Dual-frequency spectral radar retrieval of snowfall microphysics: a deep-learning based approach

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Better understanding and modeling snowfall microphysical properties and processes is a key challenge in atmospheric science, crucial for snowfall quantification, snowfall remote sensing, and weather prediction in general.

The use of meteorological radars for this intent has become quite popular, in particular through two approaches: the use of multi-frequency radar variables, and of radar Doppler spectra. Retrieving snowfall microphysics however remains a challenging task, due to the variability of ice crystals properties and atmospheric conditions, in addition to measurement errors and artifacts such as radars' imperfect calibration and beam matching.

We propose a novel approach to this problem, making the most of dual-frequency Doppler spectrograms while relaxing some assumptions on beam-matching and non-turbulent atmosphere. The technique is based on a two-step deep-learning framework inspired from auto-encoder models, which are generally used for dimension reduction purposes: an encoder maps a high-dimensional signal to a lower-dimensional “latent” space, while the decoder tries to recover the original signal from this latent space. In the proposed framework, dual-frequency Doppler spectrograms constitute the high-dimensional input, while the dimensions of the latent space are constrained to represent the snowfall properties which we seek to retrieve.

As a first step, a decoder neural network is trained to generate Doppler spectra from a set of microphysical variables, using simulations from the radiative transfer model PAMTRA as training data. In a second step, the encoder network learns the inverse mapping, from dual-frequency spectrograms to the microphysical latent space, and is trained directly on real data.

In comparison with classical methods, which provide a gate-to-gate inversion, the proposed framework allows to take into account the spatial continuity of the microphysics by using convolutions in the architecture of the models, thereby reducing the ill-posedness of the problem.

The method was implemented on X- and W-band data from the ICE GENESIS campaign that took place in January 2021 in the Swiss Jura. Comparisons with in-situ airborne data collected during the campaign allow for in-depth assessments of the performance of the algorithm, and preliminary analyses show satisfactory agreement for the different retrieved variables.