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Atmospheric
Measurement
Techniques
Discussions

Interactive comment on "Pore structure 3-D imaging by synchrotron micro-tomography of graupel grains" *by* F. Enzmann et al.

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Reply to referee #3

The authors are grateful to the referee for his/her review and much appreciate for all comments elaborated. Our main replies and changes to be made to a revised manuscript are listed below.

Comment 1 – Terminology

We will provide a brief description in the Introduction of the formation process and differences between graupel and hail, thereby refrain from using the term "grain", and will ask an English native speaking atmospheric chemist to check grammar and word

choice.

Comment 2 – XMT and optical properties

We agree that the gas adsorption SSA cannot measure internal (disconnected) pores, yet these would obviously contribute to the optical properties of an ice particle. The exercise to determine the SSA by x-ray microtomography (XMT) has already been published by some of our co-authors on snow (Kerbrat et al. 2008), but is not in the primary focus of this study. We will add this conclusion to our related discussion. Modeling the optical properties of the ice particles from x-ray tomography data was in fact the original aim of the project when started. However, it became clear during the progress of the work as reported here, that this is not a trivial task. There is some more recent literature how to model multiple light backscattering on external and internal (porosity) surfaces, e.g. by Kaempfer et al., 2005; Randrianalisoa et al., 2006; Bänninger et al., 2008; and Lipinski et al., 2010. This approach is applicable in the domain of parameters only where the scattering of radiation can be considered in the approximation of geometrical optics. The ray-tracing approach will work therefore in case the size of the individual pores is minimum two orders of magnitude larger than the wavelength of the scattered light, but not when the diameter of the dispersed pore medium scatterers becomes inferior to the wavelength. However, the mean sizes of the pores we found with our graupel samples were in the same order of magnitude as the wavelength (few micrometers) and hence beyond the geometrical optics limit. For the latter case, a reliable radiative transfer model has to be derived from the Maxwell equations and Lorenz-Mie theory directly, neglecting the effects of dependent scattering for a first approximation. We are not aware yet of any literature report on such an approach to model light backscattering by multiple pores, and couldn't do it either. We will consider using an iterative solver based on the discrete dipole approximation once our new 600 node HPC will be available next year, with a dipole grid identical to the XMT voxel grid. Meanwhile we hope also that this article will help us to find a colleague willing to verify his new model development with our data. This implication will be made clearer in the revised manuscript.

Comment 3 – XMT data processing

We agree that thresholding is a subject of significant concern in XMT because the structural parameters thus deduced are highly dependent on a reliably determined threshold value, and this will be more detailed in the revised manuscript. Segmentation for 3D image (=tomogram) reconstruction was done by thresholding into the two classes (=features, like ice and air filled voids) as apparent from the two well-separated peaks in the x-ray attenuation coefficient histogram for the two-phase material. The peak at a lower attenuation coefficient is associated with air-filled voids (= pores), while the peak at a higher value is associated with the ice. No other phases contribute for overlapping threshold ranges as common in many materials, except influence of edge enhancement effect (see below). We will provide a plot of this histogram for a typical sample as an additional figure in the revised manuscript, from which it will become clear why visual estimation was deemed sufficient for an accurate threshold value determination. The thresholding for converting gray-scale images to binary images was performed on each sample tomogram separately. Sensitivity testing was performed manually by changing threshold parameters and finding an optimum by direct visual inspection of the plotting results in 2D and 3D with help of Amira/Avizo. Moreover, typical for monochromatic synchrotron XMT is an edge enhancement rather than a beam hardening effect in reconstructed cross-sectional slice images. This effect can be exploited additionally to separate phase boundaries and helps in segmentation (see slice figure). Main contribution to uncertainty in both surface and volume parameters at the time this study was performed was the problem of cutting segmented datasets by Amira as mentioned on p. 4771, line 15-20. More recently, this main Amira problem became obsolete, since object memory can be allocated without any restrictions (except of available RAM of the SMP computer). In principle, we use Amira mainly for visualization of features and determination of surface/volume by triangulation of the objects. Prefiltering calculations are done by homebrew Matlab codes and in part also by

ImageJ. Our "burning" algorithm has been described by Turek (1999) and was applied to volumes. Our approach is used commonly for fluid flow simulations in porous media. The maximum ball analysis was not applied, because absolute surface/volume ratios were deemed more important.

Conclusions between temperature history and the porosity of the samples will be much reduced at the benefit of more details about data collection and processing part of the manuscript.

We will work further on the visualization of the Figures, two drafts are attached below. The main problem is to reproduce the ice-air contrast calculated by the software on a printed paper which is not a trivial task. It is not surprising for as that XMT figures of graupel internal porosity are yet virtually absent in literature.

Technical Corrections

We agree with all technical corrections, thanks a lot for that! We will also clarify on the figure captions and scale bars as requested.

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Interactive comment on Atmos. Meas. Tech. Discuss., 3, 4761, 2010.

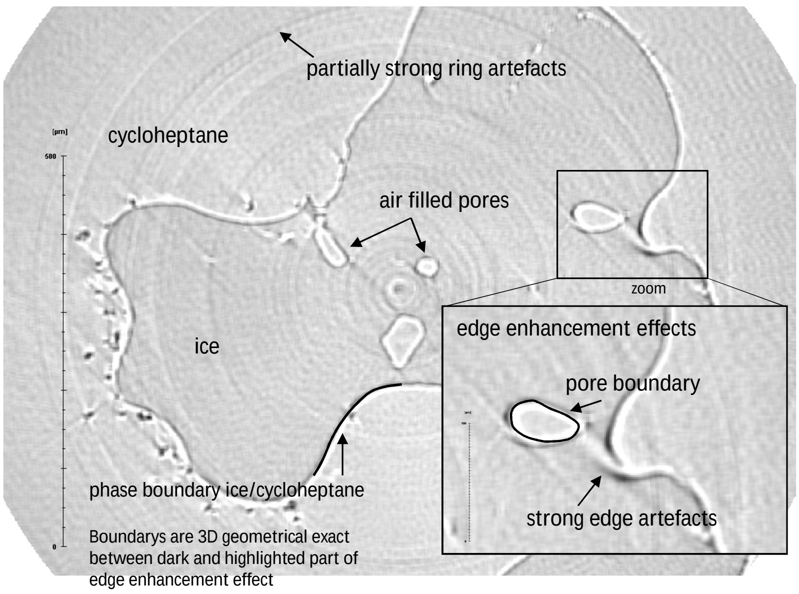

Fig. 1. 1: Unsegmented slice of the ice particle #1

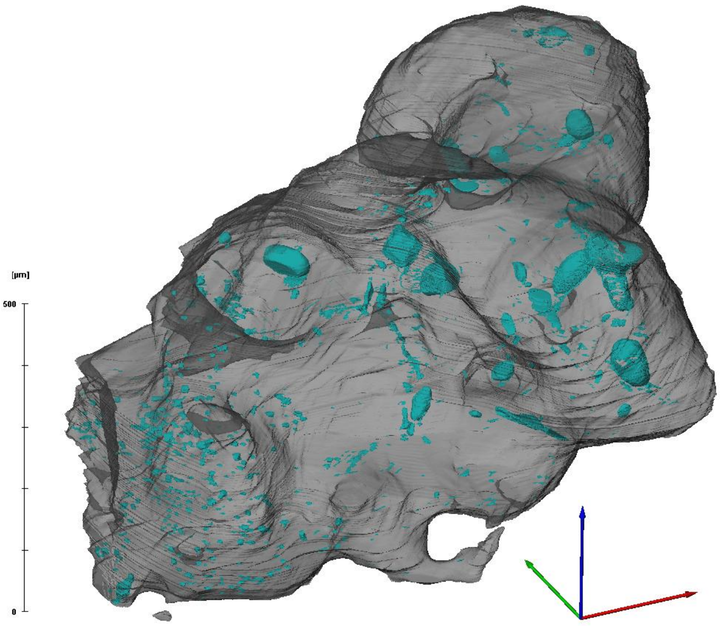

Fig. 2. 2: This figure will replace the figure 3a of the first version of our manuscript.