

Interactive comment on “Denitrification and polar stratospheric cloud formation during the Arctic winter 2009/2010” by F. Khosrawi et al.

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We thank reviewer 2 for the constructive, helpful criticism. We followed the suggestions of reviewer 2 and revised the manuscript.

Some questions and confusing points:

11388.25: If dissolution of the PSCs renitrifies the air then the denitrification was not permanent? Clarify this statement.

Denitrification is only permanent when the PSC particles sediment out and thus permanently remove HNO_3 from this layer. We made some changes in the paragraph and hope that this statement is more clear now.

C6526

Fig. 2: The denitrification occurs very rapidly over about a 10 day period in early January. There is then a rapid recovery to hno_3 levels about 30% below the mid December levels, but it does not remain at the 50% lower values observed in early January. The authors may wish to consider this point in light of the previous comment.

Fig 2 (now Fig 3): A rapid removal of HNO_3 occurs during the first half of January due to PSC formation and denitrification. That denitrification and not only uptake of HNO_3 by PSC particles had occurred can be seen from this figure when HNO_3 is released back into the gas phase due to the dissolution of the PSCs after the major warming. Since the HNO_3 values are much lower than before the PSC season started and also much lower than what one would expect from the seasonal decrease we know that denitrification had occurred in January 2010. We describe this coherence in the paragraph following P11388, l25.

11391.11-14: Confusing. Suggest, “However, NAT formation has also been observed at temperatures above T_{ice} suggesting heterogeneous formation of NAT on particles other than ice, e.g. meteoric smoke particles (Voigt et al., 2005)”.

The sentence has been revised as suggested.

11393.15: What does it mean that PSCs are simulated? Do you mean the PSC simulations indicate the presence of PSCs in these areas? It would be clearer to state, “The box model simulations predict the presence of PSCs at the trajectory end (time of the lidar measurements) and occasionally at the beginning (5 to 6-days before the lidar measurements), when trajectories passed through the cold pool between Scandinavia, Svalbard and Novaya Zemlya.

Yes, we mean that the simulations show HNO_3 uptake and thus the presence of PSCs in these areas. We changed the sentence as suggested, but we cannot use “predict” since our trajectories are simulated backward in time and thus give the history of the air mass and not the future development of the air mass. We agree that the fact what we use backward trajectories with box model simulations that are done forward in time is confusing. We included the following sentences: *The box model simulations starts at*

C6527

the end of the trajectory, thus at the location and time from which the air mass originated. Note, the box model simulations are performed forward in time while the trajectories are calculated backward in time.

In general the starting and ending points of the trajectory are confusing as used in the manuscript. I expect, as would most English readers, that the trajectory is ordered in time. Thus the ending point of the trajectory is the measurement, or the point where the back trajectory is initiated, whereas the starting point of the trajectory is the first point of the back trajectory, or 140 hours prior to the measurement. Another example occurs at 11395.6. In my view this sentence would be easier to understand if it read, . . . along the trajectories which ended between 22 and 24 January . . . Then the following dates make more sense, since they do not occur before the previous trajectories 'started'. Another way to handle this is to be very clear whether it is a trajectory (usually assumed forward) or back trajectory. Thus a back trajectory can be started at Esrangle, but not a trajectory.

We agree and we changed "trajectory" into "back trajectory" throughout the manuscript to make clear that we use back trajectories.

Fig. 6: These data would be much easier to understand if presented in the conventional form as backscatter and depolarization ratio. Then the layers of cloud containing some fraction of NAT would be clearly shown. As presented now the figure requires the reader to do the work of forming the ratio in their mind to see the regions containing aspherical particles.

Fig 6 (now Fig 7) shows the backscatter ratio measured by the lidar at Esrangle while in Fig 7 (now Fig 8) only the PSC particle type is given. However, the PSC type is in both figures given by a color coding plus an additional hatching for the PSC type in Fig 6. For a lidar expert backscatter and depolarization would indeed be very valuable parameters, however for the common reader a simple color coding showing which type of PSC has been measured is more valuable. From the PSC type one also gets the information if the particles are spherical or non-spherical. Liquid particles as STS are spherical and solid particles as NAT and ice are non-spherical. So, adding

C6528

figures showing backscatter and depolarization would not provide any additional information. Details on which backscatter ratios and depolarization ratios were used for characterising the PSCs measured by the Esrangle lidar can be found in Blum et al. (2005). A short description on the characterization scheme is given in section 2.3.

11396.14: The authors have no basis for this statement that ice formed on NAT particles. How do they know that? Why could not the ice form in the very cold STS particles? Some believe that NAT forms only after ice forms, so the authors should be more careful here, stick to the observations, and avoid speculation. The sedimenting ice particles would still cause denitrification, I believe, even without NAT being involved, but this would be a good thing to check. How would denitrification resulting from sedimenting ice particles formed from STS compare to sedimenting ice formed from NAT? If there is a significant difference then this would provide support for the authors' suggestion of ice on NAT.

For the homogeneous formation of ice very low temperatures (3-4 K below T_{ice}) are needed. Ice can form heterogeneously at higher temperatures. Since NAT clouds had frequently formed until mid of January, sufficient NAT particles on which ice clouds could form were present. Thus, formation of ice on NAT during mid of January is a possible formation process. In fact, an increase of ice observations with a coincident decrease in NAT mixtures was observed by CALIPSO suggesting that under these conditions heterogeneous nucleation on NAT particles may be an important process for ice PSC formation (Pitts et al., 2011). Further, dehydration was observed at the same time as denitrification was observed. If ice would have formed on STS, one would only observe dehydration but not additionally denitrification. We will not discuss homogeneous ice formation in our manuscript. However, due to the comments given by reviewer 1 our discussion on which PSC formation mechanism prevailed and which particles could have caused denitrification should be much clearer now.

11397.21: In this paragraph the PSCs are characterized as STS, NAT, ice. Why now slip back into type 1b, and then in the next sentence back to STS?

C6529

We agree and changed type 1b to STS to be consistent with the text parts before and after.

Problems with begin

11388.21 . . . while at the beginning of . . .

This has been corrected.

11393.22: . . . at the beginning (or start) and end . . .

This has been corrected.

11394.11: Here and elsewhere “begin” is used incorrectly. I have already noted this a couple of times. This will be my last notice, but the authors should check the rest of the manuscript for the use of both begin. Here the sentence could be, *ĪĎ. . . by NAT in the beginning of January. . .’ or ĪĎ. . . by NAT at the start of January . . .’* The first option would be chosen by most writers. Oddly, in English, the construction at 11394.13, *ĪĎ. . . to end of January . . .’* is okay, because end is both a noun and verb, whereas begin is only a verb, with the noun being start or beginning.

We corrected our usage of “begin” throughout the manuscript.

Other minor corrections

11388.10: . . . cooled synoptically . . .

This has been corrected.

11392/16: . . . occurred . . . 2010 and was . . .

This has been corrected.

11396.10: . . . The ice PSCs measured . . .

This has been corrected

C6530

11397.10: Here and elsewhere use the plural of PSC when plural is intended. Thus change this to . . . area the PSCs were . . . January and then by . . . Also check for this construction throughout the manuscript. Up to here I have been ignoring the mistake.

This has been corrected and we checked the manuscript for similar errors and corrected them, too.

11398.1: . . . consistency suggests . . .

This has been corrected.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 11379, 2011.

C6531