Interpretation of cloud radar Doppler spectra in Arctic mixed-phase clouds: evaluation using co-located in situ measurements

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Low-level mixed-phase clouds occur frequently in the Arctic and are known to be important for the surface energy balance while not well represented in climate models. Our work aims to gain understanding of how features of the cloud radar Doppler spectra can be used to evaluate micro-physical processes in mixed-phase clouds (MPC). We used vertically pointing cloud radar (94 GHz) observations carried out at the Arctic Research Base AWIPEV in Ny-Ålesund, Svalbard. We further utilized in situ cloud observations taken by the holographic imager HOLIMO that was deployed on a tethered balloon during the Ny-Ålesund Aerosol Cloud Experiment (NASCENT) [1]. The tethered balloon was operated directly next to the radar installation allowing for the direct characterization of the hydrometeors within the radar volume over several hours, spread over the course of several days with varying cloud conditions. To test the interpretation of features of the cloud radar Doppler spectra, we have both evaluated radar moments on a statistical basis against other long-term remote sensing observations, as well as performed detailed case studies taking advantage of the co-located in situ measurements.

In the cloud top liquid layer of shallow MPCs, we found features in the Doppler spectrum skewness profiles that relate to changes in the partitioning between liquid and ice, similarly to the case study by Kalesse et al. [2]. To allow a statistical evaluation, an algorithm to detect the positive-turning-negative skewness profile, describing the change from liquid- to ice-dominated radar signal when moving downwards from cloud top, was developed. The skewness feature was found in 60% of the persistent low-level MPCs identified in the 2.5-year data set. We further evaluated the occurrence and variation of the skewness feature in combination with other radar parameters, the liquid water path, and cloud top temperature. Our investigation suggests that close to cloud top, ice depositional growth is likely impacting skewness and that Doppler spectrum skewness can provide insights into the early stages of precipitation formation.

To facilitate the comparison of the cloud radar and in situ measurements, we used the Passive and Active Microwave radiative TRAnsfer tool (PAMTRA) [3]. Synthetic cloud radar Doppler spectra were produced based on in situ measured particle size distributions and compared to the corresponding radar measurements. In the first analyses, habit-dependent mass- and area-size relations from the literature have been used to model the fall velocity and scattering of ice particles based on the measured particle size distributions. PAMTRA allows including multiple hydrometeor populations, making it possible to include the full variety of observed ice particle habits simultaneously as well as testing how different hydrometeors contribute to the observed Doppler spectrum. We find that the main challenges for obtaining closure between HOLIMO and the cloud radar are the different sampling volumes and the forward modeling of complex ice particles. In particular, low concentrations of larger ice particles cause a strong radar signal but are not representatively sampled by HOLIMO due to the several orders of magnitude smaller sampling volume. Furthermore, the simple approach for describing the ice particle properties for scattering and fall velocity modeling was not able to reproduce the observed Doppler spectrum when ice particle properties were highly variable, and we are considering ways to take advantage of the more detailed information on particle structure available from the holographic imager measurements.

With increasing complexity of the cloud scene, the interpretation of the cloud radar Doppler spectra becomes increasingly challenging. In such cases, the detailed description of hydrometeor properties provided by HOLIMO shows its value to guide the evaluation of the radar Doppler spectra. The work presented contributes to the understanding of how the features of the cloud radar Doppler spectra, and the moments of the spectra, can be used for interpreting micro-physical properties and processes in MPCs. Moreover, by using the radar forward operator we will also be able to evaluate model simulations of MPCs directly in the observational space.

References

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