PAL MOD GERMAN CLIMATE MODELING INITIATIVE

EGU General Assembly

Coupled solid Earth – Antarctic Ice Sheet simulations with VILMA and PISM

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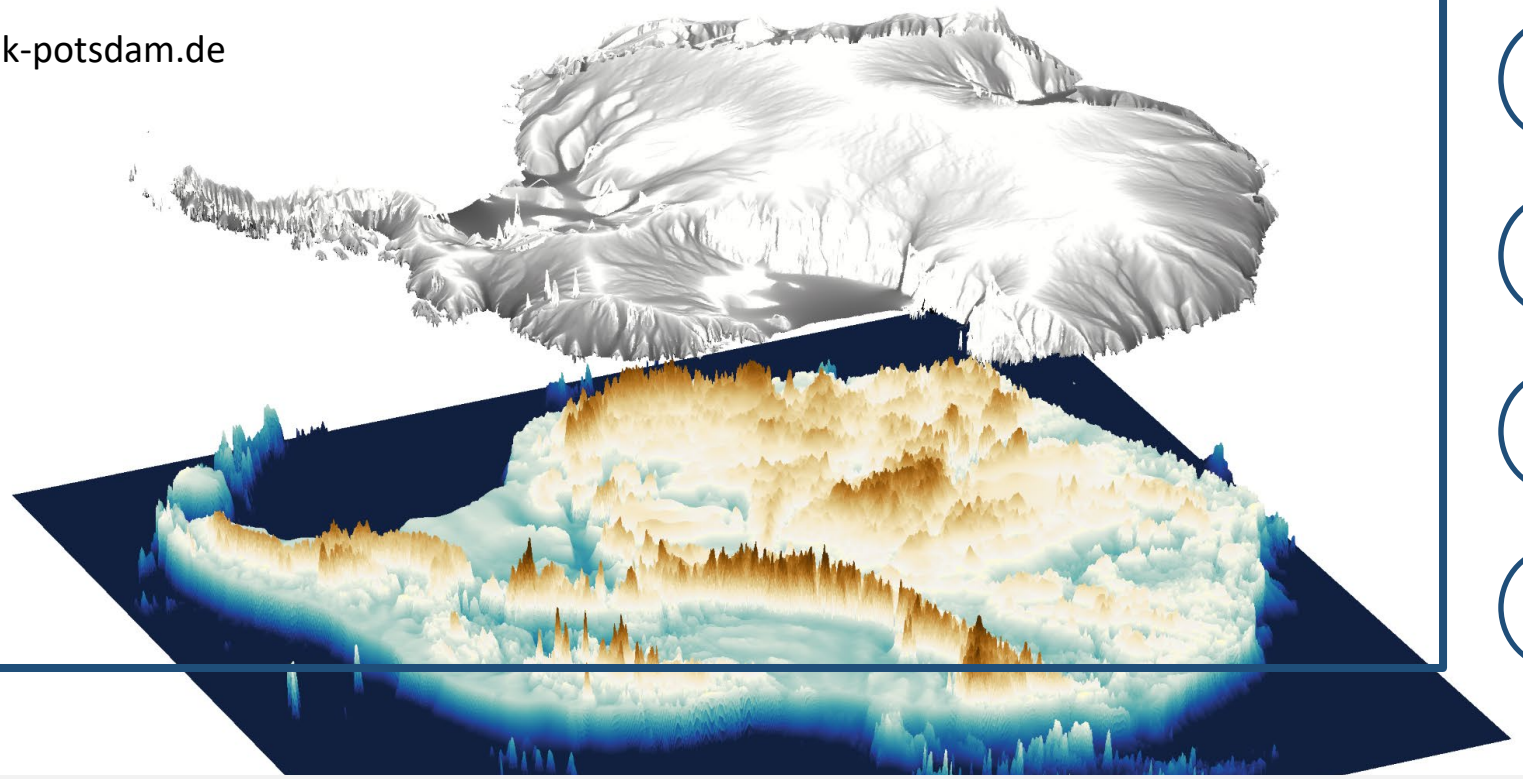

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1 Motivation :

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Part of German Paleo Climate Modeling Initiative **PalMod** II (2019-2022): Simulation of **last glacial cycle** to aim for a better understanding of how slow **feedbacks in the Earth system** operate.

PISM-PICO: Parallel Ice Sheet Model with Potsdam Ice Shelf Cavity Model that accounts for the melt pump in the ice shelf cavities linking ocean and ice *(click to learn more)*

***VILMA**: The global VIscoelastic Lithosphere and MAntle model with 3D Earth structure and gravitationally self-consistent solution for sea-level equation*

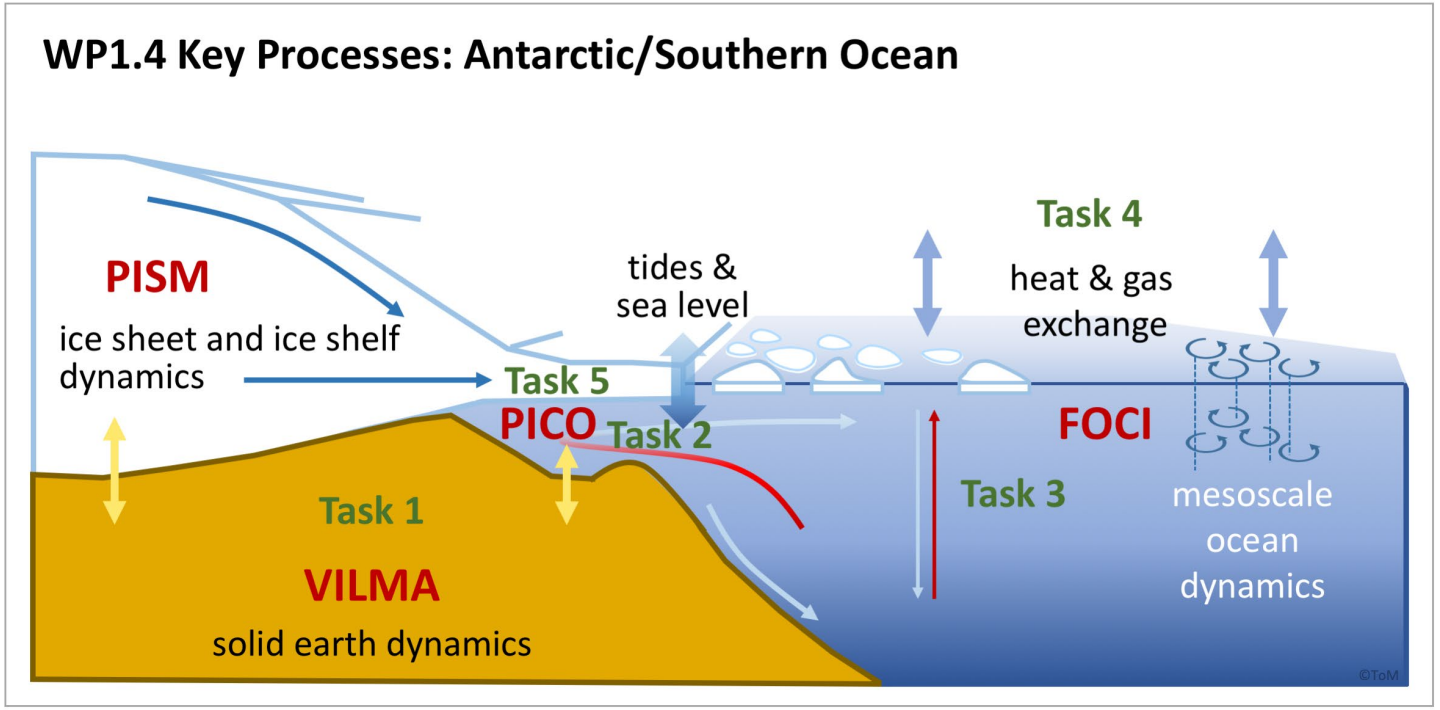

Figure: Key processes of ice, ocean and solid Earth and their interaction as studied in WP1.4 of PalMod II (by T. Martin, Geomar)

Learn more about PalMod

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2 Motivation: variability in mantle viscosity

work in progress

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Antarctic ice-sheet reconstructions and solid Earth rheology are subject to substantial uncertainty and debate

Collaboration with Meike Bagge and Volker Klemann (GFZ) within PalMod context to infer for **3D reference rheology of mantle**

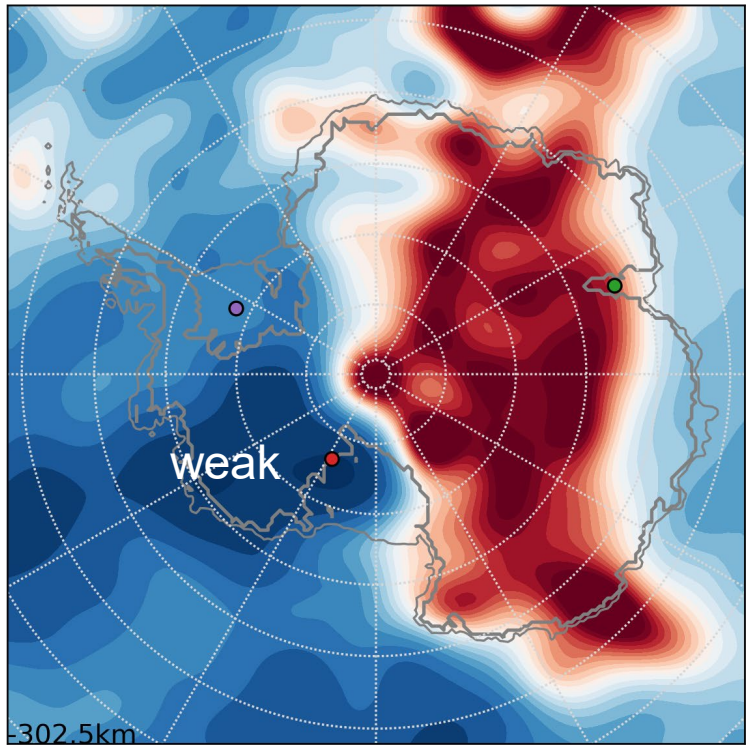

Figure: 3D mantle vicositiy at 300 km depth underneath Antarctica

→ weak Earth structure in West Antarctica may imply higher grounding line stability

→ Variation in mantle viscosity by one or two orders of magnitude can alter the characteristic response time by one or two orders of magnitude (from millenia to decades)

see EGU21-13479 by Meike Bagge

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3 Spin-up

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→ iterative convergence in relative sea-level (reduce misfit to present-day observed bed topography)

Step 1: PISM standalone Antarctica:
2 x 2 glacial cycles (246ka) on 16km resolution with Lingle Clark bed deformation module

Step 2: VILMA standalone global:
3.5 x 2 glacial cycles on n128 Gaussian grid with 1D mantle viscosity profiles or 3D (x1000)

Step 3: PISM-VILMA offline coupled:
4 x 1 glacial cycle with 100 yr coupling time step using python calling CDO and NCO subprocesses

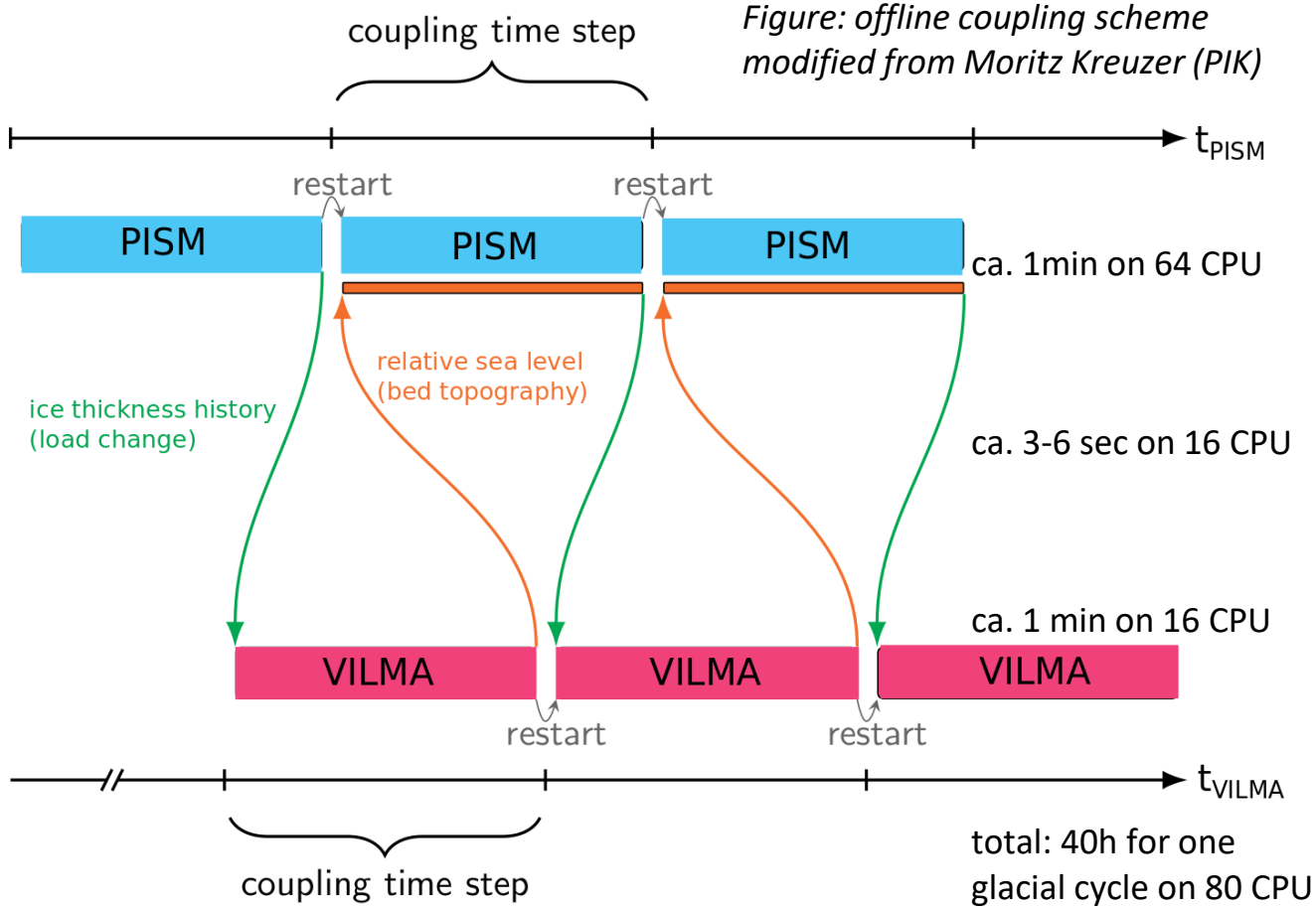

Figure: offline coupling scheme modified from Moritz Kreuzer (PIK)

All simulations were done with the Parallel Ice Sheet Model:

PISM (website)

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4 Variation in 1D mantle viscosity

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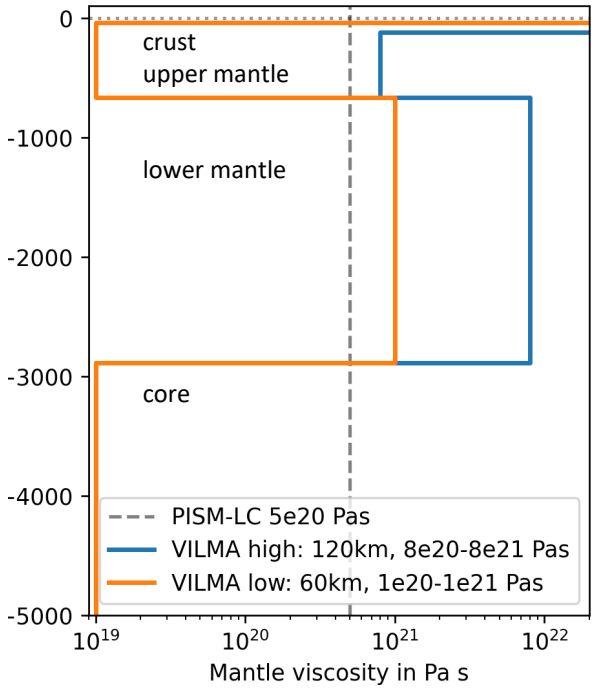
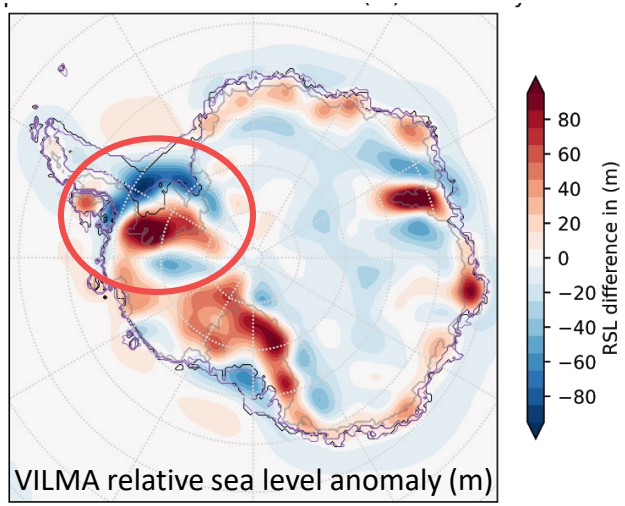
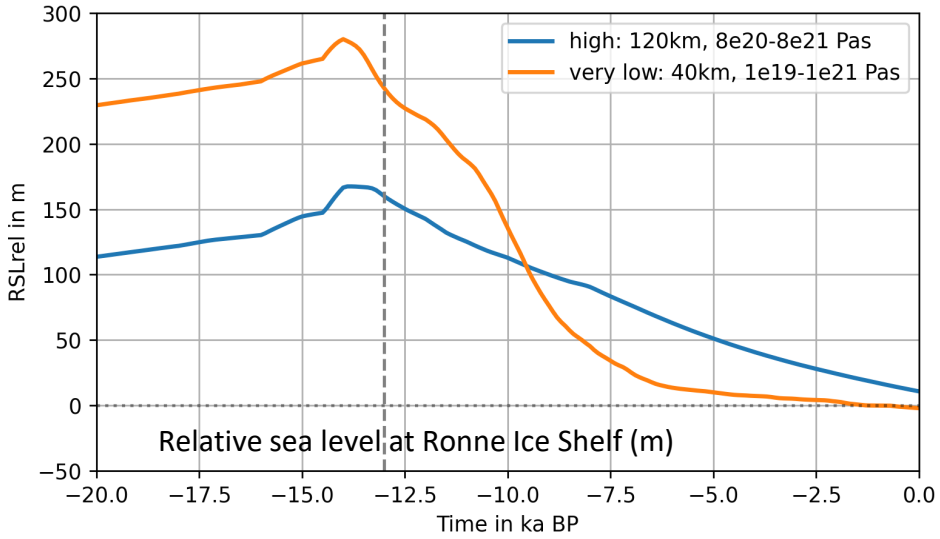
Figure: Variation in vertical mantle viscosity



*Figures: Difference in VILMA relative sea level (RSL) at **onset of deglaciation** 13 ka BP: low viscosity (orange) - high viscosity (blue) and RSL evolution at Ronne Ice Shelf (right)*





→ 100m deeper bed depression at Glacial Maximum for weaker viscosity in large marine basins of Ross, Ronne-Filchner and Amery (red shades)

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5 Variation in 1D mantle viscosity

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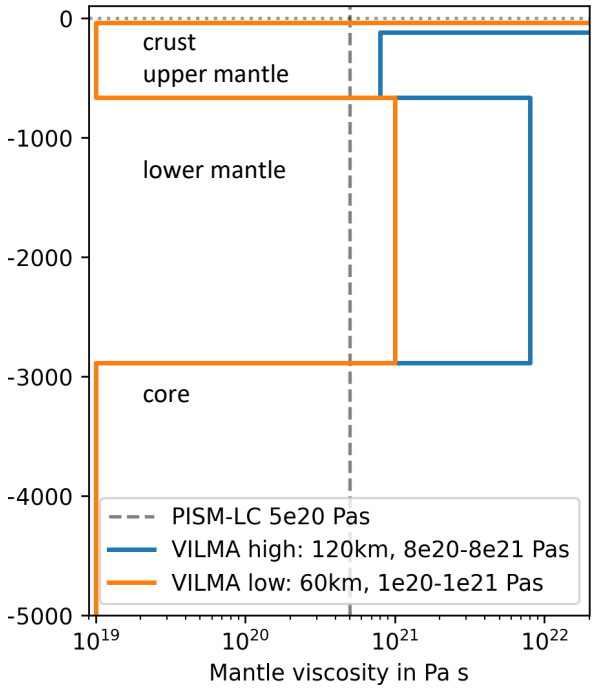
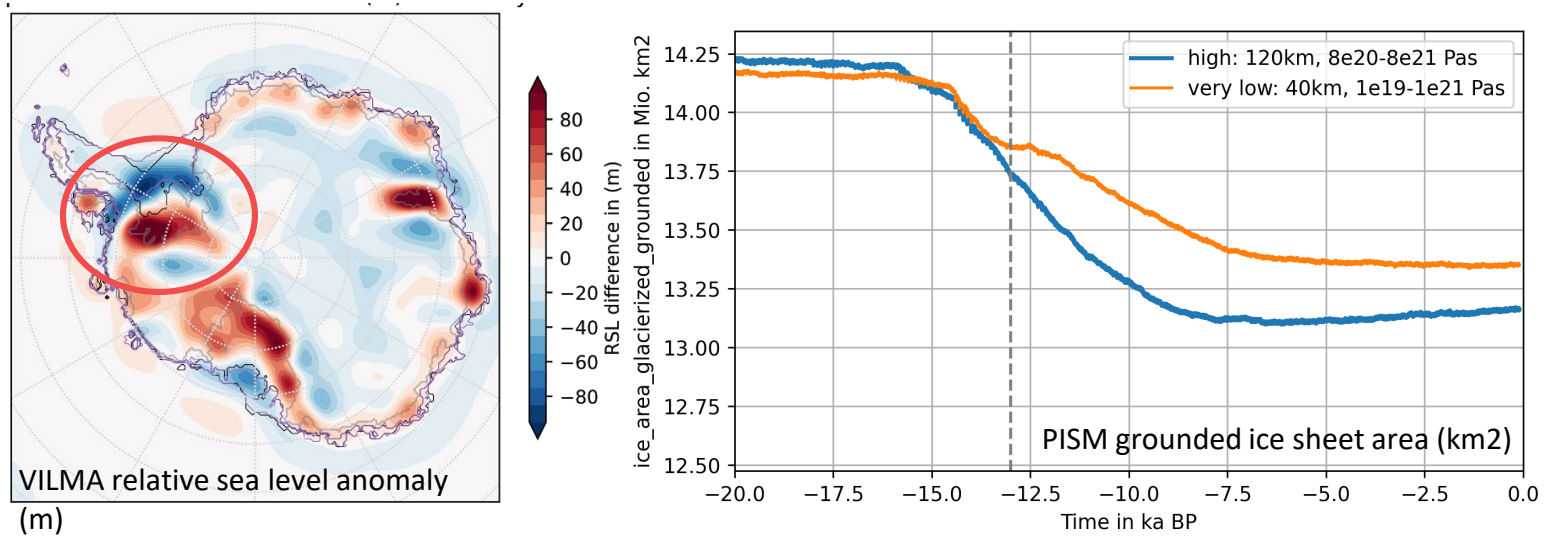
Figure: Variation in vertical mantle viscosity



*Figures: Difference in VILMA relative sea level (RSL) at **onset of deglaciation** 13 ka BP: low viscosity (orange) - high viscosity (blue) and grounded ice area evolution (right)*



→ delayed deglacial retreat for weaker Earth structure, as faster rebound stabilizes grounding line (blue shaded)

6 Comparing to 3D mantle viscosity

work in progress

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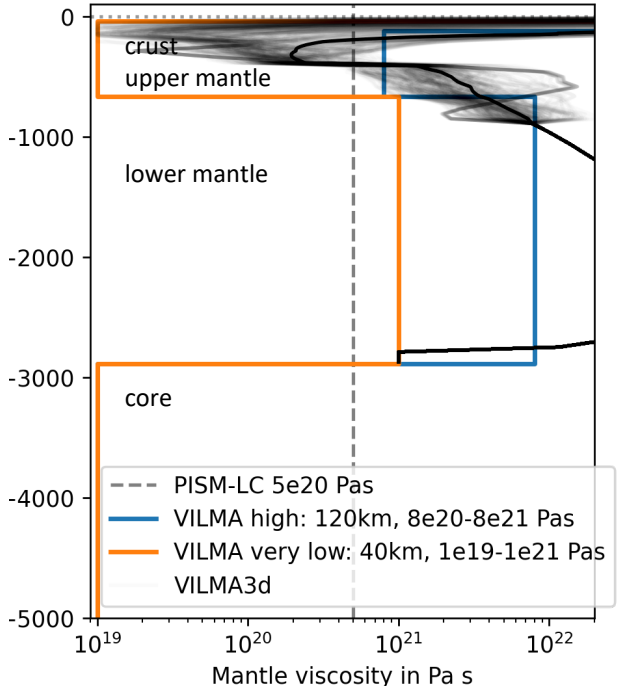
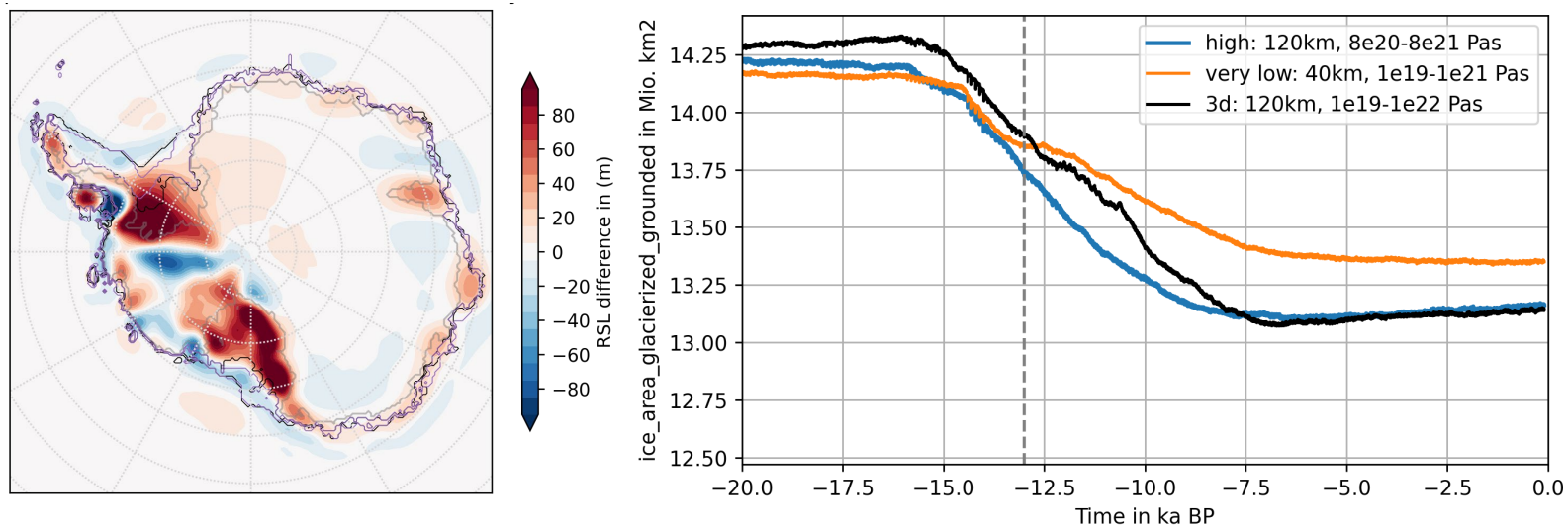
Figure: Variation in vertical mantle viscosity Including spread of 3D profiles (black)



*Figures: Difference in VILMA relative sea level (RSL) at **onset of deglaciation** 13 ka BP: 3D viscosity (black) - high viscosity (blue) and grounded ice area evolution (right)*



→ the lower the mantle viscosity and the thinner the lithosphere,
the higher the relative sea level (water depth) at LGM,
the faster the deglacial rebound,
the slower the deglacial retreat

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7 Outlook

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What?

- We coupled VILMA and PISM-PICO within the PalMod Project – ready to use!
- First simulations reproduce feedback related to variation in Earth structure

Next steps?

- Run set of experiments to investigate feedbacks between ice, ocean and solid-Earth around Antarctica at present and on paleo time scales (onset of deglaciation, Last Interglacial, future scenarios)

So what?

- Mantle viscosity and lithosphere thickness distribution matter in terms of characteristic response times determining the strength of feedbacks related to Glacial Isostatic Adjustment and in terms of ice sheet stability

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PISM-PICO:

J. Kingslake*, R. P. Scherer*, T. Albrecht*, J. Coenen, R. D. Powell, R. Reese, N. D. Stansell, S. Tulaczyk, M. G. Wearing & P. L. Whitehouse; Extensive retreat and re-advance of the West Antarctic Ice Sheet during the Holocene; Nature, 558, 430-434, (2018) DOI:10.1038/s41586-018-0208-x

T. Albrecht, R. Winkelmann and A. Levermann; „Glacial-cycle simulations of the Antarctic Ice Sheet with the Parallel Ice Sheet Model (PISM) – Part 1: Boundary conditions and climatic forcing“; The Cryosphere, 14, 599–632, (2020), DOI: 10.5194/tc-14-599-2020

T. Albrecht, R. Winkelmann and A. Levermann„Glacial-cycle simulations of the Antarctic Ice Sheet with the Parallel Ice Sheet Model (PISM) – Part 2: Par; ameter ensemble analysis“; The Cryosphere, 14, 633–656, (2020), DOI: 10.5194/tc-14-633-2020

R. Reese, T. Albrecht, M. Mengel, X. Asay-Davis and R. Winkelmann; Antarctic sub-shelf melt rates via PICO; The Cryosphere, 12, 1969-1985 (2018), DOI:10.5194/tc-12-1969-2018

VILMA:

Bagge M, Klemann V, Steinberger B, Latinović M, Thomas, M. Glacial isostatic adjustment models using geodynamically constrained 3D Earth structures. submitted to Geochemistry, Geophysics, Geosystems

A9 Appendix: Iterative convergence

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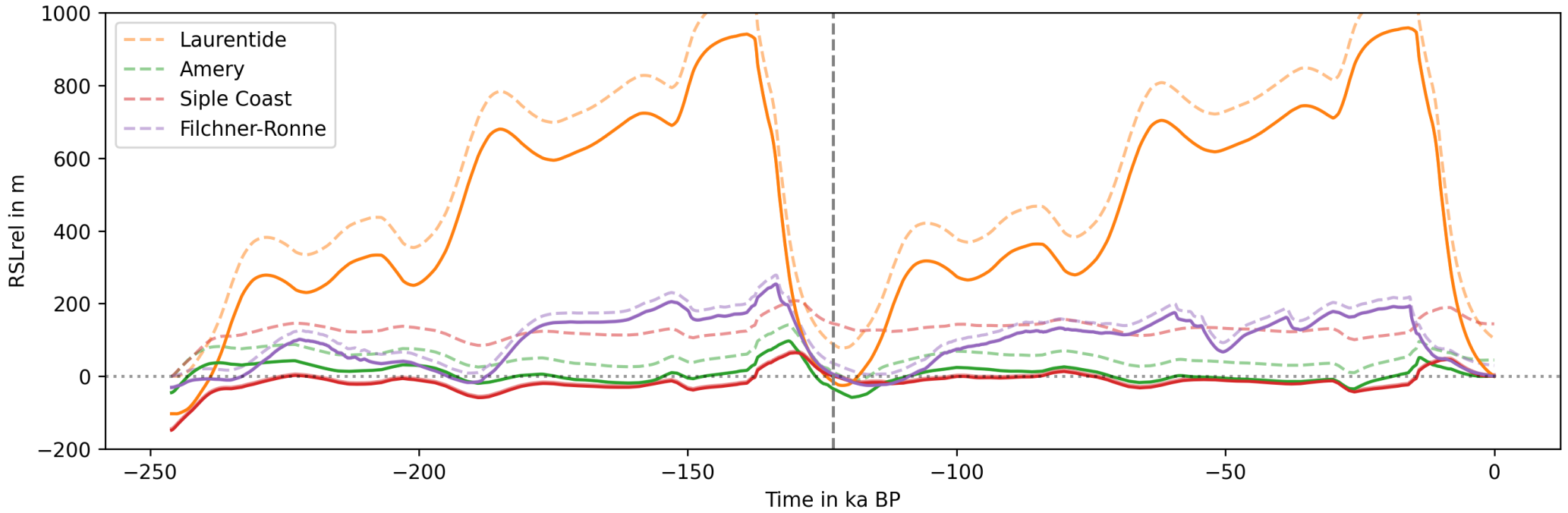
Figure: VILMA relative sea level (RSL) over 2 glacial cycles (246 ka) at 4 cites on the globe (dashed is first iteration), solid is 2nd to 4th iteration



→ adjust initial bed topography (relative sea level) with anomaly at present (according to Bedmap2 observations)

A10 Appendix: near vs. far field sea level

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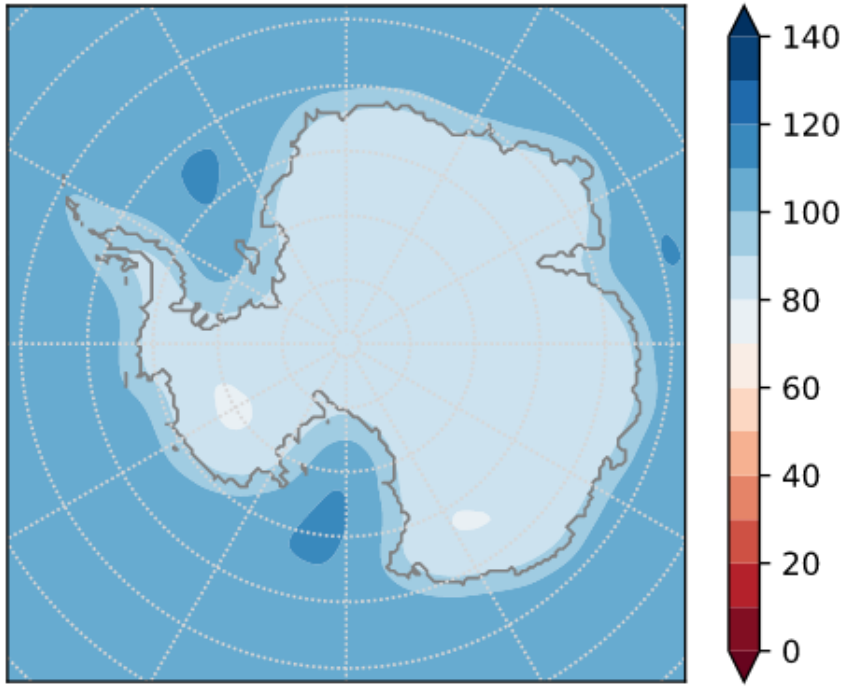
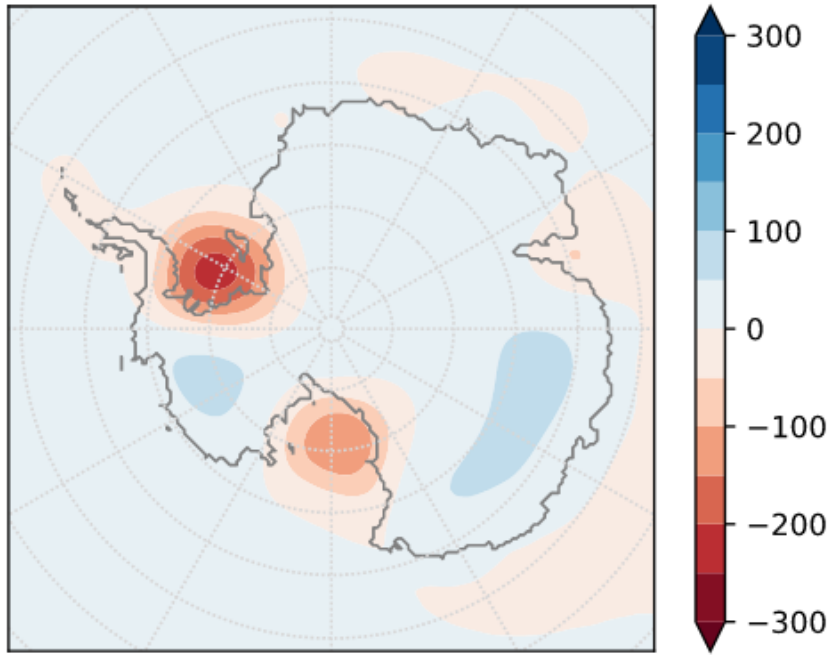
Figure: Antarctic relative sea level change (m) since 21 ka BP related to
Northern Hemisphere ice cover change (Ice5G) (far field)



Antarctic ice cover change (local sea level)



→ similar range but less rotational effect,
compare to Fig 1c,d in Gomez et al., 2020 (https://doi.org/10.1038/s41586-020-2916-2)