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6, S7160–S7172, 2007

Interactive Comment

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

by Paul Glantz, Douglas Nilsson and Wolfgang von Hoyningen-Huene

The reviewer claim that the positive correlation found between SeaWiFS AOT and ECMWF surface wind speed found in the present study may be due to artifacts rather than real physical processes. The suggested artifacts include influences due to white caps, sun glints and cloud pixels that are not efficiently excluded in the present cloud screening approach. Considering the latter we agree with the reviewer and realize that the present cloud screening is not enough restricted to exclude the cloud pixels accurately. Therefore, we have introduced a new cloud screening method in the revised version of the manuscript, which more trustfully exclude cloud contamination and prob-

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ably is not to conservative to screen out aerosol pixels to a large degree (see major concern 2 below). After the introduction of this new cloud screening approach the SeaWiFS retrieved AOT values are now, however, lower compared to the previous results. On the other hand approximately the same difference in AOT with a factor of 2 for the present wind speed range is obtained. The latter means that this new cloud screening has removed pixels more or less evenly spread over the present wind speed range. The differences in the results of the absolute AOT values obtained in this study for the two different cloud screening approaches are of course not satisfied. In any case we believe that this new cloud screening introduced in the revised version of the manuscript is more reliable and more accurately separate aerosol and cloud pixels. If clouds (wind dependent) should have a large influences on the positive correlations between SeaWiFS AOT and ECMWF surface wind speed we should probably not expect to obtain this smoothly increase in AOT shown in Figure 6 (revised version of the manuscript). Considering white foam we have included an additionally reference that supports that this influence on AOT is relatively small (see major concern 1 below). We agree with the reviewer that surface reflectance have a negative influence on the satellite nadir retrieval of AOT, for example; MODIS, MERIS and SCIYMACHY. The present study is on the other hand based on the SeaWiFS instrument, for which data has been obtained according a viewing angle of +20 or -20 degrees oriented in the long-track direction to avoid sun glint effects from the sea surface. We will argue that sun glints are then probably not a major problem over the present operation area (higher than 15N) and for the period of September, due to the sun and satellite/orbit azimuth angles and the tilted viewing angle (see major concern 1 below). 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. More detailed answers to the major concerns are found in the following sections. Since a more reliable cloud screening approach has been included in the revised version of the manuscript and which is illustrated with new figures (Fig. 3a and 3b), our answers below refer to the new numbering of the figures.

Major concerns:

1) In the original version of the manuscript we refer to a study (Ignatov et al., 1995) that have found that white foam presented on the sea surface has a small effect on the retrieval of AOT, which means that the AOT increased by less than 0.005 according a wind speed range of 5 to 8 m s-1. The reviewer means that this value is obtained when the production is weak. For the present upper wind speed range (9 - 12 m s-1) you probably expect higher production while not a dramatic increase. We have also included an additionally study (Moore et al., 2000) that support relatively small increase in AOT due to white foam according to this wind speed range (see also end of Section 5.4). They find that the augmented reflectance of whitecaps over the open ocean for the 410 - 670 nm spectral range is between 0.001 and 0.002 for wind speeds between 9 and 12 m s-1. Thus, these values are significant lower than the surface reflectance over sea water used in the retrieval approach for the wave length 555 nm (Hoyningen-Huene et al., 2003). The reviewer means that sun glints also influence satellite observed radiances not only at glint angles but also at non-glint angles as well, and which have already been shown to hamper MODIS. In that perspective the SeaWiFS instrument is operated with the scanner tilt mechanism described above. We do not claim that sun glint effects are completely avoided due to the tilt angle, but are probably of minor concern for the period of September and areas higher than 15N. This is because the present satellite/orbit zenith angles are above 20 degrees in combination with the present sun and satellite/orbit azimuth angles that were similar and both in the backward direction (retrievals on the side of the orbit facing away from the sun) over the present operation area. Thus, because of the present geometry the SeaWiFS instrument was not operated in the region associated with pure glint angles (Zhang et al., 2005). In any case, we agree with the reviewer that higher wind speeds probably also influence AOT at areas associated with non-glint angles near sun glint angular regions. This is because higher wind speeds cause broader glint regions. Even so, for the present study this effect is small for wind speeds in the range 0 - 9 m s-1 and probably not much higher for the range 9 - 12 m s-1

ACPD

6, S7160–S7172, 2007

due to the geometry described above (Zhang et al., 2005). Based on satellite data Zhang et al., 2005 found that for higher wind speeds the anisotropic factor (R, ratio between the assumed Lambertian and the actual fluxes) decrease in glint regions due to higher aerosol loading. This was found for AOT (550 nm) values in the range 0 - 0.1. The present validation of the present results suggests that beside aerosol loading also hygroscopic growth of the aerosol particles in the marine boundary layer (see comments to major concern 3 below) causes more efficient scattering of the short wave radiation, despite that we use wind speed and relative humidity as well as boundary layer height from the ECMWF model. Zhang et al. 2005 conclude also that an overall uncertainty of not more than 10% will be introduced in derived shortwave aerosol direct forcing over cloud-free oceans if aerosol angular distribution models are constructed without considering aerosol brightening over non-glints regions. In the perspective to the above discussion it appears that the present SeaWiFS satellite retrieval of AOT over the North Pacific, associated with non-glint angles, for September 2001 is major caused by real physical processes, while artifacts at the sea surface may induce minor errors in the results. See also our comments at the end of point 4 below (major concern).

2) We agree with the reviewer 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 restricted cloud screening approach that could be used for SeaWiFS 8 visible channels (second paragraph of Section 4.2 in the revised version of the manuscript). 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 the revised version of the manuscript) in which we describe this new cloud screening approach over regions, marked with the upper and lower rectangles shown in Figure 2. Note that lower and higher AOT values are presented over the upper and lower areas, respectively. 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. Over the area marked with the upper rectangle in Figure 2 the aerosol and cloud pixels are separated at a value of about 0.006 (Figure 3b). Thus, this is somewhat higher than the MODIS operational threshold value above. Even so, 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 present wind speed range is almost the same. Note that the stratospheric contribution (0.01 in AOT) has been reduced in the new results (see the third major concern by reviewer 1 and our comments). The differences in the absolute AOT values obtained in this study based on the two different cloud screening approach are, of course, 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. Furthermore, we have also included a long term study from Gape Grim (Wilson and Forgan, 2002), which present similar slope of the relationship between aerosol optical depth (AOD, reduced for the stratospheric contribution) and wind speed (end of Section 5.4). However, the latter AOD values are significant lower compared with the present study. For the low wind speed of about 3 m s-1 an AOD value of 0.012 is obtained and for a wind speed of about 12 m s-1 a value of 0.03 is obtained (Wilson and Forgan, 2002). Furthermore, a long term study at the west coast of Irland (Mace Head) present a even stronger relationship between column AOD and surface wind speed, with a AOD value of ˜0.5 for the lowest wind speeds and ˜0.2 for a wind speed of 11 m s-1. The significant higher values found in this latter study compared with results obtained at Cape Grim and over the North Pacific could be explained by stratospheric aerosols that contribute to the AOD values obtained at Mace Head. The stratospheric aerosols have probably also larger influence on the scattering of short wave radiation over the North Atlantic compared with the two more pronounced remote areas above, particularly Gape Grim. See also end of Section 5.4 where results from some other studies that have been included in the revised versions of the paper.

3) We do not know exactly the sea salt fine and coarse mode fractions. In the present validation approach we assume that that 90% of the total sea salt particle mass concentrations were associated with shorter lived sea salt coarse-mode particles over the North Pacific, while the remaining 10% was associated with longer lived accumulation-mode particles (Glantz et al., 2004; Gong et al., 1997). Even so, the reviewer may be right that the remote ocean optical depth could be evenly split between fine and coarse mode particles, since it is the particle area property that are important for the extinction effects. Even so, we mean that a correlation also with the fine mode particles is good assumption 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. Here we argue that both

ACPD

6, S7160–S7172, 2007

Interactive Comment

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 Pacific ocean for September 2001. The wind speed fields also varies relatively smoothly from day to day over the operation area for September 2001 (the latter not shown). We mean that the local wind can be representative of the wind over a larger scale. 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 all support relatively strong relationships between AOT and local surface wind speed for marine background marine air masses (see end of Section 5.4). 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 1 and 2 by reviewers 1 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

ACPD
6, S7160–S7172, 2007

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 can sent 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.

For the lowest wind speed range we assume that a background ammonium sulfate aerosol actually dominant the scattering of the incoming shortwave radiation over the North Pacific. 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. 7 (squares) are, thus, caused both by sea salt and ammonium sulfate particles. In any case we have included the following text "(Eq.3)" at the end of the third sentence of Section 5.2 in an attempt to make it easier for the readers to understand Fig.6. Additionally, the following sentence in the same section has been changed to; "The squares describe the changes that are associated only by hygroscopic growth of the sea salt and ammonium sulfate particles (Eq.3 - Eq.1 -

Eq.2).”

4) As a first step we suggest that this relationship is only valid over the North Pacific. We agree the present relationship should be tested over other regions of the globe, which we also intend to do in subsequent studies. We also discuss this in the second and third sentences after the conclusions in Section 6 and also at the end of the same section. The reviewer suggests a clear AERONET validation of the results. However, we must be aware of the limitation that the AERONET instruments are located only at disturbed places on earth, like islands or coastal sites and do not reflect undisturbed sea conditions. Particularly the Lanai and Coconut Island stations are seems to be classified as disturbed conditions. The Lanai Island is located down stream or in the shadow of the elevated Maui in the northeast trade wind field. The Coconut Island is on the other hand located on the east coast of Oahu, but even so the wind conditions are also here to some degree influenced by the somewhat elevated island. Furthermore, the latter station is not entirely exposed to open ocean winds, since narrow land area is extended east of the Coconut Island. The reviewer also discusses a work by Smirnov et al., 2002, which we also beside other studies (Platt and Patterson, 1986; Moorthy et al., 1997; Wilson and Forgan), refer to in the revised version of the manuscript (end of Section 5.4). A relationship between AOT and surface wind speed is supported by these studies according to the present wind speed range, although the retrieved AOT values differ somewhat between the studies (see end of Section 5.4). Furthermore, by comparing the scatter plots of satellite and land retrievals of AOTs shown in the present Fig. 5 and Fig. 4a-4b in Smirnov et al., 2002, respectively, similar results appear. The minimum in AOT is approximately constant for the lowest wind speed range (0 - 4 m s-1) in both studies. For the higher wind speeds similar relatively distinct increase in the minimum values of AOT occur in the two studies. This support that the present relationship is mainly caused by physical processes and to minor degree of artifacts due to changes in the characteristics of the sea surface. Finally, this suggests also that the data points presented in Fig. 4a and 4b in the paper by Smirnov et al., 2002 may be better represented by a non-linear fit than the linear fit that has been introduced in

ACPD

6, S7160–S7172, 2007

Interactive Comment

EGU

this study.

Minor concerns

1) Compared to other ECMWF quantities it is quit well established that the wind speed parameter over the sub tropical region is associated with relatively small uncertainties in climate model calculations, particularly then the surface wind speed. Furthermore, the weather conditions over the North Pacific in summer are highly influenced by a persistent sub tropical high pressure system, which is also suggested by the 10 days back trajectories shown in Figure 1. This means that estimated wind speeds over this region are probably associated with smaller uncertainties compared with other region influenced by cyclone activities, tropical region and other period of the year when the sub tropical high pressure system is weaker. The relatively strong relationship between AOT and ECMWF surface wind speed presented in this study also support the use of ECMWF surface wind speed. Furthermore, you could question how important a comparison of the relatively large wind speed fields over the North Pacific, for which the present study is based on, with observations limited to the area of Hawaii actually is. A more serious problem could be that the AERONET instruments are located only at disturbed places on earth, like islands or coastal sites and may not reflect undisturbed sea conditions. To include ship measurements (if there is any at all for September 2001) will, in any case, somewhat support a validation but only if data to a relatively large extend are available. We do not argue that a validation of the ECMWF surface wind speeds are not necessary in an attempt to validate the estimations but it seems more realistic to perform comparisons when new generation of satellite data is available. For example the Earth Explorer Atmospheric Dynamics (ADM-Aeolus) satellite is planed to be launched in 2008 (http://www.esa.int/esaLP/LPadmaeolus.html) and the major objective is to improve the wind speed fields on earth, particularly in the tropics and at higher levels.

2) See our comments to the major concerns above

ACPD

6, S7160–S7172, 2007

Interactive Comment

3) We agree this should be clarified. Therefore, the following text “ĚRH1 and BLH1 are the relative humidity and boundary layer heightĚ” has been changed to “ĚRH1 and BLH1 are the mean relative humidity and boundary layer heightĚ”. Additionally, the following text “Ě.50% of the BLHi estimated by the ECMWF model.” has been changed to “Ě.50% of the mean BLHi estimated by the ECMWF model.” Finally, the following text “Ě..BLHi/BLH1 is the relative change in the boundary layer height.” Has been changed to “ĚĚBLHi/BLH1 is the relative change in the mean boundary layer height.

4) “Furthermore” has been excluded in this sentence.

5) We agree with the reviewer and have, therefore, included information about the distribution of AOT including all data values for September 2001, subdivided according to the wind speed bins and presented as percentage values in Figure 6.

6) The R2 value is based on the 12 averaged AOT values shown in Figure 5. We agree with the reviewer and therefore also present results of R2 corresponding to all average values (275) of the 26 days of September 2001 as well as according to all data points (see paragraph 2 of Section 5.1). With one exception the same approach has been performed in Section 5.2, according to results obtained by the validation. However, we have not calculated a correlation coefficient according to all values in the validation approach.

7) For the lowest wind speed range (0-1 m/s) we assume that the SeaWiFS retrieved AOT of about 0.03 (reduced for stratospheric aerosols) is mainly caused by ammonium sulfate aerosol. The relative change in AOT associated with the ammonium sulfate aerosol is then caused by hygroscopic growth due to higher wind speeds (first term in Equation 3).

8) The criteria introduced here include data for each day corresponding to a time period as long as possible, around the time for the pass of the SeaWiFS satellite, without any large change in AOT (described by the one standard deviation shown in Fig. 9). For each day and for each of the AERONET stations the time periods extend at least one

hour before or after the time for the satellite passage. Thus, the time periods seems to be long enough to support the present comparisons between AOT values obtained at the AERONET stations and with the SeaWiFS retrievals, respectively. The second sentence in the last paragraph of Section 5 has been rewritten; "For the latter two stations the AOT shown in the figure have been averaged around the time when the SeaWiFS satellite passed over Hawaii (includes data values obtained at least 1 hour before and after the passage) and the error bars correspond to one standard deviation."

9) We agree that the present comparisons between SeaWiFS and AERONET derived AOT is relatively weak mainly because we can not use SeaWiFS land retrieval of AOT because these values are significant higher than the values obtained the surrounding ocean areas. This is probably due to uncertainties in the surface reflectance over the island included in the retrieval approach. We think that the comparisons shown in Figure 8 should, in any case, be presented for the readers, despite the limitation described above. The AERONET instruments are located only at disturbed places on earth, like islands or coastal sites and do not reflect undisturbed sea conditions, which means that a relationship between AOT and wind speed may not be perfect representative for open ocean conditions (see major concern 4 above). In any case, a more appropriate comparison between SeaWiFS derived AOT and AOD obtained at AERONET ground based stations are important in an attempt to validate the satellite retrievals. However, the comparisons should be performed over the land pixel corresponding to the land stations but then when land reflections are better described in the aerosol retrieval model for remote islands and coastal sites.

10) The results of the comparisons are beside the symbols also explicit written in Fig.8, which correspond to differences in % between SeaWiFS satellite and AERONET retrieved AOT for Lanai and Coconut Island, respectively. Therefore, the readers have opportunity to decide how well the satellite and ground-based derived AOT agree. In any case we agree with the reviewer and has rewritten this sentence to "Ě.and actually much better on several of the days."

ACPD

6, S7160–S7172, 2007

Interactive Comment

11) We agree with the reviewer and have, therefore, changed this sentence to "From empirically derived parameterizations, we know that the emissions of both sea salt and water vapor over the oceans are dependent on the surface wind speed (e.g., Gong et al., 1997; O'Dowd et al., 1997 Svensson et al., 2000; Glantz et al., 2004)." We agree with the reviewer that higher wind speeds probably result in higher boundary layer heights. The latter we also have found for several of the cases/days we analyzed in the present study. However, it is not obvious that the wind-entrainment influence is positive or negative. The consequences of a higher boundary layer height (BLH) we also discuss in the second paragraph of Section 5.4 in the manuscript: "As noted above, the available water vapor depends also on that higher wind speeds increase the emissions of water vapor into the MBL, but could on the other hand increase the boundary layer height as a result of more efficient vertical mixing and then entrain dry free tropospheric air, which would tend to decrease the humidity. In any case, the assumption that the marine aerosols grow to larger particle sizes due to water uptake and consequently influence the direct radiation back to space significantly is supported by the validation of the present result. Evidently, the column relative humidity is increasing due to higher wind speeds, despite that we use both wind speed and boundary layer height from the ECMWF model. If the height of the boundary layer increases the sea salt aerosol is diluted in a larger volume, resulting in lower concentration, but not less AOT as the same aerosol mass will remain in the boundary layer although distributed over a deeper column. Hence, it is reasonable to assume that the wind influence on the boundary layer height is a) minor and b) have been incorporated in our parameterization. Considering entrainment, the free troposphere aerosols that may be entrained in such conditions could also grow rapidly according to the higher RH in the marine boundary layer and, therefore, contribute to the increased scattering of short-wave radiation back to space. It is therefore not obvious that the wind-entrainment influence is positive or negative."

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 11621, 2006.