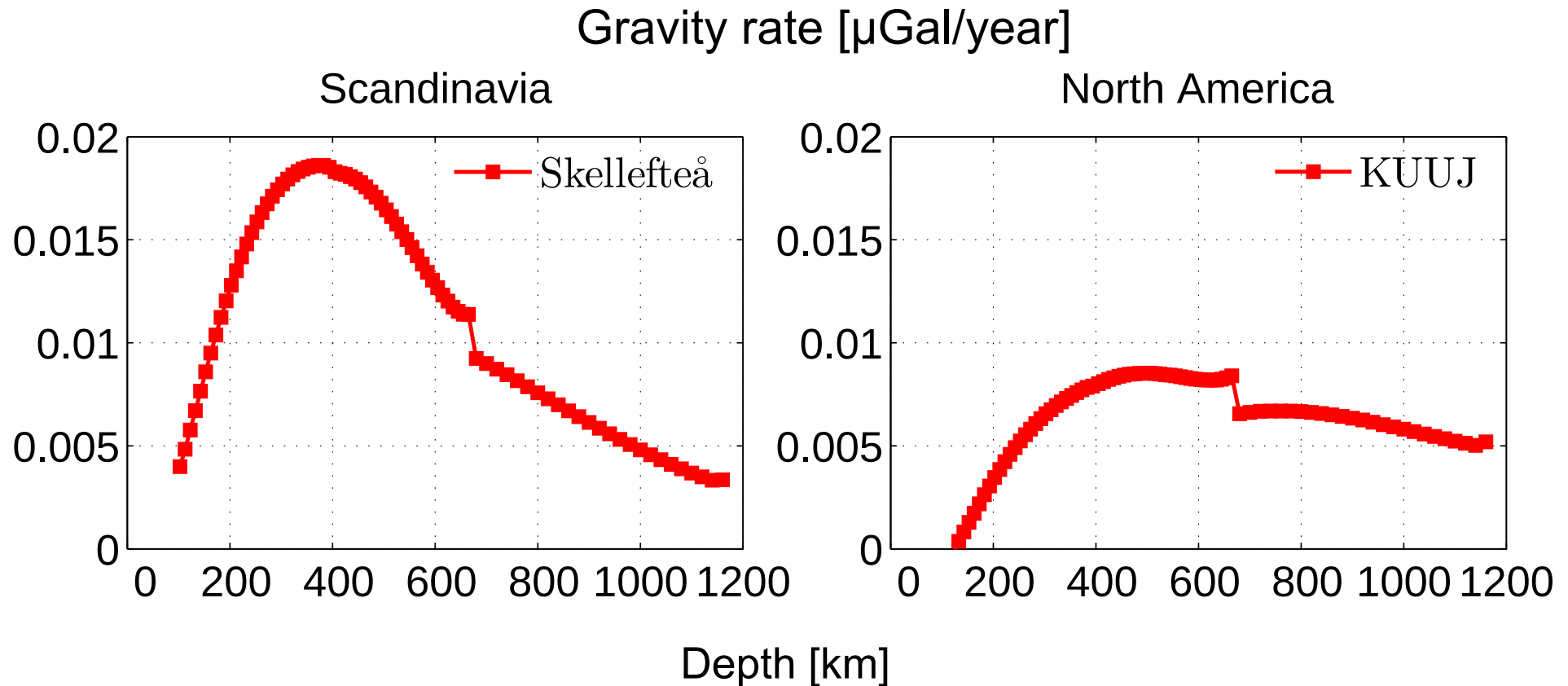
GRACE – Paulson et al (2007)



GRACE – Peltier (2004)

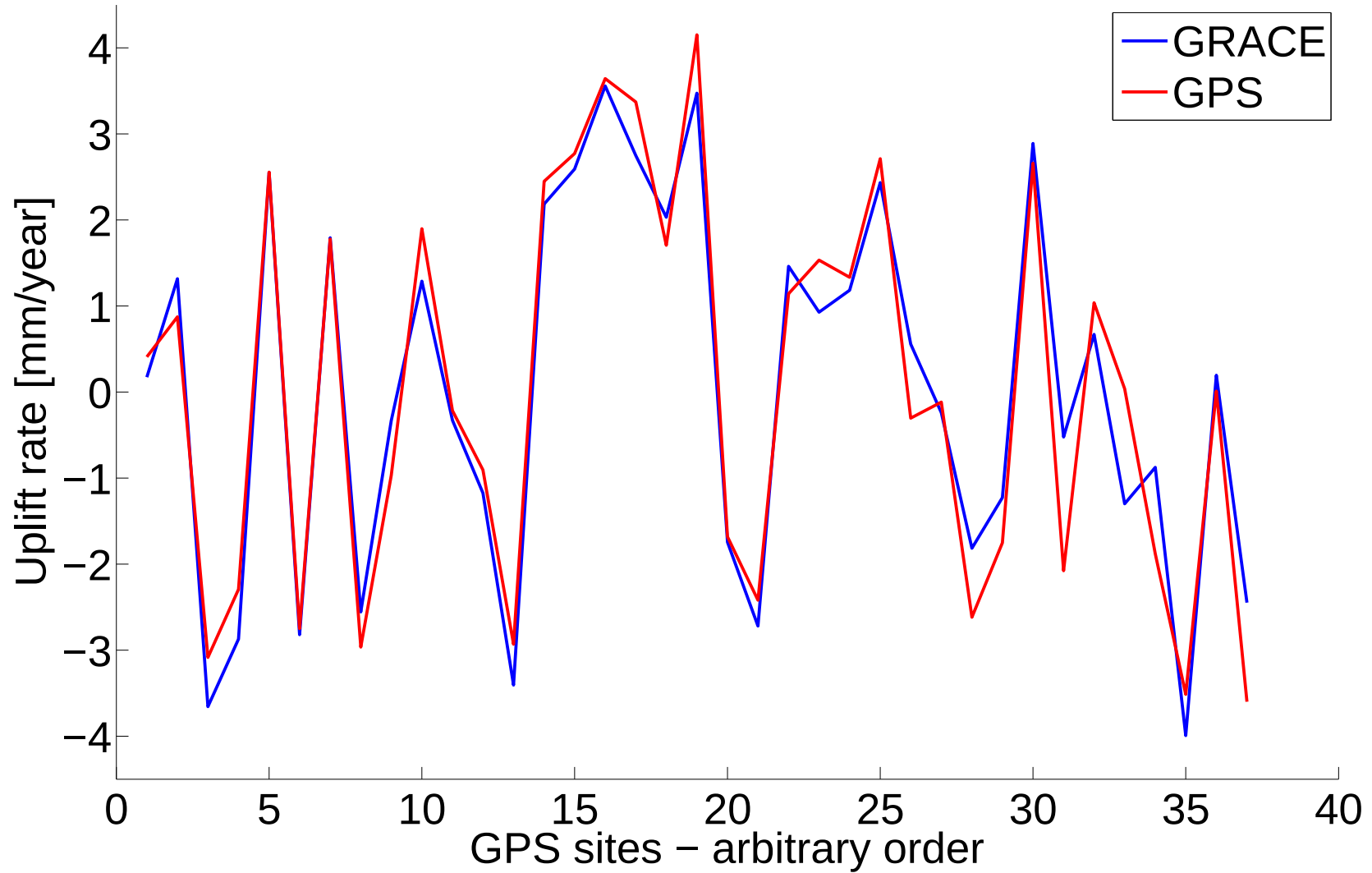


Sensitivity kernels

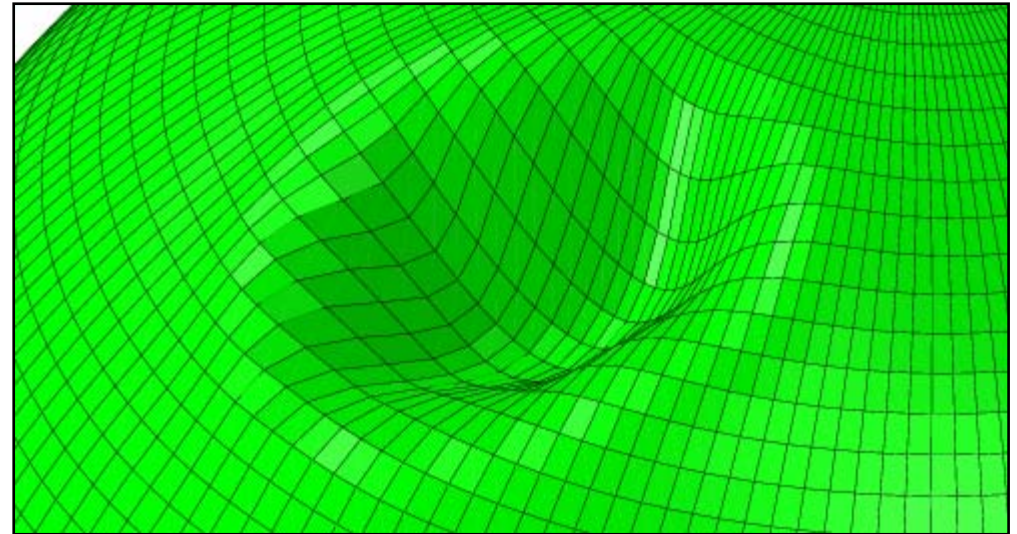
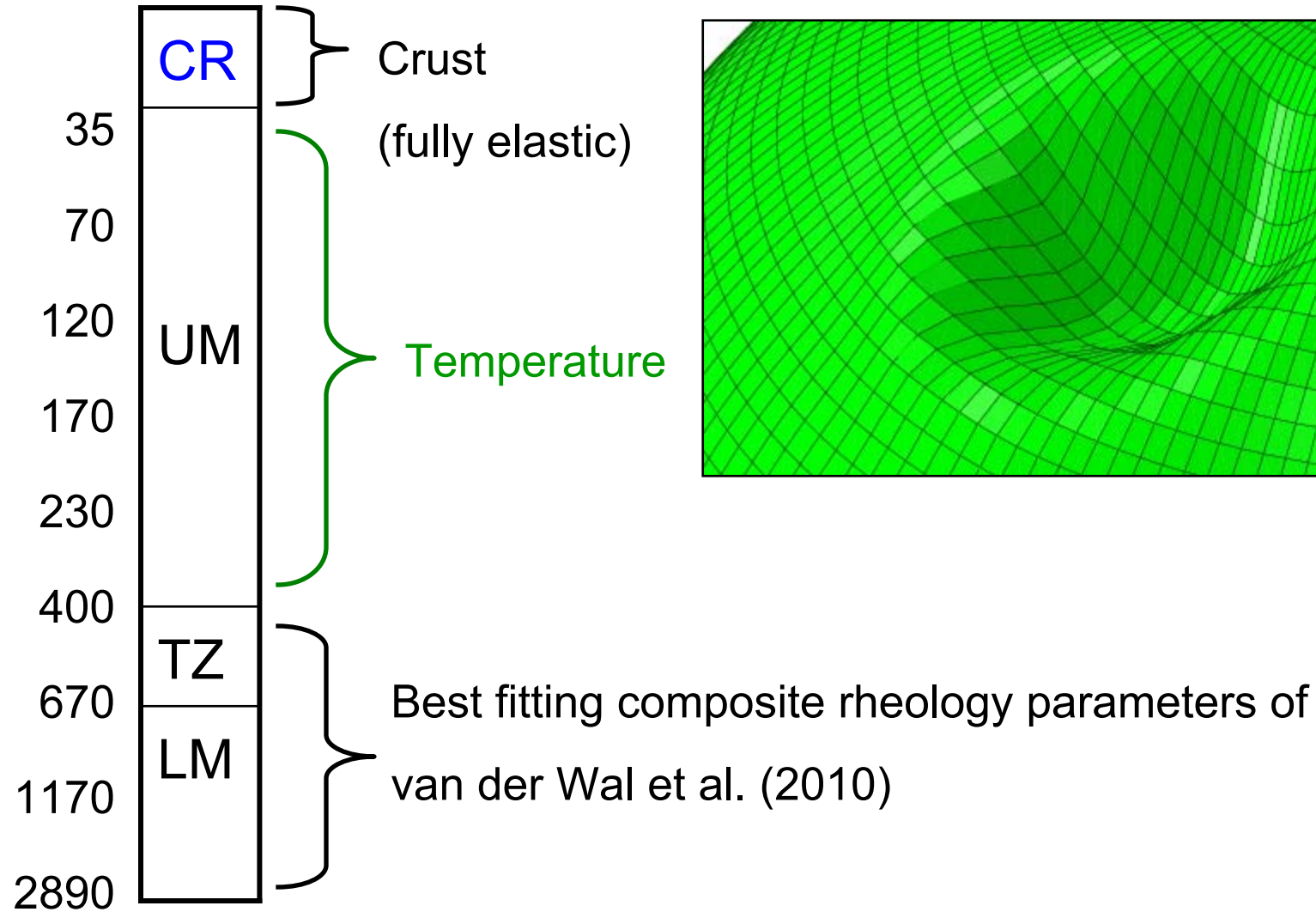


Gravity rate (uplift rate) in North America is more sensitive to the lower mantle viscosity

After scaling



Model



Model

Hirth & Kohlstedt (2003)

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

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)

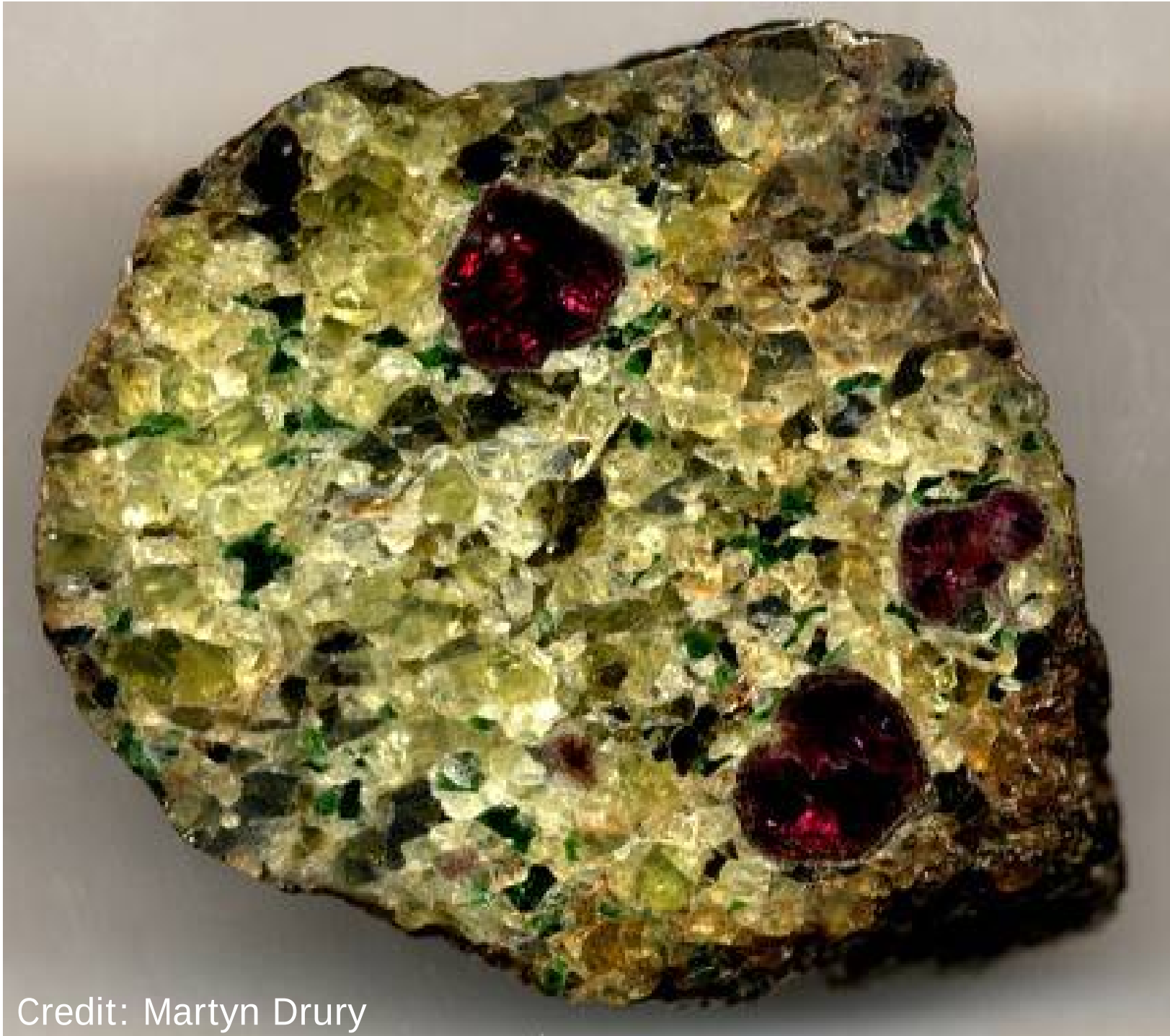
E activation energy

P pressure

V activation volume

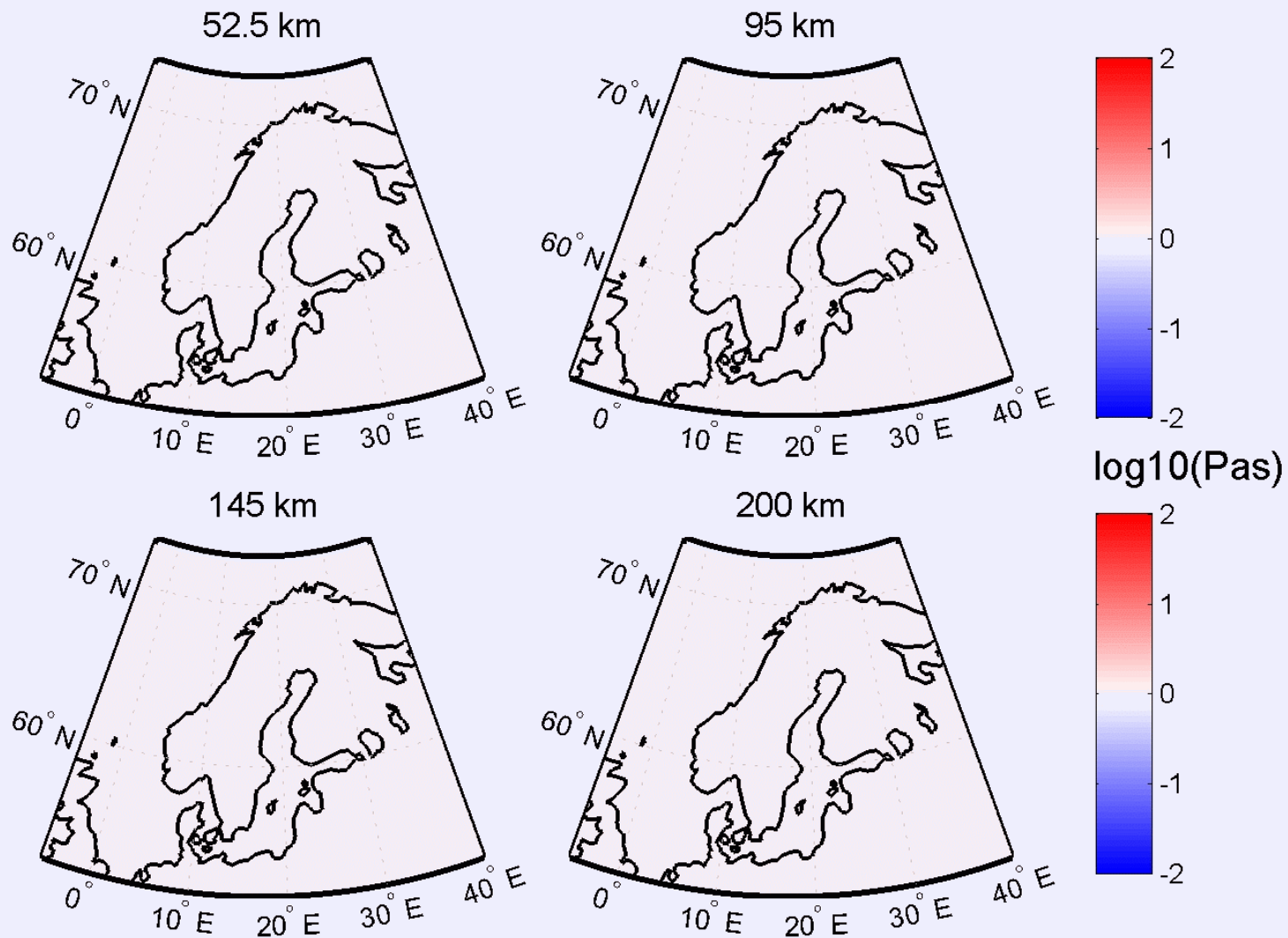
T temperature

R gas constant



Credit: Martyn Drury

30 ka B.P.



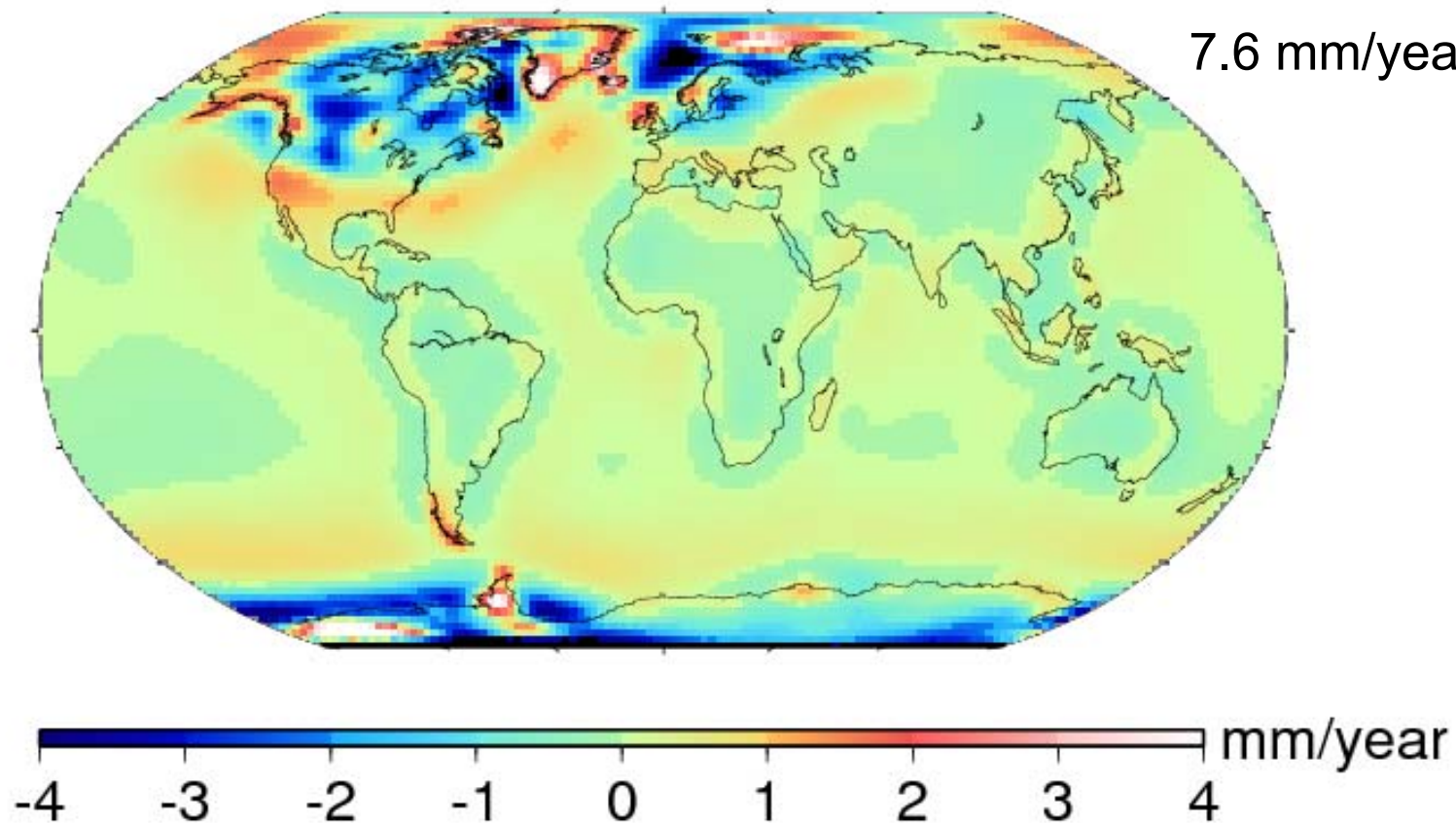
Barnhoorn, van der Wal, Drury, Vermeersen (G-cubed 2011)

Uncertainty: 3D temperature

Temperature II – Temperature I

Max.

7.6 mm/year



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