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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Evidence of ice crystals at cloud top of Arctic boundary-layer mixed-phase clouds derived from airborne remote sensing" *by* A. Ehrlich et al.

Anonymous Referee #1

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Evidence of ice crystals at cloud top of Arctic boundary-layer mixed-phase clouds derived from airborne remote sensing

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General Comments:

This paper discusses the vertical distribution of ice in mixed-phase stratiform cloud layers observed during the ASTAR campaign. Measurements of cloud top reflectance were compared with simulated reflectance in order to determine information on the vertical distribution of ice within these layers. Generally, this is a well written paper, and the work completed is easy to follow. As discussed in the following section, I am somewhat concerned about the originality of some of the major findings in this work, namely that it seems to me that the presence of ice crystals in the upper regions of mixed-phase clouds has been accepted as reality for quite some time. Although the methods used in this work are, to my knowledge, a new way of looking into this, it does not necessarily seem to me that the finding (ice near the top of mixed-phase stratiform clouds) is really that new. In the following section I've presented some comments on the scientific content of the work.

Specific Comments:

- As mentioned in the previous paragraph, I don't believe the finding of the presence of ice up to cloud top to be a new one. Numerous recent papers discuss similar features, including (but likely not limited to):

de Boer et al. (JAS, 2009): "Since the radar is most sensitive to larger ice crystals and likely misses small liquid droplets near cloud top, a question to address is whether the uppermost radar returns are indicative of cloud top. In-situ measurements from MPACE (McFarquhar et al., 2007) indicate that ice indeed extends throughout the mixed-phase layer to cloud top. Additionally, radar-estimated cloud-top heights were compared with those calculated from the CALIOP lidar on the CALIPSO satellite for two overpasses that occurred within 1 kilometer from Eureka. Both cases resulted in discrepancies of smaller than 30 meters, the resolution of the CALIOP instrument."

McFarquhar et al. (JGR, 2007): Figures 12-15 all indicate that there is ice present up to cloud top.

Shupe et al. (JAS, 2006): Figure 9 illustrates mean normalized ice water content of approximately 0.1 at cloud top for mixed-phase clouds over a year of data.

What worries me is that of these examples, two (McFarquhar and Shupe) are used in the conclusions section of the manuscript (p. 13822, lines 14-15) as examples of the "common vertical structure of ABM clouds" that this paper is trying to improve upon.

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I'm not sure that this work provides any new insight into the vertical distribution of over those papers. In fact, the following sentence states "Ice crystals are present within the entire cloud although liquid water droplets are dominant at cloud top"... I believe that this is what the Shupe and McFarquhar papers show as well.

- Since some of the work is justified by, and involves the use of in-situ ice measurements, I think it's relevant to include some discussion on the potential sources of error from these sensors. For example, the effects of shattering, icing (while within the super-cooled layer), etc.

- The use of the "ice volume fraction (IWP/TWP)" on page 13808 confuses me a bit. This does not really provide any useful information on the vertical distribution of ice and liquid, and does not provide very much information in terms of how the two phases interact. I would think it would make more sense to compare the IWC/TWC fraction throughout the cloud layer. This is still a "volume" estimate, and more clearly defines the extent of the volume used. In addition, it provides vertically resolved information.

- Although the authors state that the selection of particle shape does not have large impacts on the results of the simulations, it would be nice to include a quantitative analysis of this. Particularly, since particle effective size is a predetermined value, and particle growth rate and fall speed are both strongly related to particle shape, I would think that by default the particle shape would significantly alter the vertical distribution of particle effective size, resulting in changes in the simulated optical properties. Are there any measurements/observations that provide information on particle shape (CPI for example?)

- I'm not an expert in spectral reflectance measurements, and I believe that it would be nice to have further discussion on how particle sizes and number concentrations may effect the simulated optical properties. In particular, the assumption that the layer from 1200-1600 m is liquid only (p. 13810, lines 22,23) does not totally seem to agree with the measurements. Yes, in an absolute sense, there is far more liquid mass than ice mass, but there is ice mass present, and depending on the instrument used (lidar vs. radar for example), you are going to be sensitive to one or the other because of the wavelength used. Further discussion on the relative sensitivity of the SMART-Albedometer to the concentration and mass of the different particles would help to justify the assumption that the top of the cloud is liquid only.

- I'm not sure that I believe that large ice crystals are present in the upper portions of the cloud (p. 13816, line 22). This seems to not only counter radar observations, which show decreasing dBZ as you approach cloud top, but also physics. What keeps these large ice crystals from quickly falling to lower altitudes within the cloud? How do they stay around cloud top and not demonstrate a presence at lower altitudes? I think that these are very important considerations that need to be addressed before making a claim such as this. Discussion on other factors that may lead to the albedometer measurements would be helpful as well.

- The simulations with the additional ice near cloud top are interesting. The fact that placing the layer within the liquid or above it result in very similar solutions makes me wonder what would happen if the ice layer was distributed more evenly throughout the entire liquid layer…in other words, could different vertical distributions of ice concentration and size (maybe some that more closely match in-situ and remote sensing observations) possibly result in similar cloud top reflectances that match observations?

- What are the errors or possible nuances of using the polar nephelometer measurement? Could it be skewed towards liquid in regions where liquid mass dominates?

- On line 4 of page 13822, a mention of "homogeneous mixed clouds" is made. What is meant by this? This requires clarification. By nature, the liquid water content will be higher at the top of the cloud. Do you mean that the ice water content increases equally? This seems unphysical. Or, do you mean that the ice stays the same throughout the cloud layer? Again, this does not seem likely. Please clarify this statement!

- Also in this paragraph, the effects on the solar radiative cooling are discussed. How

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are these thought to compare to the longwave radiative effects? Are they important?

- I found the discussion of simulation of different nucleation processes somewhat lacking. It appears to focus on only evaporation freezing, while there are other nucleation processes that could lead to ice formation at cloud top. For example, condensation and immersion freezing (see: Khvorostyanov and Curry, 2004; Diehl and Wurzler, 2004; de Boer, 2009) would also lead to ice formation in the regions of strongest supersaturation. Also, it is mentioned that simulations neglecting evaporation freezing show ice crystals to be dominant at lower cloud layers only…Isn't that what the observations show? Ice dominating at lower levels, with smaller amounts of ice extending to cloud top?

Technical Corrections:

– I recommend the authors take some time to go through the manuscript and remove any unnecessary words. As an example, I've gone through lines 8-17 of page 13804…all words in double parentheses are suggested for removal:

"A simplified scheme of ABM clouds is presented by Harrington et al. (1999) in which ((the)) coexistence of ice and liquid water relies on the balance between the nucleation rate of liquid water droplets and ice crystals, ((the)) ice crystal growth rate, and ((the)) removal of ice nuclei by precipitating ice crystals. ((The)) persistence of updrafts responsible for ((the)) formation of liquid water droplets by condensation is ensured by radiative cooling at ((the)) cloud top and ((the)) heat release of the open sea. In this scheme liquid water droplet nucleation is most efficient within ((the)) updrafts at cloud top and exceeds the ice crystal nucleation rate. This process leads to the typical vertical structure of ABM clouds with a cloud top layer dominated by liquid water and an ice layer with precipitating ice crystals below (e.g. Pinto, 1998; Shupe et al., 2006; McFarquhar et al., 2007)."

– p. 13807, line 3: "to calculated" should be "to calculate" – p. 13807, line 11: recommend changing "have been observed" to "were observed" – p. 13808, line 11:

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“IWC” should be “LWC”? – p. 13808, line 16: recommend changing 1200-800m to 800-1200m, to stay consistent with earlier altitude references – p. 13808, line 16: recommend changing “amount of ice crystals” to “amount of ice mass” . . . the number of ice particles and the IWC are not necessarily correlated! – p. 13813, line 9: “cases matches” should be “cases match” – p. 13815, line 9: Figures are numbered incorrectly (8a and 8b should be 6a and 6b, I think?) – p. 13815, line 17: Again, figure numbered incorrectly (8b instead of 6b).

Additional References Cited:

de Boer, G., E.W. Eloranta, M.D. Shupe, 2009: Arctic Mixed-Phase Stratiform Cloud Properties from Multiple Years of Surface-Based Measurements at Two High-Latitude Locations, Journal of Atmospheric Science, 66, 2874-2887.

de Boer, G., An Improved Understanding of the Lifecycle of Mixed-Phase Stratiform Clouds Through Observations and Simulation, PhD Thesis, University of Wisconsin - Madison, Department of Atmospheric and Oceanic Sciences, May, 2009, 140 pp. (available online at http://lidar.ssec.wisc.edu/papers/papers.htm)

Diehl, K. and S. Wurzler, Heterogeneous Drop Freezing in the Immersion Mode: Model Calculations Considering Soluble and Insoluble Particles in the Drops, J. Atmos. Sci. 61(2004), pp. 2063-2072.

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Interactive Comment