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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Quantifying the clear-sky temperature inversion frequency and strength over the Arctic Ocean during summer and winter seasons from AIRS profiles" *by* A. Devasthale et al.

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Reply to Referee #1

We are very thankful to the referee for her/his careful review and constructive suggestions. We have taken into account the referee's comments to clarify and improve the revised manuscript. The point by point reply to these comments is given below.

"While the data analysis will be useful to those studying the poorly sampled Arctic Ocean, the analysis and physical interpretations are limited in scope and novelty."

- While we agree that the descriptions of few aspects are short in the manuscript (which are now elaborated in the revised version), we disagree with referee that the manuscript is limited in novelty. We would like to point out below some aspects that are new in our study.

a) We have provided, for the first time, probability density functions (PDFs) of clear-sky inversion strength covering the entire Arctic Ocean for the individual months of summer and winter seasons (Figs. 3 and 4). As the referee may agree, this is extremely valuable information not only to climate modeling community, but also to researchers studying various processes over the Arctic. In order to evaluate the performance of climate models, comparison of only mean inversion strength is not sufficient. It is more insightful to understand the spread in inversion strength distribution from modeling perspective. These PDFs are based on most advanced and accurate satellite sounder data available for the study period.

b) We have also investigated year-to-year variations in PDFs of inversion strength for the entire Arctic Ocean for summer and winter. This provides us some clues on the expected degree of variability in reference to anomalous events. For example, please note different shapes of PDFs during summer of 2007, when record sea-ice minimum was observed over the Arctic (Fig. 3). Also, one can see interesting variability in the spread of PDFs during winter months (Fig. 4). Apart from the PDFs, we have investigated spatial and intra-seasonal distribution of inversion frequency and strength together for these two seasons over the Arctic.

c) We have shown, in detail, the interannual variation in the spatial pattern of inversion strength during individual summer months to contrast the stability observed during 2007 (Figs. 7-9).

1) Data sampling concerns. More details on the conditional sampling of this dataset in the Arctic should be included, especially if this dataset is to be used for model evaluation as suggested on page 2845. Perhaps the greatest limitation of the AIRS data is

the clear sky sampling. This issue needs more attention in this paper. How frequently are AIRS observations considered to be cloudy? Does this change as a function of season and year? Can you assess the clear sky bias in the results presented here? Can models compare their results to a clear-sky retrieval without conditional sampling? In addition to the clear sky sampling issue, what is the temporal sampling of the AIRS data? What is the difference between the ascending and descending passes? Why are data from only the summer and the winter analyzed?

- As suggested by the referee, more information on the conditional sampling of AIRS dataset is added in the revised manuscript. In order to avoid bias due to cloud contamination, we have investigated only clear-sky temperature inversions. However, as mentioned in previous reply, this is also very useful. As rightly pointed out by referee, the spatial-temporal variations in cloud cover have an influence on the sampling of data used for the analysis. We have actually highlighted this aspect in the Supplementary figure that shows the spatial pattern of the total number of AIRS profiles used for the analysis. It can be seen that the sampling pattern is not uniform, and the number of observations are high in winter (due to less cloudy conditions compared to summer). However, it is important to note that spatial patterns of inversion frequency and strength (Figs. 2 and 5) do not show footprints of such different sampling, thus hinting at the robustness of our results.

- The reason for analyzing only summer and winter seasons is twofold. First, the literature review shows that inversion frequency and strength are highest in winter and lowest in summer over the Arctic. Therefore, it is interesting to quantify these two contrasting episodes and to examine how well they are simulated by climate models. Second, it has been observed that the satellite sensor retrievals of cloud top height, which require ancillary knowledge on temperature inversions, are sensitive to inversion strength. It is very challenging to assign cloud top height retrieved from the passive sensors like AVHRR in such two contrasting episodes. Therefore, first we require an assessment of the statistics of inversion strength and frequency to subsequently un-

derstand the expected bias in such retrievals. Due to these reasons, we have focused on summer and winter seasons.

- When satellite is orbiting from north to south, it is in a descending pass, and vice versa. For tropics and mid-latitudes, this means that the ascending passes represent daytime conditions and descending passes nighttime conditions due to polar sun-synchronous orbital configuration of the Aqua satellite. The sampling of the Arctic region is better than in tropics and mid-latitudes due to data from overlapping orbits.

The manuscript is updated to include these discussions.

2) Physical interpretation. Explanations of what controls geographic and temporal variations in inversion frequency and strength were limited and/or not new. Why are the inversion strength PDFs broader in winter than in summer? Why are there weaker inversion strengths and less frequent inversion occurrences in the near-coastal environment as compared to the central Arctic?

- Among various mechanisms discussed over the years, the following two are considered to be most likely explanation of inversions over the Arctic. i) Radiative imbalance - During the Arctic winter, there is no solar radiation reaching the surface. However, the surface does emit the longwave radiation continuously. This leads to the emission being exceeding the input energy from sun. In such an imbalance, the surface radiatively cools down, while the atmosphere warms causing stable conditions. ii) Warm air advection and descend - For most part of the year, surface temperatures over the Arctic are low. The transport of warm air from the midlatitudes can cause extremely stable layers to be formed. During strong and persistent anticyclonic conditions (e.g. as observed during summer 2007 over Beaufort Sea), subsidence inversions are commonly present.

- During winter, the very low surface temperatures (Fig. 6) and increased sea-ice concentration play a major role in controlling inversion strength. A net deficit in radiation in such case is the dominant cause of much broader PDFs of inversion strength observed over the Arctic compared to summer. Increased temperatures, decreased sea ice, and frequent cyclonic activity contribute to lower inversion strength during summer.

The revised manuscript discusses these aspects in more detailed manner.

3) Following on from 2). While this paper does provide additional quantification of the atmospheric temperature structure during 2007, it does not add much new information beyond what is already present in the literature. As noted by the authors, work has already been done to assess the 2007 inversion strength anomaly as seen in the AIRS dataset. The monthly resolution adds more temporal detail, but as presented and discussed, is not compelling. Kay and Gettelman (2009) discuss both large-scale circulation and sea ice loss related mechanisms for year-to-year variations in inversion strength as assessed from AIRS. For example, they attribute the strong inversion strength in 2007 to warm air advection: "Warm air advection aloft produced by the southerly winds also enhanced near-surface static stability over the Pacific marginal seas." A similar situation is likely present in 2005, which also had a strong anti-cyclonic Beaufort High as discussed in Kay et al. (2008).

- Referees comments are duly noted. We are aware that there have been many studies investigating sea-ice minimum of summer of 2007 (please see our list of references). In the present manuscript, it is not our main aim to carry out full investigation of that event, but rather to complement these earlier studies. As mentioned above, we have shown, in detail, the interannual variation in the spatial pattern of inversion strength during individual summer months to contrast the stability observed during 2007 (Figs. 7-9). This useful information is missing in the earlier studies. Additionally, the results presented in Fig. 10 are based on more robust statistical analysis than earlier studies and support the results by Kay and Gettelman (2009). We have added more discussion on this aspect in the revised manuscript.

Minor comments Page 2838: I was not familiar with the work of Liu et al. (2006), but am skeptical about the utility of this data. What can you learn about the Arctic inversion

with channels peaking at 650 mb and the surface? The 650 mb level does not seem appropriate.

- We agree that the vertical resolution in the analysis of work by Liu et al (2006) was very coarse. However, it is to be noted that the AIRS instrument was not available before 2002. The analysis presented by Liu et al (2006) was based on HIRS sensors, which were the advanced sounders at the time. They have demonstrated that inversion strength and its spatial pattern are captured quite well by their methodology (although only for winter months). Our results, using the current more advanced sounder AIRS, support their estimates of inversion strength qualitatively over the Arctic. The advantage of using HIRS data in estimating inversion strength during winter is that these data are available from early eighties. This historical information is indeed very important for climate monitoring, especially over the Arctic were in-situ measurements are sparse.

Do the authors know the following papers? They seem particularly relevant. Pavelsky T, Boé J, Hall A, Fetzer E (2009) Atmospheric Inversion Strength over Polar Oceans in Winter Regulated by Sea Ice, Submitted to Clim. Dyn Boé J, Hall A, Qu X (2008), Current GCMs' unrealistic negative feedback in the Arctic, J. Clim, 22: 4682-4695, DOI:10.1175/2009JCLI2885.1

- These papers are indeed relevant. We were not able to refer the first paper as it was not published at the time of submission of our manuscript. This paper interestingly demonstrates the driving role of sea ice concentration in controlling inversion strength during winter. We have also shown that the surface temperature has inverse relationship with inversion strength indirectly corroborating their analysis. The other paper highlights the need to critically evaluate GCM's over the Arctic. Here, we would like to point out again that the comparisons of inversion strength PDFs will provide better insights in this context.

Page 2839. "discussions" to "discussion"

Corrected.

Figures. Is it necessary to include both the ascending and descending orbits? If both are included, it would be more useful to provide one orbit, and a difference map between the orbits.

- We have investigated data from both ascending and descending passes separately to understand the diurnal differences in inversion frequency and the PDFs of inversion strength. It is not methodologically possible to show differences in PDFs.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 2835, 2010.