Density, temperature and composition of Antarctica's lithosphere and impact on geothermal heat flux and mantle viscosity

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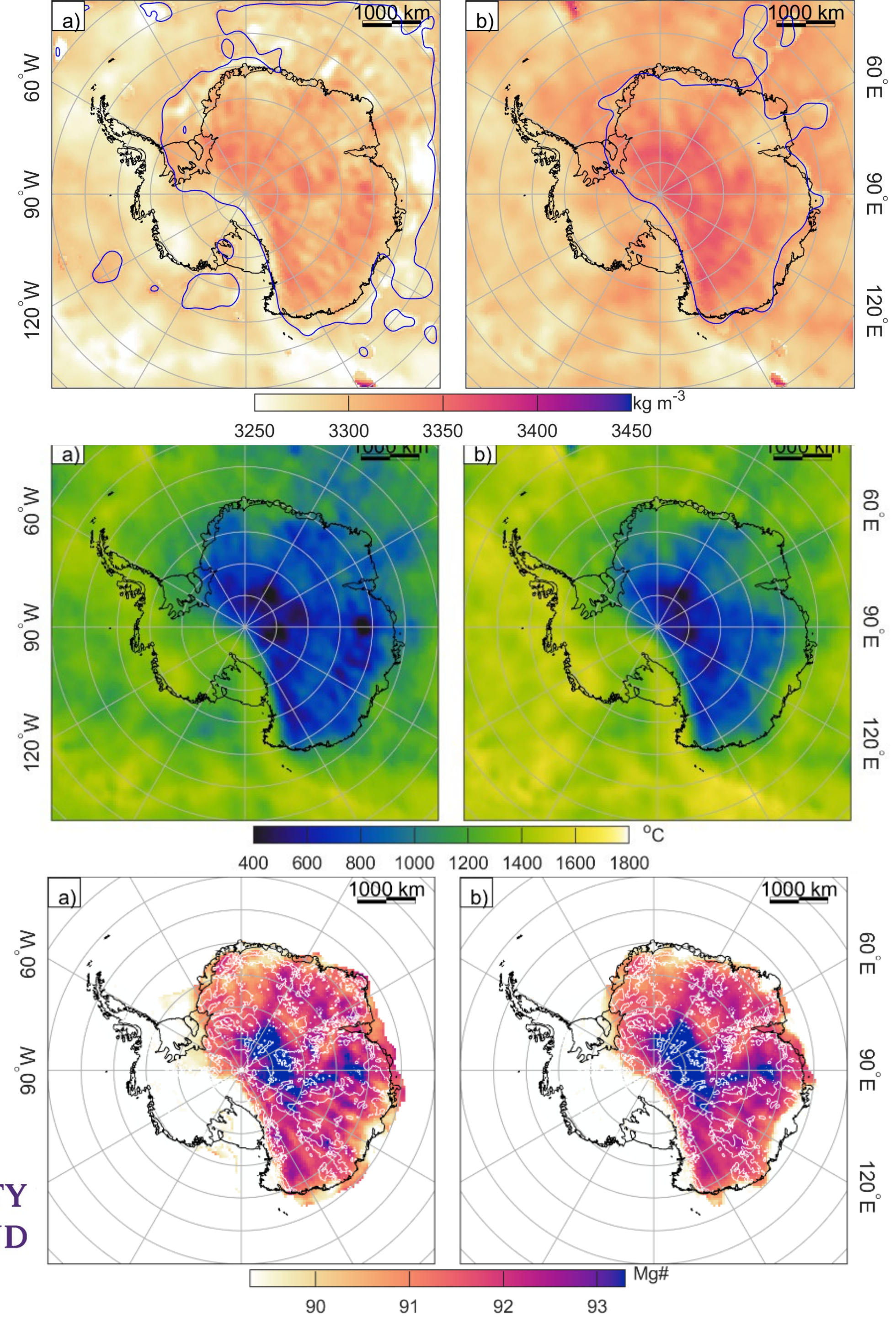
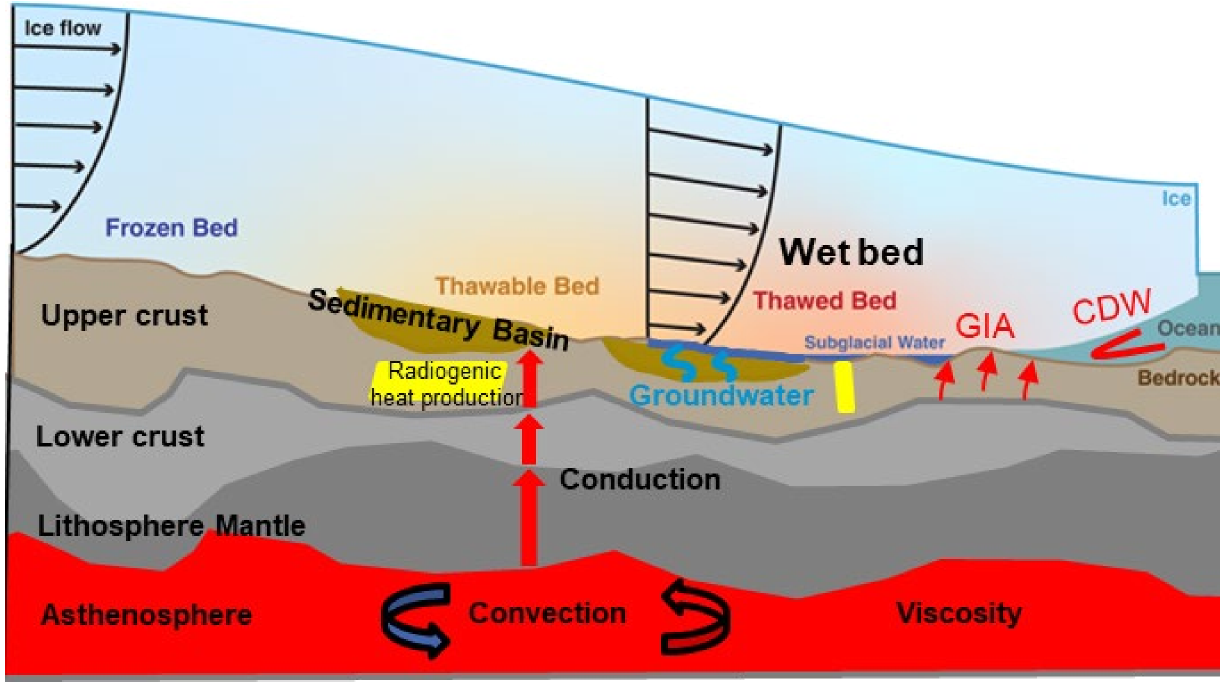


Why Antarctica?

Antarctica preserve the largest ice sheet on earth, and the mass loss in Antarctica is accelerating. The capacity to prediction future ice mass change is limited by the incomplete knowledge of basal processes and basal boundary condition for ice sheet flow.

Solid-earth provide important basal boundary conditions for governing ice sheet flow. For example, **water** and **sediment** could reduce basal friction cause basal sliding. Glacial isostatic adjustment (GIA) could recouple ice sheet and bed to stabiles ice sheet retreat.

Understanding these impacts requires knowledge about the **thermal** and **mechanical** structures of Antarctica's lithosphere. From this, we can constrain **geothermal heat flow** and **mantle viscosity**. But **how**?

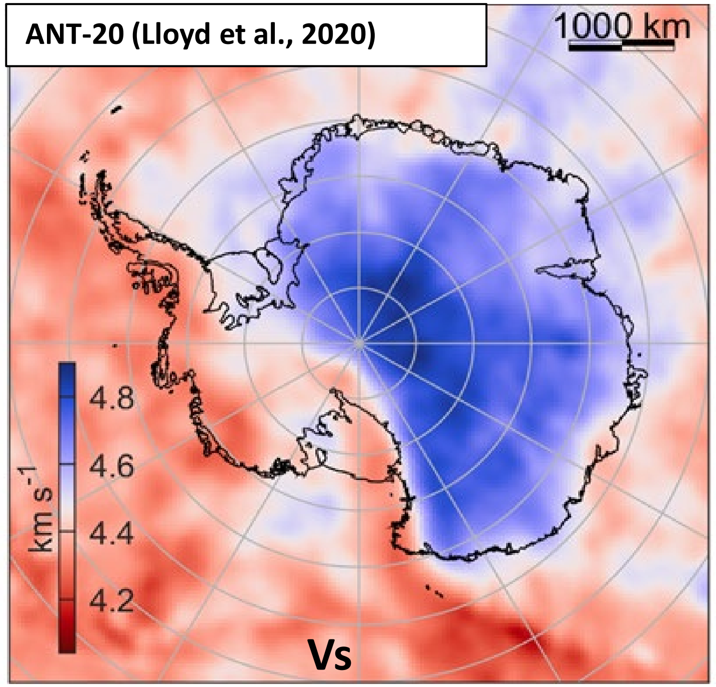


Modified from Dawson et al., 2022

Dawson, E. J., Schroeder, D. M., Chu, W., Mantelli, E., & Seroussi, H. (2022). Ice mass loss sensitivity to the Antarctic ice sheet basal thermal state. Nature Communications, 13(1), 4957.

How could we do that?

Seismology + Mineral physics

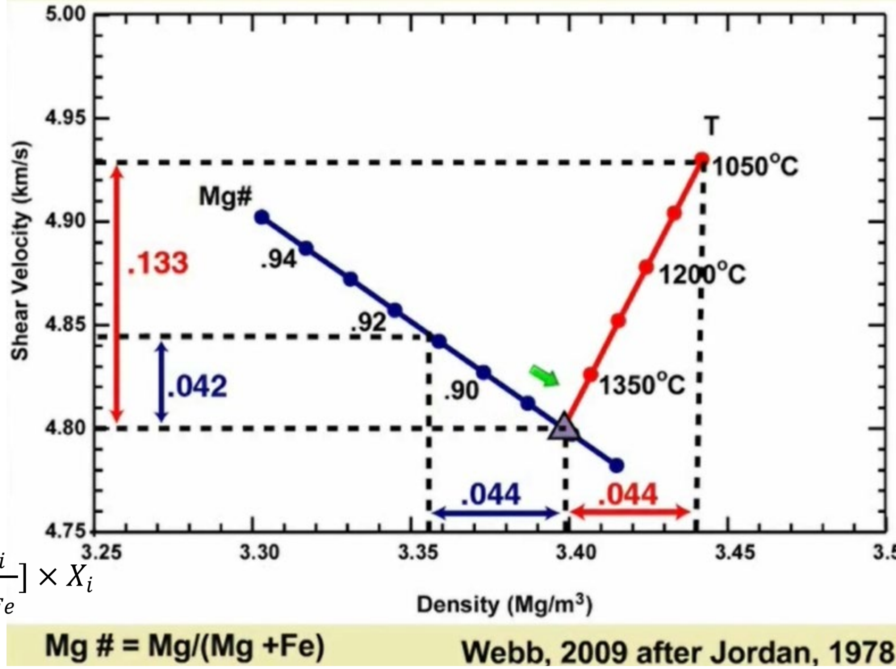


	Ol	Opx	Cpx	Gt	Mg
PUM	58.5	15	11.5	15	89.3
Phanerozc	66	9	17	8	89.9
Proterozo	70	7	15	8	90.6
Archean	69	2	25	4	92.7

$$V_s = V_{s(anh)} \times V_{s(ane)} = V_{s(anh)}\left[1 - \frac{Q_s^{-1}}{2\tan\left(\frac{\pi a}{2}\right)}\right]$$

$$V_{s(anh)} = \sqrt{\frac{\mu}{\rho}}$$

$$\mu(P,T,X_{Fe}) = \sum_i \left[\mu_i(P_0,T_0) + (T-T_0)\frac{\partial \mu_i}{\partial T} + (P-P_0)\frac{\partial \mu_i}{\partial P} + X_{Fe}\frac{\partial \mu_i}{\partial X_{Fe}}\right] \times X_i$$

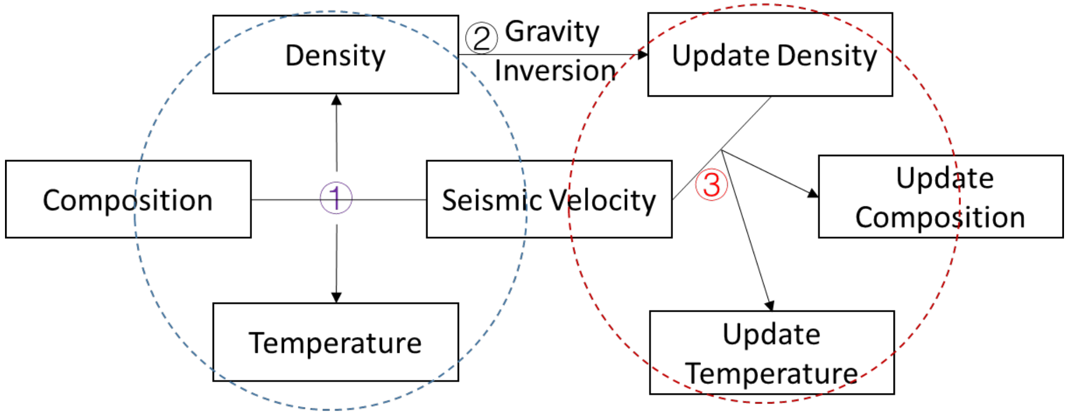


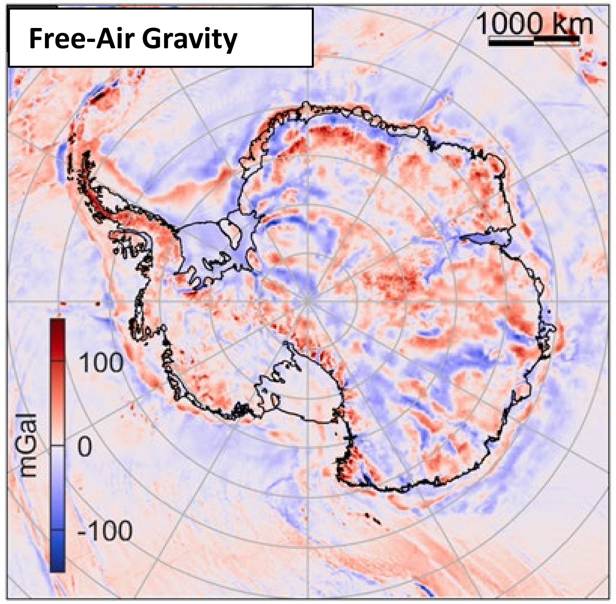
Seismology is great!
But the solution is non-unique.

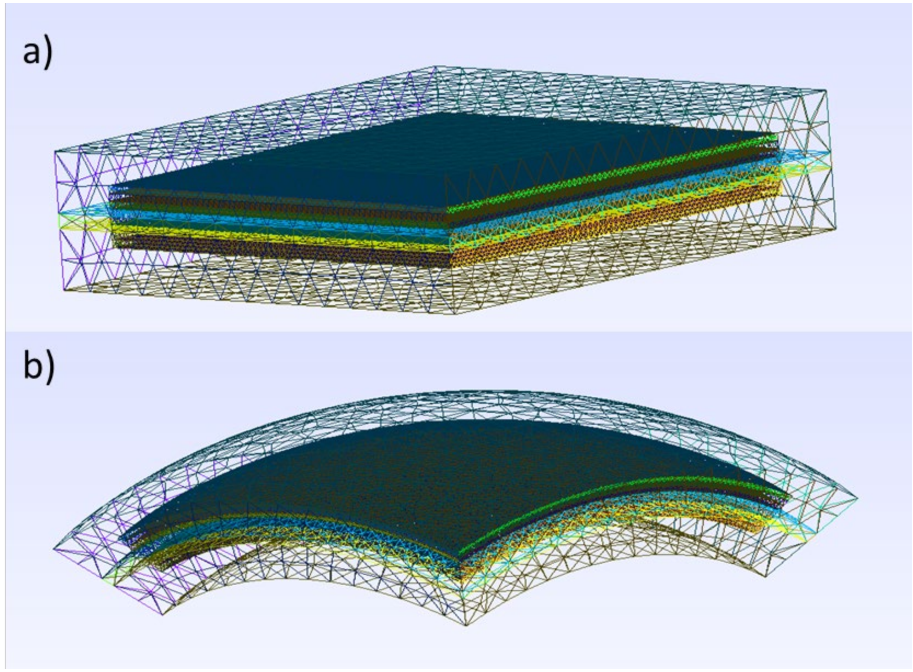
Lloyd, A. J., Wiens, D. A., Zhu, H., Tromp, J., Nyblade, A. A., Aster, R. C., ... & O'Donnell, J. P. (2020). Seismic structure of the Antarctic upper mantle imaged with adjoint tomography. Journal of Geophysical Research: Solid Earth, 125(3).
Goes, S., Govers, R., & Vacher, A. P. (2000). Shallow mantle temperatures under Europe from P and S wave tomography. Journal of Geophysical Research: Solid Earth, 105(B5), 11153-11169.

Method

Density as additional constrain







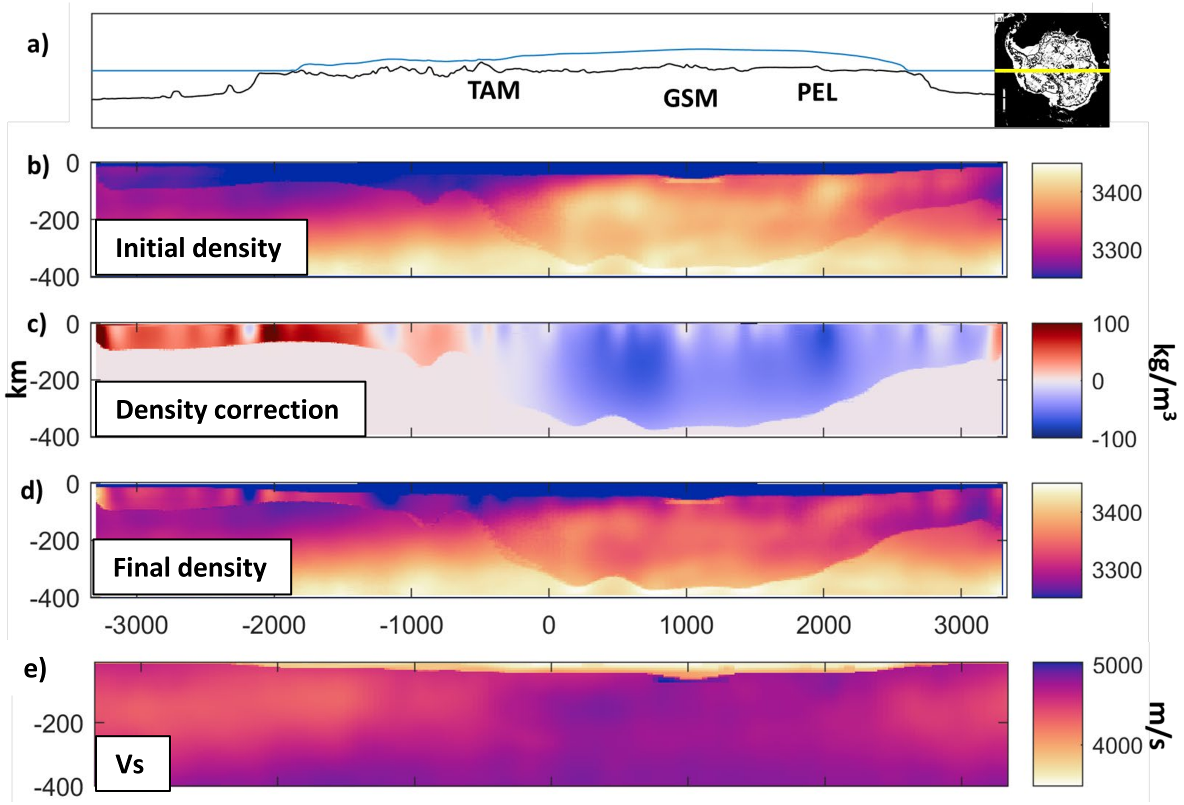
Esys-escript with a new solver (AMG-PCG matrix solver) using unstructured mesh (Codd et al., 2021) in Geodetic coordinate.

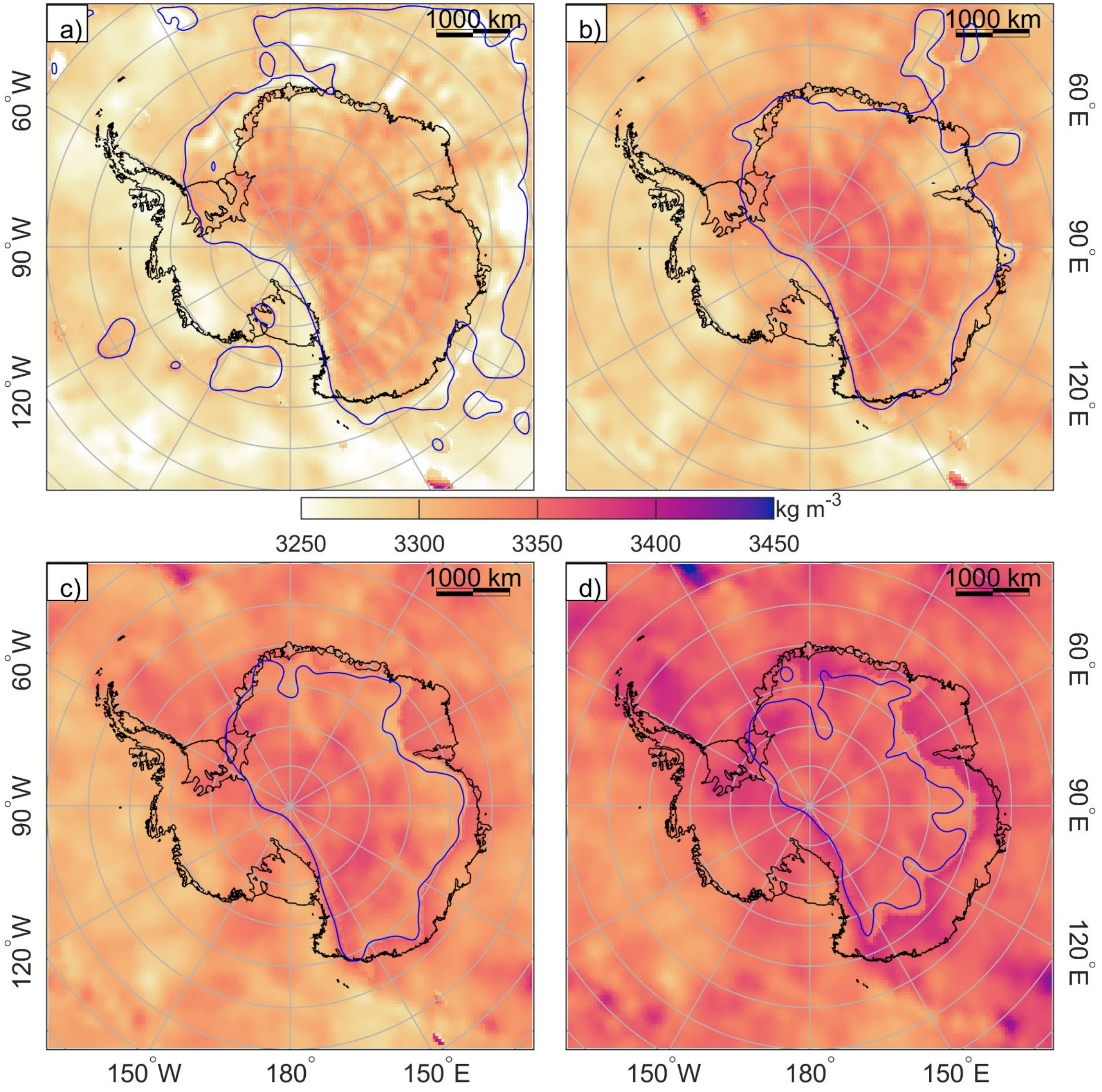
Preserve topography, mass of ice sheet, earth curvature, crust structures in the model.

Codd, A. L., Gross, L., & Aitken, A. (2021). Fast multi-resolution 3D inversion of potential fields with application to high-resolution gravity and magnetic anomaly data from the Eastern Goldfields in Western Australia. Computers & Geosciences, 157, 104941.

https://esys-escript.github.io/ esys-escript

Density





Density depth slice for 100, 150, 200, 250 km

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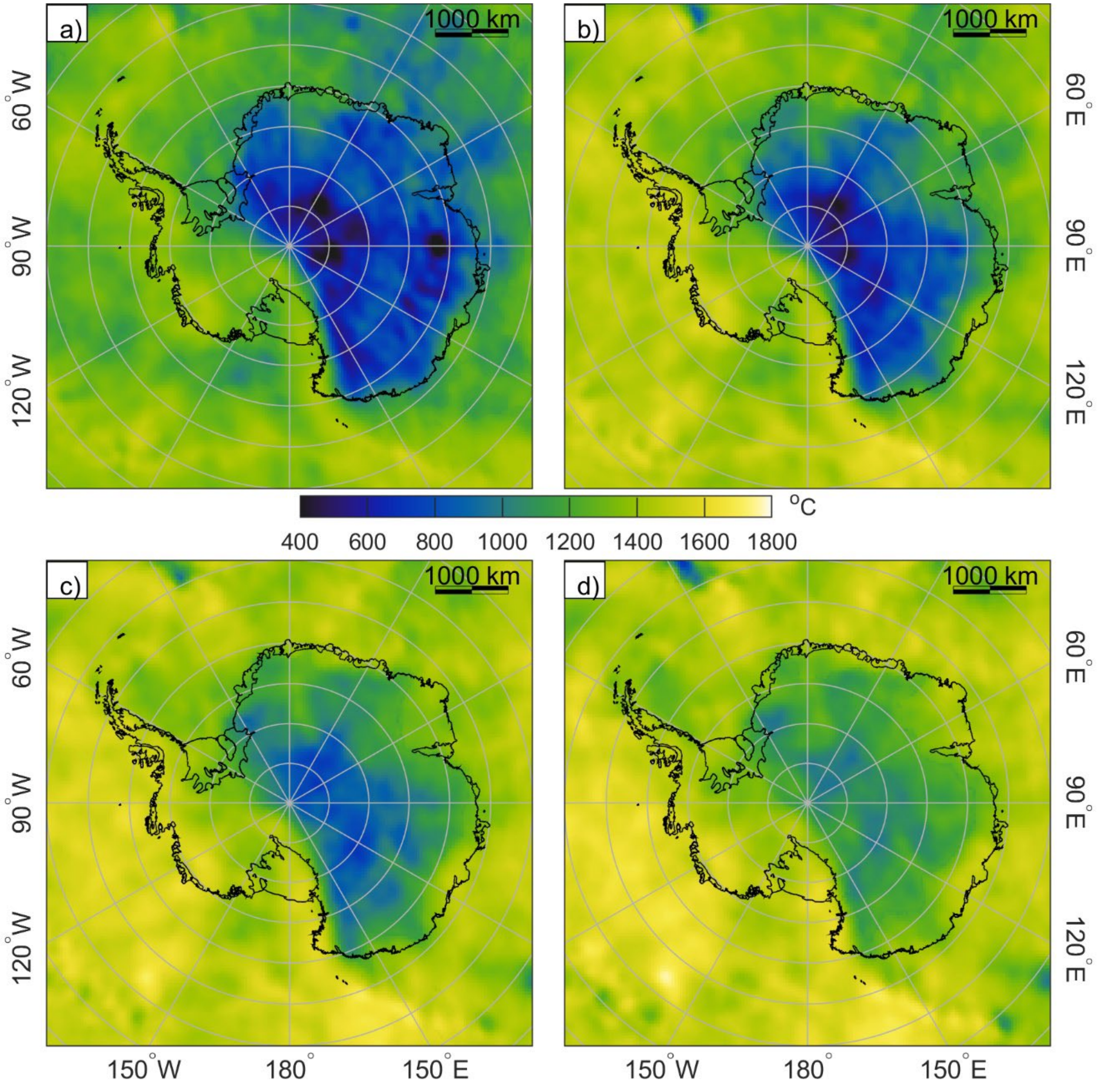
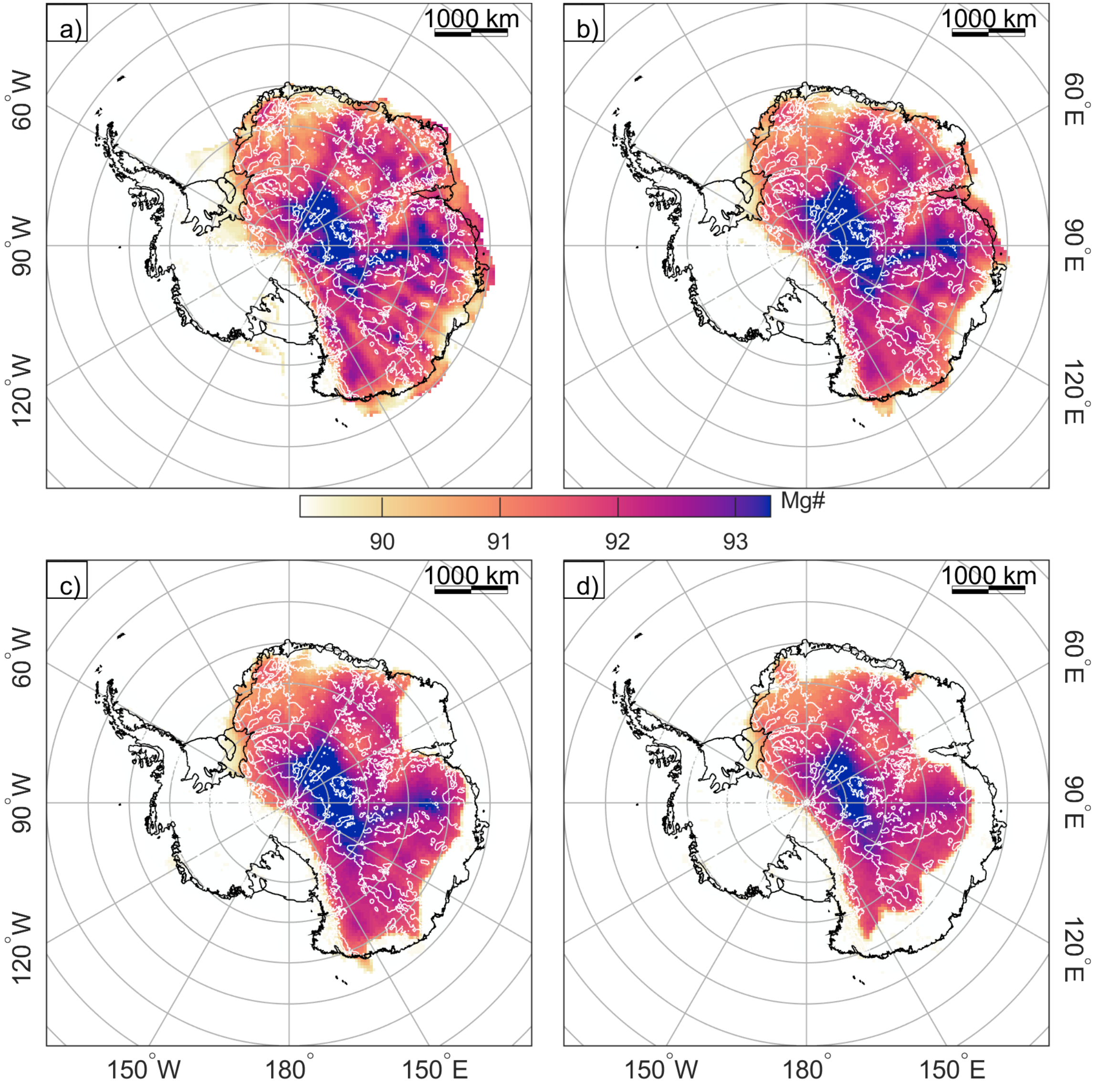
Temperature and Composition

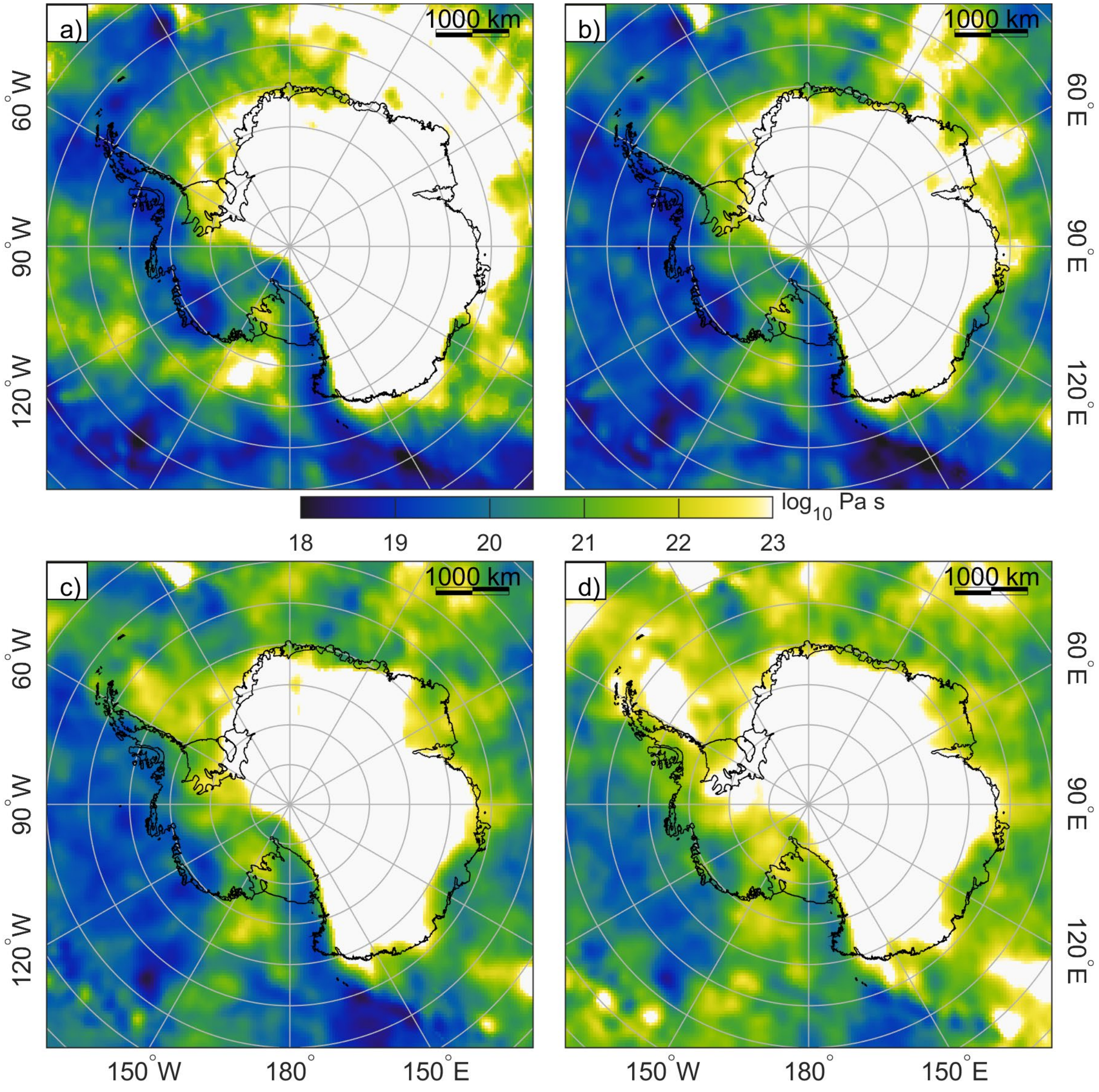


Temperature depth slice for 100, 150, 200, 250 km

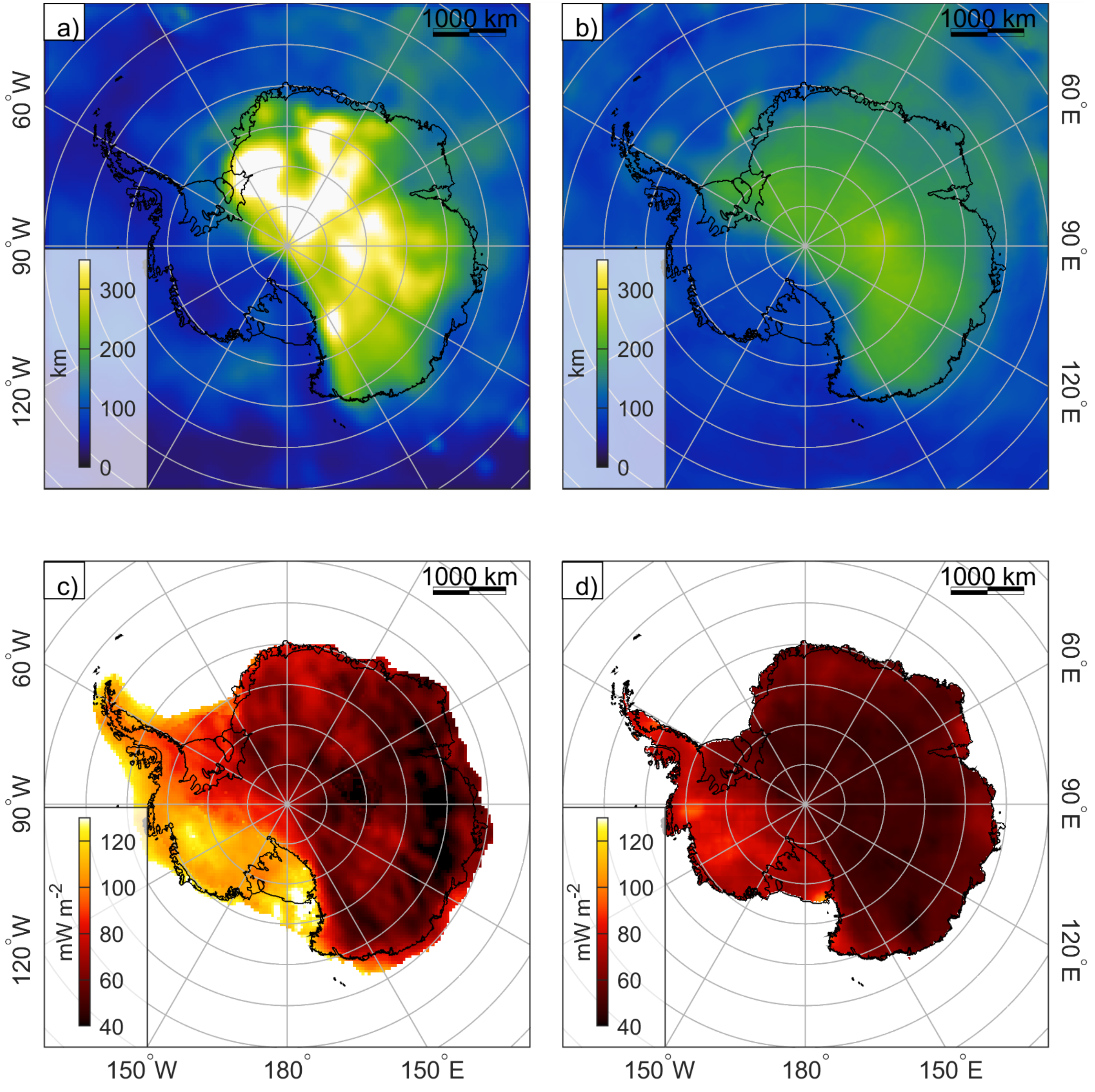


Composition depth slice for 100, 150, 200, 250 km

Viscosity and geothermal heat flow

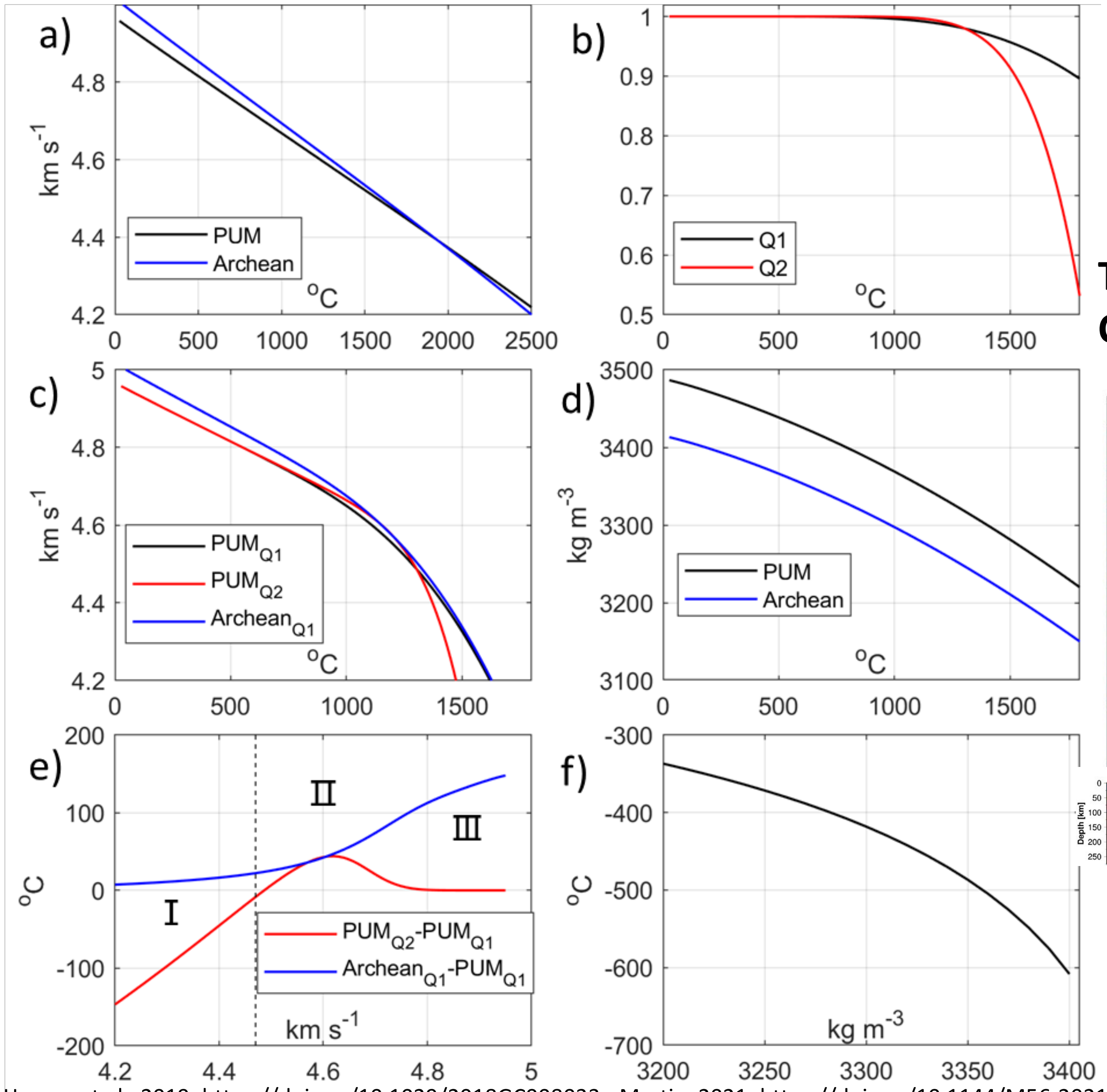


Viscosity depth slice for 100, 150, 200, 250 km

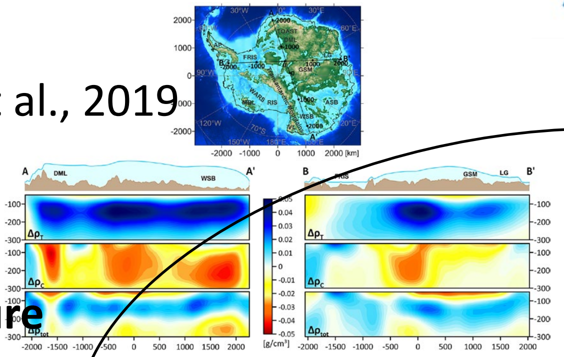


a) and c) LAB and GHF for this study, b) LAB from Pappa et al., 2019, d) GHF by mean of continental estimation

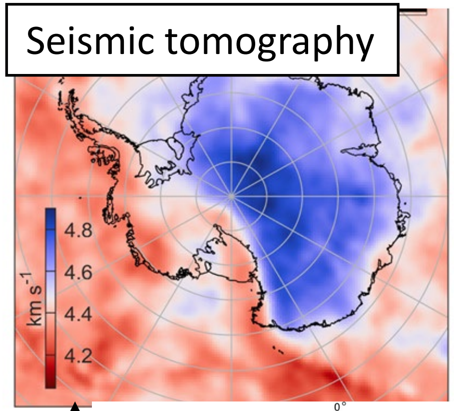
Uncertainties / Moving forward

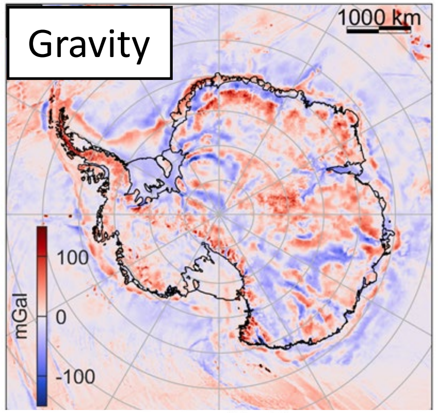


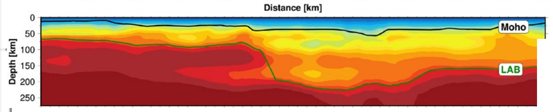
Haeger et al., 2019



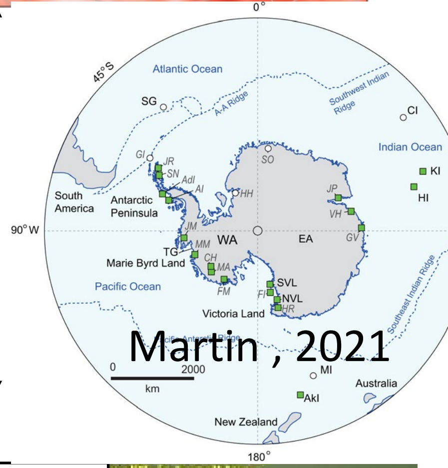
Temperature
Composition





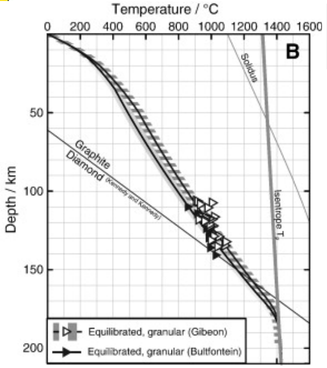


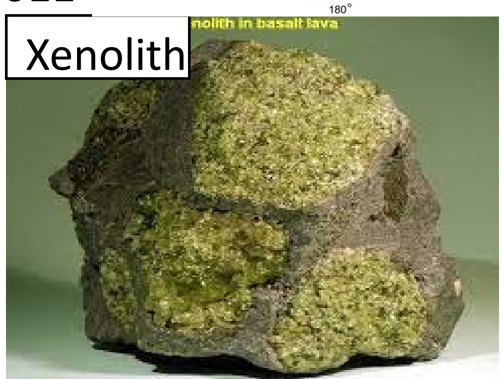
Pappa et al., 2020



Martin , 2021

Mather et al., 2011





Haeger et al., 2019. https://doi.org/10.1029/2018GC008033 ; Martin, 2021. https://doi.org/10.1144/M56-2021-2
Pappa et al., 2020 https://doi.org/10.1029/2019JB017997 ; Mather et al., 2011. https://doi.org/10.1016/j.lithos.2011.04.003

Conclusion

- 1. A new thermal mechanical model in Antarctica, can be in cooperate into numerical ice sheet model

- 2. Incorporate compositional change lead 100-150 ℃ hotter mantle in depleted region (6-10 mW/m^2), with up to 80 km thermal lithosphere thickness change.

- 3. Anelastic parameter remain large uncertainty to estimate thermal mechanical structure in Antarctica.

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