Investigating Arctic Clouds over Sea Ice from Airborne Passive Microwave Observations

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Clouds are critical in the Arctic's water balance and energy budget. Especially the liquid water path (LWP) modifies the cloud's radiative properties and affects the surface energy balance. However, only a few observations of LWP over sea ice exist from ground-based microwave radiometers, which are highly sensitive to liquid cloud emission. In contrast, microwave radiometers onboard polar-orbiting satellites provide a high temporal and spatial coverage of the Arctic sea ice region. However, variations of sea ice and snow properties, often poorly known in the central Arctic, partly mask the cloud signal. Physical retrievals inferring consistent surface and atmospheric states enable the separation of these contributions.

This study presents LWP over Arctic sea ice derived from the Microwave Package (HAMP) onboard the HALO aircraft during the HALO-(AC)³ campaign (March-April 2022) in the Fram Strait and Central Arctic. The 25-channel nadir-viewing microwave radiometer HAMP spans two water vapor bands (22 and 183 GHz), two oxygen bands (50 and 118 GHz), and atmospheric windows at 31 and 90 GHz. We employ an optimal estimation framework to derive a consistent geophysical state, including sea ice, snow, atmosphere, and hydrometeors. The retrieval inverts the sea ice-atmosphere forward operator consisting of sequential simulations with the Snow Microwave Radiative Transfer (SMRT) and Passive and Active Microwave Radiative Transfer (PAMTRA) models.

We evaluate the representation of sea ice and snow emission simulated with SMRT under clear-sky conditions using reference data from HALO's suite of instruments, including a water vapor differential absorption lidar, cloud radar, dropsondes, and infrared/visual cameras. HAMP's LWP sensitivity and accuracy are quantified using synthetic retrievals. We analyze spatial LWP variability under diverse surface and atmospheric conditions, such as warm air intrusions, by applying the retrieval to cloudy HALO transects. These observations enhance the understanding of Arctic clouds and improve the interpretation of passive microwave satellite data in polar regions.