Review of
What controls the low ice number concentration in the upper troposphere?
by Zhou et al.

General comment:
In this study the representation of ice crystal number concentrations in the CAM GCM is investigated. As a reference concentrations as obtained by in situ measurements are used. Ice crystal formation at low temperatures ($T < 235\,\mathrm{K}$) depends crucially on local dynamics. Since in large-scale models subgrid scale motions cannot be represented by definition, the relationship between ice crystal formation and vertical motions must be parameterized. In this study the authors investigate different possible parameterizations and their impact on the resulting ice crystal number concentrations in the CAM GCM.

In general, this is an interesting and important contribution to ice cloud research; thus, this study is an appropriate contribution for ACP. However, there are some issues, which should be clarified before the manuscript can be accepted for publication. Therefore I recommend major revisions of the manuscript. In the following I will explain my concerns in detail.

Major points

1. Sedimentation in GCMs
   A crucial process for the evolution of ice clouds in the tropopause region is sedimentation of ice crystals. As known from many studies using models in different configurations (box models, column models or even full 2D/3D model) sedimentation can shape the evolution of ice clouds in a very crucial way. From the manuscript it is not clear how sedimentation is treated in the used cloud parameterization of the GCM and how this parameterization would influence the results. Thus, the authors should add some text about the treatment of ice crystal sedimentation in the model. In addition, and more important, the authors should try to carry out some sensitivity studies changing the treatment of ice crystal sedimentation (e.g. changing the terminal velocities, if they are treated explicitly in the cloud scheme). This would lead to a better understanding of the interaction of different ice cloud processes in the model. In a consequence it might be that ice nucleation is less sensitive to vertical velocity representations, since sedimentation tends to smear out strong changes in number concentrations and enhances the effect of pre-existing ice

2. Combination of different approaches seems arbitrary
   In the last part of the manuscript it is suggested to use a mix of different representations of vertical velocities (or cooling rates, respectively) in order to represent ice crystal number concentrations in a better way. The combination of WGRID and WTKE by using a simple temperature criterion seems to be too simple. As indicated in minor point 6 below, the use of WGRID for the cloud parameterization is recommended by Spichtinger and Krämer (2013) only for a special regime of strong stratification (i.e. tropical tropopause layer). A simple temperature criterion changing the vertical velocity at the threshold $T_c = 205\,\mathrm{K}$ will not work, since the key property is the strong stratification, which occasionally coincides with low temperatures in the TTL. In addition, it is not clear (see minor point 4 below) what the TKE scheme is doing in the upper troposphere. Therefore, the use of WTKE is still questionable, although it might reproduce meaningful ice crystal number concentrations - but maybe due to the wrong reasons. In fact, this issue should be clarified first, although this might be beyond the scope of the study. From a practical point of view, I recommend to use a dynamical criterion to split the different regimes (WGRID vs. WTKE), e.g. a

threshold using bulk stratification as Brunt-Vaisala frequency calculated on model resolution. Of course, sensitivity due to such a criterion should be explored.

Minor points:

1. Missing references
In the introduction references about cirrus cloud distributions and properties are missing, especially new results from satellite evaluations. For instance, new global distributions of ice clouds could be derived from CALIPSO and CloudSat. Thus, it would be appropriate to include some new references, e.g. Stubenrauch et al. (2010) and Sassen et al. (2008). Concerning the issue of the net radiation effect of cirrus clouds, also some newer references should be included (e.g., Chen et al. 2000; IPCC 2013 report).

2. Measurements of IN in the upper troposphere
In laboratory experiments the ability of different types of aerosols was investigated, especially the formation of ice crystals at glassy particles. However, in situ measurements of heterogeneous INs are difficult and especially the existence of glassy particles or precursors (e.g. organic material) is still not proven by in situ measurements and this should be mentioned in the introduction.

3. Mass accomodation coefficient
Skrotzki et al. (2013) showed that the mass accomodation coefficient α should be in the range $0.1 \leq \alpha \leq 1$. Also model studies (e.g. Kay and Wood, 2008, see also references in Skrotzki et al., 2013) indicated that the low values as reported by Magee et al. (2006) are not representative for cirrus clouds. Please add some text to clarify this issue.

4. TKE scheme in upper troposphere
TKE schemes are included in GCMs in order to parameterize processes in the planetary boundary layer in a meaningful way. It is not clear what these schemes do in the free troposphere. Actually, it is even not clear that TKE schemes produce the correct kind of "turbulence" in the upper troposphere at the right regions (e.g. at regions with low stability, strong shear etc.). Thus, the use of such schemes for parameterizing subgrid scale motion is quite questionable, although this kind of parameterizations is used often in many different models. The authors should comment on that issue and add some text in the manuscript, especially, since the model results indicate that the use of this parameterization does not provide meaningful results for ice clouds.

5. Dominance of heterogeneous ice nucleation
The dominance of heterogeneous nucleation is still questionable. In fact, measurements from convective regions in the subtropics as reported in Cziczo et al. (2013) are certainly not representative for the whole upper troposphere and especially not for mid or high latitude conditions. Also the relevance of biological particles at cirrus level is not clear, since Pratt et al. (2009) could provide only one flight at about 7 kilometres (i.e. at temperatures $T > 240\,\mathrm{K}$), which is probably not representative for the whole upper troposphere. The authors should add some text, which makes clear that the importance of heterogeneous nucleation for the cold temperature regime (i.e. $T < 235\,\mathrm{K}$, which is mostly discussed in the manuscript) is still under discussion and not clear at the moment.

6. WGRID is only valid for strong stratification
In Spichtinger and Krämer (2013) a special kind of cirrus clouds in the tropical tropopause layer (TTL) was investigated. The dynamical regime for these cirrus clouds is characterized

by very low vertical updrafts ($w \leq 2\,\mathrm{cm\,s^{-1}}$), by low temperatures ($T < 205\,\mathrm{K}$) and, most important, by strong stratification (i.e. high Brunt-Vaisala frequencies). The latter one is the key property for the investigated regime, leading to short nucleation events and thus low ice crystal number concentrations. For weaker stratifications this effect vanishes. Thus, the use of large-scale vertical velocities for the ice nucleation scheme is only meaningful for such strongly stratified regions (as recommended in the article by Spichtinger and Krämer, 2013). This issue should be clarified in the text (see also major point 2).

7. WGARY seems to be wrong
   The results from the simulations suggest that the use of temperature fluctuations as parameterized by Gary (2006, 2008) does not produce meaningful results. Although this pathway of parameterization is suggested in many publications and is used in some GCMs, it should be stated more clearly in the manuscript that this parameterization lead to problems and it should probably not be used for ice cloud studies.

References

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