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Local surface heterogeneity and terrain drive disagreement between measured and modeled fluxes in the cloud-free Arctic stable boundary layer

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Our physical understanding of boundary-layer processes, particularly under the long-lived stable conditions of the polar night, is limited. In these weak-wind stable boundary layers, the exchange of energy, momentum, and matter, can be dominated by submeso-scale motions on scales larger than those of classical turbulence, which have been found to violate assumptions of local similarity concepts.

We investigated (1) whether the magnitude of non-local flux contributions, possibly arising from submeso-scale motions in concert with terrain, is systematically connected to certain boundary-layer states and flow directions, and (2) to what extent non-local forcings impact turbulent heat fluxes as well as the local surface energy balance including advection.

Data were collected during the NYTEFOX (NY Alesund TurbulencE Fiber-Optic eXperiment) field campaign 2020 at the scientific AWIPEV Arctic station in Ny-Ålesund, Svalbard at the end of polar night. Non-local influences were detected and quantified by comparing the measured sensible heat flux from sonic anemometry to the flux modeled from local first-order closure using temperature profile observations from fiber-optic distributed sensing. The spatial structure of the time-variant flow and of the horizontal advection were computed from a unique set of observations from a large horizontal fiber-optic distributed sensing array spanning hundreds of meters.

First results indicate an influence of cloud cover with stronger non-local flux contributions during clear skies causing an increased radiative cooling of the surface. Additionally, such contributions were generated and/or guided by the heterogeneous terrain in the source area of the incoming flow. Steep mountain slopes caused very cold katabatic currents and, hence, promoted vertical decoupling. This resulted in stronger non-local impact on the local fluxes, causing large disagreement between modeled and measured sensible heat fluxes. The conditions featuring large non-local flux contributions were also associated with large magnitudes of horizontal advection of sensible heat.

Advection, as well as conditions that promote strong surface-based inversions, appear to cause an increased violation of the assumption of local similarity in the Arctic weak-wind stable boundary

layer.