Atmospheric Chemistry and Physics - Manuscript acp-2021-332: "Multiyear statistics of columnar ice production in stratiform clouds over Hyytiälä, Finland"
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1 Summary

This manuscript investigates the formation of columnar ice crystals in different types of (winter) clouds at temperature warmer than $-10\,^{\circ}$C, by analyzing two years of vertical profiles of reflectivity, Doppler velocity and LDR collected by a W-band polarimetrioc radar over the Hyytiälä site in Finland. Environmental conditions (mostly temperature and relative humidity) are provided by the ICON NWP model. The identification of columnar ice crystals is based on their typical linear depolarization ratio (LDR) signature, and their occurrence can be quantified and analyzed as a function of the cloud type (single vs multi-layer cloud) as well as the temperature difference between cloud top and the altitude of columnar ice formation. Those analyses suggest that (i) columnar ice formation is relatively frequent (from 5 to 30% depending on the cloud top temperature), (ii) columnar ice formation is associated with more intense surface precipitation, (iii) the liquid water path (LWP) is larger when columnar ice crystals are produced compared to when there is no such production, and (iv) some secondary ice production (SIP) mechanisms are likely involved to explain the larger number of ice crystals than ice nucleating particles in the case of single-layer clouds.

2 Recommendation

Taking advantage of a nice set of vertical profiles of radar observations at W-band over well-known site in Finland, this work relevantly combines radar measurements and model output to investigate the importance (in terms of occurrence and impact on surface precipitation) of columnar ice production in "warm" ice or mixed-phase clouds and to characterize those. In addition, the discrepancy found between the estimated order of magnitude of ice crystal number on the one hand and of ice nucleating particle number on the other, the latter being smaller, suggest that secondary ice production mechanisms must be active in order to complement primary ice production. The proposed approach and the obtained results are sound (although some aspects remain rather speculative), and they are relevant for the ACP readership. I do not have major concerns, so I recommend to send the manuscript back to the authors for minor revisions. A list of comments and questions is provided below.

3 Specific comments

1. P.2, l.2-3: in high latitude regions (Arctic, Antarctic, Southern Ocean), INP concentration has been estimated to be lower than at mid-latitudes (e.g. *DeMott et al.*, 2016; *Wex et al.*, 2019).

2. P.2, l.18: other SIP processes than HM have been already implemented in different atmospheric models. For instance: *Hoarau et al.* (2018); *Sullivan et al.* (2018); *Zhao and Liu* (2021).

3. P.4, l.9-13: what is the horizontal resolution of ICOM simulations above Hyytälä?

4. P.6, l.24: the used statistics of relative humidity from the ICOM simulations likely depend on some of the microphysica parameterizations. This should be mentioned and those parameterizations could be listed (no need of exhaustive descriptions).

5. P.8, l.12-13: "the majority of columnar ice production cases took in areas of high supersaturation, which is potentially favorable for liquid water droplet formation or existence", according to Fig.2.b, most cases are below 100% of RH with respect to liquid water...

6. P.8, l.17: smaller than $-8\,°C$ would be more correct I think.

7. P.10, l.8: the argument that "precipitation processes are more complex" is a bit short, please elaborate.

8. P.12, l.11-16: I would suggest to make a more explicit reference to Section 5 here, to inform the reader that this question is addressed later in Section 5.

9. P.12, l.30: "is responsible" should be "could be responsible" as this is speculative.

10. P.12, Section 4.3.2: there is no reason (even speculative) provided to explain how the supercooled liwuid water could be generated in such clouds...

11. P.13, l.2-3: it was not totally clear to me where are these waves in Fig.8.b, maybe circling them would help...

12. P.13, l.2-5: more explanations about those waves (nature, origin...) shold be provided. If they are related to larger scale processes, are they reproduced in ICON simulations?

13. P.13, l.5: "pointing to a possible connection between the two": between 06:30 and 07:30, I do not see any wave signature (I may have missed it) but the period is still identified as "columnar ice productive", so the connection is not that clear in my view...

14. P.14, l.3: the explanation about the atmospheric waves generating SLW is too short (and speculative): the Doppler velocities (Fig.9.b) do not show significant updraft around 1 km of altitude between 06:00 and 10:00 while columnnar ice crystals are identified by their LDR signature...

15. P.15, l.17: detectably?

16. P.16, l.6-9: there are also ice only SIP mechanisms (e.g. *Korolev and Leisner*, 2020).

17. P.18.l.25: a " ," is missing between 0.03 and 5.

18. P.19, l.27-28: "It was found that... formation of ice particles": I find this formulation rather confusing: this work focuses on the formation of columnar ice crystals at temperatures warmer than $-10\,°C$, not on the formation of ice crystals in general.

References

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