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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Technical note: An automated cirrus classification" *by* Edward Gryspeerdt et al.

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General Comments:

: This is a very innovative approach for classifying the various types of cirrus clouds in a way that provides qualitative knowledge about cloud updrafts and whether the cirrus ice crystals formed near -38°C from supercooled liquid cloud droplets advected into the T < -38°C zone, classified as "liquid origin cirrus", or from another ice nucleation process (e.g. immersion freezing, vapor deposition or homogeneous freezing), classified as "ice origin cirrus". As such it represents a potentially significant contribution to scientific progress within the scope of ACP.

Reply: We thank the reviewer for their comments, which are addressed in turn below. Line numbers related to the diff'ed version of the manuscript. A short section on the seasonal variation of the regimes has been added to demonstrate their utility and help better characterise them for future work.

: However, a key parameter not mentioned in the methodology for determining cirrus cloud regimes is temperature T. To begin with, the authors need to define what they mean by "cirrus cloud". Most investigators define cirrus as a pure ice cloud (i.e. no liquid water is present), and the best way to insure this is to require T < -38°C. Such a restriction was not applied in this study, making the proposed classification scheme ambiguous, especially in regards to cloud radiative properties. Unless I have not understood this classification scheme properly, this appears to be the main drawback.

Reply: We agree that this is an important factor of cirrus clouds. This classification is primarily intended to classify gridboxes, irrespective of the cloud that had actually formed there, similar to the dynamic regimes described in Medeiros and Stevens (2011). As noted here, this then leads to the issue observed in Fig. 6, where the CRE is a strong function of the underlying low-level cloud. Although we have not completely removed cloud properties from the regime classification, having a classification that is mostly independent of the cloud properties then allows global models to be assessed on their ability to form these regimes separately from their simulation of the cloud properties within them. This has been expanded upon in the methods section (P4L11) and noted at the end of the introduction (P4L5).

: It is evident from Fig. 3 that the classification scheme is applied for T < -20°C, and supercooled liquid water may exist between -20 and -38°C. Over this T range, the clouds should not be regarded as cirrus clouds. The differences between the cirrus categories in Fig. 3 become much more subtle if cirrus are defined as being colder than -40°C, but the cloud categories can be distinct for -40°C < T < -20°C. Perhaps this classification scheme could be improved if each class were divided into two T regimes; T < -40°C

and -40°C < T < -20°C.

Reply: Following the previous point, classification according to the observed cloud phase would conflate the occurrence of the regimes with the occurrence of different cloud types within them. This also limits the possibility of splitting the regime by temperature vertically by cloud occurrence.

The liquid/in-situ origin dataset is derived from ERA-Interim, which contains a relatively simple ice parametrisation, lacking the impact of aerosols such that most clouds are glaciated by -20°C. This means that the occurrence of liquid-origin cirrus becomes very low even at temperatures warmer than -40°C, whilst this might not be the case in the atmosphere, where liquid drops can persist to colder temperatures (possibly allowing liquid origin cirrus a colder temperatures). This then suggests that the difference between the regimes might persist to higher altitudes in the atmosphere, even though it cannot be determined from this dataset. The methods section has been expanded to include this point (P7L8).

: Figure 4 introduces even more mixed phase ambiguity by applying the classification scheme to cloud temperatures between 0°C and -90°C.

Reply: See previous points

: Although I am familiar with the concepts of liquid origin and ice origin cirrus clouds, I felt that these complex concepts were not clearly explained in this paper, especially in regards to what kind of knowledge they impart to this classification scheme. More explanation should be given.

Reply: Extra explanation is included in the introduction (P2L19) and in the relevant results sections.

The paper is well organized and well written, with a sufficient number of quality figures to illustrate the main points. Many other important concerns are listed below. Given these concerns, I recommend major revisions.

Major Comments:

***Page 2, line 18:**: In this section on "Existing Classifications", the authors might also want to mention the work of Tselioudis et al. (2013, J. Climate), who used cluster analysis to define 11 atmospheric weather states (WSs) based on optical depth and pressure level. While only one WS is primarily cirrus, other WSs contain cirrus contributions.*

Reply: Thank you for suggesting this, it has now been included.

***Page 3, line 15:**: This is the 1st mention of the ICON model that is used extensively in this work. The full name of the model and/or a reference should be given here (along with acronym).*

Reply: The acronym and reference are now included here

***Page 3, line 31:**: In some mountainous regions, 850 hPa may be below the surface. What is done when this occurs?*

Reply: Following the ERA-Interim extrapolation algorithm, this windspeed is replaced with the surface windspeed. This is now noted in the text.

***Section 2 (Methods):**: Since MODIS was used to develop this classification scheme, it would be helpful to show in this paper a mean visible cloud optical depth (OD) associated with each cirrus cloud category, as well as the corresponding standard deviations. This would be helpful for understanding the net CRE of each category that is discussed later.*

Reply: This is now included towards the end of the results section (Fig. 6)

***Section 2 (Methods):**: A temperature criteria of T < -38°C is not used to select cirrus in any of these cirrus categories, raising the possibility that some clouds classified as*

cirrus may actually be mixed phase clouds. Figures 3 and 4 suggest that this classification scheme was applied for T < -20°C and T < 0°C, respectively. If either is correct, then mixed phase conditions are built into this classification scheme, and this should be made clear. Moreover, the word "cirrus" in the paper's title should be replaced by "ice cloud", and all references to "cirrus" in the paper should be replaced by "ice cloud".
Reply: Thank you for pointing this out, we agree that the phase is ambiguous for some of these cloud, but as mentioned previously, we feel that adding cloud phase to the classification would reduce the separation between the meteorological state and the cloud formed due to it. While "ice cloud" or "cirriform" might be a broader term to cover this classification, we feel that the term "cirrus" is also a good way to indicate that this classification aims to separate out many different types of high cloud, from anvil cirrus through to the thinner synoptic cirrus varieties.

***Page 9, lines 2-8:**: Since this classification scheme is for cirrus clouds, this implies only ice exists. But when classifying clouds between -20 and -40 C, what assurance is there that these clouds are "ice only" based on Wernli et al. (2016)? And even if the Wernli et al. analysis shows that the classified "cirrus" in Fig. 3 between - 20 and -40 C are ice only, the phase partitioning in cloud resolving models is not an exact science, is highly variable between models, and depends strongly on the parameterization scheme used. Thus it is difficult to understand just what exactly is being shown in Fig. 3 at warmer temperatures (e.g. are the clouds ice only or mixed phase?). Please address these concerns, clarifying all these issues. If the authors insist on using their classification scheme at these warmer temperatures, they need to be clear just what kind of cloud they are classifying (e.g. all-ice or mixed phase).*
Reply: Following the points made earlier, we have noted that the classification attempts to avoid basing the classification on the retrieved cloud properties (such as phase), to enable a clearer distinction between the meteorological state and the clouds it produces. Further notes on this have been included in the methods section (P4L11) and introduction to better justify this.

***Figure 5c and associated discussion:** : Two questions come to mind here: (1) How much do mixed phase conditions contribute to these CRE values? Even if liquid water comprises only 10% of the total water content, it can still have a large impact on cloud radiative properties (e.g. Mitchell and d'Entremont, 2012, AMT; Shupe and Intrieri, 2004, J. Climate). Thus, a small liquid water fraction is likely to have a strong impact on the net CREs given in Fig. 5c, increasing the SW over the LW contribution.*
Reply: It is likely that mixed-phase clouds play a role in the CRE of these regimes, especially given the importance of liquid water in these clouds. An investigation into this is beyond the scope of this work, which is mainly to provide a description and brief characterisation, but is definitely considered for the future.

***Figure 5c**: And regarding the 2nd question (wrt Fig. 5c), CRE is evaluated from CERES SYN1deg daily data at 1:30 pm LST. At this time, SW CRE is near maximum, whereas LW CRE is much less variable over a 24 hr. daily cycle. This sampling time will negatively bias the net CRE, making it non-representative of the daily-mean net CRE associated with cirrus clouds having low-to-moderate ODs.*
Reply: The data is actually taken from the daily mean SYN product. This has been corrected in the text

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***Fig. 5b and c:**: It is commendable that the authors have partly explained why all the in situ cirrus categories have more SW CRE than LW CRE (due to low clouds). These cirrus are typically having lower optical depth and thus lower SW and LW CRE (Fig. 5c), with TOA LW CRE > SW CRE (e.g. Fu, 2008, Fig. 4; Hong and Liu, 2015, J. Climate). But after removing the low clouds in Fig. 5c, in situ cirrus still have a net CRE < zero, whereas other studies infer positive values. For example, for cirrus OD < 3.6 and cloud top pressure <440 mb, the net CRE reported by Chen et al. (2000, J. Clim.) was positive, as was also true for Hartman et al. (1992, J. Clim.) for cirrus OD <9.4. Based on the ECHAM6 GCM, the global average net CRE of cirrus clouds is +5.7W/m2 (Gasparini and Lohmann, 2016, JGR). The proposed technical note ap-*

pears to be at variance with the literature in regards to the overall sign of the net cirrus forcing, and this discrepancy should be addressed. Note that the calculations in Fu are for the equator during an equinox when the sun is highest in the sky, which maximizes the SW CRE.

Reply: Thank you for drawing our attention to these studies. We have gone back to look at the CRE data again. The average net synoptic CRE is slightly positive, at around 3Wm^{-2} (similar to previous work), when removing any liquid clouds, which is more consistent with methods in previous work. The overall cirrus net CRE is still negative, but this is mostly due to the strong negative effect on the frontal and convective regimes. We suspect that the difference to previous work most probably comes come the different pressure levels used to separate out low cloud. Hartmann et al, 1992 used 440 hPa, whereas we have used 550 hPa. This results in a slightly less positive LW CRE, contributing to the overall smaller CRE. A clause has now been added noting that the net synoptic CRE is now positive (P17L25).

***Page 14, line 16:**: "As seen in previous studies, the net cloud radiative forcing (CRE) is negative". Yes, but this paper is about cirrus clouds, and their net CRE is positive. Please cite these "previous studies" that pertain to cirrus clouds. One study by Chen et al. (2000, J. Clim.) was cited in the Introduction and could be cited again here. As noted above, Chen et al. (2000) and Hartman et al. (1992) found that for cirrus OD $<$3.6 or 9.4, respectively, their net CRE is positive.*

Reply: This sentence was intended to point out that the total CRE is negative and has now been amended.

Minor Comments

***Page 2, line 2:**: Remove "and" from this sentence.*

Reply: Done

***Page 2, line 12:**: Comma not needed*

Reply: Amended

***Page 2, line 18:**: "Existing Classifications" should be given a sub-header value of 3.1.*

Reply: Amended

***Page 3, line 27:**: determines => determining?*

Reply: Amended

***Figure 4:**: Please label all the panels as a, b and c. Also, what do the 3 horizontal lines indicate in the middle-regions of Fig. 4b and 4c?*

Reply: Amended. The caption now states that the grey lines are gridlines.

***Page 12, line 15:**: Fig. 5a does not show RFO; please clarify. Also, "frontal convective regimes" => "frontal and convective regimes"? Based on Fig. 5b, frontal and convective regimes appear to account for slightly $>$ 12%.*

Reply: Corrected to refer to Fig. 2, percentages and missing "and" amended.

***Page 13, line 8:**: "once" => "until"?*

Reply: This sentence has been re-written for clarity.

References

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