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The Impact of Large-scale Flow Direction on the Formation of a Glacier Boundary Layer: Two LES Case Studies

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The mass balance of mountain glaciers needs correct assessment for several applications, e. g. sea level rise estimates, catchment hydrology, and natural hazard warnings. It results, at any point on a glacier, from energy, mass, and momentum fluxes at the glacier-atmosphere interface. However, surface fluxes on glaciers are highly heterogeneous in space and time.

To learn more about the processes leading to the spatial surface flux structure over a glacier surface, we employ large-eddy simulations with the WRF model at a horizontal grid mesh size of 48 m over the Hintereisferner, an approximately 6 km long valley glacier in the Austrian Alps. For model evaluation purposes, we use, besides our permanent measurement framework, four turbulence flux towers located on along- and across-glacier transects which were maintained in August 2018 on the glacier surface. Simulations were conducted for two case studies, namely one day with synoptic flow from the South-West (SW), and a day with synoptic flow from the North-West (NW). Comparison with the observations suggests that the model is able to reproduce the larger-scale flow structure and the local processes over the ice surface.

On the SW day, thermally-induced flows dominate the near-surface wind patterns and a stable boundary layer forms above the ice surface due to the alignment of the katabatic glacier wind with the larger-scale flow. Under these conditions, the glacier surface is exposed to horizontal cold-air advection. However, on the NW day, the local terrain leads to the formation of a gravity wave with severe turbulence. The resulting cross-glacier flow erodes the glacier boundary layer, and the glacier ice experiences horizontal warm-air advection. In both cases, the model simulates the complex flow structure on different length scales that affect the vertical and horizontal exchange processes over the glacier surface and the local heat advection during the daytime. The spatial sensible heat flux pattern is strongly connected to the horizontal wind speed, wind direction, and TKE. The experiment suggests a major impact of the large-scale flow structure and the flow modification by the underlying terrain. Our model setup is able to resolve the relevant scales and is therefore a valuable tool to gain insight on the surface fluxes over truly complex, heterogeneous terrain.

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