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How do patchy snow covers affect turbulent sensible heat fluxes? – Numerical analysis and experimental findings

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The surface energy balance of a snow cover significantly changes once the snow cover gets patchy. The substantial progress in knowledge about the surface energy balance of patchy snow covers is a mandatory requirement to reduce biases in flux parameterizations in larger scale meteorological or climatological models.

The aim of this project was to numerically improve energy balance calculations late in the melting season when the spatial variability of turbulent fluxes is especially high owing to the complex feedback between bare/snow-covered areas and the atmosphere above.

In order to account for the feedback between the atmosphere and the patchy snow-cover we calculated three-dimensional air temperature and wind velocity fields with the non-hydrostatic atmospheric model ARPS for an idealized flat test site initialized with different snow distributions and atmospheric conditions. The physics-based surface process model Alpine3D has been forced with these atmospheric fields close to the snow surface in order to resolve the small-scale spatial variability. We further initialized the model with atmospheric fields above the blending height as a reference case.

The numerical analysis shows that for simulations initialized with fully-resolved atmospheric fields below the blending height, turbulent sensible heat fluxes are up to 50 W/m^2 larger than for calculations forced without resolved atmospheric fields. This difference in turbulent sensible heat fluxes over snow increase with increasing number of snow patches and decreasing snow-cover fraction. This is mainly attributed to an increase in the mean near-surface air temperature over snow due to horizontal and vertical exchange processes induced by the heterogeneous land-surface.

We used flux footprint estimations to analyse turbulence data measured during three ablation periods in the Dischma valley (Switzerland). This fundamental theory was deployed for eddy-covariance measurements revealing the origin of the measured turbulence as a function of the measurement height, atmospheric stability and wind speed. For patchy snow covers with flux footprints larger than the fetch distance, the observed turbulence is typically recorded as a combination of the turbulence over snow and the turbulence over the adjacent bare ground. These conditions were observed in the upper Dischma valley at the end of the melting period for a small snow cover fraction (< 30 %). The strong influence of the bare ground on the heat exchange over snow leads to much smaller measured heat fluxes than calculated in the physics-based one-dimensional snow model SNOWPACK. We show that at least two eddy-covariance measurements in different vertical heights and a snow cover mask to detect the fetch distance are required to clearly separate the turbulence over snow and the turbulence over the adjacent bare ground. Using the footprint technique turbulent sensible heat fluxes towards the snow patch significantly increase by this separation. This approach will allow an improved parametrization of turbulent heat fluxes over patchy snow-covers in larger-scale energy balance models.