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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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: In the manuscript, a classification system for cirrus clouds that is based on re-analysis and satellite data is presented. Cirrus clouds are separated in four main types, differing by meteorological/dynamical situation and thus microphysical and radiative properties. The topic of the study is very interesting and timely and I recommend the paper for publishing in ACP. However, before final publication, I think that the manuscript should be revised taking into account the following points.

Reply: We thank the reviewer for their useful comments and address each of them 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.

***1**: To my opinion, the study has more potential and relevance than currently elaborated. Though it is claimed to be a "technical note", the link or physical mechanisms, respectively, between cirrus classes (meteorology), updraft, microphysical property (IWC or OD) and radiative property (CRE) needs to be shown and discussed in more detail to make the study scientifically sound. The exciting is that with the applied method it seems that these links can be identified!*

- *In Fig. 4 the link between cirrus class and updraft is seen (the standard deviation of the respective updraft distribution could serve as measure for class specific updraft);*
- *Also, the mean CREs of the cirrus classes shown in Fig. 5 must be caused by a respective microphysical property (IWC, OD).*

Reply: This paper was originally pitched as a technical note, as it aimed primarily to describe the occurrence of the regimes and how they are defined. With the inclusion of the model output and CRE data it has become a bit more in-depth and so it has now been shifted so that it is listed as a research article. We have re-worded parts of the paper to make these links more explicit and have included information about the cloud optical depth in Fig. 6. However, We do not believe that we are yet able to account for the properties of the clouds within regimes. While this study shows that the convective and orographic regimes have a higher updraught than the synoptic regime, other properties, such as the aerosol environment remain uncertain, preventing an attribution of the differences in radiative and cloud properties to any particular factor. Further studies are planned to explore these differences in more detail.

2a: *The aim of the paper is to identify cirrus clouds by their formation mechanisms: orographic, frontal, convective, in-situ. The name "in-situ" does not match to the other names, which describe the meteorological situation - it should be renamed to "synoptic".*
Reply: Thank you for this comment, "synoptic" is a better fit for this class and it has now been renamed.

2b: *The defined classes refers to meteorological (dynamical) situations, not to formation mechanisms (as stated in the abstract and elsewhere). Formation mechanisms are:*

- *homogeneous or heterogeneous ice nucleation for in-situ origin cirrus (here called ice origin cirrus, see comment 3 below) and*
- *heterogeneous or (sometimes) homogeneous drop freezing for liquid origin cirrus.*

So it should better be stated that cirrus clouds should be identified by the meteorological (dynamical) situation, which is what has been done in the paper.
Reply: Thank you for pointing out the potential confusion here. Following previous regime definitions, it is not clear that "dynamical regimes" should be used either, as it has previously been applied to regimes defined using only meteorological variables (e.g. Nam and Quaas, 2013; Zhang et al., 2016). We note that some previous studies (e.g. Heymsfield et al., 2017) refer to ice formation mechanisms (homogeneous and heterogeneous) somewhat separately from the mechanisms that create the cloud in the first place (processes creating the cloud updraught, radiative cooling). We have modified the text to refer to cirrus or cloud formation mechanisms where there is a potential for misunderstanding.

2c: *I also recommend to link the meteorological to the dynamical situation: synoptic (in-situ), frontal, orographic and convective cirrus are cirrus in increasing updraft regimes from low to high. To identify cirrus by their formation mechanism, I would recommend to define for example three updraft regimes (weak, middle, high) and assign the them to the meteorological types:*

- *synoptic (in-situ) - weak updraft,*
- *frontal - middle updraft,*
- *orographic/convective - high updraft.*

Then, the cirrus formation mechanisms can be identified (to a certain degree) by the updrafts

- *weak updraft: mostly heterogeneous freezing - low IWC/OD - low CRE ?*
- *Middle/high updrafts: increasing homogeneous ice formation - higher IWC/OD - higher CRE ?*

: This is true for "liquid origin" as well as for "ice origin" cirrus. As far as I can see, these links apparant in the paper and I would recommend to point that out in the paper.
Reply: We have added some more discussion on the updraughts within the different regimes (e.g. P14L1), but we do not believe that there is enough information to add updraught information to the classification as it stands. The model results with ICON indicate that there is a link between the regime type and the cloud scale updraughts, but without more large scale measurement efforts, we do not believe it is possible to classify the regimes by updraught yet.

3: *"in-situ" : beside the previous comment on the term "in-situ" (2a), I also like to mention that "in-situ origin cirrus" is recently introduced (by Kraemer et al. (2016),* *ACP, Luebke et al. (2016) and Wernli et al (2016), GRL) for those cirrus that you name "ice origin cirrus". Though "ice origin" might be the better companion of "liquid origin", for consistency reasons I would recommend to keep the terms as they are now introduced.*

Reply: references to "ice-origin" have now been updated to "in-situ origin" in line with previous work.

4: *Cirrus formation mechanisms of in-situ origin and liquid origin cirrus and their link to cirrus properties and meteorological situations are also discussed in Kraemer et al. (2016), ACP, and Luebke et al. (2016), ACP. Also, cirrus clouds classification, formation and so on is summarized in the recent review article of Heymsfield et al. (2017), Meteorological Monographs (see http://journals.ametsoc.org/doi/pdf/10.1175/AMSMONOGRAPHS-D-16-0010.1). These studies should be considered in your work. In more detail, Luebke et al. (2016) compared aircraft measurements in mid-latitude frontal liquid origin and in in-situ origin cirrus. They show the microphysical properties of the cirrus types and their distribution with temperature, which is quite similar to what is found in this study. This should be discussed, it is a good confirmation of the approach used here. Liquid and in-situ cirrus are classified by means of trajectory analysis, similar as in Wernli et al (2016)*

Reply: Thank you for bringing these studies to our attention, they are now included in the introduction.

5: *The CRE is shown for the various cirrus types in Fig. 5 c). The highest total CRE is for F and C, followed by O1 and O2, and around zero CRE is for the other types. This seems to be related to the optical thickness or IWC, respectively of the cirrus types, which in turn depend on the updraft. A plot showing this would greatly improve the paper. Also, it would be good to know if the cooling effect from F and C is because thick liquid origin cirrus constitute a large part of these cirrus types ? In general, it would be good to see the difference in microphysical and radiative properties between*

liquid origin and ice origin in more detail.

Reply: A plot showing the COD for the regimes has been included in Fig. 6. The large negative CRE of the F and C classes is indeed due to their large COD, as they are the only regimes that have selection criteria based on their COD (mentioned P14L14). While it would make sense, unfortunately we do not have enough data to know if the liquid origin cirrus in the F and C regimes is the dominant cause of the strong negative CRE, as the liquid-ice origin classification only exists for a single year over the North Atlantic.

6: *Methods: The "Criteria for regime assignment" (please specify regime in Table 1, I guess the cirrus classes are meant) are not very clear. I strongly recommend to add two columns, one containing the range of updrafts for each class and one with their range of microphysical properties, IWC or optical depth.*

Reply: Information on the optical depth is now included in Fig. 6. The table currently contains the information necessary to reproduce the regime classification. We would prefer not to add information on the cirrus class properties at this point in the paper, as they are not used in the regime classification and are now covered in more detail later in the paper (e.g. Fig. 6)

7: *Abstract: Include not only the method but also the most important results! In the current form, the paper will not get much attention when potential readers look at the abstract – which I think is a pity.*

Reply: Information on the results has now been included.

8: *Conclusions: The properties of the cirrus classes are described, but I miss explanations of physical mechanisms leading to the properties. Two examples:*

- *"The in-situ (synoptic) regimes in this classification are primarily composed of in-situ/ice-origin cirrus clouds, even to temperatures as warm as -20°C while the* *frontal and convective regimes contain a much higher proportion of liquid-origin cirrus to much colder temperatures." This is related to the updrafts, yes? The larger the updrafts, the higher the liquid origin cirrus can rise = colder temperatures.*

- *"The frontal and convective regimes have the strongest LW, SW and net negative CRE." This could again be related to the updrafts, yes? High updrafts → thick cirrus, many liquid origin → strong CRE, yes?*

This comment relates to comments 1 and 2.
Reply: This may be the case, but we do not feel that we have enough data to claim that this is purely an updraught effect. For example, it could be that the cloud bases are higher in the synoptic class (as indicated by the model results), rather than just a change in the cloud top height of clouds with lower bases. A comment related to the updraught has been added to the (new) section on the cloud optical depth (P13L3).

Specific comments

***Page 1, line 15:**: Please delete "While"*
Reply: Done

***Page 1, line 20-21:**: "... aerosol influence on ice clouds would likely modify ice nucleation processes, changing the ICNC, perhaps by orders of magnitude ..." - "orders of magnitude" is definitively too high, please scale back this statement. Also, aren't more recent publications available studying the effect of IN on cirrus properties ? Another point to think about is that the most prominent parameter influencing the radiative cirrus properties is the ice water content (IWC). Changing the ICNC by influencing the IN number does not necessarily means that the IWC is changed, since the available water vapor distributes on the present ICNC. The result are different sizes of the ICNC*

(but not IWC) and thus differing sedimenation behavior, which influences the further development of the cloud.
Reply: This has been changed to "an order of magnitude", the maximum change observed in the Kärcher and Lohmann, (2003) paper. We agree that the IWC is a more important component of the cloud albedo and that a change in ICNC may not modify it. However, even at a constant IWC, a change in the ICNC would modify the radiative properties of the cloud, similar to the Twomey effect in liquid clouds. The IWC has been included in the first paragraph along with the ICNC (P1L21).

***Page 1-2, lines 23-1**: "... ice crystals are formed either by heterogeneous nucleation from ice nucleating particles (INP) or freezing of liquid droplets by either INP or existing ice crystals." Do you mean either immersion freezing or contact freezing ? Please specify.*
Reply: This sentence was intended to provide a brief mention of the role of INP. It has been expanded to indicate that both contact and immersion freezing are possible.

***Page 2, line 2:**: "..freezing of and remaining liquid droplets." Please remove "and".*
Reply: Done

***Page 2, line 5:**: ".. (e.g. Kärcher, 2017), .." Since this is the introductary part of the manuscript, I would recommend to cite some more basic studies on the influence of freezing mechanisms on cirrus microphysical properties, e.g. the work of P. Spichtinger, E. Jensen, M. Kraemer, A. Heymsfield. Include references.-→ Heymsfield 2017, review article.*
Reply: Thank you for pointing this out, we have now included the Heymsfield et al., 2017 review article here.

***Page 2, line 6-7:**: Heterogenous freezing in cirrus is in most cases determined by the INP number. This should be mentioned here.*

Reply: Done

***Page 2, line 8:**: "Convective clouds can contain liquid water to temperatures as low as -37°C ..." - This happens only in very strong updrafts, please explain.*
Reply: A clarification about the high updraught speeds is now included.

***Page 2, line 10:**: ... importance of the origin of the ice in a cloud (liquid or ice) has recently been introduced and demonstrated by Krämer et al. (2016).*
Reply: Amended.

***Page 2, lines 14-16:**: "However, information on the in-cloud updraught and the ice origin has a strong dependence on the microphysics and convection schemes used in a model and so may not be suitable for use as an observations-based constraint on cloud ice microphysics parametrisations in general circulation models (GCMs)." - To me this sentence is not very clear - can you reformulate what you mean ?*
Reply: Replaced with "However, the cloud scale updraught and the ice origin are not often directly simulated in atmospheric models, being calculated through parametrisations. As such, reanalysis values of these quantities may not be suitable for use as a constraint on cloud ice microphysics parametrisations in general circulation models (GCMs)."

***Page 2:**: Existing classifications - I highly recommend to cite here the recent overview article of Heymsfield et al. (2017)(see http://journals.ametsoc.org/doi/pdf/10.1175/AMSMONOGRAPHS-D-16-0010.1).*
Reply: This reference has now been included, although slightly earlier in the manuscript (P2L13) so that it provides a good reference for the introduction on cirrus in general.

***Page 2, last paragraph:**: This paragraph reads clumsy*

Reply: This paragraph has been re-worded.

***Page 3, lines 23-24:**: "..., irrespective of whether a cloud is observed such that a simpler comparison with models (which may produce sub-visible cirrus) can be made." ????*
Reply: This is simplified to "...irrespective of whether a cloud is observed. This ensures that every location is assigned to a regime, such that the regime occurrence is not biased by any satellite cloud detection threshold." We has also removed the "aim of classifying the uppermost layer" from later in this paragraph due to it's potential to confuse this issue.

***Page 4, lines 1-3:**: What is the meaning of the "windspeed-height variation product" that defines O1 and O2?*
Reply: This has been changed to "windspeed-surface topography variation product" to better align with the terminology in the previous paragraph.

***Page 9, lines 6-8:**: "In all the regimes, almost all clouds colder than -60°C are formed directly as ice and many of those warmer than -40°C are originally formed as liquid (Fig. 3, "Total" column). However, there is considerable variation between the regimes between these temperatures." This nice result should appear in the conclusions and maybe also in the abstract.*
Reply: The abstract has been re-worded to make a clearer link to the variations in ice origin between the regimes. The temperature dependence of the in-situ/liquid origin cirrus had previously been noted in the Wernli et al, 2017, paper describing the classification.

***Page 14, lines 6-7:**: "The in-situ regimes in this classification are primarily composed of in-situ/ice-origin cirrus clouds, ..." I guess you mean liquid here.*
Reply: This sentence was intended to show that the liquid-origin cirrus is much less

common in the synoptic regime at warmer temperatures than in the frontal or convective regimes. The renaming of the in-situ regime to synoptic should make this clearer.

Page 14, line 16:: *"As seen in previous studies, the net cloud radiative forcing (CRE) is negative, ..." - Which previous studies ?*

Reply: This was intended to reference the overall mean CRE. This sentence has now been corrected to read "As seen in previous studies (e.g. Hartmann et al., 1992), the mean cloud radiative effect (CRE) is negative ..."

References

Hartmann, D. L., Ockert-Bell, M. E., and Michelsen, M. L.: The Effect of Cloud Type on Earth's Energy Balance: Global Analysis, J. Climate, 5, 1281–1304, doi:10.1175/1520-0442(1992)005<1281:TEOCTO>2.0.CO;2, 1992.

Heymsfield, A. J., Krämer, M., Luebke, A., Brown, P., Cziczo, D. J., Franklin, C., Lawson, P., Lohmann, U., McFarquhar, G., Ulanowski, Z., and Van Tricht, K.: Cirrus Clouds, Meteorological Monographs, 58, 2.1–2.26, doi:10.1175/AMSMONOGRAPHS-D-16-0010.1, 2017.

Medeiros, B. and Stevens, B.: Revealing differences in GCM representations of low clouds, Climate Dyn., 36, 385–399, doi:10.1007/s00382-009-0694-5, 2011.

Nam, C. C. W. and Quaas, J.: Geographical versus dynamically defined boundary layer cloud regimes and their use to evaluate general circulation model cloud parameterizations, Geophys. Res. Lett., doi:10.1002/grl.50945, 2013.

Zhang, S., Wang, M., Ghan, S. J., Ding, A., Wang, H., Zhang, K., Neubauer, D., Lohmann, U., Ferrachat, S., Takeamura, T., Gettelman, A., Morrison, H., Lee, Y., Shindell, D. T., Partridge, D., Stier, P., Kipling, Z., and Fu, C.: On the characteristics of aerosol indirect effect based on dynamic regimes in global climate models, Atmos. Chem. Phys., 16, 2765–2783, doi:10.5194/acp-16-2765-2016, 2016.