Atmos. Chem. Phys. Discuss., 9, C6411–C6426, 2009
www.atmos-chem-phys-discuss.net/9/C6411/2009/

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.

A. Rozwadowska et al.

ania@iopan.gda.pl

Received and published: 30 October 2009

The authors thank the Anonymous Reviewer #3 for the very helpful comments and remarks.

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

1) Data and methodology:

"This section presents the data sets, the backward trajectory calculations and the clustering analysis. In all three sections I miss essential pieces of information.

Data (2.1): What is the Angstroem exponent? What does the number 500 mean in

1 AOT(500)? What is AOT_fine and AOT_coarse standing for? In addition to these

basic questions, I would appreciate some information about the temporal resolution and the accuracy of the measurements."

AOT(500) means AOT for wavelength lambda=500 nm. The Angstrom exponent is a slope of the AOT spectrum presented in log-log scale. It is defined as follows:

AOT(lambda)=AOT(lambda_0)*(lambda/lambda_0)ˆalfa

AOT_fine and AOT_coarse (AOT(fine), AOT(coarse)) are AOT values resulted from respective fine and coarse mode aerosol attenuation. The modes used in this instance by AERONET are defined optically. The coarse mode spectral variation is approximately neutral. Details of the algorithm for the spectral discrimination of coarse and fine mode optical depth can be found in O'Neill et al. (2003).

In cases of clear sky conditions the measurements were made 6 times an hour (time periods of 6-15 minutes between measurements). In cases of cloudy conditions the measurements were unevenly distributed during a day. The AOT measurement accuracy is 0.02 for UV and 0.01-0.2 for VIS (lambda>380 nm) (Dubovik et al., 2000)

O'Neill, N. T., Eck T. F., Smirnov, A., Holben B. N. and Thulasiraman S.: Spectral discrimination of coarse and fine mode optical depth, J. Geophys. Res., 108, D17, 4559, doi: 10.1029/2002JD002975, 2003.

Dubovik, O., Smirnov, A., Holben, B. N., et al., Accuracy assessments of aerosol optical properties retrieved from AERONET sun and sky radiance measurements. J. Geophys. Res., 105, 9791-9806, 2000.

“ Is ist furthermore correct that the aerosol optical

thickness is dimensionless? “

AOT is dimensionless.

“Then, on line 29 (page 15428) it is written that "the original spectra obtained

from ERONET were additionally cloud screened". Please explain why this is the case!”

The AERONET cloud screen algorithm (Smirnov at al, 2000), as any other authomaticated algorithm is not 100% successful. Lidar cloud observations prove imperfection of the algorithm. An application of lidar observations smoothed the AOT daily coarse much better then the AERONET algorithm. The algorithm imperfection can be also confirmed by the analysis of AOT time series from Hornsund. An increase or strong temporal variations in coarse mode AOT are often associated with chopped/discontinuous data set, only few measurements during the day (signs of a cloudy day), and happen near breaks in the measurements (edges of clouds). In spring small snow crystals appear in the air which originate from the nearby hills. During ASTAR campaign the high correlation of the elevated concentration of coarse mode aerosol (measured with CSASP-100-HV-SP) with the blowing snow and precipitation cases was observed. Both cloud particles (droplets/crystals) and blowing snow particles belong to the coarse mode. Sand storms are unlikely in Hornsund. The only source of aerosol coarse mode particles is the ocean, but such cases must be related to strong wind from the ocean. Therefore cases when higher AOT temporal variability was caused only by coarse particles and could not be justified by a storm on the ocean, indicating high probability of thin cirrus clouds or drifting snow crystals were rejected.

Smirnov, A., Holben, B. N. , Eck, T. F., Dubovik, O. , and Slutsker, I.: Cloud-screening and quality control algorithms for the AERONET database, Remote Sens. Environ., 73, 337-349, 2000.

“Backward trajectories (2.2): This description needs some important improvements. It

is not sufficient to say that "the reanalysis" data base was used. Which reanalysis?

What is the horizontal and the vertical resolution of the reanalyis? What is its temporal

resolution? Note that these aspects have a considerable impact on the quality/accuracy

of the backward trajectories? “

“Reanalysis” in this case means the name of the data set in the HYSPLIT services to calculate trajectories. i.e., Global NOAA-NCEP/NCAR pressure level reanalysis data archives reprocessed into the HYSPLIT compatible format (NCAR/NCEP reanalysis project, Kalnay et al, 1996, Draxler ae al., 2009). The global data are on a latitude-longitude grid (2.5 degree) at 17 pressure levels (18 sigma levels). The time resolution of the data is 6 hours.

Roland Draxler, R., Stunder, B., Rolph, G., Stein, A., Taylor, A., HYSPLIT4 USER’s GUIDE, Version 4.9 - Last Revision: January 20091

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Leetmaa, A., Reynolds, R., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Jenne, R.,and Joseph, D.: The NCEP/NCAR 40-year reanalysis project, Bull. Amer. Meteor. Soc., 77, 437-470, 1996.

“Furthermore its has to be considered that one single

trajectory is very often not representative for the air mass arriving at one specific site.

Often this shortcoming is overcome by running backward trajectories not only at the

measurement site, but also at horizontally displaced starting points. This allows to

assess the coherence of the air streams arriving at the site. Please comment on this

aspect of the backward trajectory calculation.”

Trajectories used in the paper are representative for Hornsund area.

Beside the trajectories ended at Hornsnd also those for points shifted by 2.5 deg E and W and 0.5 deg N and S versus Hornsund have been calculated for the same altitudes as in Hornsund. In cases of trajectories, which arrive in Hornsund at a single altitude in almost 70% of cases trajectories, which reach 4 or 3 points around Hornsund are very similar to that which simultaneously reaches Hornsund at the same altitude. In other 23 % two are similar. While comparing sets of 3 trajectories simultaneously (i.e. trajectories which arrive at all 3 altitudes) in 72 % at least 2 cases (2 trajectory sets which reach the points which surround Hornsund) are in agreement at all 3 altitudes with the trajectories for Hornsund, and in 40 % at least 3 sets. For selected cases with strong trajectory divergence trajectories were also calculated with a denser grid. It was confirmed that strong spatial trajectory divergences also occur for a denser meteo grid cases (1 degree of latitude and longitude).

The spatial distribution of additional points with trajectories in agreement with those for Hornsund is variable. We must remember that distances of some 120 km are already synoptic and thus the trajectories can differ.

In further calculations only trajectories for Hornsund have been used.

“Cluster analysis (2.3): It is stated that "the distortion related to the projection had a secondary impact on the classification". I am not completely convinced that this is the case. This is obviously the case for short-time trajectories. However if the backward trajectories extend for several days into the past and hence cover a large horizontal distance, the projection might become important. Have you really checked that the distortion due to the projection can be neglected?”

The projection is equidistant along the “meridians” (In this nomenclature Hornsund - the tangent point of the projection, is located at the pole), however there is some distortion along any other lines/directions. It is the greatest along the “parallels” and increases

along with angular distance from the tangent point from 0.4% for 20 deg, 2.0% at 30 deg, 4.6% at 40 deg, 8.5% at 50 deg, and 13.8% at 60 deg. The given cases are extreme. The error decreases when the points are not on the same “parallel”. Majority of trajectories are within 40 deg and only some exceed 60. Besides the respective points of two trajectories are rarely on the same “parallel”.

“ I also wonder how As a further

point: You are identifying a huge number of clusters ("cluster numbers ranged from 30 to 5")? How statistically significant are the individual clusters?

Note also that the number of clusters is quite large and looks arbitrary. How is the number of clusters determined? What about the statistical significance of the clustering results? Stated in another way: If you repeated your analysis for some other time period, would you expect the same results?

30 clusters are just a working version and certainly does not make too much sense. This misleading information will be withdrawn from the text. Ten clusters were necessary in order to compare the changes of the relative variance for different cases of clustering.

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 65^{O} 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.

We agree that not all clusters are statistically different in terms of AOT and Angstroem exponent. Different trajectory directions and air mass sources can be characterized by similar AOT values and the opposite, clusters with similar trajectories do not have to have very similar optical properties. The aim of this paper was to determine the aerosol optical properties for different advection directions. Since the cases are grouped according to trajectory character and not optical properties, then the wider the clusters (and smaller their number) the greater the chance that a given cluster includes cases of different features influencing AOT even if the trajectories are similar. For example the clustering algorithm does not include the type of the surface and thus the same cluster includes trajectories from over the land and sea if their coordinates are similar. The surface factor is important both in summer (advection path) and in spring (source). Decreasing the number of clusters the probability of connecting clusters with different surface features increases.

Taking in consideration possible combinations of trajectory shapes and directions at 3 levels then 10 clusters are not many.

One of the criteria for the selection of the number of clusters involves the points of a strong increase of the minimized factor (eq. 2) with a decrease in a number of clusters. One of the "breaks" in the function plot usually occurred in the range 7 to 11 clusters.

If we repeat the analysis for some other time (but for the same season), general conclu-

sions regarding the relations between advection directions and trajectory lengths with the AOT values should not be too much different, however, the exact plots of the average trajectories for clusters and relative numbers of cluster members may be different.

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 following information will be included in the final manuscript

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 precipitation. 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. This is proved by the analysis presented below. The analysis also shows that differences in the mean AOT related to the direction of the direct advection to the station (from the

sea or from the island) are more pronounced for trajectories from North America and the Eurasia than for trajectories without any contact with the continents. Therefore we think that the summer AOT variability is influences by local processes in a sense of cleaning processes rather then by local aerosol sources.

In the analysis mentioned above 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.

The comparison given above 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.

“ In particular, how to you

justify to keep clusters with only one member?”

The clustering algorithm starts with a large number of clusters and then the most similar

ones are joint. The program does not eliminate one- element clusters, however, they can be treated as outliers. The number of elements in the discussed clusters is given in figures.

One-element cluster has got an average variance zero. In order to check their impact on relative variance discussed in this paper, also relative variance was calculated with zero variance in these clusters replaced with values equal 3-time variance for the entire season (without clustering). The differences in relative variance were negligible.

“ Finally, I do not see why you are mixing

different levels in your distance measure (equation 1)?”

Pollution advection may occur at different altitudes. Similarity of trajectories, which arrive to the point at a given altitude is not relevant for trajectories which arrive at this moment at other altitudes. This paper shows the analyses of the dependence of AOT on the advection of chosen “single” altitudes and on the advection on different altitudes simultaneously. This is to represent the advection in the entire column of lower and middle troposphere. Then each cluster is represented by 1, 2 or 3 trajectories together. This is why the authors use the mixing different levels in the distance measure.

Making it simple, e.g. instead of cluster which is for northerly advection at 5 km we can have 2 clusters – the first with northerly trajectories at 5 km and westerly advection at 1 km and the second one with northerly advection at 5 km and easterly advection at 1 km. The AOT values will be different in both cases.

Figure 3 shows that with a proper number of data such approach makes sense.

2)” Results:

At the moment th whole paper is strongly focused on the statistical aspects of the

clustering, i.e. the clusters are used to determine how the relative variance of

rel_VAR(AOT) is reduced. I would appreciate very much if some further refinements on

the meteorology of the clusters themselves can be included. Actually, I would propose a restructuring of the whole results section into four distinct parts:

- part 1 only introduces and discusses the different clusters. Here, some additional information about the meteorology associated with the clusters could be given, e.g. source region, number of members, coherence. Note also that the average of a cluster might sometimes be misleading. So how strong is the spread around the cluster averages? “

In the current version of the manuscript trajectories belonging to each cluster are described in section 3.2. We agree that these pieces of information are not clearly stated and are hard to read. The decription will be replaced with figures showing source region, number of members and coherence of each cluster. Moreover the information on atmospheric circulation type on the day of trajectory arrival will be given on the basis of synoptic analysis (Niedzwiedz, 2009). The fact that AOT measurements demand a nearly clear sky results in “filtering” of circulation types. Typically cloudy types are rare in AOT study. The most frequent are anticyclonic circulation types with advection from NW to E, however for some clusters cyclonic circulation is typical.

NiedŸwiedŸ, T., Kalendarz typów cyrkulacji atmosfery dla Spitsbergenu — zbiór komputerowy, Uniwersytet ŒlÂźski, Katedra Klimatologii, Sosnowiec. 2009,

-“ part 3 discusses how the individual clusters impact on the AOT. This part essentially coincides with section 3.2 of the submitted manuscript. As a specific question to this section: Why are now all cases included, even the extreme ones. This was not the case for section 3.1. How does this affect the whole analysis?”

All AOT values should be included since they are part of the data set, however, in case of the relative variance analysis the “outliers” with very high AOT values very strongly influence AOT relative variance. They may mask the impact of the distribution of other days/cases in clusters. Thus they would dominate the dependences given in Figures 2 and 3 (AOT relative variance in function of a trajectory length). While discussing particular cases of trajectory division in clusters high AOT cases were included since they influence the mean AOT and variance values only for their own clusters. It is not very drastic. Moreover, their placement in clusters is discussed in the text.

- part 4 finally present the link to the ASTAR campaign (present section 3.3).

In the final paper Section 3 will be restructuring according to the suggestions by Reviewer.

2) Minor points:

“- The abbreviation rel_VAR(AOT) is not a very lucky one. It looks "bulky" and I would suggest to define a "lighter" one, e.g. rv(AOT) or ...”

The abreviation will be changed to rv(AOT).

-“ page 15430, line 14: "Figure 1 shows temporal variations of AOT during measurement

years in Hornsund station": Why is this sentence in this section 2.3. It has nothing to do with the clustering? Additionally: as far as I can see there is no detailed discussion of this Figure in the text!.”

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 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)

- The first three paragraphs of section 3.1 (up to line 17, page 15431) introduce the relative

variance of AOT. I would strongly suggest that this definition of the rel_VAR(AOT) becomes a fourth subsection in the data and methodology section. Note, here you are not discussing a result but are defining a quantity which will be used throughout the paper. Furthermore, the newly defined quantity rel_VAR(AOT) would be easier to understand if some basic statement was added. Why not state that low values of rel_VAR(AOT) are found if atmospheric transport, as specified by the clusters, is able to explain the variance. The formula is clear and it can be understood, but some helpful comment make life easier for the reader!”

We will add such information and move the definition to Section 2.4

- “A question to Figure 3: Why is the combined variance (in yellow) smaller than the separated ones (in red an black)? Is this obvious?”

The “combined variance” is the relative variance for a case of simultaneous clustering of trajectories arriving at two levels height above the station. From AOT point of view such clustering better classifies aerosol advection then clustering of trajectories arriving at a single level. See the answer to “why you are mixing different levels in your distance measure (equation 1)?”

-“ I would suggest to pass the whole manuscript to a native Englsih speaker who then could improve some complicated sentence structures. Being myself not a native

speaker, I don’t feel really able to make many suggestions in this respect.”

It will be read by a native speaker.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 15423, 2009.