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Understanding ice sheet evolution to avoid massive sea level rise instead of experiencing it (Louis Agassiz Medal Lecture)

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With unabated climate warming, massive sea level rise from the melting of ice sheets in Greenland and Antarctica looms at the horizon. This is unfortunately an experiment that we can afford to run only once. Satellite and airborne sensors have significantly helped reveal the magnitude of the mass balance of the ice sheets, where the changes take place, when they started, how they change with time and the nature of the physical processes controlling them. These observations have constrained the maturation of numerical modeling techniques for projecting changes in these ice sheets, including the coupling of ocean and ice sheet models, yet significant uncertainties remain to make these projections directly policy relevant and many challenges remain. I will review the state of balance of the ice sheets as we know it today and the fundamental processes that will drive fast ice sheet retreat and sea level change: ice-ocean interaction and iceberg calving. Ice-ocean interaction are dominated by the wind-forced intrusion of warm, salty, subsurface waters toward the ice sheet periphery to melt ice from below at rates orders of magnitude greater than at the surface. In Greenland, these rates are difficult to observe, but model simulations indicate rates of ice melt along vertical calving faces of meters per day, along with undercutting of the ice faces. Constraining the temperature of the ocean waters from high resolution models and observations, however, remains a significant challenge. I will describe the progress we have made in addressing one major issue which is the mapping of fjord bathymetry around Greenland to define the pathways for warm waters. In Antarctica, the rates of melt are measured from remote sensing data but averaged over long periods, so that we are dependent on in-situ observations to understand the interaction of ocean waters with ice within the sub-ice-shelf cavities. I will describe progress made in mapping the bathymetry of the ice shelves and how the results have impacted our understanding of these interactions. In terms of calving, there is a range of processes acting upon the glacier and ice shelf faces, proceeding from the surface and mostly from below, that are still not sufficiently well explored. I will discuss processes elucidated in Greenland (undercutting and rotation of ice blocks near floatation) and those that are not well known in Antarctica.