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Discussions

Interactive comment on "Estimating a relationship between aerosol optical thickness and surface wind speed over the ocean" *by* P. Glantz et al.

P. Glantz et al.

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Estimating a relationship between aerosol optical thickness and surface wind speed

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General revision to Reviewer comments

In this work a relationship between mean aerosol optical thickness (AOT) and surface wind speed is presented. The reviewer's main comment is that this relationship may not exist due to the argument that transported sea salt will provide a varying background to any local direct source of sea salt. Here we will argue that both the emission of larger sea salt particles and water vapor fluxes are highly sensitive to the local wind speed, and that the longer lived sea salt particles varies relatively little backwards in time due to the properties of the wind speed fields, which seems to be relatively homogenous distributed over the oceans. We will argue that the local wind can be representative of the wind over a larger scale, see below. Based on the high amount of aerosol optical thickness values estimated according to a relatively large range of wind speeds over the North Pacific this means that we expect that a relationship actually exist between mean AOT and surface wind speed. We have also included several references, which both support relatively strong relationships between AOT and local surface wind speed for marine background marine air masses (end of Section 5.4). Even so, much of the reviewer's comments are constructive criticism of the paper which we have taken into consideration in an attempt to improve the revised version of manuscript. Our answers to the specific comments follow below. Since a more reliable cloud screening approach has been included in the revised version of the manuscript (see point 4 below), which is illustrated with new figures (Fig. 3a and 3b), our answers below refer to the new numbering of the figures.

Major revision to Reviewer comments

1) The reviewer discusses the transport of sea salt particles. Considering extinction effects sea salt can be subdivided according to accumulation and coarse mode ranges, with a relatively long turn over time (2 days, Gong et al. 1997) for the former while expected strong local wind dependence for the latter. Furthermore, we actually expect that a background ammonium sulfate aerosol influence the incoming short wave radiation over the North Pacific, while then also more efficient due to hygroscopic growth (see also point 3 below). It is also reasonable to assume that the sea salt and vapor emissions are the dominant wind driven factors behind the present AOT-wind relationship. We have also subdivided this into two separated effects in Section 5.2 (Fig. 7). Thus, based on previous parameterizations of sea salt (no hygroscopic growth) and hygroscopic growth of both sea salt and ammonium sulfate aerosols, we have estimated change in the AOT separately according to the present wind speed range. We agree that the longer turn over time for the sea salt accumulation mode particles could reduce the local wind influence on AOT. We also discuss this in the last paragraph of

Section 5.4 which could explain, at least partly, the large variability that occurs around the mean AOT when a single scene is analyzed (Fig.5). Even so, by analyzing the relatively large SeaWiFS and ECMWF scenes (Figures 4a and 4b) over the North Pacific it seems realistic that the averaged of retrieved AOT is also more or less sensitive to the more long-lived sea salt particles. This is because the wind speed fields, estimated by the ECMWF model, are homogenous over a relatively large area (Fig. 4a) and also varies relatively smoothly from day to day over the North Pacific for September 2001 (the latter not shown in the paper). Additionally, once again the two remaining effects, increase in the coarse mode sea salt particle surface and hygroscopic growth of both sea salt and ammonium sulfate particles, occur during time scales short enough to respond locally. The results obtained by the present box model (section 5.2 and Fig. 7) also support that the hygroscopic growth of the aerosols seems to be sensitive to the surface wind speeds, despite that a simplified validation approach is used and that we use both wind speed and relative humidity as well as boundary layer height from the ECMWF model. To estimate the transport of the accumulation mode sea salt particles and its influences on the local derived wind and AOT relationship is a challenge and deserve indeed to be investigated, but then in a separated study. However, we have included several references, which all support relatively strong relationship between instantaneous AOT and local surface wind speed at the end of Section 5.4. Here the surface wind speed has been averaged according to difference in the length of the time periods. Smirnov et al. (2003) found that AOT and wind speed correlated best for a period of 24 hours in their study.. The referee is not the first one to wonder how local sea salt concentration can agree so well with the local wind (see for an example major comments 3 and 2 by reviewers 2 and 3, respectively), when the aerosol concentration is a product not of the local wind, but of the accumulated wind driven sources and the sinks backward in time along the lagrangian air parcel history. Despite this, Gong et al. 1997 related successfully sea salt mass to the local wind, as numerous other investigators. Indeed, the co-authors of the current manuscript was been deeply worried about this problem when we first entered this field if research. It was not difficult to understand why the aerosol emission fluxes by eddy covariance measurements varied with the local wind when we published the first successful such measurements from the AOE-96 expedition (Nilsson et al., 2001). However, in the same study we showed a good sea-salt aerosol concentration to wind speed correlation from 0.161 to 10 micrometer diameter from impactor mass analysis, and 0.015 to 2.2 micrometer in terms of aerosol number concentration. The life time of the aerosol in these wide size ranges varies from <1 hour to days. How could they all have such a good correlation to the local wind? The explanation we found was that when we compared the local wind with the average wind over a longer and longer time interval of lagrangian wind speed, it remained on about the same level of correlation for 24 hours, and then only gradually decreased to a lower level after 96 hours (which was the peak synoptic time scale in the wind power spectra). At the 2 days life-time for the accumulation mode aerosol (according to Gong et al., 1997), the correlation was still better than 0.6. We concluded that the local wind over the ocean was a good substitute for the lagrangian wind over scales up to a considerably part of the scale of the synoptic weather systems, that is, if you are on for example the most windy side of a low pressure system, your local conditions are similar to the conditions over almost half that low pressure system. Not identical, but similar. We believe that this is the general explanation to why local wind is such a successful substitute for lagrangian wind when analyzing marine sea salt aerosol data. Since we never included any figure for our analysis on the lagrangian versus local wind speed in the 2001 paper we could send the figure if the reviewer ask for it.

Of course the current paper is a different data set, in a different region of the planet, but if anything, the weather patterns in the current study area are slower than those we studied in 1996, which would make the assumption even more valid. In fact, one of the key points in our current study is to show how surprisingly well correlated even the AOT is with the local wind speed. We agree with the referee that large scale models should use sea salt emission schemes, not simpler sea salt concentration parameterizations, if one wish to understand the processes involved, or if one want to construct a model that is valid also for example with a changing climate and changing weather systems.. However, if short cuts are more or equally accurate, there is no reason why they should not be tested as an alternative. All models are anyway simplifications.

2) Considering the reviewer's comment about using the word "validation" in the present text please see our respond in point 10 below. We certainly hope that our relationship will be implemented in large scale models, but that is beyond the scope of the current manuscript. To apply our simple box model on the data does not require any steady state flux assumption. We do not solve for the change in aerosol concentration (or AOT) over time for any air parcel or grid point, and are hence not dependent on that dc/dt=0 or that fluxes sum up as zero. What we can say is that we assume that the local wind is a good substitute for the lagrangian wind along the back trajectory history of each data point, and that hence aerosol mass sea salt components can be derived from the local wind, see discussion above.

3) As for transported ammonium-sulfate and aged sea salt components, they naturally play a role. Our resulting fit has a substantial zero bias in the AOT, which most probably include these. For the lowest wind speed range we assume that a background ammonium sulfate aerosol dominant the scattering of the incoming shortwave radiation over the North Pacific. The corresponding lowest AOT value of ˜ 0.03 (reduced for stratospheric aerosols), estimated in the revised version of the present manuscript (see below), is lower than the column AOT of ˜ 0.05 obtained for a wind speed of 1 m s-1 by Jennings et al. (2004), obtained for the North Atlantic region. On the other hand the present value is higher than ˜ 0.01 (reduced for stratospheric aerosols) obtained for the lowest wind speeds measured at Gape Grim (Wilson and Forgan (2002). See also end of Section 5.4 where other studies have been included in the comparison of retrieved AOT. The role of ammonium sulfate for the present relationship is discussed in Section 4.3 and also included in equation (3) as well as discussed in Section 5.2. The hygroscopic growth of the marine aerosols and the corresponding effect on the box model derived AOT shown in Fig. 6 (squares) are, thus, caused both by sea salt

and ammonium sulfate particles.

The AERONET measurements from Hawaii indicate that daily averaged aerosol optical depth (AOD) obtained at Mauna Loa are approximately in the range 10 to 20 % of the AOD at the sea level, during September 2001 (Fig. 8). In line with the reviewer's comment we have decided to take the background aerosols presented in the free troposphere into account in the estimation of the AOT and wind speed relationship, despite that these values are only obtained at a very limited area compared with the present operation area. In any case we assume then that the background aerosols in the free troposphere were relatively homogenous distributed over the operation areas. Relatively small variability in AOT is also obtained at the high altitude station for September 2001 (see Fig. 8). Furthermore, it is not clear what the SeWiFS retrieved mean AOT and the corresponding one standard deviation represents in the original manuscript (Section 5.1 and Fig. 5). Therefore, we have included the following sentences; "The resultant data set was sorted into bins based on the wind speed. Each bin is 1 m s-1 wide and the mean AOT of each bin has then been calculated." after the second sentence in the first paragraph of Section 5.1 and "Figure 6 shows aerosol optical thickness for the wavelength 0.555 m (SeaWiFS, channel 5) and as a function of 10 m wind speed (ECMWF), averaged according to the mean AOT values obtained for all SeaWiFS scenes retrieved over the North Pacific for September 2001. The contribution from stratospheric aerosols, AOT of 0.01 (ś 0.005), has also been reduced in the results shown in the figure. The latter value of 0.01 represent mean AOT of the daily averaged values obtained at the high altitude Mauna Loa AERONET station for September 2001 (Figure 8). Additionally, the one standard deviation around the mean values shown in Figure 6 is estimated according to a combination of the range ś0.005 above and variability corresponding to the SeaWiFS retrieved mean AOT values." instead of the first sentence in paragraph 2 of Section 5.1

4) We assume that the reviewer mean an upper threshold for estimated AOT of 0.15 instead of 0.2. The threshold value has been introduced in an attempt to exclude pix-

els partly covered with clouds (which could eitherwise be wrongly identified as aerosol pixels) and influenced by continental aerosols. The latter may be a minor problem due to the location of the operation area and time of the year (September). In any case the results obtained at the AERONET stations shown in Fig. 10 suggest that the value of 0.15 introduced in the present study seems to separate the significant higher AOT, caused by continental aerosols, and the significant lower values, caused by remote marine aerosols, with good margin. In any case the reviewer may be right that this upper threshold of 0.2 on the AOT-wind relationship should be quantified. However, according to reviewer 2 first comment we have introduced a new cloud screening approach to separate aerosol and cloud pixels in a more appropriate way, which will be described below and in the second paragraph of Section 4.2 in the revised version of the manuscript. We agree with reviewer 2 and realize that the cloud screening approach used in the present study is not enough restricted to separate aerosol and cloud pixels accurately. Therefore, we have introduced a more reliable cloud screening approach that could be used for SeaWiFS 8 visible channels. This method has been presented at the ACENT AT2 meeting in June 2005. (http://troposat.iup.uni-heidelberg.de/index.html). We have also introduced two new figures (Figure 3a and 3b) in which we describe the cloud screening approach over regions, marked with the upper and lower rectangles shown in Figure 2, where lower and higher AOT values, respectively, are presented. First of all, which is already used in the original version of the manuscript, the "white" (thick) clouds are excluded by a introducing a radiance boarder of 0.2 (Section 4.2), which is denoted by "cloud screening A" in Figures 3a and 3b. Secondly, clouds are "elevated", which means that we can use the ratio of top of the atmosphere (TOA) reflectance of SeaWiFS channel 1 and 2 to exclude these pixels ("cloud screening B" in Figures 3a and 3b). If the ratio is $>$ 1.15, we assume the pixel is cloud free. For an elevated cloud the Rayleigh scattering decreases and then the ratio also decrease. Finally, clouds are "inhomogenous" and from a 3 * 3 pixel mask we calculate average and standard deviation of AOT and use the ratio of standard deviation to the average as criterion ("cloud screening C" in Figures 3a and 3b). Here we use a value of 0.05 to separate cloud and aerosol pixels. The present approach to separate cloud and aerosol pixels can be compared with the cloud screening that has been developed for the MODIS satellite and is used for remote sensing of aerosols over oceans using spatial variability (Martins et al., 2002). This 3 * 3-STD test resolves most of the cloud contamination in the retrievals without deselecting aerosol cases (Martins et al., 2002). Small remaining contaminations are, however, resolved by applying IR tests. The latter tests could then not be used for SeaWiFS data. Martins et al. (2002) use an operational threshold of 3 * 3-STD = 0.0025, defined as the separator between aerosols and clouds for  = 0.55 m. For the present higher AOT values (the area marked with the lower rectangle shown in Figure 2), thus, a higher threshold value is obtained (Figure 3b) compared with the 0.0025 above. In any case, we think the present new cloud screening mask is enough restricted to exclude cloud contamination, and also not to conservative to screen out aerosol pixels to a large degree. Based on this new cloud screening approach the results of the relationship between AOT and surface wind speed are somewhat changed. The absolute values of AOT (compare Figures 5 and 6 in the original and revised versions, respectively, of the manuscript) are now lower compared to the results presented in the original version of the manuscript, while the difference in AOT with approximately a factor of 2 for the wind speed range is almost the same. Note that the stratospheric contribution (0.01 in AOT) has been reduced in the new results. The differences in the absolute AOT values obtained in this study based on the two different cloud screening approach are, not satisfied. In any case we believe that this new cloud screening introduced in the revised manuscript is more reliable and separate aerosol and cloud pixels more accurately and, therefore, support the present results. We have also included several references, which all support relatively strong relationship between measured AOT and local surface wind speed at the end of Section 5.4.

We have also included a reference, which support the range of SeaWiFS retrieved AOT values over North Pacific. Therefore, the following sentence has been included in the text; “This range of SeaWiFS retrieved AOT values are supported by AERONET

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(AErosol RObotic NETwork) long term measurements at Midway Island and Coconut Island for remote marine conditions (Halthore and Caffrey, 2006). However, a small amount compared to the total number of the present SeaWiFS retrieved AOT values shown in Fig. 5a is lower than the minimum in AOT of about 0.02 observed at these ground based stations above. Even so, the lowest wind speeds, estimated north of the AERONET stations, are also obtained in the area where these low SeaWiFS retrieved AOT values are obtained (Figure 4)." after the first sentence in Section 5.1. Furthermore, the end of the first paragraph of Section 5.1 has been rewritten "Note that the mean AOT is less sensitive to wind speed in the lowest wind speed range up to about 4 m s-1, which is the wind speed when ocean surface waves typically begin to break and white cap formation starts. The latter is also supported by the ground-based retrievals of AOT from the Midway Island (Smirnov et al., 2003)."

5) We have rewritten the paper and improved the language as well as somewhat shortened the text in the original version of the manuscript according to the reviewer's comments. However, new sentences have been included in the revised version according to the reviewer's comments.

Detailed remarks

6) We do not agree with the reviewer (see end of point 29 below)

7) See point 25) below

8) See point 6) above

9) This 50% of the enhancement is estimated according to a combination of the sea salt and ammonium sulfate aerosols. Thus, the hygroscopic growth of these remote marine aerosols is based on the present parameterizations which in turn are based on the relative humidity estimated by the ECMWF model (see point 3 above)

10) Section 4.3: We agree with the reviewer and have changed the title of Section 4.2 to "Section 4.2 Combining SeaWiFS retrieved AOT with ECMWF surface wind speed",

Section 4.3 to; “Section 4.3 Box model derived AOT”, “Section 5.1 SeaWiFS retrieved AOT as a function of surface wind speed”, Section 5.2 to “5.2 Results of box model derived AOT” and Section 5.3 to “Section 5.3 SeaWiFS retrieved AOT compared with AERONET data” Furthermore, the first sentence in Section 4.3 has been changed to; “In an attempt to compare the present results the sensitivity in AOT due to increased sea alt particle mass concentrations and hygroscopic growth of the marine aerosols has been investigated”

11) We agree this sentence is not distinctly written (the third sentence in Section 4.3). We suggest the following changes; “To estimate the absolute changes in AOT due to increased sea salt particle mass concentrations, without hygroscopic growth and with an ambient size of the particles corresponding to the lowest wind speed range, the following expressions are used:” Furthermore, the first sentence in the second paragraph of Section 4.3 has been rewritten: “The total change in AOT, caused by increased sea salt particle mass concentrations and hygroscopic growth of the sea salt and ammonium sulfate aerosols due to higher wind speeds, can be calculated by the following equation:”

12) The mean RH1 and BLH1 have been averaged according to the lowest wind speed range 0 to 1 m s-1 and all days included in the study (middle of the first paragraph of Section 4.3). See also end of point 16 below. The mean relative humidity (RH1) for the lowest wind speed range is 76.3 % with a corresponding one standard deviation of +/-3.5 according to all of the ECMWF scenes analyzed in the present study.

13) See point 16

14) “Furthermore” in the second sentence of Section 5.2 has been excluded.

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