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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Cluster analysis of an impact of air back-trajectories on aerosol optical properties at Hornsund, Spitsbergen" *by* A. Rozwadowska et al.

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The authors thank the Anonymous Reviewer #1 for the very helpful comments and remarks.

A detailed response to each question and comment is attached below.

1) "The authors perform a cluster analysis of trajectories and test several set-ups by clustering trajectories with varying lengths from 1 to 8 days and for various altitudes. They then present their results by calculating the fraction of variance explained by the

cluster analysis as a function of the length of trajectories used for the clustering (Fig. 2-4). They then argue that a particular length (8 days in spring, 1 day in summer) gives optimal results. However, I am concerned that no statistical test is being performed. The number of data points available for clustering is relatively small, the number of clusters large (10) and some clusters seem to be populated by only one or two trajectories.

The dependence of explained variance on trajectory length appears to be not very systematic and I am simply wondering whether this dependence is even statistically significant. A statistical test is urgently needed before any conclusions can be drawn."

The statistical importance of the results has been investigated and according to the authors the results are statistically significant. However, in order to clarify this issue the following information will be included in the final version of the paper.

In order to evaluate the statistical significance of the results the impact of different seed files on the relative variance has been investigated. The data clustering method is not fully objective and its results depend, to some extent, on the seed file applied. In this study three types of seed files were applied (2 in the first version). The first seed file included all trajectories from a given season. The second included a selection of trajectories from a given season with a range of different shapes of trajectories. The third seed file consisted of "artificial" trajectories, which originated in Hornsund and which after 8 days reached 45 or 65deg N. Four (2 short and 2 long) of these "radii" were directed towards Asia, 2 to Europe, 2 to the Atlantic Ocean and 4 to North America, while last 2 towards the Bering Strait. With trajectory clustering at several levels simultaneously combination of these "radii" at has been used as a seed file.

Depending on a seed file applied clusters may differ with respect to a “content”, even though they described similar advection directions. The values presented in figures 2 and 3 are average values from the results obtained for 3 seed files. In figure 2 ranges of AOT relative variance values are presented (minimum and maximum from 3 cases). Usually the differences resulting from different seed files are significantly lower than the variability of an average relative variance related to trajectory length.

Additionally, the conclusions drawn from the cluster analysis found their confirmation in the results of more direct approach to the trajectory classification. The following groups have been distinguished among the seasonal cases:

- none of the trajectories (3 levels) had contact with land, except for Greenland,
- at least one crossed over North America
- at least one crossed over Eurasia.

In each of these groups 2 subgroups have been distinguished: advection over the Spitsbergen to the station and marine advection over the station.

In order to verify the impact of the “source area” on AOT, average AOT values for these 3 groups have been compared. The following mean values were obtained for summer: 0.043+/-0.004 (+/-standard error) (trajectories from over North America), 0.041+/-0.002 (Europe and Asia) and 0.039 +/-0.008 (sea). The differences among the averages are not statistically significant at a level of confidence of 0.1 (The null-hypothesis that the means are equal failed to be rejected at significance level of 0.1; two-sample unpooled t-test for means). Much higher differences were observed for AOT values for the same source but for trajectories, which crossed over Spitsbergen and for those which reached Spitsbergen from over the sea. The average summer AOT values for cases of advection from over Europe and Asia were 0.049 +/-0.005, while for advections from over the Spitsbergen equaled to 0.072 +/-0.017. The null-hypothesis that the means

are equal was rejected at significance level of 0.11. In cases of advection from over the North America the average values of AOT for marine advections and the ones from over the Spitsbergen were as follows: 0.038 +/-0.002 and 0.060 +/-0.013, respectively. The difference is statistically significant at a level of confidence of 0.1. For trajectories without contact with the continents the difference between the direct advection to the station from the sea and from the island direction the null-hypothesis that the means are equal failed to be rejected at significance level of 0.1 (the respective means: 0.037 +/-0.002, 0.043 +/-0.005).

In spring the situation was different. The average AOT values for trajectories without contact with the continents and for the cases when at least one trajectory “touched” North America and cases with trajectories from Eurasia) equaled to 0.088 +/-0.009, 0.085 +/-0.008 and 0.1131 +/-0.006. The average AOT values for the marine and North America cases are identical, while the differences between the mean AOT values for these groups and those for advections from over the Eurasia are statistically significant at a confidence level of 0.1. The impact of a direct advection over the station (marine or from over the island) is noticeable but the difference is not statistically significant at a level of confidence of 0.1. The average AOT values for air masses from over the Eurasia via the Spitsbergen or the sea are as follows: 0.104 +/-0.007 and 0.123 +/-0.010, respectively.

Statistical significance of the results is not high, but in order to obtain higher significance greater number of data is necessary. However, due to a specific features of the applied method (unobscured sun), the Arctic conditions as well as fast changes of climate the collection of a large data set may be impossible. Therefore, the authors think that despite the relatively small number of data their thorough analyses are worthwhile.

2) “Even more severe is that while the statistical results are presented, no real physical explanation for them is given. The fact that a trajectory length of 1 day seems to be optimal in summer is “mainly related to local atmospheric conditions”, whereas

the optimal 8-day length in spring is explained by the importance of long-range transport.

However, what are the physical mechanisms? For instance, are strong winds and sea-salt generation important in summer? Or what else drives the AOT variability in summer? Why is that not important in spring, too? The results need a lot more explanation, interpretation and discussion."

The revised version of the paper will include the following information

Figures 2 and 3 (numbering from original manuscript) show that long-range advection is responsible for AOT variability in spring, which is in accordance with the present knowledge. It results from the location of the main pollution sources, mainly outside the Polar Circle and easier advection of air masses from lower latitudes. This on the other hand is connected with the southerly location of the Arctic front. Besides, the relatively low cloud cover and small precipitation decrease wet deposition and make the long-range transport more effective in spring. The fact that the variability may be connected mainly with higher trajectories is likely concerned with longer ranges of such trajectories and lower chances for particles to deposit from high altitudes. In spring local production of aerosols is relatively small since vast areas of Spitsbergen are covered with ice and snow. Sea ice reduces marine aerosol production. In spring advections from NW-E-S are most frequent, which causes that the trajectories cross over rather uniform surface – mainly snow and ice.

In summer the AOT variance is several times lower than in spring. The Arctic front moves northerly, which makes the air mass advections from lower latitudes more difficult. The air mass trajectories have thus shorter ranges than in spring.

Long-range advections occur but they are much less common than in spring and either have insignificant impact on AOT values or the impact is much smaller than in spring. This is connected with an increase of wet deposition due to greater cloud cover and pre-

cipitation. While in spring advection comes mainly from northern and eastern sectors, in summer the air inflow from the western sector (S-W-N) is dominating. In summer air masses cross over ice free (to a great extent) ocean surface, and significant cloud cover is present (http://modis-atmos.gsfc.nasa.gov/MYD08_M3/browse_c5.html). Ice moves northerly which facilitates greater production of marine aerosols. They contribute to AOT. However, such generation of mainly coarse mode particles due to wave breaking causes the creation of additional deposition fluxes of smaller particles from the boundary layer. Simultaneously life is intensified in the tundra and the sea. The authors think that in summer, similarly to spring conditions long-range advection from Europe and Asia is mainly responsible for the AOT variability. However, unlike in spring the trajectory of the advection is important (direct advection from over Spitsbergen or from western and southern sectors over the sea). The importance of the source is masked by variability in the cleaning intensity on the way to the station. In cases of the highest average AOT air masses advect directly from over Siberia through the Arctic Ocean and the Spitsbergen. In general the Spitsbergen island has lower cloud cover in summer than warm sea in the southern and western parts (in August also from the east).

In cases of advection from the North America and Eurasia from over the ocean the AOT values are significantly lower than in cases of such advections via the island (see also the response to # 1) while such differentiation is not observed for the trajectories without any contact with continents. The summer AOT variability is influenced by local processes in a sense of cleaning processes rather then by local aerosol sources.

The comparison given in #1 confirms the conclusions drawn from the cluster analysis which show that in summer, unlike in spring, the AOT variability is mainly caused by local processes of aerosol cleaning which are more effective while crossing over the ocean, due to increased cloud coverage and marine aerosol cleaning potential (boundary layer).

Due to a relatively small number of data these are rather assumptions and the further discussion on this issue will be given in a separate paper.

"3) Figure 1 is referred to with one sentence at the end of section 2.1 but the text makes no use of this Figure, does not discuss it, etc. The figure could be important but without discussing it, it can just as well be removed!"

According to a suggestion by Reviewer 2 the figure will be moved to Section 2.1 to illustrate the AOT data set available. Fig. 1 is referred to in Section 2.3 to justify separate cluster analysis for spring and summer and to give a reader a general impression on AOT variability. Detailed discussion of a seasonal variability of AOT and α at Hornsund will be given in a separate manuscript "Variability of aerosol optical properties in Hornsund, Spitsbergen" prepared for Oceanologia (Rozwadowska and , 2010)

"4) Symbol names in the equations: The symbols are named like in a computer code, not as in equations in a scientific article. Names like "N_traj_j" or "i_j" are not acceptable."

It will be corrected in a revised version of the manuscript.

5) "Sections 3.2.1 and 3.2.2 describe on nearly 4 pages what Fig. 5 and 6 show. However, they do not interpret these figures but literally describe what the reader can see anyway. Again, physical interpretations are needed here instead of descriptions of the figures."

The description goes beyond the information given in Figures 5 and 6. For clusters with high and low average AOT 8-day long trajectories at all levels are presented, which is not shown in figures. In order to improve the message the detailed description of the trajectories will be replaced with figures. Additionally the chapter will be changed in accordance with the suggestions given by reviewer 3.

Physical interpretation of the results is given in our answer to #2.

Minor points:

1) "P15425, l1 (and other places): I assume you mean the Arctic front, not the polar front, which is located much further south."

This is a mistake. We meant a front between the Arctic and Polar air masses, i.e. the Arctic front.

2) "Why have trajectories at 1, 2.5 and 5 km been used and for which arrival time were they calculated? Do the arrival times coincide exactly with observation times? Especially if you speculate that local effects are important in summer, I suppose that lower-level transport might be quite important!"

The information below will be included in the final version of the paper.

Backward trajectories computed by means of NOAA HYSPLIT model (Draxler and Rolph, 2003) were used to trace the air history. For calculations the "reanalysis" data base was used. The middle time of the aerosol measuring period at a given day was selected as the trajectory arrival time input to HYSPLIT at that day. The trajectories were calculated for three arrival heights: 1 km, 2.5km and 5 km a.s.l.. These heights are comparable to those used by Engvall et al. (2008) for Ny Alesund. It must be noted that that trajectories in general change altitude as a function of transit time and these heights are only ones at which the air arrives at the station. The selection of 1 km as the lowest level resulted from the orography around the station. The fiord is surrounded by hills of 500 to 1000 m a.s.l. heights (highest peak 1431 m a.s.l.) and thus lower trajectories, even if they are calculated properly will be significantly influenced by the orography.

The is a lack of data regarding the boundary layer thickness over the Hornsund, however, it is not a typical Arctic BL over the ice-covered sea. The station is surrounded by a spatially variable terrain: fiord and ocean, glaciers and tundra and rocks. The station is located at the mouth of the fiord to the warm ocean. From 1 to 2 km north of the station there is a peak of c. 500 m elevation. Most likely the boundary layer elevation often exceeds 1000 m a.s.l.. Spring occurrence of Cumulonimbus clouds confirm the presence of a relatively thick boundary layer, which is likely similar to that in Kongsfjorden (Spitsbergen). Engvall et al. (2008) assumed the thickness of the boundary layer in Ny Alesund (Kongsfjorden) at c. 2 km for April-June. They defined the boundary layer limits using the height of cloud tops.

3) "The use of the English language should be improved. While I could understand most

sentences, the paper just doesn't read very well. One example is P15431, l10-11:

"Relative variances of AOT and alpha strongly depend on a number of clusters, i.e.,

they decrease with an increase of a number of clusters." Why not simply write: "Relative

variances of AOT and alpha strongly decrease as the number of clusters increases."?

There are many more examples and I do not list them all."

The final version of the paper will be revised by a native speaker.

4) "P15424, l7: by the at least 8-day trajectories of air: What do you mean here? It

becomes clear after reading the paper but the abstract should be self-explanatory and

the sentence is almost unreadable."

The Abstract has been rewritten according to the suggestions of the reviewers:

In this paper spectra of aerosol optical thickness from AERONET (AErosol Robotic NETwork) station at Hornsund in the southern part of Spitsbergen were employed to

study the impact of air mass history on aerosol optical thickness for a wavelength lambda=500 nm (AOT(500)) and Angstroem coefficient. Backward trajectories computed by means of NOAA HYSPLIT model were used to trace air history. It was found that in spring changes in AOT values over the Hornsund station were strongly influenced by air mass trajectories of duration 8 days or longer, arriving both in the free troposphere and at 1 km a.s.l.. However, the free tropospheric advection was dominating. In summer the AOT variability was best explained by local direction and speed of advection (1-day trajectories) and was dominated by the effectiveness of cleaning processes. During the ASTAR 2007 campaign aerosols near Hornsund showed low AOT values ranging from 0.06 to 0.09, which is lower than the mean AOT(500) for spring seasons from 2005 to 2007 (0.110+/-0.007; mean+/-standard deviation of mean). The 9 April 2007 with AOT(500)=0.147 was an exception. Back-trajectories belonged to the clusters of low and average cluster mean AOT value. Beside the maximum AOT of the 9 April 2007, the observed AOT values were close to the means for the clusters to which they belonged or were lower than the means.

5) P15425, l1 "(and other places): I assume you mean the Arctic front, not the polar front,

which is much further south."

This is a mistake. We meant a front between Arctic and Polar air masses, i.e. the Arctic front. It will be corrected.

6) "P15426, l21: Why are locally generated aerosols less effective with regard to light

attenuation? Do you mean absorption? Sea salt, for instance, is very effective at

scattering!"

By "effectiveness" we meant the contribution/impact of a given source to AOT. The sentence will be changed:

Natural, local Arctic sources of aerosol are usually far less effective with regard to light attenuation than the long-range transport.

7) “P15428, l25: I do not agree that a trajectory started at 1 km is representative of the boundary layer (BL). The Arctic BL over snow or ice is typically only a few dozen to a few hundred meters high.”

Section 2.2 has been modified as to incorporate this comment. Please, compare our answer to “minor point 2”

8) “Equation 1: I am wondering why you haven’t calculated the distances on a sphere. After all, Euclidean distances on a projection are an approximation. Even if the error is probably negligible, this is just an unnecessary approximation.”

This approximation was added in order to facilitate easier calculations. The clustering algorithm requires the calculation of an average trajectory from all trajectories of the given cluster. The arithmetic means of coordinates of components do not distinguish the point of the average trajectory. The average point is the one for with the sum of squares of distances calculated along the curve on a sphere between the point and the component points is minimum. In order to calculate the coordinates of such a point numerical methods must be employed. The transfer of the calculations to a plane made the clustering algorithm easier.

9) Language, style, etc.:

“P15424, l4: AOT(500) should not be used like this in the abstract

without explanation. “

The first sentence of Abstract has been rewritten as follows:

In this paper spectra of aerosol optical thickness from AERONET (AErosol RObotic NETwork) station at Hornsund in the southern part of Spitsbergen were employed to study the impact of air mass history on aerosol optical thickness for a wavelength

λ=500 nm (AOT(500)) and Angstroem coefficient.

P15425, l16: “Engval et al.(2007) reference does not exist. Do you

mean Engvall (double l) (2008)? “

It is a mistake. It should be Engvall et al. (2008).

P15428, l19-20: “Sentence entirely unreadable.”

The sentence has been rewritten as follows:

Further in the text AOT(500) and alfa denote daily means of aerosol optical thickness for lambda=500 nm and Angstroem exponent calculated for the spectral range from 440 to 870 nm, respectively.

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