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Retrieval of ice crystals' mass from ice water content and particle distribution measurements: a numerical optimization approach

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A new method to retrieve cloud water content from in-situ measured 2D particle images from optical array probes (OAP) is presented. With the overall objective to build a statistical model of crystals' mass as a function of their size, environmental temperature and crystal microphysical history, this study presents the methodology to retrieve the mass of crystals sorted by size from 2D images using a numerical optimization approach. The methodology is validated using two datasets of in-situ measurements gathered during two airborne field campaigns held in Darwin, Australia (2014), and Cayenne, France (2015), in the frame of the High Altitude Ice Crystals (HAIC) / High Ice Water Content (HIWC) projects. During these campaigns, a Falcon F-20 research aircraft equipped with state-of-the art microphysical instrumentation sampled numerous mesoscale convective systems (MCS) in order to study dynamical and microphysical properties and processes of high ice water content areas.

Experimentally, an isokinetic evaporator probe, referred to as IKP-2, provides a reference measurement of the total water content (TWC) which equals ice water content, (IWC) when (supercooled) liquid water is absent. Two optical array probes, namely 2D-S and PIP, produce 2D images of individual crystals ranging from 50 μm to 12840 μm from which particle size distributions (PSD) are derived. Mathematically, the problem is formulated as an inverse problem in which the crystals' mass is assumed constant over a size class and is computed for each size class from IWC and PSD data:

$$PSD.m = IWC$$

This problem is solved using numerical optimization technique in which an objective function is minimized. The objective function is defined as follows:

$$J(m) = \|PSD.m - IWC\|^2 + \lambda.R(m)$$

where the regularization parameter λ and the regularization function $R(m)$ are tuned based on data characteristics.

The method is implemented in two steps. First, the method is developed on synthetic crystal populations in order to evaluate the behavior of the iterative algorithm, the influence of data noise on the quality of the results, and to set up a regularization strategy. Therefore, 3D synthetic crystals have been generated and numerically processed to recreate the noise caused by 2D projections of randomly oriented 3D crystals and by the discretization of the PSD into size classes of predefined width. Subsequently, the method is applied to the experimental datasets and the comparison between the retrieved TWC (this methodology) and the measured ones (IKP-2 data) will enable the evaluation of the consistency and accuracy of the mass solution retrieved by the numerical optimization approach as well as preliminary assessment of the influence of temperature and dynamical parameters on crystals' masses.