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Atmospheric rivers drive summer Greenland Ice Sheet melt through enhanced radiative and turbulent energy fluxes

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The Greenland Ice Sheet (GrIS) has experienced increased mass losses since the turn of the 21st century and has become the largest contributor to global sea level rise. Several recent episodes of intense GrIS melt occurred during periods of enhanced moisture transport over Greenland by atmospheric rivers (ARs). Recent studies have found that summer ARs promote widespread GrIS surface melt, with particularly strong melt occurring when strong ARs impinge upon the west coast of Greenland.

In this study, we examine the physical mechanisms underpinning the GrIS melt forced by ARs. Focusing on strong ARs affecting western Greenland during summer, we first assess the characteristic changes to the surface energy balance that occur during these events. We then analyze the local- to synoptic-scale atmospheric processes and land-atmosphere interactions that drive these anomalous energy fluxes. We employ a number of observational, model, reanalysis, and satellite-derived datasets for these analyses, including Programme for Monitoring of the Greenland Ice Sheet (PROMICE) station observations, the Modèle Atmosphérique Régional (MAR) regional climate model, MERRA-2 and ERA5 reanalyses, and CERES SYN1deg data.

We find that the odds of anomalous warm events at low-elevation PROMICE stations – with spikes in temperature, specific humidity, and wind speed – increase significantly in the presence of strong ARs. Specifically, we classify strong “AR90+” days as those with ARs whose vertically integrated water vapor transport exceeds the 90th percentile of the local climatology. These AR90+ events are found to force GrIS surface melt through complex, spatially varying changes to the surface energy balance. In the region of the ice sheet where the AR90+ makes “landfall”, clouds reduce net shortwave radiation and increase net longwave radiation at all elevations. Highly anomalous turbulent fluxes of sensible heat contribute to intense melt in the low-elevation ablation zone, with latent heat fluxes also contributing. These turbulent fluxes are enabled by enhanced wind speeds which are, in turn, generated by an anomalous synoptic-scale pressure gradient and an enhanced local thermal contrast between the ice sheet and surrounding atmosphere. Finally, we find that AR90+ events in northwest Greenland trigger melt remotely in eastern Greenland through a distinct “warm, clear, and windy” weather regime induced by downsloping flow.