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Interactive comment on "Rare temperature histories and cirrus ice number density in a parcel and one-dimensional model" *by* D. M. Murphy

Anonymous Referee #2

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General comment:
In this study ice crystal number concentrations inside cirrus clouds are investigated using a parcel model and a one-dimensional column model. For this purpose, the models are driven along trajectories including large-scale updrafts and temperature fluctuations. Different nucleation pathways are investigated, i.e. pure homogeneous freezing and competition between heterogeneous and homogeneous nucleation within the same environment. The results are compared with observations in order to explain the "shape" of the measured distributions in a concentration vs. temperature plot.

Ice crystal number concentrations are still an important issue in cirrus cloud research; thus, this manuscript might be an appropriate contribution for increasing our knowledge about cirrus clouds. However, I have the general feeling that the presented results are not really new, although they were not presented in this form in former studies. There are many former studies on ice formation and ice crystal number concentrations in cirrus clouds, using parcel models, column models and also full 2D/3D models, including dynamics in terms of approximations of Navier-Stokes equations. Especially from studies involving 1D and 2D models, it is well known that sedimentation is the key property for spreading ice crystals over larger vertical layers leading to low concentrations.

However, there are some details in this study, which are new and might be important. Therefore, I recommend major revisions in terms of investigating the new features in more details, before this manuscript can be accepted for publication in ACP. In the following I will explain my concerns in details.

Major points:

1. Main results:
   It is well known that sedimentation is of major importance for shaping cirrus clouds in the vertical. Sedimentation might spread larger crystals over a large vertical range, leading to lower ice crystal number concentrations at lower levels. This is a feature already found in column model studies (e.g. Lin et al., 2005; Kärcher, 2005; Comstock et al., 2008). In addition, two-dimensional simulations (e.g. Spichtinger and Gierens, 2009; Sölch and Kärcher, 2010, 2011) showed that the impact of sedimentation on cirrus clouds becomes more pronounced by including horizontal dimensions and fluid dynamics. Especially, studies by Sölch and Kärcher (2010, 2011) already used particle tracking for their investigations. It is also well known that parcel models will not be able to represent the effect of spreading ice crystals, since many important processes are lacking. However, even some parcel models tried to include sedimentation as a process, leading to results similar to column models (see, e.g., Haag and Kärcher, 2004; Kay and Wood, 2008; Spichtinger and Cziczo, 2010).

   Thus, the qualitative results about the role of sedimentation in comparison with the observations seem not really new. Therefore, I would like to see a more detailed quantitative analysis. For instance, it is stated in the text that few nucleation events of low number concentrations might lead to the fallstreaks and contribute most to the low number concentrations. Since all events were tracked, I would like to see a quantitative statistical analysis about the frequency of occurrence of such events.

The comparison with observations is difficult because measurements were usually obtained (far) away from the nucleation zone. For the stratiform cirrus clouds in the model study, the vertical extensions of nucleation zone and sedimentation dominated vertical layer could be estimated and used for a more quantitative comparison with observations. In addition, it would be interesting to investigate how representative these results are.

2. Lack of model description and setups
The model is almost not described in the text, there is only a reference to a model, which was developed more than 10 years ago for polar stratospheric clouds; this model was obviously adapted for cirrus clouds. However, I miss the details of included processes, especially nucleation, diffusional growth and - most important - sedimentation, since this process is a key issue for the whole study. It is also not clear if aggregation is included. Since the model was originally developed for very dry conditions, it is not clear if latent heat release due to diffusional growth/evaporation is also included in the model.

In addition, the setup of the simulations is only marginally described. For instance, the description of prescribed large-scale motion components remains very vague; it is not clear to me, how this was implemented. It is also not clear to me, why the author did not use more different scenarios of large-scale upward motions. From this point of view, the question remains how representative the results are for comparison with observations.

Minor points:

1. Role of temperature fluctuations:
   It is not clear how the temperature fluctuations are generated and, more important, if these fluctuations are really representative for small scale dynamics in different scenarios. Although this type of driving models along trajectories was done in many studies before, it is not clear, how well this procedure describes the impact of dynamics on cirrus clouds. Fluctuations in the atmosphere are not just noise but they stem from dynamic features on different scales (e.g. waves, turbulence due to breaking waves etc.). Thus, it is not clear if this approach is meaningful.

2. Ice nucleation:
   In addition, the role of different ice nucleation pathways is investigated as in many studies before, leading to the well-known effect of modification and/or suppression of homogeneous nucleation events due to previous heterogeneous nucleation events - some basic literature is here missing (e.g. Gierens, 2003; Haag and Kärcher, 2004; Ren and MacKenzie, 2005; Kärcher et al., 2006; Spichtinger and Cziczo, 2010) and should be included. The new study by Cziczo et al. (2013) should be treated carefully, since most of their observations were obtained in sub tropics (maybe in anvil outflows) and are not representative for extratropic cirrus clouds, which are dominating the measurements. Thus, I would like to see a discussion about the representativity of high values of ice nuclei concentrations, i.e. higher than the usual background of $\leq 10\,\mathrm{L}^{-1}$ (DeMott et al., 2003).

3. Accommodation coefficient:
   There is a recent review including new measurements on the role of the accommodation coefficient for phase transitions vapour-ice (Skrotzki et al., 2013). They report values in order of 0.5 to unity for the accommodation coefficient. The author should include this reference and explain his choice of the accommodation coefficient value.

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4. Interpretation of low ice crystal number concentrations: It is not correct that low ice crystal number concentrations are hard to obtain at low temperatures. Spichtinger and Krämer (2013) have shown that under certain conditions this work quite well. In addition, former studies by Lin et al. (1998) showed that for wavy structures phase shifts might lead to low number concentrations, even in a high velocity regime.

5. Mixing of different scenarios in the discussion:
In the discussion, different scenarios were mixed in a confusing way. For instance, the comparison with cold stratospheric conditions including NAT particles is misleading. In contrast to NAT particles, which might introduce new nucleation events due to sedimentation into a supersaturated layer, ice particles behave differently. Sedimenting ice particles will quench further nucleation, if they fall into supersaturated layers; thus, they reduce further ice formation, therefore these few events can be so persistent. This feature was investigated in details in former studies (e.g. Spichtinger and Gierens, 2009). The comparison to liquid clouds is also not really meaningful, since the conditions for pure ice clouds are quite different. Maybe these lines of arguments could be streamlined and formulated in a more consistent way.

6. Cirrus clouds in a supersaturated environment:
This issue is strongly related to the former point. Ice formation requires high supersaturation (in contrast to droplet formation), thus from theory it is very clear that ice clouds are embedded into a supersaturated environment. This was shown in many former measurements, thus some articles of the relevant literature should be cited (e.g. Jensen et al., 1998; Ovarlez et al., 2000; Vay et al., 2000; Haag et al., 2003; Krämer et al., 2009) and not only the recent study by Diao et al. (2013).

7. Missing processes in parcel models and column models: Beside the microphysi-

cal processes, many important processes are missing in parcel models and column models, e.g., (independent) sedimentation (in parcel models), mixing and any kind of real dynamics governed by atmospheric motions. Please state this in the text more clearly.

8. Page 10703, lines 8 -11: I do not understand, what you mean, please explain this.

9. Page 10703, lines 22-23: I do not understand, what you mean, please explain this.

Technical comments:

1. Figure 2 is very hard to read, the quality is quite low, please change it.

2. P 10707, line 9, please check

3. P 10711, line 17, please check

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