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Damage accelerates ice shelf instability and mass loss in Amundsen Sea Embayment

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Pine lsland Glacier (PIG) and Thwaites Glacier (THW) in the Amundsen Sea Embayment are among the fastest changing outlet glaciers in West Antarctica. Over the last decades both glaciers have accelerated, retreated and thinned rapidly and if these changes continue, a sufficient weakening or loss of their ice shelves may result in marine ice sheet instability with substantial grounding line retreat and large consequences for global sea level. Yet, assessing how much, how fast the ice in the Amundsen Sea Embayment will change, remains a major uncertainty.

In this study, we use time series of multi-source satellite imagery (i.e. Landsat, Sentinel-1, Sentinel-2, Aster, Cryosat) to show the rapid development of damage areas on the PIG and THW ice shelves that appear crucial to the future of both glaciers, but are not included in current models of their retreat. These damage areas consist of highly crevassed areas near the grounding line and of open fractures that contain dense ice melange within the shear zones of both ice shelves. The observed damage compromises the integrity of both PIG and THW ice shelves, similar to the preconditioning of the shear zones of Larsen B prior to its collapse.

To assess the importance of the damage in the shear zones, a continuum damage model (CDM) was coupled to the BISICLES ice sheet model. The model was applied on an idealized marine ice sheet geometry following the MISMIP+ setup which has strong similarities to PIG conditions. Several time-dependent simulations were carried using the CDM-BISICLES model with different ocean-induced melting and damage parameterizations. In this framework, several damage scenarios were implemented by locally enhancing damage in the shear zone at the grounding line.

The model results highlight the importance of damage in the shear zones as driver for ice shelf instability as they precondition the ice shelves with structural weak zones. The model results also indicate that damage enhances thinning at the grounding line, in the shear zones and of grounded ice upstream. Finally, the model shows a speedup of the glacier tongue as a result of the damage, which results in an increase in strain rate and in velocity gradients across the shear zone similar to the increasing velocity gradients across PIG and THW observed by satellites since 1992.

The damage also has an important impact on the modeled grounding line retreat as the enhanced damage scenarios in the model initiate a grounding line retreat equivalent to quadrupling the oceanic melting near the grounding line from 25 to 100 m/year. This illustrates that weakening these glaciers at their most vulnerable locations is a very effective way of introducing grounding line retreat, increased ice flux and hence mass loss.

The combination of these satellite observations and model results suggest that damage processes are key to ice shelf stability, grounding line retreat, and future sea level contributions from Antarctica. Moreover, they underline the need for incorporating damage processes in models to improve sea level rise projections.