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Glaciers on the northern Antarctic Peninsula are more sensitive to temperature change than precipitation change

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Glaciers peripheral to the Antarctic ice sheet are projected to make a large sea level contribution over coming centuries. However, there is high uncertainty in future contributions, because increased precipitation may offset future surface melting from higher air temperatures. Whether or not this will be the case depends on whether air temperature or precipitation is the primary control on mass balance. To investigate this, we examine glacier-climate relationships during the Holocene by bringing together geomorphology, well-constrained glaciology, a local, highly-resolved ice core record and numerical ice-flow modelling.

James Ross Island, NE Antarctic Peninsula, preserves a rare, detailed record of Mid-Holocene glacier and ice-shelf interactions in an area of contemporary rapid warming, glacier recession and ice shelf collapse. Geological evidence shows that, following deglaciation after the LGM, ice sheet configuration on Ulu Peninsula was similar to present by $\sim$6 ka. During the Holocene, a 10 km readvance of Glacier IJR45 on Ulu Peninsula, James Ross Island, is documented by a large boulder train from the glacier to a prominent moraine, which post-dates 4–5 cal. ka BP. Ice core records indicate that the period 2–5 ka BP was $\sim$0.5°C warmer. This was also a period of ice-shelf absence. This implies that any readvances at this time must have been driven by increased precipitation, and that the glacier is more sensitive to precipitation than air temperature.

A high resolution numerical flowline model was used to relate glacier fluctuations to climate. Our modelling strategy uses flow parameters tuned to the present day to reproduce observed glacier extent, volume and velocity as closely as possible. Sensitivity tests of $\pm$ 20% were carried out on key variables. A 1°C decrease in mean annual air temperature was sufficient to force a 10 km advance of IJR45. In contrast, a $\pm$20% change in mean annual precipitation was sufficient to force only a 2 km difference in glacier length. By driving the model with ice core climate data, we found that glaciers on Ulu Peninsula remained largely stable during the Mid-Holocene. From 2–5 ka, simultaneous ice-shelf collapse and a small amount of glacier recession occurred during the 0.5°C warming. During a period of rapid cooling starting 2 ka, the ice-shelf reformed and IJR45 advanced to its maximum Holocene position. Despite aggressive scaling of precipitation with temperature, we were unable to force a glacier advance during the warmer mid-Holocene. Following climatic amelioration starting 600 years ago, the glacier receded to its most recent stable position. Twentieth century warming resulted in ice-shelf collapse and regional glacier recession, thinning and acceleration.

Like many glaciers around the Antarctic Peninsula, IJR45 shows high sensitivity to atmospheric air temperatures and low sensitivity to precipitation, meaning that advance during a warm period is unlikely. Our study indicates that forecast increases in precipitation are unlikely to significantly offset melt-induced glacier recession. Consequently, the currently observed trends of glacier recession, thinning and acceleration will most likely continue throughout the next century.