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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.

Anonymous Referee #3

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This manuscript describes a synchrotron-based micro computed tomography technique for examining porosity in atmospheric ice particles, something which has an important bearing on their optical properties. While the samples examined to date are few, this technique appears to hold promise and may lead to a better understanding of the bulk optical properties of graupel.

General Comments:

Although English is obviously the authors' second language, this Reviewer found the meaning generally clear and believes the manuscript requires some corrections to grammar and word choice rather than a complete rewrite (see Technical Corrections at the end of this review). This Reviewer otherwise agrees with the issues raised by

Reviewers #1 and #2, and will concentrate herein on additional points.

First, on terminology: The authors should provide a brief description in the Introduction of the formation processes and differences between graupel and hail, and should define terms including: (in)homogeneous ice crystals (4763/21...), ice cloud models (4763/27). Further to this point, it would be greatly appreciated if the authors could stick with the term "graupel" or "graupel particles", and refrain from using the term "grain". To the ice microstructure community, grain is synonymous with crystal, implying a homogenous solid having a single regular atomic structure. A particle, such as graupel, may contain multiple crystals. Hence, the word "grains" should be dropped from the title and replaced with "particle" in the manuscript.

Second, the discussion of the state of the art of micro computed tomography of snow (beginning on 4764) should be expanded to examine the meaning and appropriate measurement of specific surface area (SSA) as it pertains to optical properties. That is, gas adsorption SSA, while high resolution and quite useful for understanding the surface area available for heterogeneous chemical reactions, cannot measure internal (disconnected) pores, yet these would obviously contribute to the optical properties of a particle. In this sense, provided the resolution is adequate, XMT, while potentially more time consuming and expensive than IR and gas adsorption methods, may offer an advantage when the objective of a study is optical properties. Also in this section, a brief discussion of the work of Chen and Baker (2009, 2010) should be included, as it pertains not only to the use of XMT on snow but to the study of metamorphism, both isothermal and in a temperature gradient. The experimental setup described in Section 2.2, and the accompanying schematic (Figure 1) is reasonably detailed, and in some ways quite clever. The embedding of crystals in "an organic cyclohexane matrix" does need further explanation and description, however, and the term "shape metamorphism" needs to be explained (it appears here and in 4776/10). Perhaps the authors simply mean a change in shape of internal pores? The data processing section (2.3) requires clarification and more detail. In lines 4770/17-18, the authors say, “The very low absorption contrast between ice and air…” Other authors have shown good contrast between ice and air. Perhaps it was low here because of the low beam energy (10 keV)? Did the authors experiment with different beam energies? Also, the removal of noise (4770/19-20) needs to be explained in more detail. A noisy image will lead to overestimated porosity. One way around this is to consider only voids comprised of a certain number of voxels, with a basis given for the number selected. Thresholding is a subject of significant concern in XMT. The authors need to explain the thresholding method in more detail, and the steps taken to ensure that the threshold is set properly so that the resulting porosity is accurate. Line 4770/17-18 mentions “automatic gradient thresholding.” In line 4771/6-7, it says, “The optimum threshold was determined for each tomogram, and the mean for each class was finally applied to segment the images.” What are the classes? Does this mean that a thresholding value was chosen for each set of tomograms (i.e. each scan), and then the average value determined was applied to each? If so, was any sensitivity testing done to assess how much effect the choice of a different value made? Finally, what do the authors believe IS the uncertainity in surface area and volume? While this Reviewer has not used AMIRA, it does not appear as though it is ideal for this type of analysis. This leads us to wonder if the authors have tried using another 3D analysis tool. As with thresholding, this part of data analysis has a tremendous effect on the outcome. Hence, further details and a discussion of alternative approaches would be useful. Which grassfire (burning) algorithm as used? Was a maximal ball analysis attempted? (This might be a useful approach for semi-spherical pores.) This Reviewer has trouble reconciling the values given in line 4774/6-7 and 11-12, with those later in 4774/21-22 and 25. Should the former be total surface area and volume, rather than average?

Section 3.4 is confusing. In 4775/24-26, the authors state that the number of pores decreased during annealing, and that this indicated some loss of air from the sample. This would seem to suggest that temperature gradient metamorphism is taking place.

The temperature history of the samples and the potential for error in the resulting data

(>15% error attributed to the artificially created surface area discussed in Section 2.4 (4771/23-25) PLUS the uncertainty due to thresholding) make it premature to draw conclusions on the porosity of such particles from this work. However, it is a useful contribution as a techniques paper, provided the authors add more and higher magnification figures and a better discussion of the data processing steps.

Technical Corrections:

4763/2-3 Dynamics really isn't the right word to describe the characteristics of a size distribution.

4763/11 Remove "in" at least. Better yet, reword this sentence, or split it into two.

4763/19 Replace "with the case of" by "to"

4763/19 It is not clear which "These features" are. Do you mean opacity?

4763/21 What are "the asymmetry factors of inhomogeneous ice crystals"?

4764/1-2 This Reviewer agrees with Reviewer #2 that the last sentence of this paragraph is a stretch. It could be eliminated altogether.

4764/14 Replace "is not always justified in having" with "does not always give", although this Reviewer agrees that this statement requires some qualification, or else a diversion into stereology. Recommend rewording this statement.

4764/23 Replace "microstructure" with "microstructural"

4765/16 Its not clear to this Reviewer what "collector particles" are.

4765/20 Is "volume radius" the radius of a sphere of the same volume? Please define.

4765/25-26 The sentence regarding the weather is unclear as written. Replace "determined" with "defined". A "stable air mass" suggests zero horizontal wind. Do you perhaps mean a "stable boundary layer", which means no vertical wind (i.e. no convective mixing)?

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4766/4 Change “besides” to “beside”, and reword the rest of this sentence.

4770/9 Change “yields in” to “requires”

4774/10 Change “Like” to “As”

4774/11 Should “posed” be “possessed”?

4774/15 Change “neither” to “nor”

4775/4-8 The same thing is said twice here

4777/10 This sentence makes more sense if you remove “Even” 4778/2 Delete “already”

4778/4 Change “spheroid” to “spherical”

4778/21 Replace “If to compare with” with “From”

4778/23 Delete “then” and Change “fit to” to “have”

4779/4 Delete “(minutes?)”

4779/15 Change “already at the time” to “when”

4779/17 Change “is presently already reduced” to “has already been reduced”

4779/21 Change “used to collect” to “taken to preserve”

4780/1 Change “, therefore, allows, for example, studying” to “permits the study of”

4780/4 Change “shape delineation” to “morphological parameters”

4780/7 Change “pore structure statistics” to “microphysical processes”

Figure 2 – The two images should be presented at the same scale. Is the bottom image a plane cross section of the particle? If black areas represent air filled pores, what are white areas?

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Figure 3 – The text refers to “CLACE (particle) #1” and “CLACE particle #2” (Sections 3.2-3.3). Please label the figure clearly so that this is no doubt which these are. Also, the top image appears to contain a pore (black) which is partially external to the particle (top surface). How can this be?

Figure 4 – It is hard to compare the two images. Is the scale the same in each? Are the two images before and after images of the same particle, taken from the same perspective? Is this CLACE particle #1?

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