Climatic Thresholds for WAIS Retreat: Onset of Widespread Ice Shelf Hydrofracturing and Ice Cliff Calving in a Warming World

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The loss or thinning of buttressing ice shelves and accompanying changes in grounding zone stress balance are commonly implicated as the primary trigger for grounding line retreat, such as that observed in Amundsen Sea outlet glaciers today. Ice-shelf thinning is mostly attributed to the presence of warm ocean waters beneath the shelves. However, climate model projections indicate that summer air temperatures could soon exceed the threshold for widespread meltwater production on ice-shelf surfaces. This has serious implications for the future stability of ice shelves, because they are vulnerable to the propagation of water-induced flexural stresses and water-aided crevasse penetration, often referred to as 'hydrofracturing'. Once initiated, the rate of shelf loss through hydrofracturing can far exceed that caused by sub-surface oceanic melting, and could result in the complete loss of some buttressing ice shelves, with marine-terminating grounding lines suddenly becoming calving ice fronts. In places where those exposed (unbuttressed) ice fronts are thick enough (>900m), deviatoric stresses can exceed the strength of the ice, and the cliff face will fail through brittle processes leading to rapid calving like that seen in analogous settings on Greenland such as Jakobshavn and Helheim.

Here we explore the implications of hydrofacturing and subsequent ice-cliff collapse in a warming climate, by parameterizing these processes in a hybrid ice sheet-shelf model. Model physical parameters controlling sensitivity of surface crevasse penetration to meltwater and ice-cliff calving rate (a function of cliff height above the stress-balance threshold for brittle failure) are based on observations of calving in analogous settings, and model performance relative to observed mass loss and paleo sea-level estimates. Including these processes and exploring a range of atmospheric and ocean climate forcing scenarios, we find the potential for major future WAIS retreat if global mean temperature rises more than ~2ºC above preindustrial. We also find that strict mitigation, with net negative carbon emissions initiated ~2060 substantially reduces the magnitude and rate of long-term WAIS retreat. In simulations following a 'worst case' RCP8.5 scenario, the model produces rates of equivalent sea level rise that would be measured in cm per year by the end of this century. Importantly, parameterized Antarctic calving rates at thick ice fronts are not allowed to exceed those observed in Greenland today. This may be an overly conservative assumption, considering the very different spatial scales and physical settings of Antarctic outlet glaciers like Thwaites. Clearly the potential for mechanical/brittle processes to deliver ice to the ocean, in addition to viscous and basal processes, needs to be better constrained through more complete, physically based model representations of calving.