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Using in-situ measurements of ice water content to characterize the cloud radiative effect of Arctic cirrus

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The radiative energy budget in the Arctic undergoes a rapid transformation compared to global mean changes. Understanding the role of cirrus in this system is vital, as they interact with short- and long-wave radiation at the top of the tropopause, aside other indirect radiative effects through heterogeneous processes and interaction with humidity. Between autumn and spring, the presence of cirrus can be decisive as to a net gain or loss of radiative energy in the polar atmosphere. To improve modelling capabilities with respect to cirrus, their well observable radiative effect needs to be linked to the occupied atmospheric volume and microphysical properties, accessible through in-situ measurements.

In an effort to derive radiative properties of cirrus in a real scenario in this sensitive region, we use in-situ measurements of ice water content (IWC) performed during the POLSTRACC aircraft campaign in the boreal winter and spring 2015/2016 employing the German research aircraft HALO. A large dataset of IWC measurements of mostly thin cirrus at high northern latitudes was collected in the upper troposphere and also frequently in the lowermost stratosphere. From this dataset we selected vertical profiles that sampled the complete vertical extent of cirrus cloud layers. These profiles exhibit a vertical IWC structure that will be shown to control the instantaneous radiative effect both in the long and short wavelength regimes.

We perform radiative transfer calculations with the UVSPEC model from the libRadtran program package in a one-dimensional column between the surface and the top of the atmosphere (TOA), taking as input the IWC profiles, as well as the state of the atmospheric column (temperature, humidity, trace gases) at the time of measurement, as given by ECMWF IFS and CAMS products. In parameter studies, we vary the surface albedo and solar zenith angle in ranges typical for the Arctic region, we find the strongest (positive) radiative forcing of cirrus over bright snow, whereas the forcing is mostly weaker and even ambiguous over the open ocean in winter and spring. The vertical IWC structure over several kilometres in the vertical affects the irradiance at the TOA, at times by means of symmetrically or asymmetrically distributed effective radiative layers. A strong heating rate profile within the cloud drives dynamical processes and may contribute to the thermal stratification at the tropopause.

Our case studies highlight the importance of a detailed treatment of cirrus clouds for estimations of the radiative energy budget in the Arctic. Furthermore, as they still rely on various assumptions regarding ice crystal microphysics, they provide a path to further substantiate the results using recent observations from the dedicated DLR lead HALO mission CIRRUS-HL on cirrus in high latitudes.