A Long-Term Record of Antarctic Ice Sheet Loss During Millennial-Scale Ocean Warming

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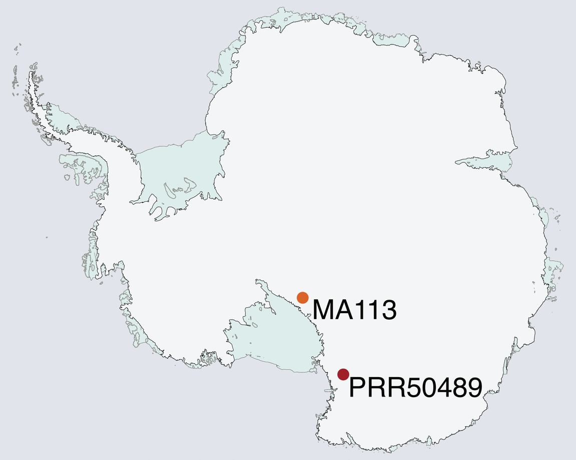
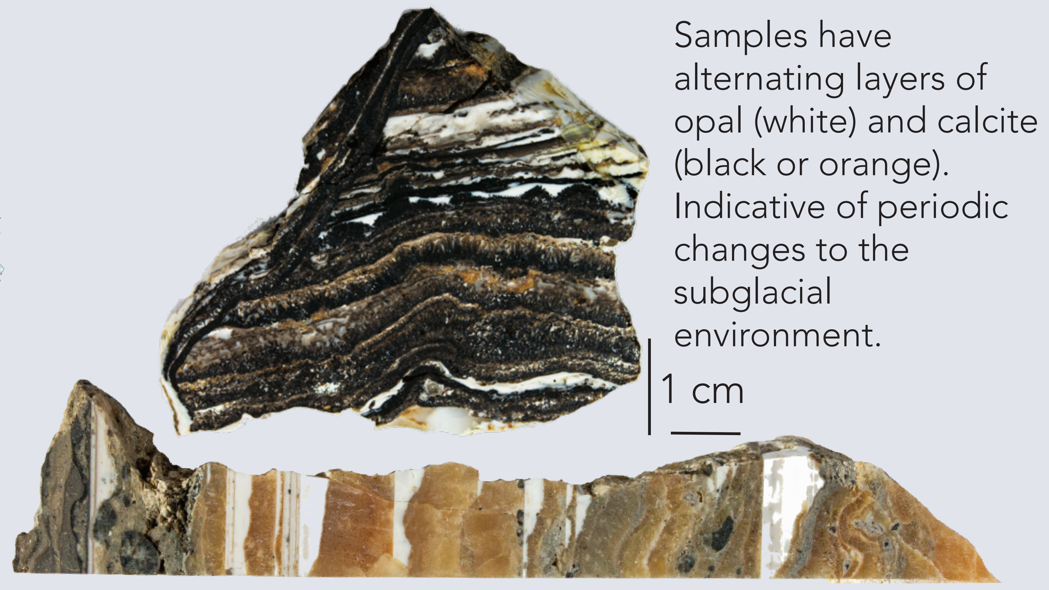
1. Plain Language Summary

Throughout the Late Pleistocene, the Antarctic ice sheet underwent millennial-scale episodes of acceleration around the Ross Embayment in response to ocean thermal forcing. Periods of enhanced ice velocity led to increased subglacial hydrologic connectivity, allowing interior waters to reach the margins.

2. Antarctic Subglacial Precipitates

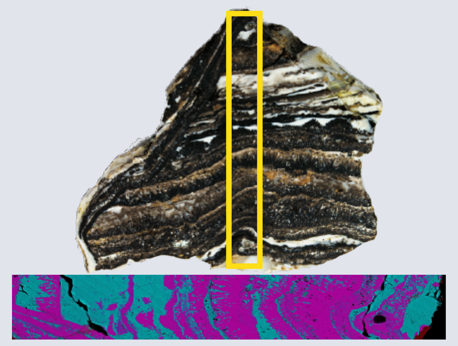


We studied chemical precipitates that formed on the East Antarctic side of the Ross Embayment.

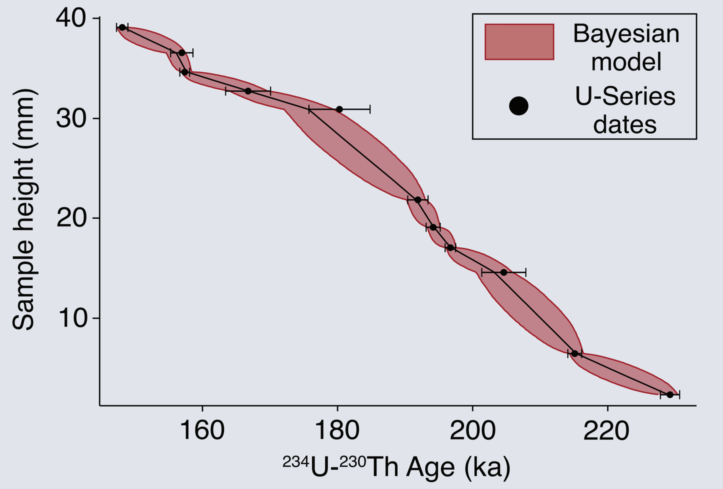


Samples have alternating layers of opal (white) and calcite (black or orange). Indicative of periodic changes to the subglacial environment.

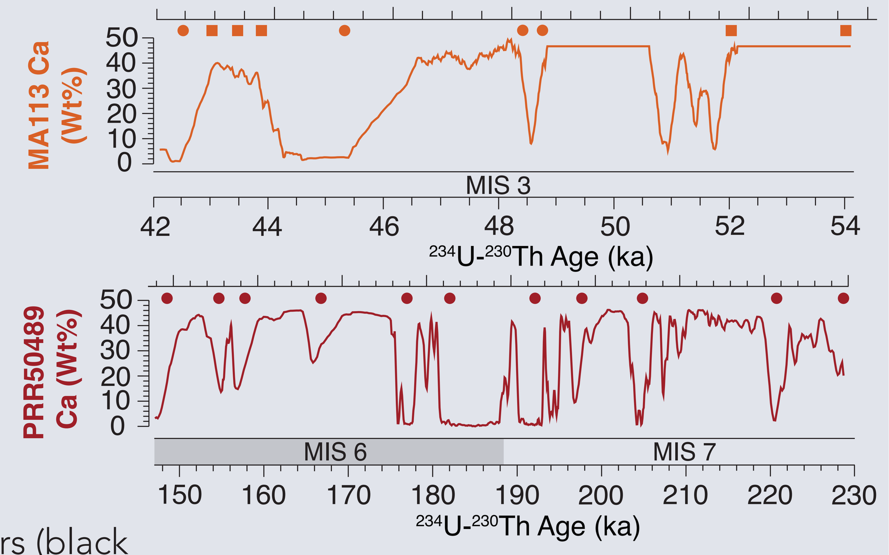
3. Opal-Calcite Timeseries

We use maps of Ca and Si across the samples (above and right) to output spectra describing mineralogy versus depth.

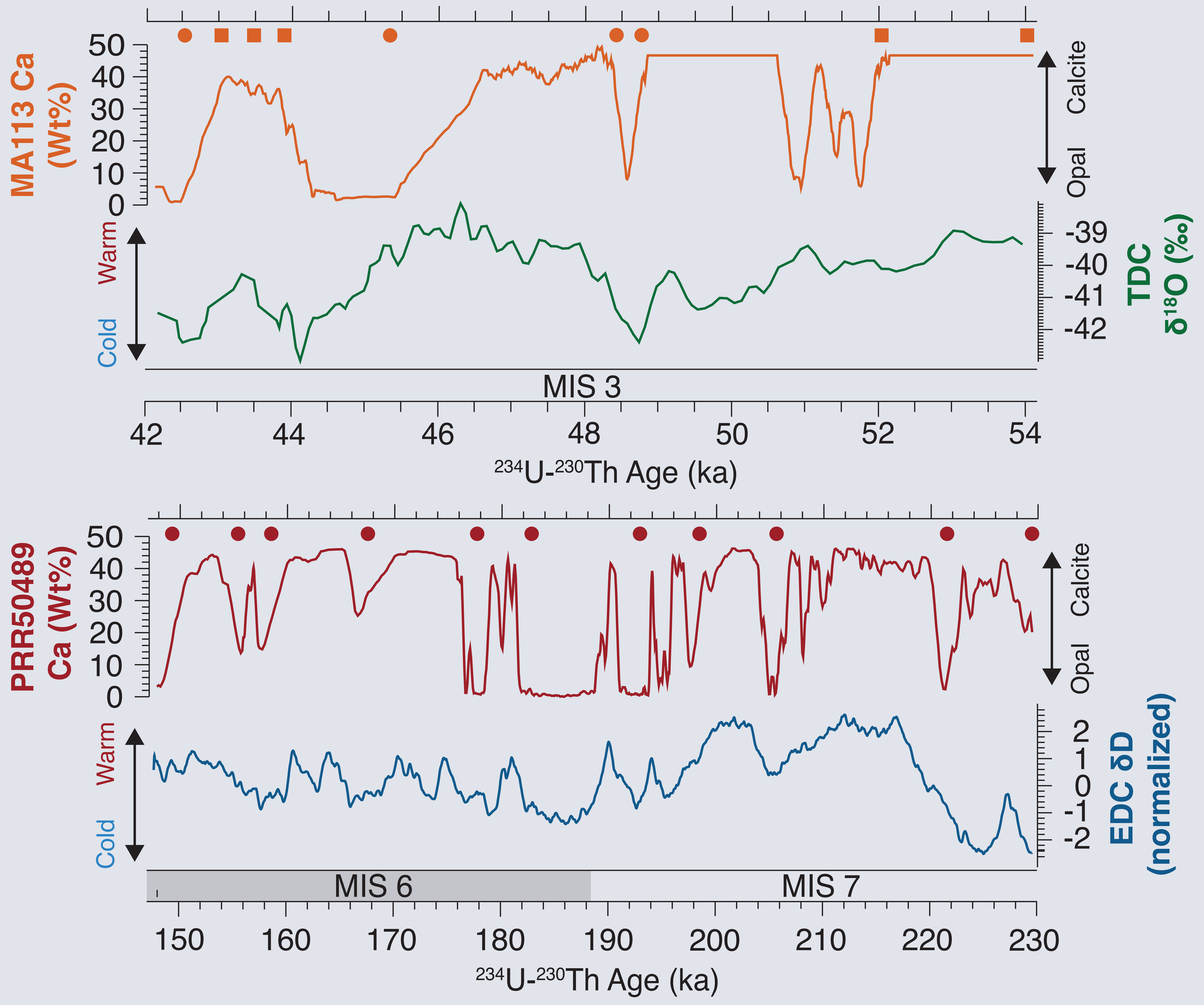


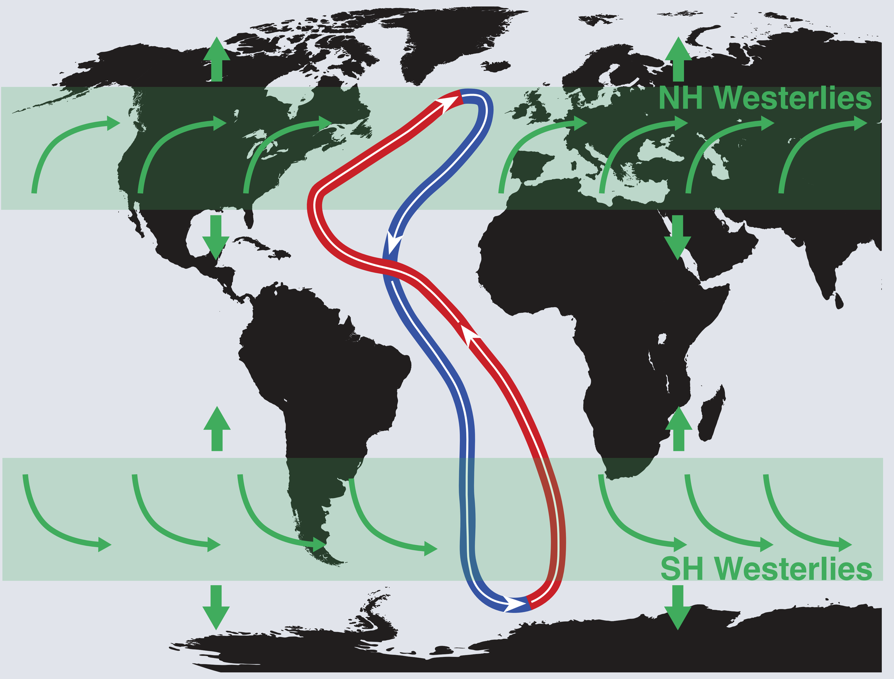
^{234}U-^{230}Th dates of individual opal-calcite layers (black markers, above) inform Bayesian models[1] of age versus depth (e.g., red envelope, above).



Opal-calcite timeseries (above) decribe mineral transitions through time.

4. Synchrony with Climate Cycles

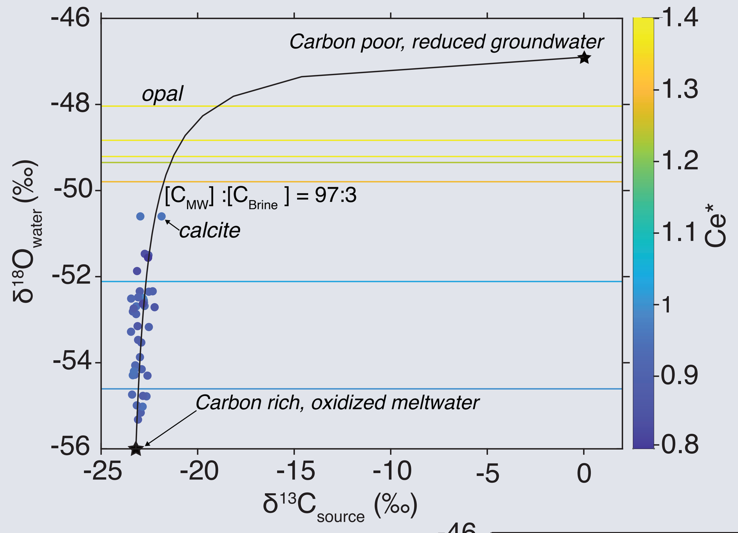




(above) Feedback between Atlantic Meridonal Overturning Circulation (AMOC; red-blue curve) and westerly winds (green) cause millennial cycles in polar temperature and Southern Ocean upwelling.

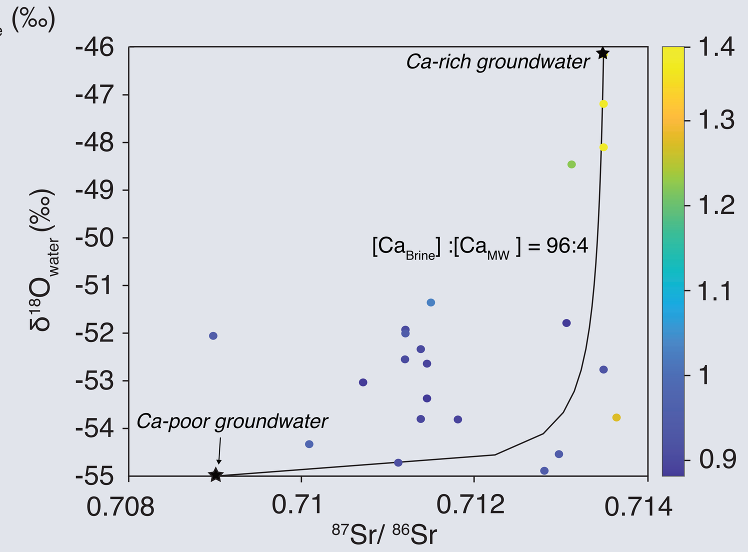
(left) Opal-calcite layers in chemical precipitates (orange and red curves) are synchronous with millennial cycles in Southern Hemisphere temperature (green and blue curves).

5. Stable Isotope Mixing Models



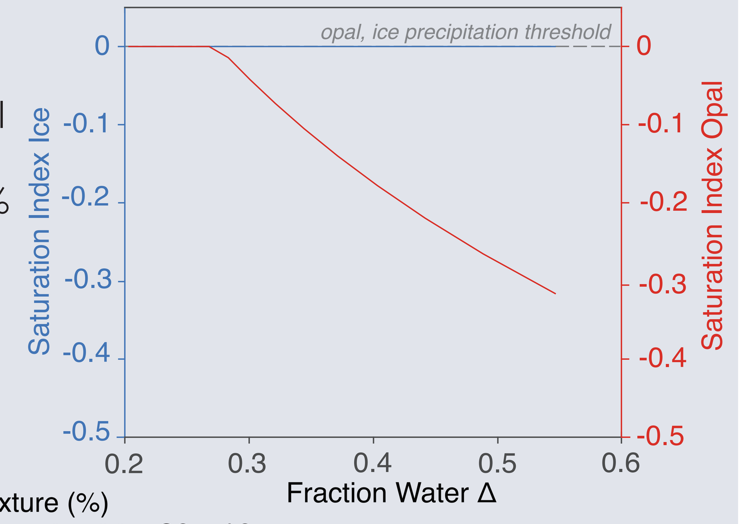
Stable isotope data suggest that opal (lines) and calcite (markers) were precipitated from marginal groundwater and interior meltwaters respectively.

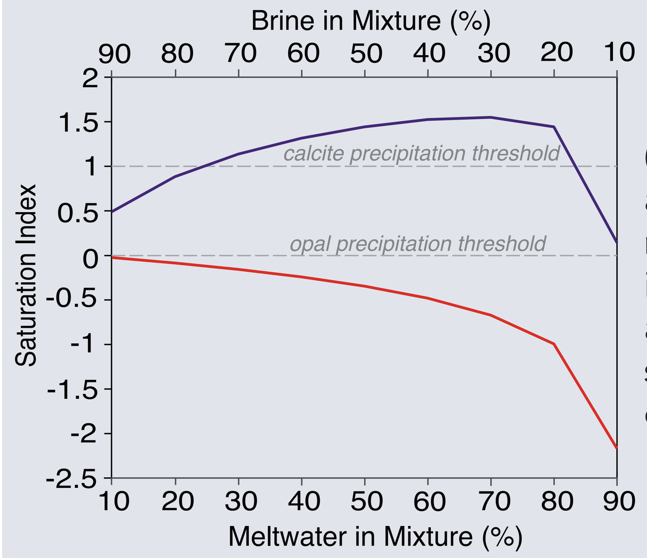
Two component mixing models in $\delta^{18}O_{water}$ versus $\delta^{13}C_{source}$ (above), and $\delta^{18}O_{water}$ versus $^{87}Sr/^{86}Sr$ (right) space support opal precipitation from a brine and calcite precipitation from a glacial meltwater.



6. Opal-Calcite Formation Models

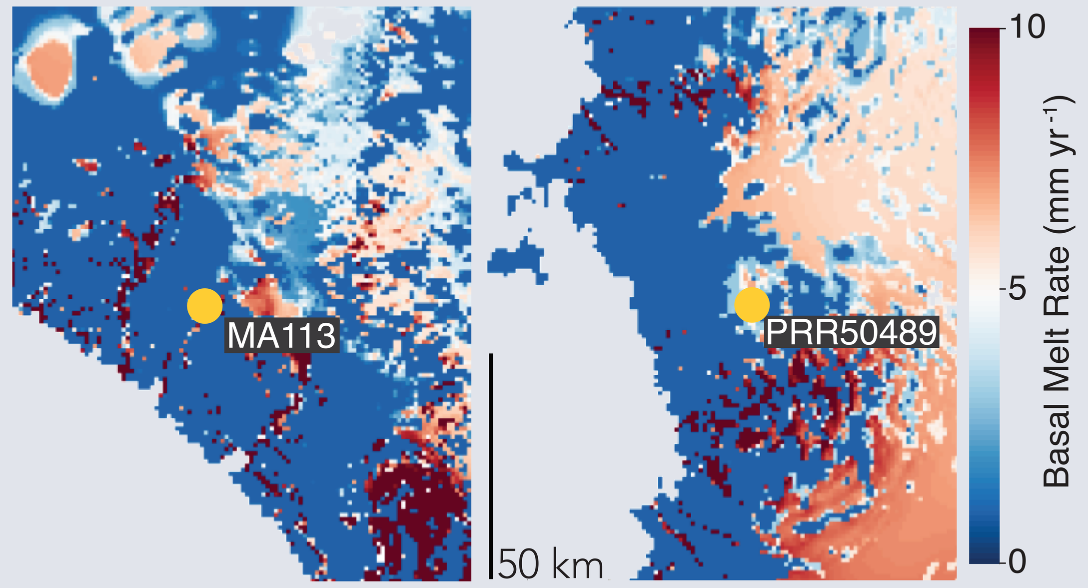
(right) Simulation of freezing of a subglacial brine results in opal precipitates after ~70% of brine is frozen. A lack of carbon in the brine prevents calcite precipitation.

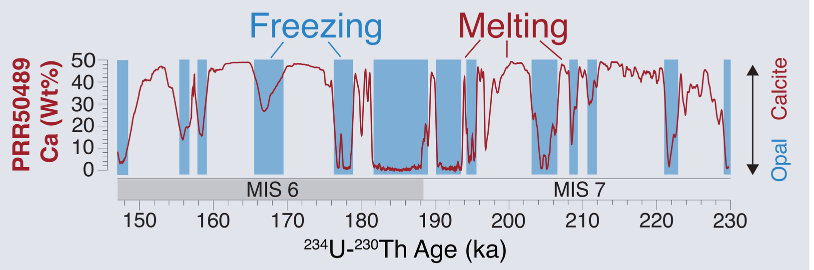




(left) Simulation of the admixture of glacial meltwater with brine results in calcite precipitation across a wide range of mixing scenarios. Dilution prevents opal precipitation.

7. Subglacial Hydrologic Connectivity

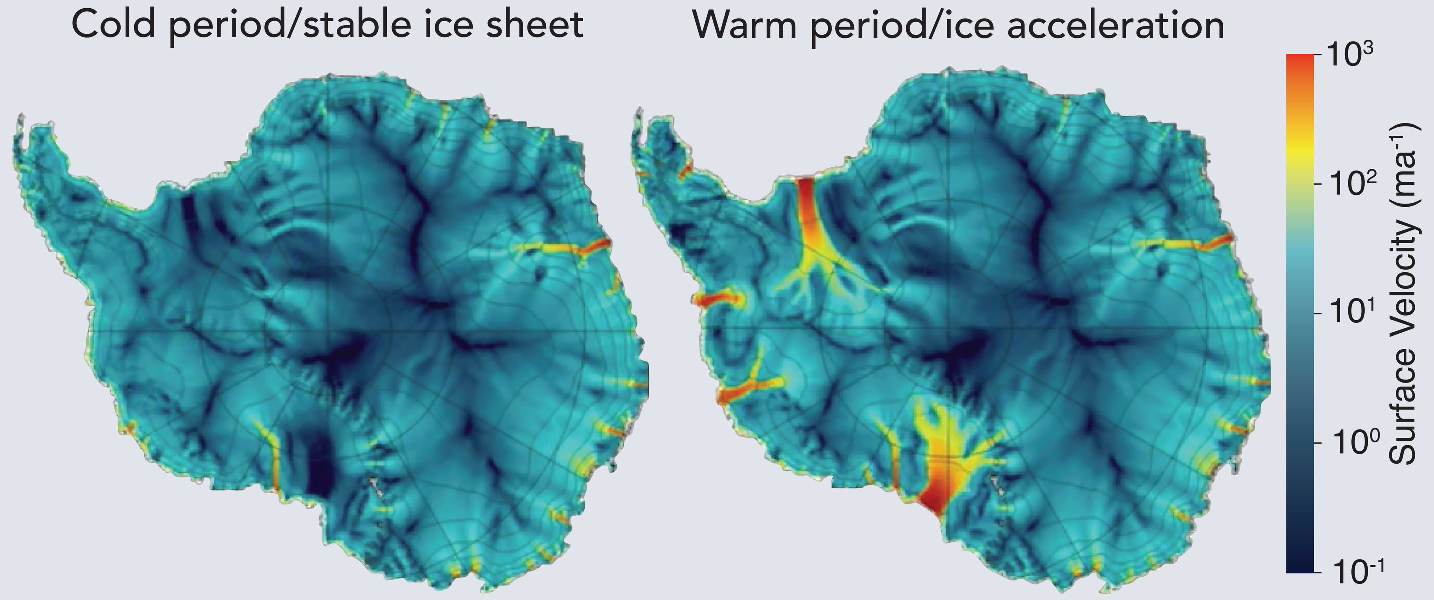




(left) Modeled subglacial melt rates of the modern Antarctic ice sheet[2] show that precipitate collection locations are within 10 km of the boundary between basal freezing and melting.

(above) We hypothesize that opal-calcite transitions represent subglacial freeze-flush cycles triggered by the migration of this hydrologic boundary.

8. Millennial-Scale Ice Sheet Response



Ice Sheet models[3] predict a millennial-scale ice velocity response, where millennial cold periods (left map) lead to marginal stability and millennial-warm periods (right map) lead to ice acceleration and thinning.

We hypothesize that periods of ice acceleration drive basal shear heating and lead to enhanced hydrologic connectivity (see section 7).

9. Conclusions

Opal-calcite transitions in subglacial precipitates result from millennial-scale cycles in basal hydrologic connectivity caused by an ice dynamic response to Southern Ocean temperature change.

10. Acknowledgements

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11. References

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3. Golledge, N. R. et al. Antarctic contribution to meltwater pulse 1A from reduced Southern Ocean over-turning. Nat. Commun. 5, 1–8 (2014).

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