ARM CLIMATE RESEARCH FACILITY

Observed Relations Between Snowfall Microphysics and Triple-Frequency Radar Observations

Research Highlight

Recent theoretical and observational studies indicated that triple-frequency measurements (e.g., combining Ku, Ka, and W band) bear the potential to derive important snowfall microphysical parameters like median mass diameter, fractal dimension, or particle habit. These observations further revealed that naturally occurring snowflakes exhibit scattering signatures that are in some cases consistent with spheroidal particle models (e.g., T-Matrix approach) and in others can only be explained by complex aggregates. However, direct comparisons with in situ observations were missing, which are needed to validate the predicted link between snowfall properties and triple-frequency signatures.

Kneifel et al., 2015 analyzed collocated, vertically pointing triple-frequency (X, Ka, and W band) radar observations from the recent deployment of the AMF2 during the Biogenic Aerosols Effects on Clouds and Climate (BAECC) field campaign that took place in Hyytiälä, Finland, between February and September 2014. Three snowfall cases from February 2014 were selected that covered light to moderate snowfall rates with transitions from heavily rimed snow to open-structured, low-density snowflakes. The comprehensive set of snowfall in situ instruments at the ground provided snowfall properties like bulk snowfall density, particle size distribution, terminal velocity, and particle morphology. The collocation of triple-frequency and in situ observations allowed for the first time to investigate whether triple-frequency signals can be related to key snowfall properties like characteristic size or habit of the snowflakes.

The observed triple-frequency signatures agree well with the previously published findings from airborne radar observations. Thanks to the better radar volume matching and a collocated microwave radiometer, the ground-based data could be better corrected for attenuation, and less spatio-temporal averaging was required. As a result, the triple-frequency data are less noisy compared to the airborne data and revealed an unexpected richness of details of the triple-frequency signatures throughout the cloud. When the triple-frequency data are combined with other sensor information, e.g., temperature and humidity profile, liquid water path, or mean Doppler velocity, one finds the triple-frequency signals to be particularly related to cloud regions affected by riming (e.g., enhanced Doppler velocity and liquid water path) or aggregation (e.g., close to -15 C region).

The comparison of triple-frequency signatures from the lowest altitudes with the ground-based in situ measurements confirmed the expected relations: In the presence of large (>5 mm) snow aggregates, a bending away or hook feature in the triple-frequency space from the curve of classical spheroid scattering models is always observed. Rimed particles appear along an almost horizontal line in the triple-frequency space, which was not observed before. Interestingly, the observed riming signatures cannot be reproduced by any of the classical spheroidal approximations independent on the density used. However, the riming signature agrees closely with predictions from recent scattering simulations using realistically rimed aggregates calculated with the discrete dipole approximation (DDA) (Tyynelä and Chandrasekar 2014). The study also confirms conclusions of previous studies that neither currently available DDA data sets nor widely used spheroidal approximations are able to consistently reproduce all of the observed snowfall scattering signatures in the multi-frequency space. Therefore, a better understanding of the scattering properties is clearly needed in order to develop improved snowfall retrievals and to fully exploit the potential of triple-frequency radar measurements.

The triple-frequency data reveal that rimed and aggregate snowfall particles can be clearly distinguished in the triple-frequency space. The combination with a third frequency particularly avoids ambiguities between rimed and large aggregate particles present in commonly used dual-frequency systems (e.g., Ka/W band). The triple-frequency data allow a basic classification of the snowfall into low-density

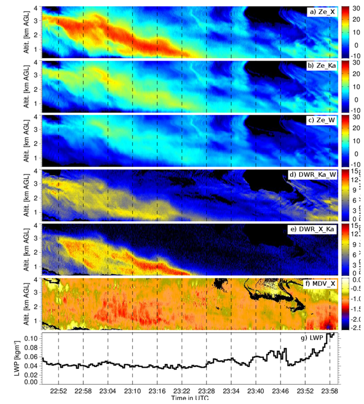

Figure 1. Light snowfall event observed during AMF2 deployment in Hyytiälä, Finland with vertically pointing X, Ka, and W band radars and collocated microwave radiometer. Although the measured snowfall rate on the ground was less than 0.4 mm/h, the few large fluffy aggregates (see Fig. 2) observed during the first half hour caused large differential scattering visible in the very different reflectivities measured at the three frequencies.

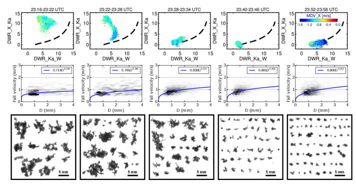

Figure 2. Comparison of triple-frequency reflectivity differences (DWR) from the lowest altitudes with snowfall properties observed by the ground-based in-situ sensors. The triple-frequency signatures transition from a “hook-shape” to an almost horizontal curve in accordance with a change of the snowfall particles from open-structured large aggregates to small, rimed particles.

aggregate snowfall and high-density rimed snowfall, which can be compared in the future e.g., with hydrometeor classifications based on polarimetric radar observations. Particularly, the high sensitivity to riming, allows to detect this process within clouds even under conditions where methods based only on Doppler velocity are difficult to apply (e.g., regions with high turbulence or strong vertical air motion). Triple-frequency observations allow not only to improve future snowfall retrievals but also provide a powerful new tool to study microphysical processes especially when combined with Doppler spectra and radar polarimetry.

Reference(s)

Kneifel S, A von Lerber, J Tiira, D Moisseev, P Kollias, and J Leinonen. 2015. "Observed relations between snowfall microphysics and triple-frequency radar measurements." Journal of Geophysical Research – Atmospheres, 120(12), doi:10.1002/2015JD023156.

Contributors

Stefan Kneifel, *McGill University*

Working Group(s)

Cloud Life Cycle