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Predicting Realistic Snow Shape for Improved Polarimetric Radar Simulations

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Radar Forward Operators (RFOs) bridge the gap between the physical properties of clouds and precipitation and the observed radar quantities. A significant source of uncertainty in RFOs arises from assumptions about the scattering properties of frozen and mixed-phase hydrometeors. Polarimetric RFOs often use simplified, homogeneous shape models. These cannot reflect the multifaceted structure of snow, which, however, significantly affects the polarimetric radar properties. This study explores the use of Discrete Dipole Approximation (DDA) scattering models to incorporate realistic shapes of snow particles to overcome this limitation. However, it is well-known that snow particles appear in a vast variety of habits, and it is not straightforward to assume one shape that fits it all. Conversely, operational weather models do not provide sufficient constraints to model ice particle shapes that unambiguously represent the generic internal ice microphysical assumptions (i.e., mostly just mass-size relation). The present study uses a cascade of progressively more detailed models that explicitly predict the shapes of ice crystals and snow aggregates to be used to model their radar multi-frequency (C, X, Ka, and W-band) polarimetric signature with DDA.

The core of the modeling framework is the shape-predicting, semi-Lagrangian, cloud model McSnow that takes the ICON atmospheric state and simulates the evolution of the microphysical properties of cloud and precipitation particles (mass, size, aspect ratio, rime fraction, melted fraction) as well as the number of monomers composing snow aggregates. By tracking the sequence of aggregation events that originated each aggregate, it is possible to reconstruct the properties of each monomer. This information can be used to simulate realistic aggregate shapes using a physically based aggregation model. This model reproduces the collision process with great detail and provides snowflake shapes that match the properties of the snowflake as they are modeled by McSnow.

Key questions of the present study that enhance the process understanding of cloud microphysics include: (1) To what extent do multi-frequency and polarimetric radar signatures of snow depend on the detailed shapes of the aggregates? (2) Can DDA improve over the T-matrix and provide a reliable representation of the scattering properties of snowflakes for use in RFOs? (3) Can a snow particle model be identified that represents polarimetric radar properties of snow for most weather scenarios, and what uncertainties are inherited in such generalized assumptions?

Presenting Author

Soumi Dutta

Email Address of Presenting Author

sdutta1@uni-koeln.de

Affiliation of Presenting Author

University of Cologne

Address of Presenting Author

Pohligstrasse 3, 50969, Cologne, Germany

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Author: DUTTA, Soumi (University of Cologne)

Co-authors: SEIFERT, Axel (Deutscher Wetterdienst); SIEWERT, Christoph (Deutscher Wetterdienst); ORI, Davide (Institute of Geophysics and Meteorology, University of Cologne, Cologne, Germany); MENDROK, Jana (Deutscher Wetterdienst, Offenbach, Germany); VON TERZI, Leonie (LMU, Munich); KNEIFEL, Stefan (Ludwig--Maximilians-Universität München); BLAHAK, Ulrich (Deutscher Wetterdienst)

Presenter: DUTTA, Soumi (University of Cologne)