Review of "Conditions favorable for secondary ice production in Arctic mixed-phase clouds" by Pasquier et al.

Overview

The paper presents an important in-situ observation of secondary ice production in Arctic clouds from a tethered balloon with the help of a high-resolution imaging probe HOLIMO. The HOLIMO provided photographic quality images of cloud particles, which, in the majority of cases, allowed for unambiguous identification of particles habit and their phase. The in-situ observations were complemented by remote sensing observations, which allowed for accurate positioning of the HOLIMO measurements with respect to cloud boundaries. Ground based measurements of INPs provided a significant contribution to the value and quality of the collected data set. One of the major outcomes of this study is lowering the threshold concentration of ice particles separating primary and secondary ice production. This is different from the past observations when SIP was identified as an explosive increase in the number concentration of ice particles exceeding hundreds and thousands per liter. In the present study, the threshold concentration was reduced to the order of 0.1-10 per liter. The paper provides an important contribution to the understanding of the role of SIP in ice formation and, undoubtedly, it should be published in ACP. The paper is well written, and I do not have any significant comments on this work. There are a few minor comments which are worth addressing prior to publication.

Recommendation: The paper should be published in ACP after minor revisions

Comments

1. Line 204 and throughout the text: "*drizzle drops (defined with diameter larger than 64 μm*)"
   Following commonly accepted definition (e.g., Glossary of Meteorology), drizzle is defined as drops in the size range 100μm<D<500μm. The authors may consider using the term "supercooled large droplets" (SLD) instead. SLD is defined as droplets with D>50μm at T<0C.

2. Line 124-126: "*In addition, thanks to the low true air speed of HOLIMO on the tethered balloon system and the adequate tower tips, the shattering of ice crystals in the sample volume is minimized*."
   Reduction of the sampling speed will undoubtedly reduce the effect of shattering of ice due to decreasing the kinetic energy of particles impact. However, the HOLIMO inlet axis is unlikely to be always perfectly aligned with the local airflow, and particles with anisoaxial trajectories are likely to be frequently present during sampling. This is specifically relevant to the cases with the turbulent environment. Particle fall speed will also contribute to the deviation of the particle trajectories from the inlet flow. Such particles will impact with the HOLIMO inlet walls at a speed of ~ 1-2m/s, and they may get fragmented and contaminate measurements shattering artifacts. Fragmentation of freefalling (1-2m/s) particles on impact with a solid surface of observed by Vardiman (JAS, 1978). In this regard, it would be reasonable to make a disclaimer when talking about the effect of shattering.

3. Line 158-159: "*Non-pristine crystals cannot have formed from vapor deposition growth, and could originate from breakups during impact with the instrument payload or from rime falling from the tethered balloon*."
   The first part of this statement should be corrected. For example, non-pristine ice particles can be formed during water vapor deposition growth on polycrystalline frozen droplets or developed after formation dislocation in the ice crystal lattice of pristine particles.

4. Line 290: "*Indeed, particles resembling broken branches were observed (highlighted with the dark brown box in Figure 7a)*."
   Could you elaborate why the images of the boxed particles were identified as broken branches. Particle having such shape could be formed without fragmentation.

5. Line 320: "*The CDNCs measured by HOLIMO was generally below 1 cm-3 except at 13:10 UTC or between 13:45 and 14:15 UTC, when increases in CDNC were observed (Fig. 8b). These comparatively large CDNCs (> 10 cm-3) are observed when HoloBalloon was in the transition region from low to high radar reflectivity (i.e. in the embedded supercooled liquid layer). It suggests that in this region water saturation was sustained and promoted the formation and growth of cloud droplets, while below, the environment was subsaturated with respect to water and the cloud droplets were evaporating*."
   I have serious concerns regarding the existence of sustainable liquid clouds in the boundary layer with droplets D<40μm and number concentration <1cm-3 (e.g., as shown in Fig.8b). Such clouds have a high level of instability and may exist in a relatively turbulent environment only for a limited time since any vertical motion will result in activation of CCNs or complete evaporation of droplets. Therefore, the interpretation of observations of cloud segments with N<0.1cm-3 as liquid or mixed-phase causes a question of whether the phase of particles with D<40μm was identified correctly, or the images of these particles are a result of some non-recognized artifacts.

   In relation to Fig 8, I would like to add that the rapid increase of the radar reflectivity from -10dBZ to ~10dBZ at approximately 1km altitude is indicative of a presence of a liquid layer there. Such layers usually result in the enhanced growth of seeded from above ice crystals and an increase in radar reflectivity. On the other hand, Arctic clouds are frequently decoupled. I am wondering if the cloud base identified from the ceilometer measurements, as shown in Fig.8a, corresponds to the lower layer. This may result in a perception that the HOLIMO measurements were performed inside a liquid/mixed-phase cloud layer, whereas the measurements in fact were sampled in between cloud layers. Could you also comment on this?

6. Line 341-342: "*On the contrary, some ice crystals showed broken features, as highlighted by the blue frames in Figure 9a. As the ICNCs were large (up to 55 L-1) collisions between ice crystals have likely occurred.*"
   I would be conservative regarding the interpretation of the boxed images in Fig.9a as fragments. Images of ice particles with under- or non-developed corners or branches can be found in Nakaya (1954) or Bentley and Humphreys (1931), respectively. Could you comment or provide strong evidence supporting the fragmented status of some specific particles.

7. Line 342-344: "*In addition, ice-ice collisions is believed to be most efficient at colder temperature (Takahashi et al., 1995) such as observed on this day. Therefore, we deduce that the ice-ice collisions were again the most likely active SIP mechanism in the low-level feeder cloud*."
   This statement is based on the observations of ice particles that appear as fragments and association of these observations with ice-ice collision SIP mechanism. This induces the following questions: (a) Could the observed fragments be a result of anisoaxial ice particles impact with the HOLIMO walls? (b) Could the images of ice particles identified as fragments belong to intact particles? (c) Could the observed SIP particles originate from other SIP mechanisms?

Other comments

1. Line 203. *"…and drizzle drops (defined with diameter larger than 64 μm) were observed during four measurement flights*". It is worth indicating maximum droplet size D_{max} for each of those four flights.

2. Figure 7c. It is worth adjusting colors for a better reading of the diagram in Fig.7c. After printing, brown and violet appear to be too close, and they can be confused with each other.

3. Line 346 "…*and a volume of 6425 L*." It is worth indicating whether this number refers to the total or only in-cloud sampling.

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