Why we need radar, lidar, and solar radiance observations to constrain ice cloud microphysics

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Abstract. Ice clouds and their effect on Earth's radiation budget are one of the largest sources of uncertainty in climate change predictions. The uncertainty in predicting ice cloud feedbacks in a warming climate arises due to uncertainties in measuring and explaining their current optical and microphysical properties as well as from insufficient knowledge about their spatial and temporal distribution. This knowledge can be significantly improved by active remote sensing, which can help to explore the vertical profile of ice cloud microphysics, such as ice particle size and ice water content. This study focuses on the well-established variational approach VarCloud to retrieve ice cloud microphysics from radar-lidar measurements.

While active backscatter retrieval techniques surpass the information content of most passive, vertically integrated retrieval techniques, their accuracy is limited by essential assumptions about the ice crystal shape. Since most radar-lidar retrieval algorithms rely heavily on universal mass-size relationships to parameterize the prevalent ice particle shape, biases in ice water content and ice water path can be expected in individual cloud regimes. In turn, these biases can lead to an erroneous estimation of the radiative effect of ice clouds. In many cases, these biases could be spotted and corrected by the simultaneous exploitation of measured solar radiances.

The agreement with measured solar radiances is a logical prerequisite for an accurate estimation of the radiative effect of ice clouds. To this end, this study exploits simultaneous radar, lidar, and passive measurements made on board the German High Altitude and Long Range Research Aircraft. By using the ice clouds derived with VarCloud as an input to radiative transfer calculations, simulated solar radiances are compared to measured solar radiances made above the actual clouds. This radiative closure study is done using different ice crystal models to improve the knowledge of the prevalent ice crystal shape. While in one case aggregates were capable of reconciling radar, lidar, and solar radiance measurements, this study also analyses a more problematic case for which no radiative closure could be achieved. In this case, simultaneously acquired in-situ measurements could narrow this inability to an unexpected high ice crystal number concentration.

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