The Antarctic continent mapped by global similarity association

Tobias Stål[1,2,3], Anya M. Reading[1,2,3], Matthew J. Cracknell[4], Jörg Ebbing[5], Jacqueline A. Halpin[2,3], Ian D. Kelly[1,3], Emma J. MacKie[6], Mohamed Sobh[7], Ross J. Turner[1], and Joanne M. Whittaker[2]

1, Physics, School of Natural Sciences, University of Tasmania, Australia; 2, Institute for Marine and Antarctic Studies, University of Tasmania, Australia; 3, The Australian Centre for Excellence in Antarctic Science; 4, CODES, School of Natural Sciences, University of Tasmania, Australia; 5, Institute of Geosciences, Kiel University, Germany; 6, Geological Sciences, University of Florida, USA; 7, Leibniz Institute for Applied Geophysics, Germany

Motivation

Studies of Antarctica's subglacial geology are crucial to understanding the assembly of past supercontinents and reconstructing Earth's history. Recently, questions regarding the Antarctic continent have gained further importance and urgency due to the ongoing anthropogenic climate change and the uncertain predictions of how the Antarctic ice sheet responds to ocean warming.

Our knowledge of the tectonic setting of the interior of Antarctica is currently quite limited. Here, we aim to improve our understanding using recently improved data cover and novel statistical and computational methods. The uncertainty in the model is used as an advantage as it allows us to optimise the methods and communicate the ambiguities using information entropy as a metric.

Methods

We use 18 global observables with a robust and consistent cover over Antarctica. Observables include results from seismic and magnetic studies, gravimetry, the isostatically relaxed hypsometry, and observations of lithology and volcanoes. We also include derived observables as the difference between magnetically modelled depth to Curie temperature isotherm and seismically derived Moho and curvature of the gravity field (Fig. 3). Each observable improves the predictions to some degree.

We divide the globe in an icosahedral mesh, and for each node in Antarctica, we calculate the similarity to every node in the rest of the world (Fig. R4 right). The degree of similarity is defined from a normal distribution centred at the exact agreement and σ optimised for each observable using a Monte Carlo test. The sum of similarity for each pair is charged as a function, $s_i = k^{\Sigma S}$. Hence, the k-parameter controls how exact the selection is, but a high value can lead to overfitting artifacts. We can optimize the k value at each point by setting a value where the entropy reduction flattens (Fig. R4). Comparing the k value with the entropy for each grid point and the total entropy of the model allows us to map the Kullback–Leibler divergence and use it to suggest what value of k generates the lowest information entropy with preserved stability. Applied, this maps regions with the same tectonic origin.

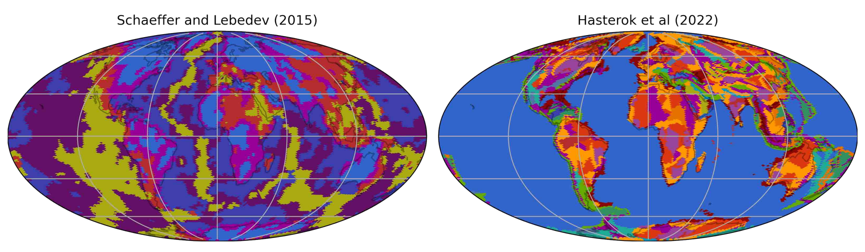

Figure 1: Tectonic models analysed.

For each location in Antarctica, we are then equipped with a global similarity map (Fig. 5). We use this map as a weighting to sample *classes* from global tectonic models (Fig. 1) and calculate the class distribution for each target location. We test the tectonic segmentation maps from Schaeffer and Lebedev (2015); 6 classes, and Hasterok et al. (2022); 15 classes (Fig. 1). The models have been constructed using different approaches and are aimed at different purposes. However, both represent robust suggestions for global tectonics.

1. Including the model for the Antarctic interior. This application is only used for quality control, as it naturally reproduces the distribution in the reference model.
2. Excluding Antarctica south of 60°S but include outcrops in Antarctica.
3. Excluding the model south of 60°S.

We also evaluate three cases in defining the extent of the reference model. Including Antarctic observations reduces the information entropy locally (Fig. 10), however, the high weight calculated to the few locations tends to distort the overall results.

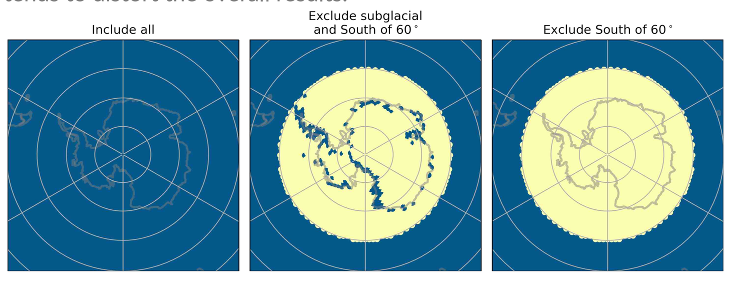

Figure 2: Approaches to limit the reference extent. Case 1 includes suggestions for Antarctica; Case 2 excludes Antarctica and the Southern Ocean but includes outcrops; Case 3 excludes all South of 60°.

The sampling is inherently Bayesian, as the prior distribution comprises the global distribution. We apply a *de-Baysean scaling*, where less common classes are weighted up.

Results and Outputs

The Schaeffer and Lebedev (2015) segmentation scheme (REG) robustly predicts Phanerozoic crust in West Antarctica and East Antarctica consisting of cratons, Precambrian belts, and reworked cratons. The phanerozoic crust is highly probable in Lützow-Holm Bay and parts of coastal Wilkes Land (Fig. 7-8). The overall pattern is similar when applying the model from Hasterok et al. 2022 (Fig. 9). However, the volcanic arch is extended further to Siple Coast, and a back-arch basin is possible. Generally, the information entropy of the distribution is higher in West Antarctica; many interpretations are possible.

We provide several probability distributions of the tectonic architecture of Antarctica. We also provide several maps covering metrics of the information content and parameters. Finally, we provide output maps that can be used in interdisciplinary studies in ice–bedrock interactions and for tectonic reconstructions. However, the uncertainty and ambiguity embedded in those maps must be acknowledged (Fig. 10).

Discussion

The most significant challenge in this kind of work lies in understanding the relationship between qualitative observations and quantitative data. Geological observations are framed in the narrative of the geological history and are deterministic. No geophysical data can unambiguously represent the geology; however, we show how multivariate analysis provides strong evidence for the tectonic setting, even for cryptical subglacial terrains that are not directly observed. Our findings add to the growing awareness of the complex interior of East Antarctica. Extrapolations of other continents' geology into Antarctica should be applied with care.

Ongoing work

A paper is being prepared to provide further details regarding the methods and discussion of the results. Code and other outputs are being updated here:

Key References

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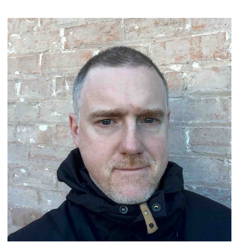
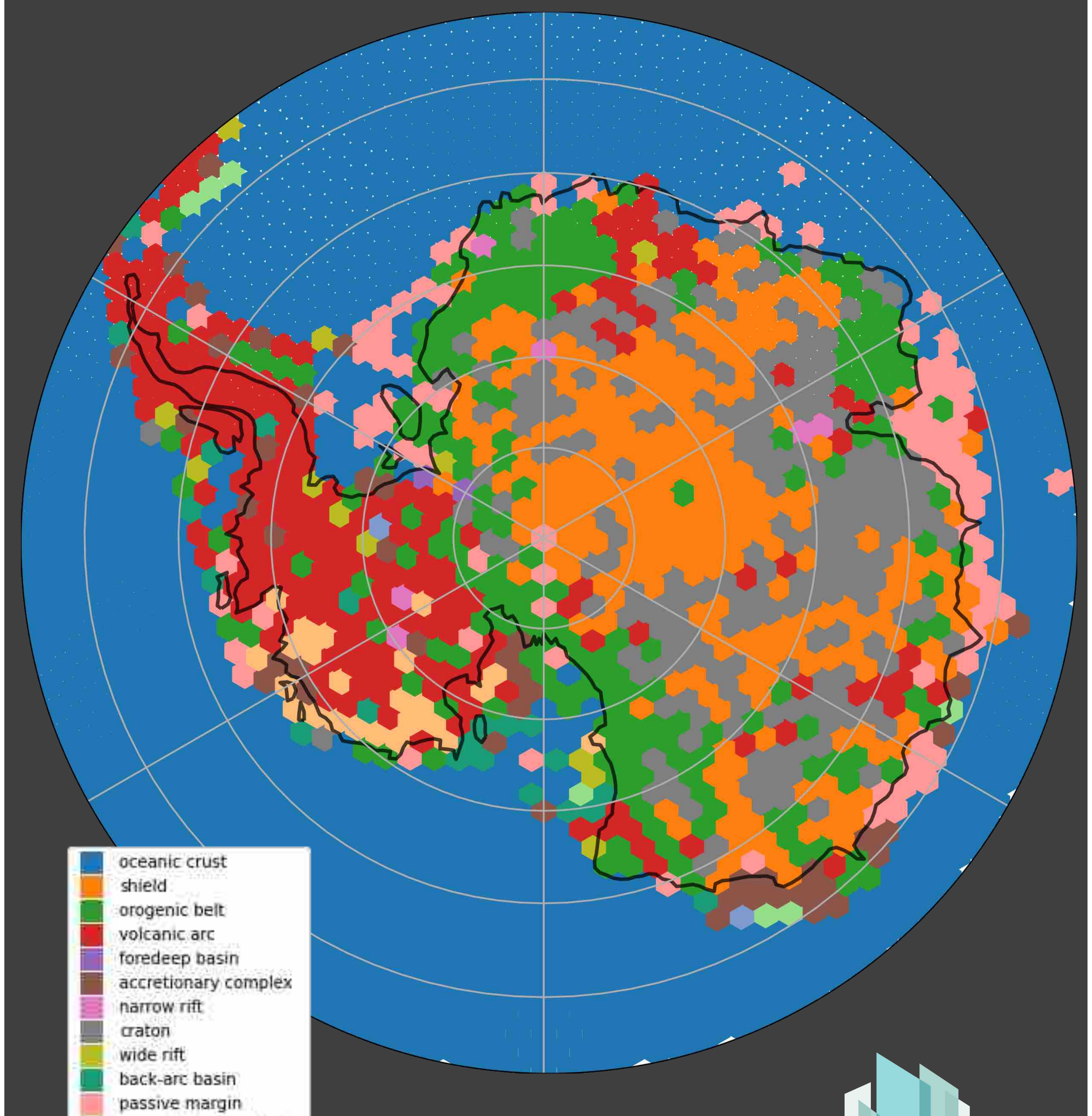
Contact

tobias.staal@utas.edu.au
@TobiasStl @comp_antarctic
TobbeTripitaka



Segmenting Antarctica's Tectonic Regions by Similarity.



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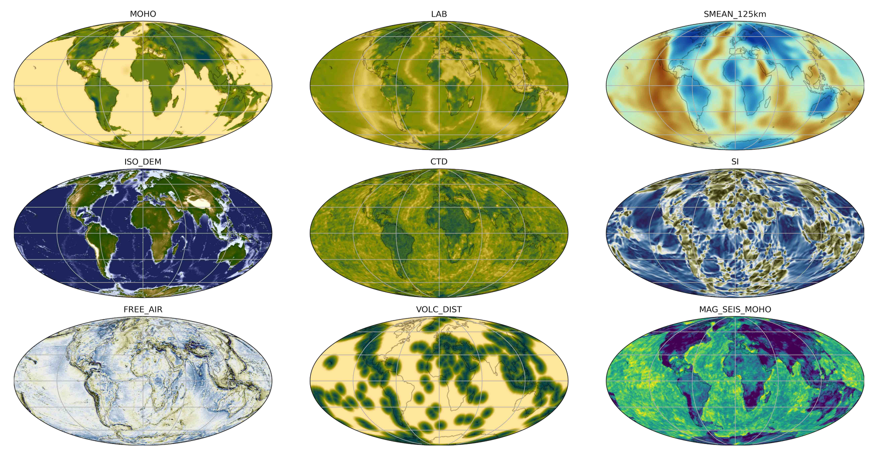

Figure 3: Examples of a few datasets used as observables.

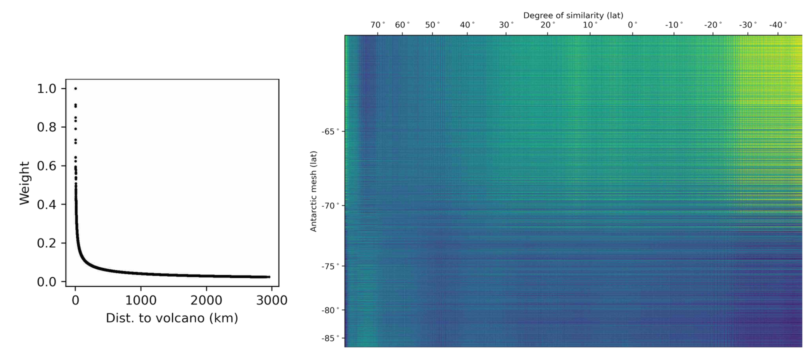

Figure 4: **(a)** Some observables are weighted. Here, the weight of observation of volcanoes decreases with distance. Such parameters are based on geological observations and reasoning rather than numerical optimization. **(b)** Similarity matrix showing nodes in Antarctica on the y-axis, sorted from North to South. Reference nodes in the rest of the planet on the x-axis, which is cropped at 60°S. The colour ramp is logarithmic.

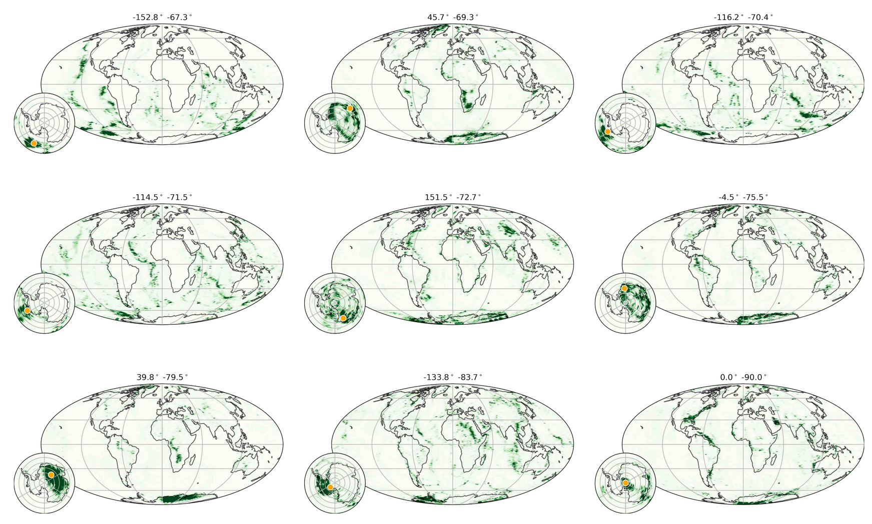

Figure 5: Similarity strength for nine locations in Antarctica.

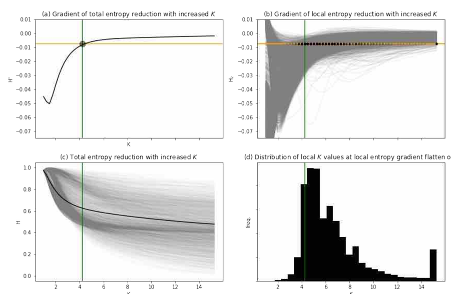

Figure 6: The K parameter impacts the total entropy of the model. Local values for k are defined from the decrease of entropy.

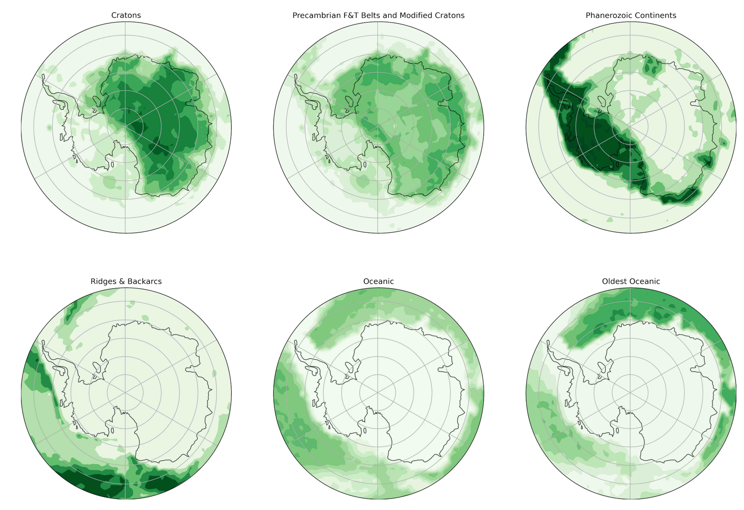

Figure 7: Classes from Schaeffer and Lebedev (2015), equally weighted. Case 3, no Antarctic insights included.)

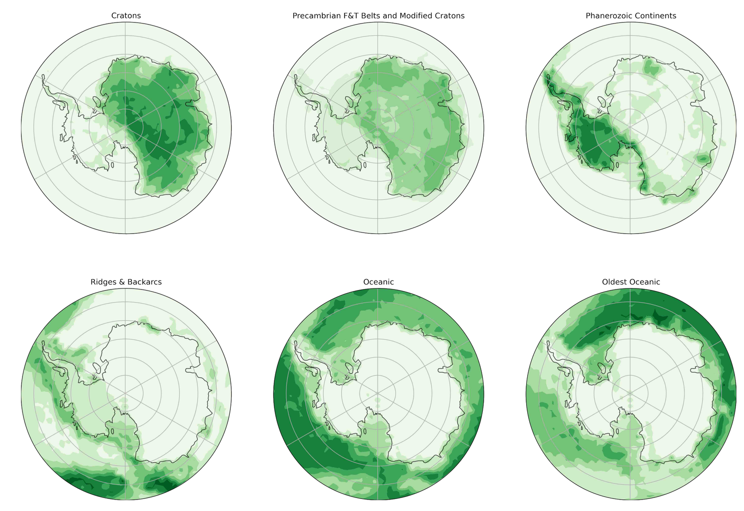

Figure 8: Classes from Schaeffer and Lebedev (2015), area proportionally weighted. Case 3, no Antarctic insights included.)

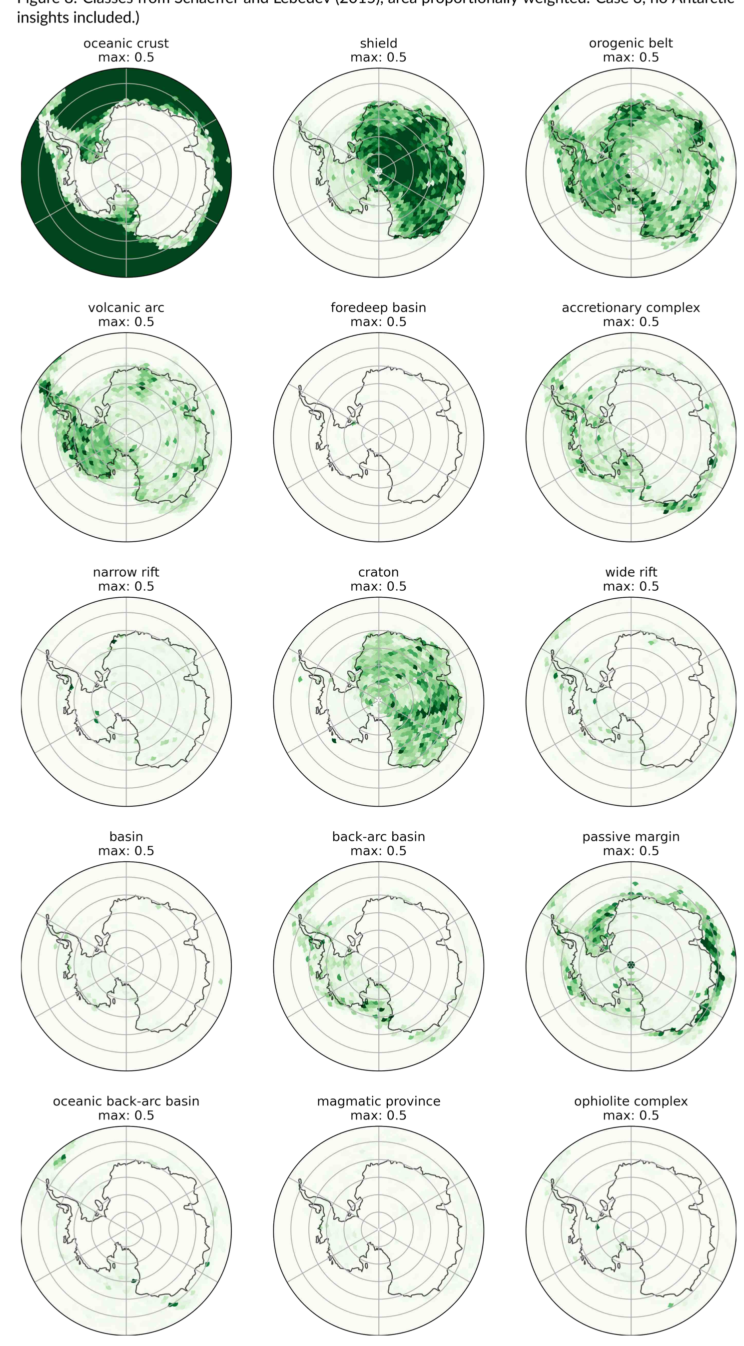

Figure 9: Classes from GPRV, area proportionally weighted. Case 3, no Antarctic insights included.)

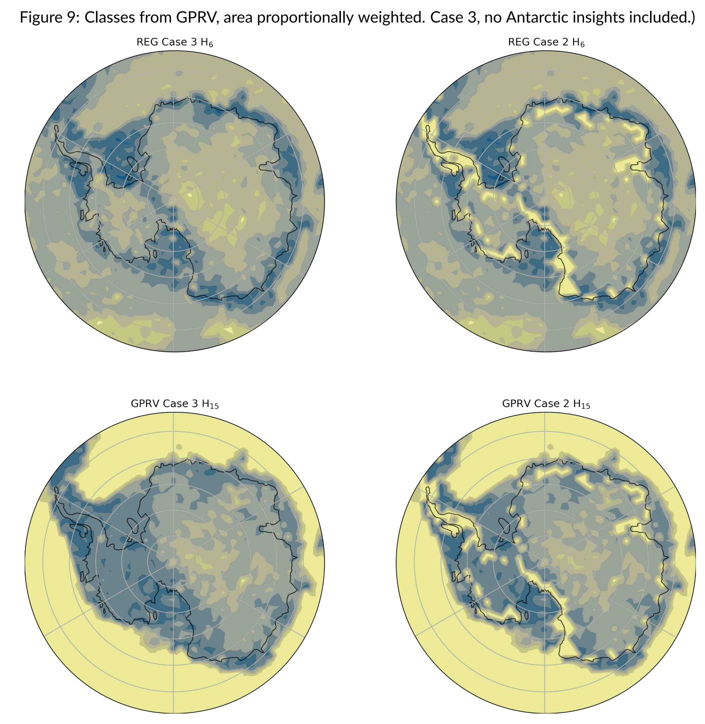

Figure 10: Information entropy for classes from the two models, for Case 3 (left) and Case 2 (right)