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Damage state and damage change assessment from remote sensing observations at Antarctic ice shelves

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The increasing contribution of the Antarctic Ice Sheet to sea level rise is linked to reductions in ice shelf buttressing, compounded by their thinning, weakening and fracturing. Ice shelf shear zones that are highly crevassed and with open fractures are first signs that these shear zones have structurally weakened. The weakening of shear zones by this damage results in speedup, shearing and further weakening of the ice shelf, hence promoting additional damage development. This damage feedback potentially preconditions these ice shelves for disintegration and enhances grounding line retreat, and is considered key to the retreat of Pine Island Glacier and Thwaites Glacier as well as the collapse of Larsen B. Although damage feedbacks have been identified as key to future ice shelf stability, it is one of the least understood processes in marine ice sheet dynamics. Furthermore, the amount of damage and its changes is yet to be quantified.

Quantifying damage efficiently and accurately is a challenging task due to the highly complex surface of Antarctica, the variations in viewing-illumination geometry, snow or cloud cover and the variable signal-to-noise levels in satellite imagery (e.g. speckle in SAR). As a result, efforts to detect damage from remote sensing are usually limited to regional studies or limited in spatial resolution, thus only identifying large rifts. Or alternatively when used to support models or machine learning techniques, mapping fractures is often done manually, with several shortcomings. Lastly, there has been little to no effort to map the changes of damage state over regional areas.

In this study we construct an Antarctic wide damage and damage change assessment from an automated approach that includes high resolution features, with regional focus on identified weak ice shelves. We apply the radon transform technique to detect damage from both optical (Sentinel-2) and SAR (Sentinel-1) imagery in the past 5 years (2015-2020). The radon transform has been demonstrated to be efficient in detecting along-flow features and also to be used for complex flow patterns with a wide range of crevasse orientations. By using two remote sensing sources, we overcome the stated challenges that relate to the respective individual sources.

In our damage assessment we are able to distinguish shallow surface crevasses from large rifts, and identify mode I (opening; tensile) and mode III (shearing) fractures. With this, we can clearly identify weak ice shelves from our results, such as Pine Island and Thwaites glacier, where the damage area in the shear margins has grown substantially over the years. The changes in mode I and mode III fracture patterns observed on these ice shelves provide additional insights in the development of shear zone. Lastly, we show a good agreement in fracture pattern retrieved from

optical and SAR imagery, and the complimentary application of SAR to detect fractures under snow cover.