Using higher radar moments to study ice clouds with vertically pointing cloud radars

More observations of ice clouds are required to fill gaps in understanding microphysical properties and processes. However, in situ observations by aircraft are costly and cannot provide long term observations which are required for a deeper understanding of the processes. Ground based remote sensing observations have the potential to fill this gap, but their observations do not contain sufficient information to constrain ice cloud properties unambiguously. This leads to high uncertainties of current retrievals of cloud properties. For vertically pointing cloud radars, usually only reflectivity and mean Doppler velocity are used for retrievals, some studies proposed also the use of Doppler spectrum width. In this study it is investigated whether additional information can be obtained by exploiting additional, higher moments of the Doppler spectrum such as skewness and kurtosis together with the slope of the peaks. For this, two main objectives are studied: (1) A consistent data set containing particle mass, area and size distribution as functions of particle size is presented based on in-situ aircraft observations of ice clouds obtained during the Indirect and Semi-Direct Aerosol Campaign (ISDAC) in Alaska 2008. Because particle mass cannot be directly measured by aircraft in situ instruments, a novel method to estimate the particle mass-size relation as a function of temperature is developed and successfully evaluated by combining aircraft in situ and radar observations. The method relies on a functional relation between reflectivity and Doppler velocity. Parameterizations of particle cross section area and particle size distribution are evaluated using lower and higher moments. (2) The presented data set is used as prior information to develop a retrieval based on optimal estimation theory and synthetic observations. To quantify the additional information higher moments can contribute to the retrieval, the degrees of freedom for signal are estimated. Eventually, the error characteristics of the retrieval solution is explored in order to assess the uncertainty of the retrieved ice cloud parameters.