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Discussions

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Interactive comment

Interactive comment on "Widespread persistent polar stratospheric ice clouds in the Arctic" *by* Christiane Voigt et al.

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Reply to Anonymous Referee #2

The authors would like to thank the reviewer for the comments, which helped to increase the scientific quality of the paper and set it into a broader context. Below we reply (R) to the comments (C) of referee #2.

Referee #2:

C: The authors thoroughly analyze the observation of ice PSCs in the Arctic winter 2015/2016 Ice PSC occurrence in the Arctic has so far been found related to mesoscale

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Discussion paper

processes (e.g. gravity waves), but never on the larger synoptic scale. . . ..

SPECIFIC COMMENTS

C: - Does the newly defined threshold of the lidar backscatter ratio for ice PSCs affect the results of earlier Arctic PSC studies based on lidar measurements?

R: The effect of the newly defined threshold on PSC abundance in previous studies depends on which classification scheme was used in those studies. The new threshold does a better job of discriminating ice from NAT mixtures in denitrified conditions, but in most years the effects in the Arctic are probably small overall as synoptic ice is uncommon.

C: - While denitrification and its implications are discussed, there is no mentioning of dehydration which alters the formation conditions for PSC particles occurring later during winter. Has denitrification actually been observed during winter 2015/2016? Are there indications for dehydration? Could this information been drawn from Figure 1?

R: Denitrification and renitrification has been observed onboard HALO at flight altitudes by the NOy in-situ instrument and below by the GLORIA limb sounder onboard HALO. In addition the Aura Microwave Limb Sounder (MLS) showed that exceptional denitrification and dehydration throughout the polar vortex in the Arctic winter 2015/16 (Manney and Lawrence, Atmos. Chem. Phys., 16, 15371–15396, 2016). We now discuss the effects of ice PSC formation on dehydration/denitrification in the introduction. As suggested, we find indications for dehydration in Fig. 1, where the difference between the potential ice area (derived for a fixed water vapour mixing ratio) and the CALIPSO derived ice area increases throughout the winter, possibly caused by dehydration. In addition, we explicitly discuss dehydration /denitrification in the Arctic winter 2015/16 in section 8.

C: - Although persistent ice PSCs and temperatures below the frost point were observed on the synoptic scale for the first time, the later dynamics of the polar vortex (as described in lines 87 – 92) prevented from extreme ozone depletion. The actual timing of ice PSC occurrence and the observed ozone depletion in springtime 2016 thus need to be set into context at the end of section 8.

R: Thanks for this comment. We significantly extended the discussion in section 8 and set ice PSC occurrence and ozone loss in context to observations of dehydration and denitrification by MLS and to ozone loss in previous winters.

New text: "Sedimentation of the large ice particles led to significant dehydration of the Arctic winter stratosphere 2015/16. MLS data show severe dehydration between 400 and 500 K potential temperatures from January to early March 2016 (Manney and Lawrence, 2016). In addition, ice PSCs serve as efficient transporters for nitric acid. NAT is stable below Tice and NAT can be included in ice particles. The large ice particles sediment faster and therefore lead to efficient denitrification at PSC altitudes. This slows down the passivation of active chlorine species and further enhances ozone loss. Massive denitrification has also been measured by MLS with an onset in mid-December 2015 throughout the Arctic winter (Manney and Lawrence, 2016). Denitrification and dehydration were terminated by a major stratospheric final warming in early March 2016. In-mixing of ozone rich mid-latitude air by the early March dispersal of the vortex also terminated the Arctic ozone loss in the winter 2015/16. Thus ozone loss was significant in the Arctic winter 2015/16 but ozone concentrations did not drop below the extreme low values of the winter 2010/11 (Manney and Lawrence, 2016), when the vortex persisted till the end of March."

C: While I agree that Arctic ice PSCs may serve as indicator for low Arctic stratospheric winter temperatures, the relation between the occurrence of ice PSCs and ozone trends is more complex. With the final statement in section 9, this complexity needs to be discussed in more detail. Generally, I suggest merging sections 8 and 9 to an "Implications" section.

R: We agree that the occurrence of ice PSCs and ozone trends is complex and now discuss ozone and Arctic winter temperature trends in the merged Implications Section 8. To disentangle ozone trends we rephrase the last sentence to “Therefore, future observations of Arctic ice PSCs may serve as indicator to assess Arctic stratospheric winter temperature trends.”

TECHNICAL CORRECTIONS

Line 40: “more alternated” instead of “stronger”

Done

Line 158: regions which correspond:

Done

Line 170: Has the descending movement of the NAT particles been observed? Otherwise I suggest “: a layer of larger potentially sedimenting NAT particles”

R: There is no reason to believe that larger NAT particles do not sediment at temperatures below TNAT. The larger size of the particles is estimated from the lidar ratio. In addition, sedimenting NAT particles have been observed on another flight by the in-situ NOy instrument at HALO flight altitudes of 14 km.

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