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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Estimating the maritime component of aerosol optical depth and its dependency on surface wind speed using MODIS and QuikSCAT data" *by* Y. Lehahn et al.

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We would first like to thank the reviewer for his or her useful comments that helped us improve the manuscript. Based on the reviewers' suggestions, we have made the following changes: 1) More attention is given to pointing out and discussing the limitations and consequent uncertainties associated with the datasets; 2) We performed a similar analysis using measurements from AMSR-E and MODIS-Aqua; and 3) We performed a more detailed time scale analysis for determining the appropriate time difference for correlating wind and aerosol measurements.

Below we address all the reviewers' comments one by one.

1) This paper attempts to determine the marine component of the aerosol optical depth (AOD) by looking at its dependency with satellite derived wind speeds. The idea deserves to be explored and studied in detailed given that a number of studies have recently pointed out that such dependency probably exists. However, this paper limits it analysis to interpret correlations between AOT and winds and offers very little in depth justifications or consideration of the limitations of the instruments and datasets used. This important because the authors intend to analyze MODIS data in conditions that has not been well characterized and studied (clean marine conditions with low optical depth). The authors do not discuss the reliability of MODIS aerosol data in clean marine conditions. There have been a number of studies challenging the quality of MODIS aerosol clean marine data (Zhang et al. papers , see references) with proposed practical corrections. Such discussion is missing. As result, I consider this work not suitable for publication as it is unless the major concerns and suggestions described below are addressed.

1) answer: Aerosol optical depth and size parameters, over the ocean, are standard MODIS products that have been validated extensively against the ground Aerosol Robotic NETwork (AERONET) observations (e.g. Remer et al., 2008). The validation process includes comparisons at low aerosol loading conditions, resulting in a remarkably good agreement, with an estimated uncertainty of $0.03 \pm 0.05\tau$. In addition, recent results by Yu et al. (2009), showed good consistency between seasonal and geographical variations of the fine mode fraction parameter (ff), in pure marine aerosol environment (defined by the authors as $0.03 < \tau < 0.10$) from MODIS and from two chemical model simulations. It indicates that MODIS over-ocean retrievals provide a reliable estimates of ff even in very low aerosol loading condition. This supports Remer et al. (2008) conclusion that over ocean MODIS ff can be considered as a tested, well-understood product that delivers a quantitative measure of aerosol particle size.

In the revised manuscript more emphasis is given to discussing the limitations and uncertainties associated with the analysis performed in this study. We discuss sources of uncertainties (including those pointed out in the suggested bibliography) in MODIS over-ocean aerosol retrievals, and add information on the validation process and on the validity of our results in view of the instrument's limitations. The additions are included by extending the section "Satellite data" (section 2.1.) and adding a new section entitled "Uncertainties and limitations" (section 4.1.). All the additions are detailed below.

Main concerns:

2) The authors do not discuss the reliability of MODIS aerosol data in clean marine conditions. There have been a number of studies challenging the quality of MODIS aerosol clean marine data (Zhang et al. papers , see references) with proposed practical corrections. Such discussion is missing.

2) answer: We acknowledge that a discussion on the reliability of MODIS aerosol data in clean marine conditions was missing in the previous version of the manuscript. This is corrected in revised manuscript (see bellow). We find it important to note that MODIS τ retrievals have been validated also in low aerosol loading conditions. Although in such conditions the accuracy of τ retrievals indeed decreases, it remains within the expected 0.03 accuracy (see Remer et al., 2008). In addition, we note that with the background aerosol optical depth being approximately 0.08, most of the wind induced marine aerosol variability is associated with relatively high aerosol loadings of $\tau > 0.1$.

The following additions are included in the revised manuscript (note that further additions are detailed later on, with respect to specific comments):

Section 2.1.1. - "Aerosol properties" (page 06, lines 05-08):

"The different factors influencing MODIS over-ocean retrievals of τ and FMF are especially important in low aerosol loading conditions (e.g., $\tau < 0.1$, Kleidman et al., 2005), where MODIS is less sensitive to aerosol characteristics and the accuracy of the retrieval decreases."

Section 4.1. - Limitations and uncertainties (page 13, lines 20-23):

"In addition, we note that with $\tau 0$, which is independent of the wind speed, having an averaged value of approximately 0.08 (Fig. 5a), most of the wind related variability is associated with $\tau > 0.1$, thus not included in the somewhat problematic category of very low aerosol loading conditions."

3) Also, they do not discuss the fact that MODIS τ retrievals assume a constant wind speed in the retrieval. For example, if the wind is calm, there is less or no foam but the MODIS algorithm assumes a constant 6m/s wind and assumes a higher ocean reflectance than the true one, as result it derives an τ smaller than the real one. This is not mentioned in the paper and it must be included and discussed.

3) answer: Although taken into account (hence the comparison with data from the Midway Island AERONET station), we agree that the issue of possible biases due to unaccounted for wind effects deserves more attention. This is corrected in the revised manuscript (see below).

The uncertainty associated with possible wind related biases is significantly reduced when considering the similarity of our results with the wind – coarse τ relationship in the Midway Island AERONET station measurements and the very good agreement with the results of Smirnov et al., 2003 and Mulcahy et al., 2008, which are based on ground measurements and are thus not affected by reflectance from the sea surface. The uncertainty associated with possible wind and cloud effects is furter reduced by avoiding using data from the roaring 40s, where such effects are considered to be especially important.

The issue of possible wind related biases and the steps taken for reducing the uncertainties associated with them, are included in the revised manuscripts as follows:

section 2.1.1 - "Aerosol properties" (page 05, lines 24-25 and page 06 lines 01-04):

"MODIS over-ocean aerosol retrievals can be disrupted by a number of factors including cloud contamination (Kaufman et al., 2005c; Zhang et al., 2005), and sea surface reflectance by sun glint (Cox and Munk, 1954) and whitecaps (Moore et al., 2000). The latter, which is directly linked to the surface wind speed, may lead to systematic biases in the MODIS over-ocean aerosol retrievals that assume a constant wind speed of 6 m/s for estimating reflectance from the sea surface (Zhang and Reid, 2006). ".

section 4.1. - "Limitations and uncertainties" (page 13, lines 06-20):

"Since this study is focused on linking marine aerosols and W , our main concern is with unaccounted founar wind effects that may lead to underestimates of τ at low wind cases and overestimates at high winds (Zhang and Reid, 2006). This uncertainty is significantly reduced when comparing the relationship between W and aerosol retrievals from MODIS to that of W and ground based aerosol measurements from AERONET station in Midway Island (Sec. 2.5). The reliability of the satellite derived W - τm relationship found here is also strongly supported by the good agreement with the studies of Smirnov et al. (2003) and Mulcahy et al. (2008), which are based on ground measurements and are thus not affected by reflectance from the sea surface (Fig. 5a). Further reduction of the uncertainty associated with aerosol retrievals accuracy is achieved by avoiding the "roaring forties" region, where the effect of cloud contamination and retrieval biases due to wind effects are considered to be especially important (Zhang et al., 2005, Zhang and Reid 2006) ".

4) Further, the authors use the MODIS fine mode fraction product (FMF) which can be a unreliable when used at low τ condition such as the clean marine conditions here studied. Because FMF critical depdend on the spectral dependance of the observed radiances, it is very sensible to small relative variations between MODIS bands. These conditions become more obvious at low aerosols conditions when the signal of interest becomes comparable with noise level of each band.

4) answer: Indeed ff in low aerosol loading conditions is a poorly validated product that deserves more attention – this is corrected in the revised manuscript (see below). We note however, that the remarkable consistency found by Yu et al., (2009) between vari-

ations in pure marine aerosol ff from MODIS and from two chemical model simulations, indicate that over-ocean MODIS retrievals provide a reliable estimates of FMF even in very low aerosol loading conditions. This isn't to say that we should validate an aerosol retrieval with a model, but when results are so consistent with accepted physical and geobiological theory, it indicates that there is solid information in the retrievals, even in low aerosol loading. We also note that as indicated above, most of the wind induced variability is associated with relatively high aerosol loadings of $\tau > 0.1$.

In the revised manuscript the issue of MODIS over-ocean ff retrievals is discussed in section 2.1.1 - "Aerosol properties" (page 06, lines 08-18):

"While the validation of MODIS over-ocean τ also includes comparison with AERONET measurements at low aerosol loading conditions, resulting in a remarkably good agreement, with an estimated uncertainty of 0.03 $\pm$ 0.05, validation of FMF is still limited to higher τ conditions (e.g., Kleidman et al., 2005). Nevertheless, recent results from Yu et al. (2009), showing remarkable consistency between seasonal and geographical variations in pure marine aerosol (defined by the authors as $0.03 < \tau < 0.10$) ff from MODIS and from two chemical model simulations, indicate that over-ocean MODIS retrievals provide a reliable estimates of ff even in very low aerosol loading condition. This supports Remer et al. (2008) conclusion that over- ocean MODIS ff can be considered as a tested, well-understood product that delivers a quantitative measure of aerosol particle size."

5) In support of the observed correlation between satellite τ and wind, the authors show a similar correlation between satellite based Wind and surface based τ (Aeronet in the Midway Island). The similarities between the MODIS-Quickscat and the AERONET – Quiskcat plots make an interesting point in support of the author's ideas. However, I find the analysis and approach insufficient to make the stated point: Why is there a comparison with a single AERONET station? why is the Aeronet data used at level 1.5 and not 2.0 (ie the best quality)? Some of the papers referenced (Mulcahy et al for example) compared with a single sunphotometer too but had additional in-situ datasets

in support of the comparison. In contrast the Zhang et al (see references below) papers did not have in-situ so they utilized several marine based Aeronet stations. The authors need to make a case for using a single station without additional information.

5) answer: The comparison with data from ground measurements from the AERONET station is not aimed at validating the MODIS τ retrievals but rather to asses the feasibility of comparison between the satellite derived fields. In the scope of this research, such assessment should be done in locations where a significant linkage between τ and surface wind speed was previously established using ground-based data. Midway Island station is most suitable for this purpose as it was the subject of an extensive study, showing significant correlations between ground based wind and aerosol optical measurements (Smirnov et al., 2003). When considering other island sites of the AERONET network, Smirnov et al.(2003) did not find any significant correlation between the fields, suggesting a variety of masking factors such as narrow range of wind speeds, mountainous terrain, nonuniform meteorological conditions, island aerosol influence, etc. When the analysis was originally performed the τ fine and coarse mode products were only available for level 1.5. In the revised manuscript the comparison is made with AERONET level 2.0 data.

6) The time difference of 4 hours between Terra and Quickscat is problematic. The fact that Quickscat is earlier than MODIS is useful because it facilitates the causality assumption i.e. if Quickscat measured high winds early and then Terra sees high coarse mode τ, it is very reasonable to assume that the aerosol seen by Terra was generated earlier. However in 4 hours, wind speed can change significantly in such period of time. With this regard I see the figure 2 of little value. It shows the autocorrelation between AOT and Wind at 24 hours intervasl (4,28,56hrs..) : : : long enough for a synoptic weather pattern to move in. What the authors need to determine is the time difference needed for studying causality in the wind-τ correlation. In order to address this points, I think the authors should do a simple study using wind speeds from a couple stations in the remote marine environment and compare the wind variability with the time of

MODIS pass and asses if the time difference of 4 hours is adequate or not.

6) answer: The feasibility of using a 4 hours time difference is supported by the work of Anderson et al., (2003) that showed that in situ optical measurement of aerosol optical properties maintain acceptable autocorrelation for time offsets of up to 6 hours. Figure 2 makes the point that for short time differences (as the ones identified by Anderson et al., (2003)) of a few hours, the two signals are well correlated, while no significant correlation is found when the time difference is of the order of days.

Saying that, we take the reviewers' advice and perform a more detailed analysis for determining time difference needed for studying causality in the wind - aerosol optical depth correlation. This is done by correlating 12 combinations of τc (MODIS-Aqua and MODIS-Terra) and wind speed (ascending and descending passes of AMSR-E, QuikSCAT and SSMI) measurements. The results of this analysis clearly show that the correlation between surface wind speed and coarse τ is well kept within a time frame of approximately 12 hours, while sharply dropping at longer time lags. We note that this detailed time scale analysis is of high scientific value, and significantly contributes to the quality of the study. The improved, detailed version of the time scale analysis (Fig. 07), which is included in the revised manuscript, is attached here.

7) Another important aspect is the choice of data set. Why the choice of MODIS and Quicskcat with 4 hours difference when Aqua carries another MODIS and AMSR-E which also measures wind speed collocated and simulatenously with MODIS? The use of the Aqua data set should remove the concern regarding time difference.

7) answer: Following this comment a similar analysis was performed using wind measurements from AMSR-E and aerosol measurements from MODIS-Aqua. The results, that were additionally validated using wind data from SSM/I, show almost identical relationship between surface wind speed and coarse marine aerosol depth for wind higher than 4m/s. We therefore focus the manuscript on the AMSR measurements, which is taken simultaneously on the same platform with the MODIS aqua aerosol ones.

Minor Comments:

1) Are Quickscat wind representative of the surface or 10 m above surface? Clarify

1) answer: The term surface winds corresponds to winds at 10 m height - this is clarified in the revised version.

2) Line 6: no clear the statement "correlation time". What is the meaning?

2) answer: The term "correlation time" refers to the decorrelation time scale – this is clarified in the revised version.

3) p. 1985, line 2 : the Kaufman et al, 2002 reference does not address the issue "climatological implications"

3) answer: We acknowledge this mistake and removed the citation.

4) p. 1985, lines 4-14: Authors omit to point out that biogenic aerosols (either primary or of secondary origin) make a significant contribution to the accumulation mode and it coexist with the usually seasalt dominated coarse mode.

4) answer: The following paragraph is included in the revised manuscript (page 03, lines 08-11): "Marine aerosols contribute to both fine and coarse aerosol modes, with biogenic aerosols (of either primary or secondary origin) mainly contributing to the submicron fine mode and wind induced sea salt particles dominating the supermicron coarse mode ."

5) p. 1985, line 27: Huang et al is a paper in review stage in ACPD. If it has not been published in ACP, it should be removed from here.

5) answer: Done

6) All references do are not properly formatted and they contain some extra number at each of them that do not seem to be page numbers.

6) In the revised version more attention is given to the references formatting.

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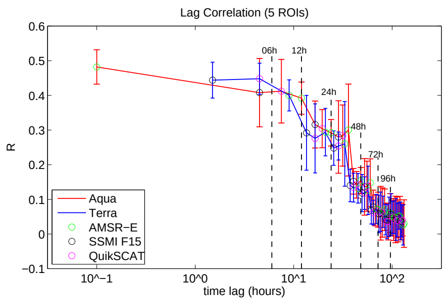

Fig. 1. Correlation coefficients, R, between coarse aerosol optical depth and W as a function of time difference between satellite measurements.