GIA model with non-linear 3D Earth rheology and plastic ice model for Scandinavia

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  (temperature, grain size, ice model)
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Introduction composite rheology

Hirth & Kohlstedt (2003) flow law for olivine

$$\dot{\varepsilon} = A_D \sigma^n d^{-p} f H_2O^r \exp(\alpha\phi) \exp\left(-\frac{E + pV}{RT}\right)$$

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

S_{ij} *deviatoric stress tensor*

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

n *stress exponent (3.5)*

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Introduction composite rheology

GIA models can constrain upper and lower mantle viscosity

GIA models can explain most observations

Why adding more parameters?

GIA viscosity is an average over:

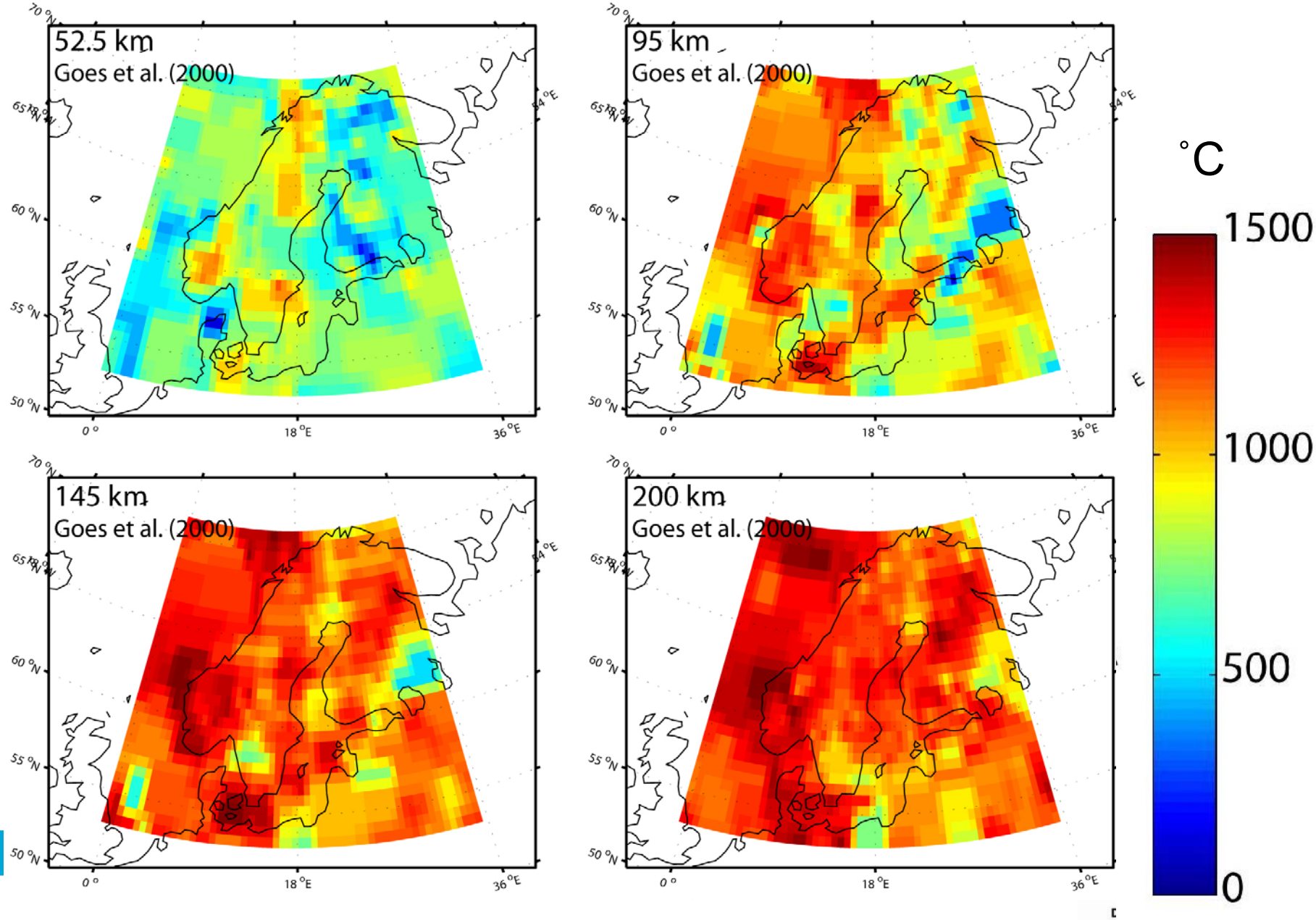
- depth regime (*upper mantle*)
- time (*glacial cycle*)
- deformation process (*diffusion creep*)
- area (*Scandinavia*)

→ a GIA lithosphere is not the same as a seismic lithosphere

Composite rheology can provide better fit to sea-level data

(*Van der Wal et al. 2010*)

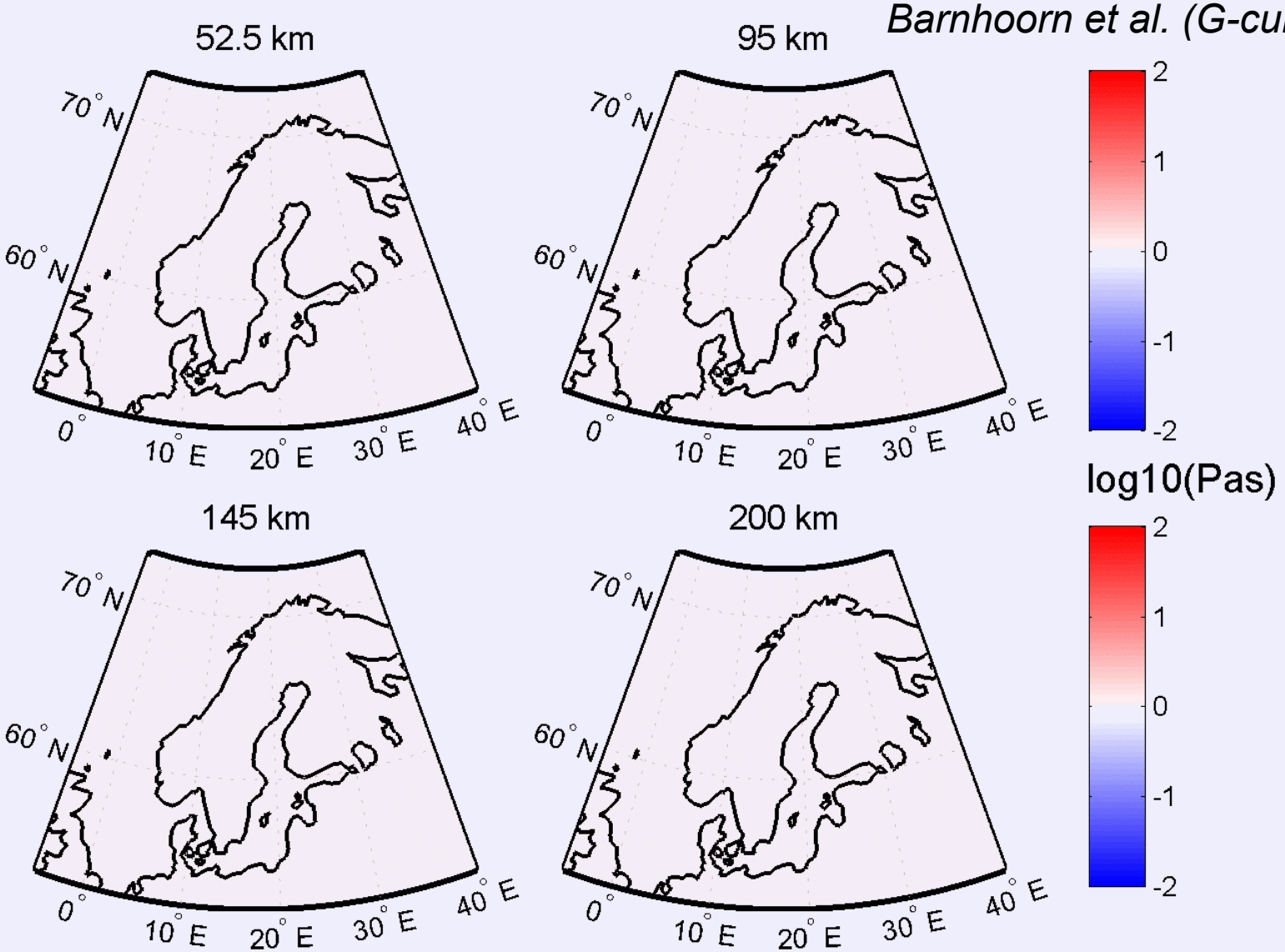
Global Temperature 1



Time-dependent viscosity

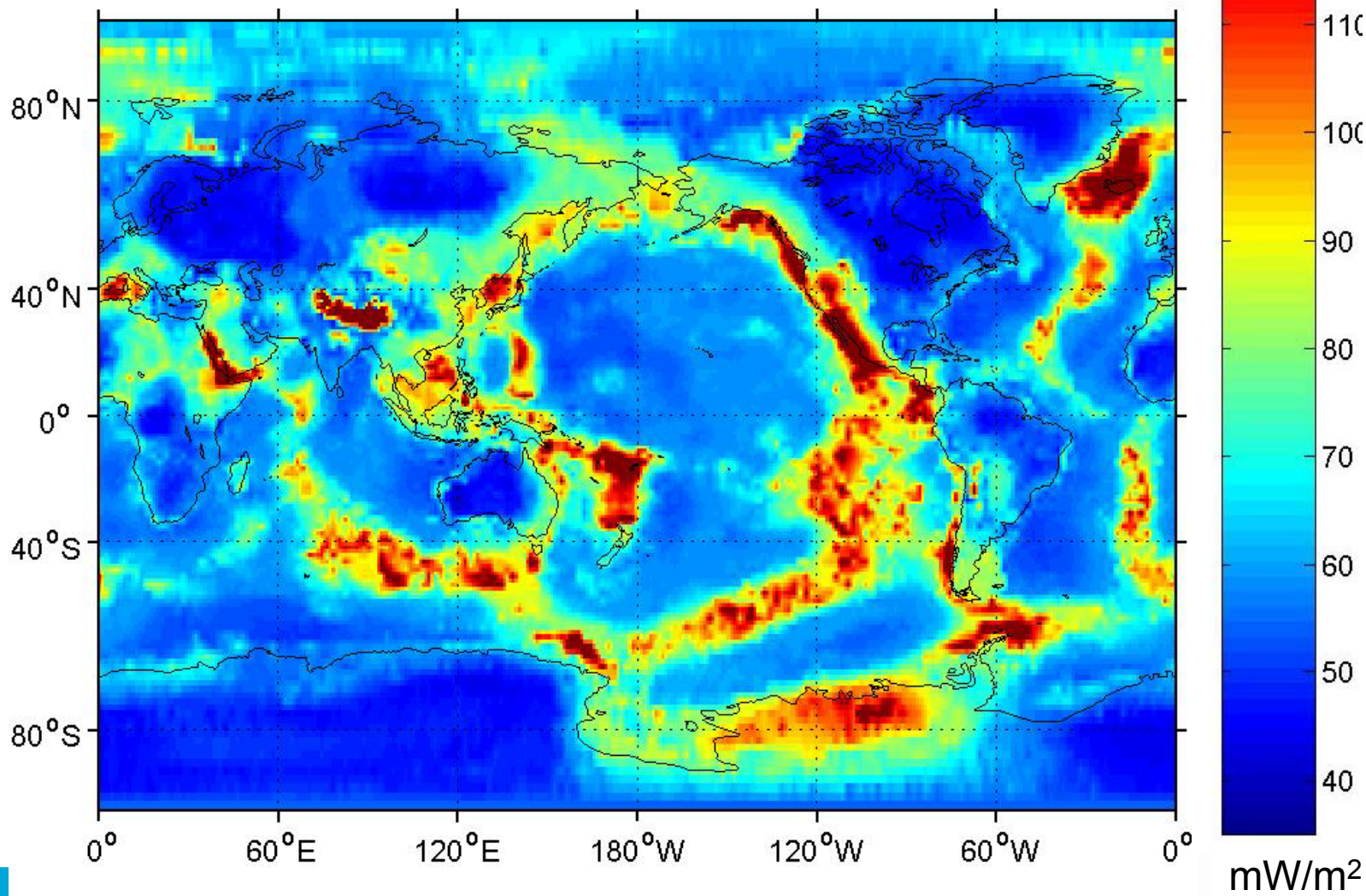
Effective viscosity change wrt 30,000 yrs before present (wet/10 mm)

Barnhoorn et al. (G-cubed, 2011)



Global Temperature 2

Global heat flow from Shapiro and Ritzwoller (2004)



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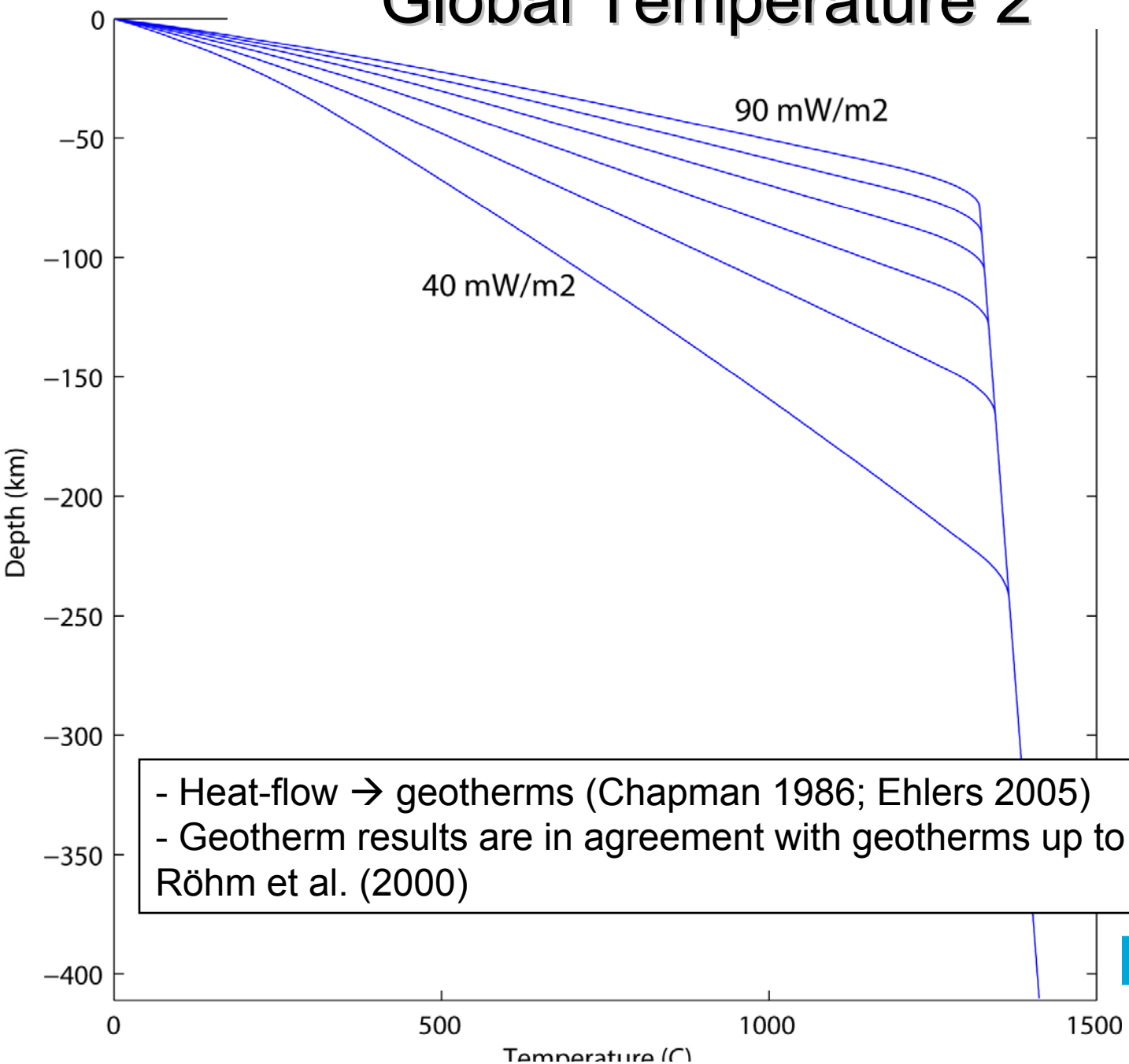
Global Temperature 2



- Heat-flow → geotherms (Chapman 1986; Ehlers 2005)
- Geotherm results are in agreement with geotherms up to 300 km depth of Röhm et al. (2000)

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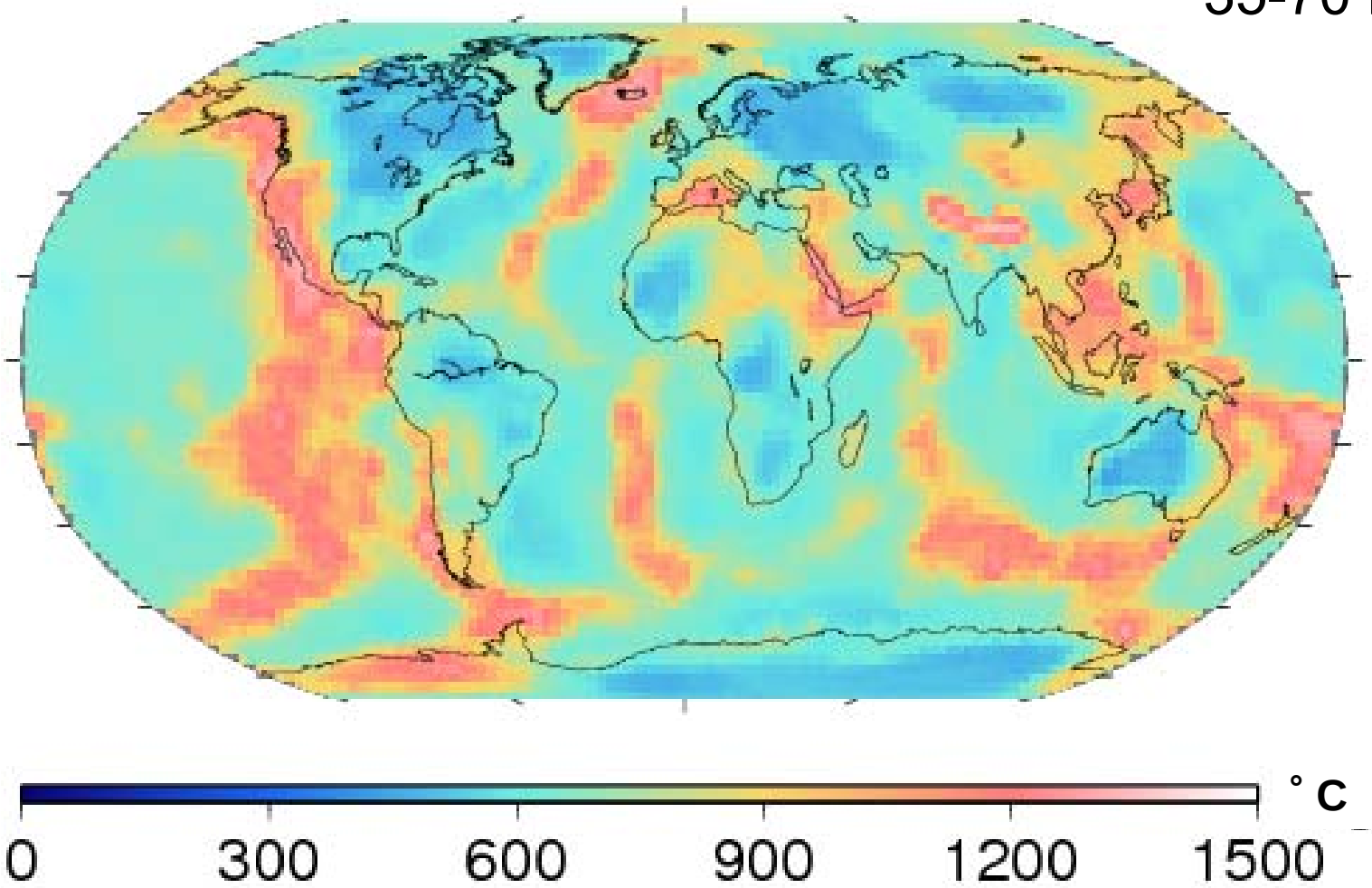
Global Temperature 2

35-70 km



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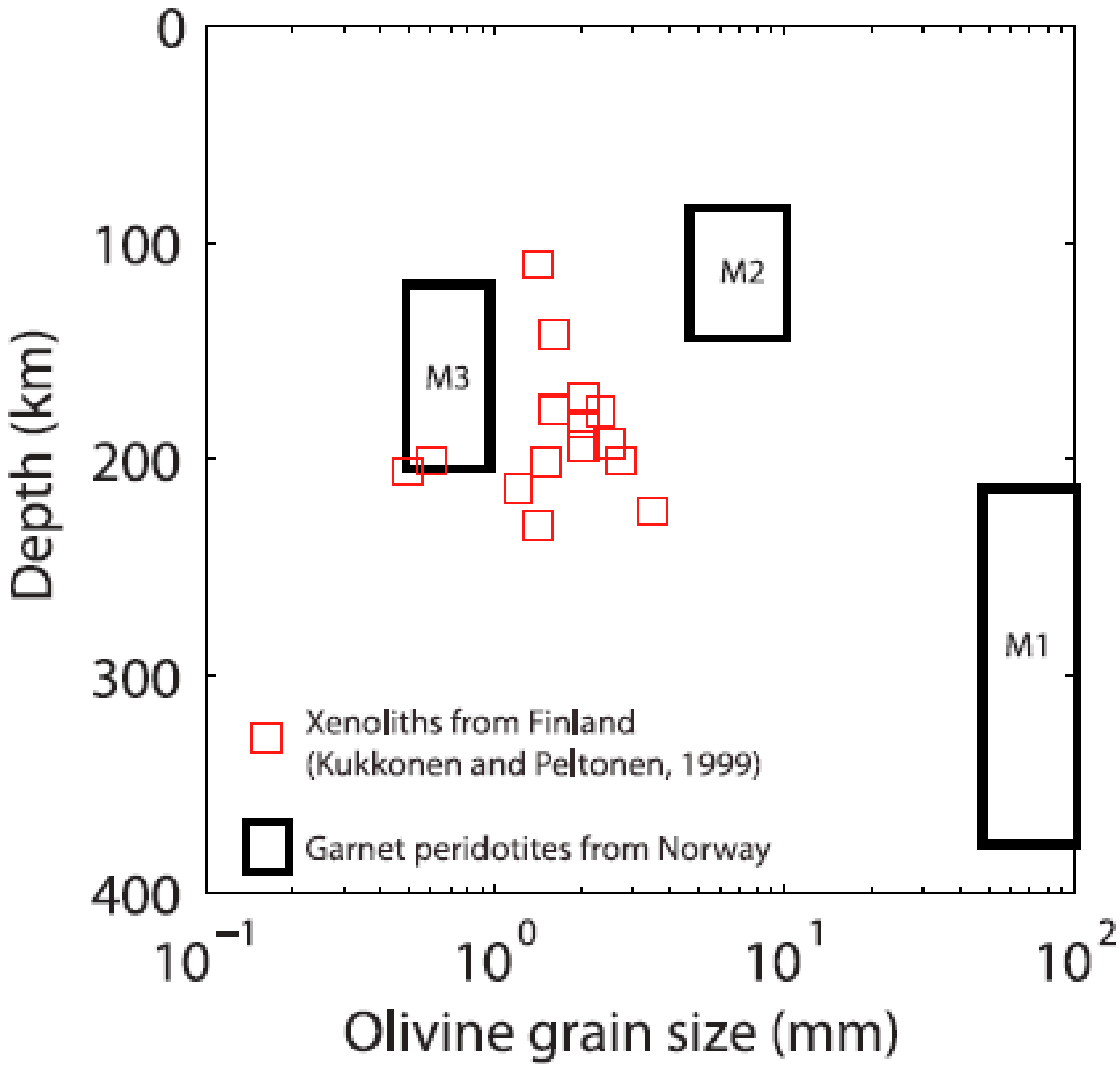
Grain Size



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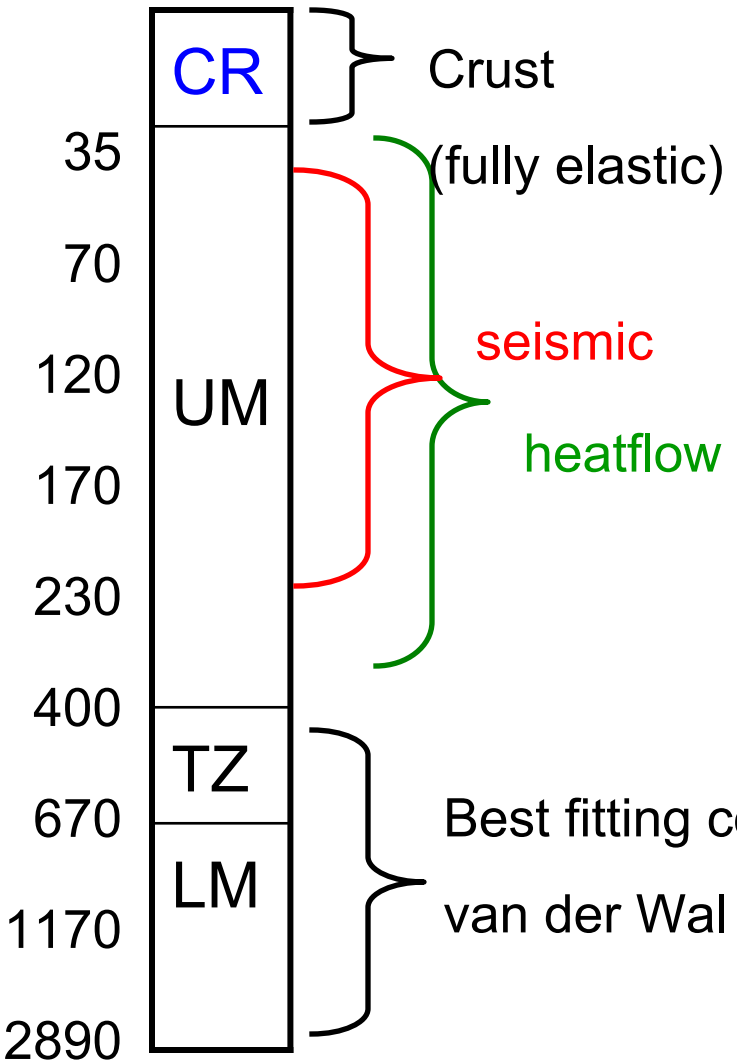
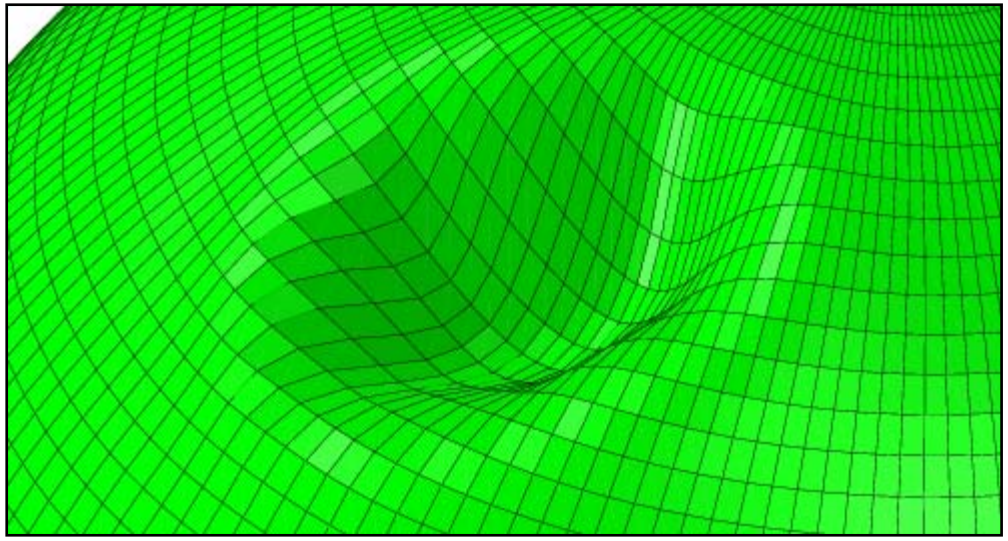
Model





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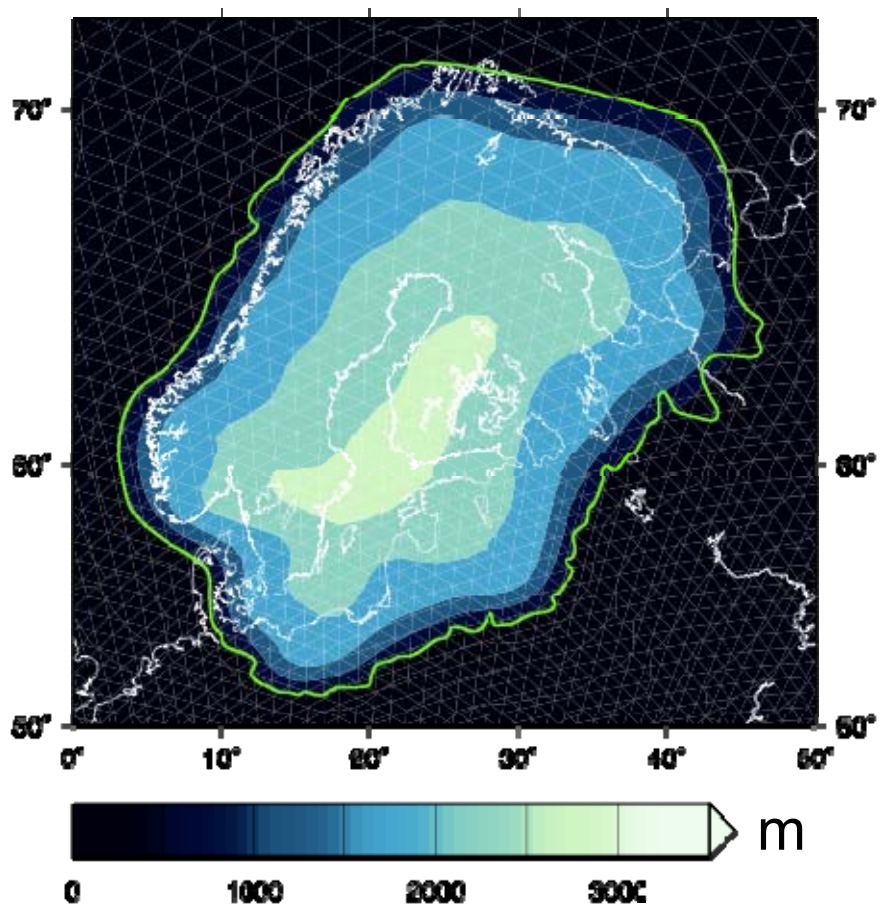
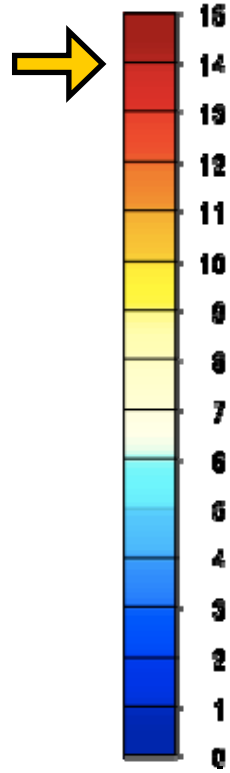
21 ka BP


70°
60°
50°
0°
10°
20°
30°
40°
50°
m
0
1000
2000
3000


ESL (m)
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0

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Results: sea-levels

$$\chi^2 = \frac{1}{M}\sum_{n=1}^{M}\left(\frac{\zeta_{observed} - \zeta_{predicted}}{\sigma}\right)^2$$

sites in Northern Europe from Tushingham and Peltier (1992)

plastic	**47**	**45**	**1 mm**
	61	**56**	**4 mm**
	dry	wet	

plastic	**222**	**98**
viscoplastic	**288**	**144**
	dry	wet

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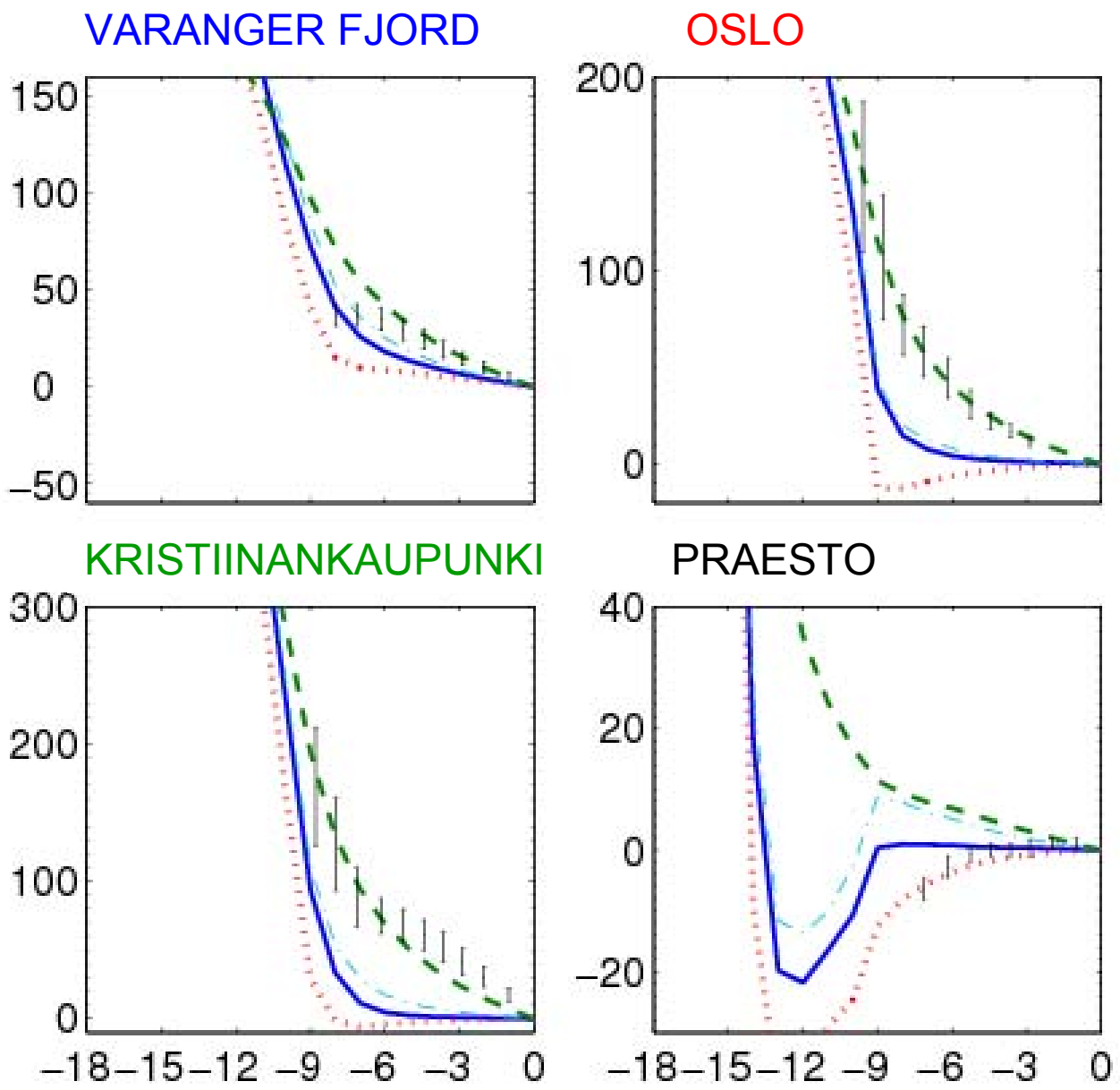
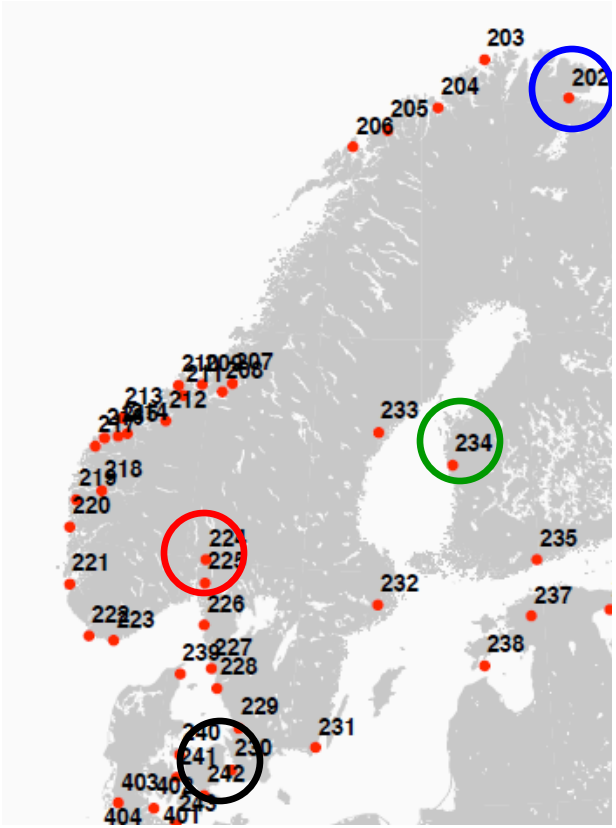
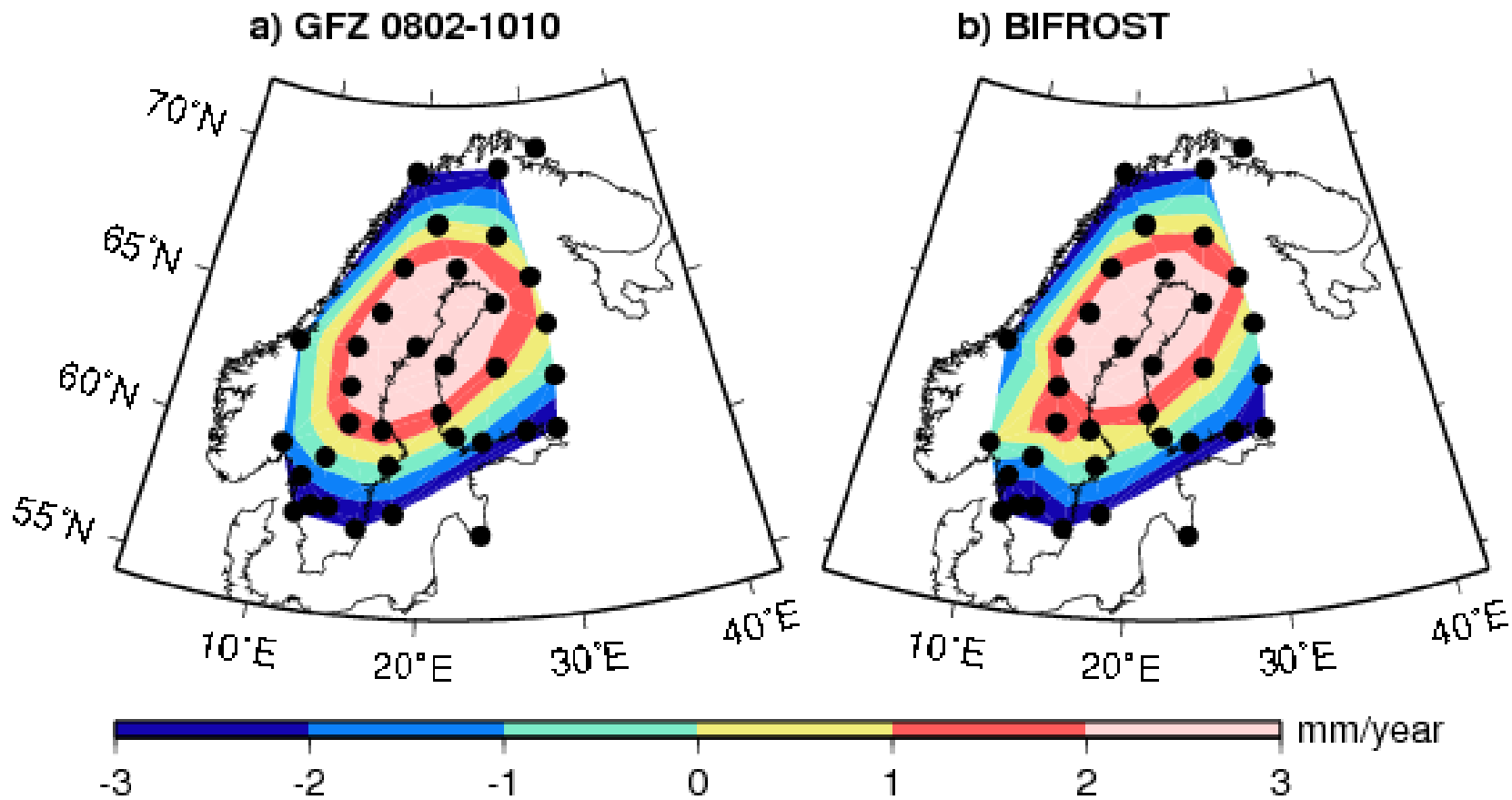




Dry – 1mm Dry – 4mm Wet – 1 mm Wet – 4mm

Gravity rate from GRACE



GRACE converted to uplift rate (Wahr et al. 2000) scaled up to account for smoothing

Uncertainty of this procedure: 0.63 mm/year

(*van der Wal et al., submitted*)

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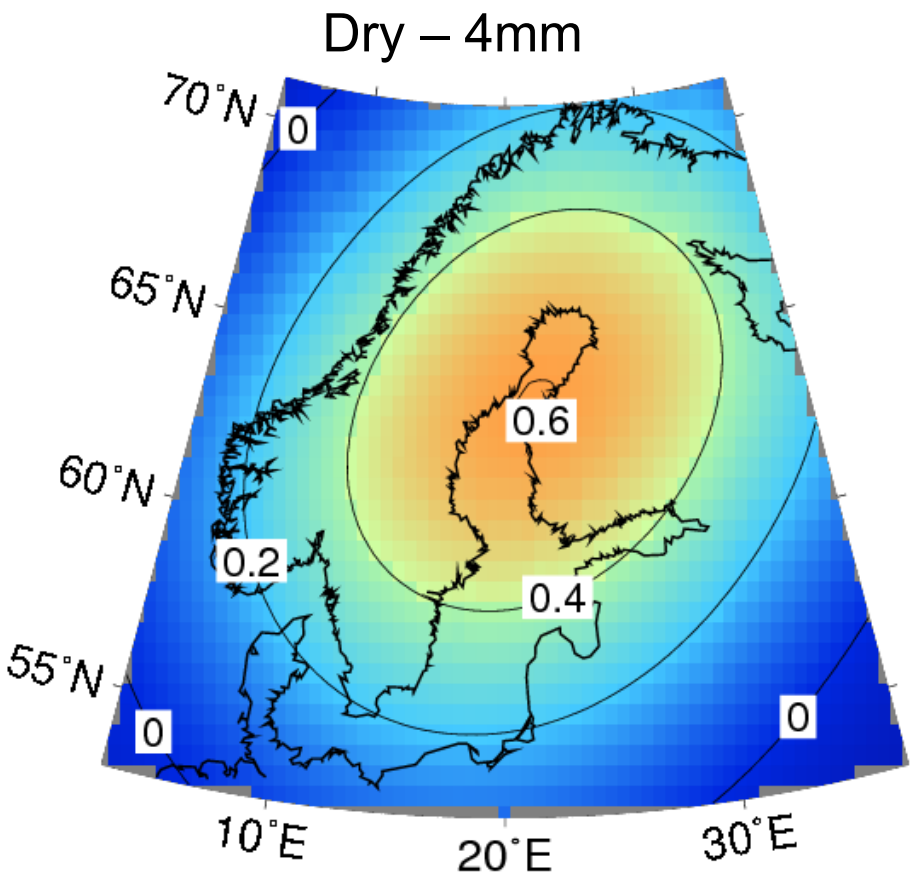
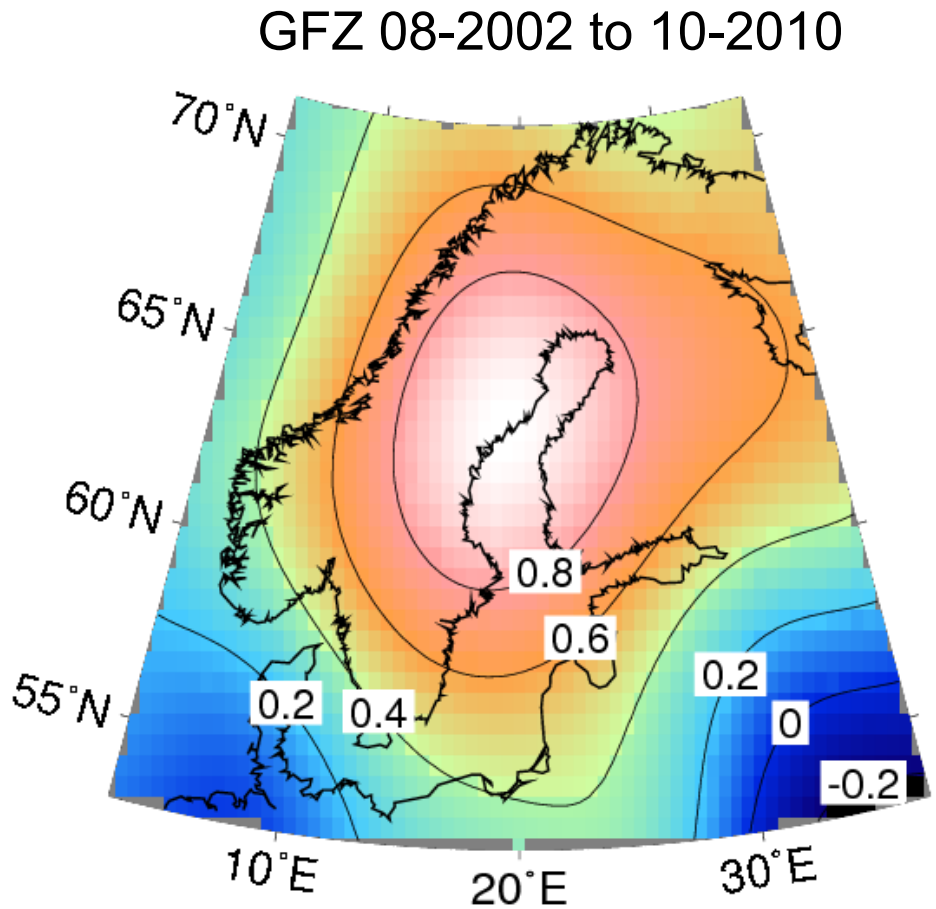
Gravity Anomaly Rate





Maximum = 0.60 μGal/year

Max 1.00 μGal/year

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Summary

- Ice model based on morraines and climatology
- Rheology: parameters derived from olivine flow laws, xenoliths, and heatflow data

  (non-linear & laterally varying)
- Good fit at some sea level sites, not so good at others (ice model; lateral inhomogeneity in grain size or wet/dry?)
- Wet rheology fits best to historic sea level data
- Gravity rate too low, even for dry rheology with 4 mm grain size: 0.6 vs 1.0 μGal/year

Future work

- Other ice sheets
- Moho thickness
- Improvements in sea-level equation

Acknowledgements

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