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Modeling Antarctica's contribution to sea-level rise during the Last Interglacial and the future: differing roles of oceanic versus atmospheric warming

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A hybrid ice sheet-shelf model with freely migrating grounding lines is extended by accounting for surface meltwater enhancement of ice shelf calving; and the structural stability of thick, marine-terminating (tidewater) grounding lines. The ice model is coupled to a high-resolution atmospheric model with imposed and simulated ocean temperatures, and applied to past and future climate scenarios. When forced by greenhouse gas and orbital forcing representing the Last Interglacial (LIG; 130 to 115ka), the model simulates an Antarctic global mean sea-level contribution of up to +5m, in agreement with observed estimates. Most of the ice sheet response is driven by circum-Antarctic oceanic warming, rather than atmospheric warming, implying meridional overturning ocean dynamics were an important factor in the timing of Antarctic ice sheet retreat. A long, coupled climate-ice sheet simulation through the entire LIG shows that two peaks in sea level (early and late in the interglacial) are possible, but depend on the timing of Southern Ocean warming relative to local insolation maxima.

Using the same atmosphere and ice-model physics used in the LIG simulations, future simulations are run following RCP2.6, 4.5, and 8.5 greenhouse-gas scenarios extended to the year 2500 CE. Ocean temperatures in each scenario are prescribed from offline simulations using the NCAR CCSM4 with 0.5º ocean resolution. As expected, the magnitude and rate of Antarctic ice sheet retreat are highly dependent on which future greenhouse gas scenario is followed, but even the lower emission scenarios produce an Antarctic contribution of several meters within the next several centuries. Once atmospheric CO_2 concentrations exceed 2x preindustrial levels, we find that hydrofracturing by surface melt on ice shelves can trigger large-scale ice sheet retreat, regardless of circum-Antarctic ocean warming. Hence, unlike the LIG, atmospheric (not ocean) warming has the potential to become the primary mechanism driving future retreat of the Antarctic ice sheet. In simulations without atmospheric warming, we find small amounts of ocean warming can still produce large-scale retreat of the West Antarctic Ice Sheet, although the timescale of ocean-driven retreat is slower than atmospherically driven retreat.

In sum, these results suggest past Pleistocene episodes of Antarctic ice loss were primarily driven by Southern Ocean warming, which in itself has serious implications for future commitment to sea-level rise given current rates of ocean heat uptake. However, we also find that atmospheric warming and surface melt on ice shelves (driving hydrofracturing and ice shelf breakup) will take over as the dominant driver of future Antarctic ice loss if greenhouse gas emissions continue unabated, making the LIG and other Pleistocene interglacials poor mechanistic analogues for future sea-level rise.