INVESTIGATING MICRO-PHYSICAL PROCESSES IN ARCTIC MIXED-PHASE CLOUDS USING CLOUD RADAR DOPPLER SPECTRA

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The structure of the Arctic boundary layer is closely related to low-level stratiform clouds (Sedlar and Tjernström, 2009). These clouds modify the boundary layer where they reside by modifying radiative fluxes, generating turbulence, and vertically redistributing moisture. Across the Arctic, low-level clouds have been found to be present 40-70% of the time (Shupe *et al.* 2011; Nomokonova *et al.* 2019), and often to be mixed-phase. However, the processes that lead to the commonality and persistence (from hours to several days) of these clouds are not well understood. The Svalbard archipelago lies in the warmest part of the Arctic and is influenced by relatively large mean transport of moisture and heat from the lower latitudes, and a large variability in this transport. Moreover, the coastal fjord environment exhibits large variations in surface properties (glaciers, seasonal snow cover, and open water) as well as orography. These features modify the local boundary layer and the associated clouds. The aim of our work is to get a more detailed understanding of the dynamics and the processes in Arctic mixed-phase clouds and the interaction between the clouds and their environment using a combination of instruments operating at the French-German Arctic Research Base AWIPEV in Ny-Ålesund, Svalbard.

The corner stone of our study is a frequency modulated continuous wave 94 GHz cloud radar installed at the AWIPEV station from June 2016 to October 2018 within the frame of the Arctic Amplification: Climate Relevant Atmospheric and Surface Processes and Feedback Mechanisms $(AC)^3$ -project. The high vertical (4 m in the lowest layer) and temporal (2.5 sec) resolution allows for a detailed description of the structure of the cloud. To supplement the radar measurements, a ceilometer is used to aid the detection of liquid inside the cloud, and the liquid water path is estimated using a microwave radiometer. We take advantage of synergistic approaches for classifying hydrometeor phase (i.e. Cloudnet). An objective algorithm for identifying persistent low-level mixed-phase clouds based on Cloudnet products has been developed. For evaluating the coupling of the cloud to the surface in a temporally continuous manner, a new method based on microwave-radiometer and surface observations has been developed and evaluated through comparison with simultaneous radiosonde observations. Persistent low-level mixed-phase clouds were found to be present at the site 23% of the time (Gierens *et al.* 2019) demonstrating the relevance of this cloud regime also in the complex coastal environment of Svalbard. Furthermore, the cloud occurrence and properties were found to be influenced by large scale wind direction as well as the local wind conditions in the fjord and the coupling of the cloud to the surface.

To study micro-physical processes we investigate selected case studies of persistent mixed-phase clouds occurring above the AWIPEV station using height-resolved Doppler spectra of the 94 GHz cloud radar. The hydrometeor phase and possible micro-physical processes can be identified from the Doppler spectra with the support of auxiliary data under certain conditions, e.g. sufficient super-cooled liquid and ice to allow radar detection is required. In many previous studies the spectrum width as well as the bimodality of the spectra have been used as indicators for mixed-phase volumes. However, higher moments of the spectra have rarely been utilized for Arctic mixed-phase clouds. Similar to Kalesse *et al.* (2016), we find features in the skewness profiles that relate to changes in the partitioning between liquid and ice. On the

8th of January 2018 a mixed-phase cloud was present above AWIPEV for 5.5 hours. At cloud top, where liquid is abundant, the skewness is small or positive as the liquid is dominating the radar signal (positive Doppler velocity indicating downwards motion). Lower in the cloud, owing to the growth of the ice particles, ice starts to dominate the signal and skewness turns negative. Approaching the cloud base, skewness is decreasing again as the liquid droplets become smaller and smaller. Interestingly, the mean reflectivity profile (black solid line in Figure 1) is almost constant with height for most of the cloud layer despite the rapid growth of ice particles. Yet, higher radar reflectivity is associated with more ice. Figure 1 illustrates the relationship between skewness and reflectivity in the vertical profile for the 8th of January 2018 case.

Based on understanding how certain processes represent themselves in the Doppler spectra, we are building an understanding on how the moments of the spectra, especially skewness, can be used for interpreting micro-physical processes. This is necessary to allow statistical analysis of the 2.5-year cloud radar data set to study micro-physical processes and how these processes are modulated by the clouds environment.

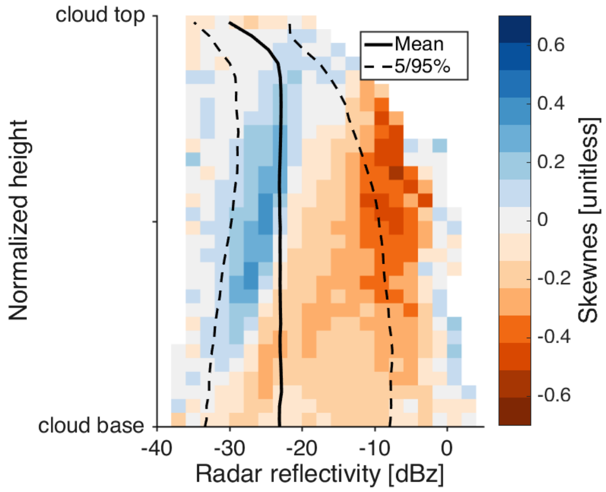

Figure 1. The solid and dashed black lines show the mean as well as 5 and 95 percentiles of radar reflectivity at each height, respectively. The color indicates the mean skewness of each normalized height-reflectivity bin. When skewness is positive (negative), the radar signal is dominated by super-cooled liquid (ice). Positive Doppler velocity indicates downwards motion.

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