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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Growth of ice particle mass and projected area during riming" *by* E. Erfani and D. L. Mitchell

Anonymous Referee #1

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Review of "Growth of ice particle mass and projected area during riming" From Ehsan Erfani and David L. Mitchell

Overview: The authors investigate the riming effects in frontal cloud systems in the sierra Nevada, on coefficients of mass-size and area-size relationships. They used a dataset (referenced as SCPP in the paper) described in Mitchell et al. 1990 and also used in Mitchell (1996) and Baker and Lawson (2006) who are often cited in recent scientific studies. In the third section, SCPP dataset is compared to a recent mass-diameter fitted curve. This fitted m-d relation was developed with mass and diameter derived from CPI images using the area-mass relationships given in Baker and Lawson 2006, and a part of the SCPP dataset (call cold habit). CPI images represent ice particles for temperature colder than -20°C in cirrus and anvil clouds during the aircraft measurement of the field campaign SPARTICUS. Ice particle of the SCPP dataset are

divided in two parts: rimed and unrimed particles. Authors shows that rimed particles are heavier than unrimed particles for a same size. Furthermore, ice particles of the SCPP dataset are stored by size bins where average mass are calculated and compared to the EM16 mass-diameter relationship, authors conclude that the EM16 fitted curve is representative of mass-size relationships of ice particles in clouds for temperatures between -40°C and -20°C. Section 4 is dedicated to the effects of riming on mass-size and area-size coefficients. In a first step the study is performed with heavily rimed and unrimed dendrites where mass-size relations are calculated for each type of dendrites. It shown that heavily rimed dendrites have around twice time the mass of unrimed dendrites in average and that power of m-d relations are similar for both types of dendrites: 1.78. Hence, authors found that riming process affects only α in m-d power law and that increase of α is a proxy to study the evolution of the riming process. Then a riming factors is defined as the ratio the mass of the ice crystal less its mass when it is unrimed divided by the difference between the mass of the ice crystal when it is a graupel and its mass when it is unrimed. Then weighted average ratio are calculated between unrimed dendrites and graupel and between hexagonal columns and graupel. Calculated ratios are: 3.3 and 2.4 respectively, which define the maximum mass of dendrites habit and columns habit such mmax=3.3*mu (u for mass of unrimed crytals) and mmax=2.4*mu, respectively. In section 5 authors provide fits of collision efficiency between ice crystals such (columns and plates) and supercooled droplets using data of WJ00. The work is done for different Froude number and Stokes number. Others references are used to avoid discontinuities in different regimes. Section 6 is dedicated to the calculation of the mass growth rate due to the riming process. To do this, results of section 5 are used. The method is applied for hexagonal plates and a droplet size distributions following a Gamma function. Results obtained show that dm/dt for riming increase with D of plates. Furthermore, for a same Liquid water content doubling mmd from 8 to 16 microns leads to times by 4 dm/dt. Note that a LWC of 0.05 g/m3 with mmd of 16 microns gives dm/dt of the same order than for a LWC of 2g/m3 and a mmd of 8microns. Increase mmd is more efficient than increase LWC

General comments: The topic of this study could be very useful for experimental and numerical simulations studies about physical processes of ice hydrometeors in clouds. However, I find that this work is not finalized and it could be improved with further investigations. Also it does not meet the basic criteria of ACP: does the study "represent a substantial contribution to scientific progress within the scope of Atmospheric Chemistry and Physics (substantial new concepts, ideas, methods, or data)" Authors shows only results for one type of ice crystals habits that the power of m-d stay constant during the riming. This result was already suggested in former studies which are cited in this study. Some results of the M90 dataset argue against the main results of this paper without being discussed. Also the M90 dataset is not appropriate to extend this kind of results for in-clouds habits conclusions, as it concerns only precipitated ice particles. Results should be take more cerfully. Section on area-size relationships should be strongly reconsidered as it based on no new experiments or numerical simulation data, there is only a discussion about older results which brings no new results. I recommend to rewrite this paper by keeping section five and developing section 6 for not only hexagonal plates but also hexagonal columns and dendrites habits (has these habits are used in this paper) while section 4 could be used to compare numerical results of section 6. Mass growth rate could be compared to the mass of unrimed ice crystals as a function of D, to confirm or not the experimental results who shows that power of m-D relation is constant during the riming process until the graupel formation. Moreover, it could be extended to a theoretical/numerical study on the riming factors as a function of time which could be useful for future studies with ground radar observations versus aircraft measurement. To finish this study could compare numerical results with experimental data as SPARTICUS and SCPP datasets.

Specific comments: P8, l3-l5: what kind of modification, is it possible to resume with few words? P9, l2: As the riming is the purpose of the paper. I suggest a figure with few examples of microprobe images to show each riming level of ice crystals who are studied. P9, l3: is it the ground temperature, or temperature are deduced using diagram (for example Pruppacher and Klet 1997; Magono and Lee 1966; Bailey and

Hallet 2009), then few explanations are expected. P9, l6 (P10, l10): CPI images doesn't give the mass of Ice crystals. Which approximation did you use to deduce the mass of ice crystals from CPI images? P11, l6-l11: Is there rimed particles in the cold habit and SPARTICUS fit? Or do you know if the ratio of rimed/unrimed particles are the same for both datasets in the comparison? If the ratio of unrimed and rimed particles are not equivalent, does it means that the fit curve is representative of ice clouds between -40°C and -20°C. "To summarize, it appears . . .. A realistic bulk estimates for ice particle masses in frontal clouds." A part of SCPP dataset is used to fit the curve of cold habit? Then what is the ratio of the SCPP dataset compared to SPARTICUS dataset in this curve fit? Because the conclusion is not surprising if the rate of SCPP dataset is significant compared to SPARTICUS dataset. P13, l3-l4: Watching the same table1 in M90, I can see that it is not true for needles and rimed needles. So it seems that it is not true for all ice crystals habit. P14, l4-l15: there is missing in your statistical analysis, the both dataset that you conclude are identical should have an equivalent ratio of rimed and unrimed ice particles. Especially if you want generalize your conclusions to all frontal clouds. P15-P16: Definition of mmax and αmax. mmax define the mass of one ice crystal when it can be considered as a graupel, as β is constant during the riming so α increase until m=mmax. After what you define a riming factor such R=(m-mu)/(mmax-mu). By looking the figure below, we can guess that mmax (αmax) is a function of D, as R. Maybe more investigations should be necessary (and/or maybe an application on the SPARTICUS dataset, or another dataset) to use R factors and understand how it quantify riming in clouds. P17, l16-l22: I think that BL06 study is also performed on the SCPP dataset!?

Technical corrections: Missing references for: P3, l6: Feng and Chang (1982) P4, l7: Fukuta and Takahashi (1999) P8, l6: Blohn et al. (2009) P9, l17: Magono and Lee (1966) P17, l8-l9: Baker and Lawson (2006) P23, l1-l14: a reference to Heymsfield and Westbrook 2010 is recommended. They also worked on the terminal velocities of ice crystals and improved Mitchell 1996 theory. Figures: Figure1a: mathematical Formula could be a plus. A curve fit for rimed and unrimed particle should be added. Figure2:

I recommend a plot of curves fit of rimed, unrimed dendrites and graupel. Figure 1 and 2: green curve and points are not visible enough. P6, l9: ice particle shapes are function of temperature and relative humidity (see Pruppacher and Klett 1997; Magono and Lee 1966; Bailey and Hallet 2009) P3, l20: "Mf = IWC times Vm"? P3, l14: NWS is not defined.

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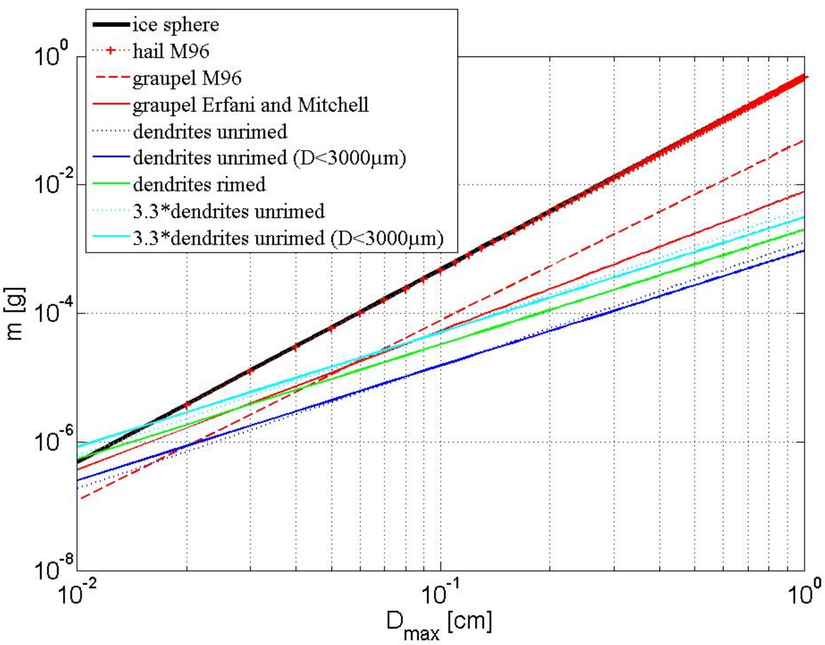

Fig. 1.