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Interactive Comment

Interactive comment on "Multi-modal analysis of aerosol robotic network size distributions for remote sensing applications: dominant aerosol type cases" *by* M. Taylor et al.

M. Taylor et al.

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We are especially grateful to Dr Sayer for taking the time to detail many insightful comments which we believe have helped to improve the interpretation of our findings. To answer his comments point by point:

"The topic of this paper caught my eye as interesting and so I took a brief read through and passed the link to colleagues for their interest. While reading, I noticed similarities between the introductory text and a recent paper of which I was lead author (Sayer, A. M., A. Smirnov, N. C. Hsu, and B. N. Holben, 2012, A pure marine

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aerosol model, for use in remote sensing applications, J. Geophys. Res., 117, D05213, doi:10.1029/2011JD016689).

Specifically, the Introduction on page 10753 of the submitted manuscript by Taylor et al. begins:

"Satellite retrievals of aerosol optical depth (AOD) and related parameters typically require the use of prescribed models of aerosol size and composition. In particular, the aerosol volume size distribution (AVSD) and the spectral complex refractive index are needed to compute properties such as the scattering phase function, the single scattering albedo and the extinction coefficient, which are in turn used to calculate quantities such as the total AOD from the columnar abundance. In general, the information content of measurements from current satellite radiometers is insufficient to unambiguously retrieve all these parameters particularly when the (spectral and directional) behavior of the surface reflectance is unknown (Hasekamp and Landgraf, 2007). For this reason, aerosol retrieval algorithms employed by most of these sensors are required to make assumptions about microphysical properties. The consequence is that these assumptions then contribute to differences in retrieved AOD – even in the idealized case of a black (non-reflecting) surface (Kokhanovsky et al., 2010)."

For comparison, the first part of the first sentence of the abstract of Sayer et al., (2012) begins:

"Retrievals of aerosol optical depth (AOD) and related parameters from satellite measurements typically involve prescribed models of aerosol size and composition,"

The introductory paragraph of Sayer et al., (2012) reads:

"The size distribution and spectral complex refractive index of aerosols are needed to compute properties such as their scattering phase function, single scatter albedo, and extinction coefficient, which are in turn used to calculate quantities such as total aerosol optical depth (AOD) from column abundance. In general, the information content of measurements from current satellite radiometers is insufficient to unambiguously retrieve all these parameters, particularly when the (spectral and directional) behavior of surface reflectance is unknown [Hasekamp and Landgraf, 2007]. For this reason, aerosol retrieval algorithms employed by most of these sensors are required to make assumptions about aerosol microphysical properties, and rely on a set of predefined aerosol models or components. The assumptions in these aerosol retrieval algorithms contribute to differences in retrieved AOD, even in the idealized case of a black (non-reflecting) surface [Kokhanovsky et al., 2010]."

The authors do cite Sayer et al. (2012) several times in their study, and we are pleased that the authors found our study useful for their research. Better ways to parametrise aerosol microphysical/optical properties for various scientific applications are useful and, following a second thorough read through, I may offer some more specific comments and suggestions on Taylor et al.'s study in the future. However, in the meantime we first suggest that the authors revise the opening of their Introduction, as it appears that much was copied verbatim from our prior study, which we do not feel is good practice".

We would like to apologize once again for this. We hope that the immediate action we took publishing a re-write of the first paragraph on the interactive discussion is acceptable. This has been implemented in the revised version of the manuscript with the following re-written first paragraph:

"As reported by Sayer et al. (2012), the retrieval of parameters such as the aerosol optical depth (AOD) from satellite measurements is accomplished by algorithms that model the optical characteristics of columnar aerosol (the spectral scattering phase function, single scattering albedo and extinction coefficient) via parameters of microphysical structure including the aerosol volume size distribution (AVSD) and the spectral complex refractive index. Retrievals are therefore rather sensitive to the choice of model of particle size and composition. Furthermore, difficulties are compounded by the fact that the complete set of required parameters cannot presently be obtained

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unambiguously (Hasekamp and Landgraf, 2007) especially when the spectral and directional behavior of the surface reflectance is unknown (Kokhanovsky et al., 2010).“

Dr Sayer's work on extraction of pure marine aerosol models provided a strong motivation for our choice of Lanai as an illustrative case used in our presentation of the OEV and GMM methods outlined in Sect. 3, and we hope that the re-written first paragraph is now acceptable to him and yourself as handling editor. Below we reply to his other general comments.

“I also had a few questions/comments at this stage about the analysis, mostly relating to the marine data. If my reading is correct, the authors have taken the AERONET/GOCART time series and extracted one AERONET inversion for each type corresponding to the case where GOCART suggests a single aerosol type for that site is most dominant (as given in their Table 1), rather than looking in a more climatological sense. I ask as several references are made in the submitted manuscript to the double-humped coarse mode at the marine site (Lanai). In our multi-site analysis of AERONET-derived climatological aerosol properties at marine stations we did not observe this double-hump (Figure 3 of Sayer et al., 2012), merely the 'long tail' which Taylor et al. also comment on. However, in our study we were looking at climatological properties in 'clean marine' conditions rather than single cases, which may explain this difference. So I am curious as to how common this double-humped coarse mode feature might be, and whether it is linked in GOCART with any particular aerosol species-dominance (for this case it looks like GOCART is saying the fine mode is mostly sulphate and the coarse mostly sea salt?”

Yes, indeed we took AERONET/GOCART time series and extracted one AERONET inversion for each type corresponding to the case where GOCART suggests a single aerosol type for that site is most dominant (as given in Table 1). As we explain in our reply to the first point raised by Anonymous Reviewer #2 with regard to selection of the data, the above approach was adopted so as to more objectively select test cases. We hope to have answered now this important question. It would be interesting in a future

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study to perform an analysis of data averaged over a longer timescale so as to inspect ambient conditions. The focus of our work was not on climatological effects but rather on how AERONET data at short (daily) timescales could possibly include fine scale information on physical processes.

Dr. Sayer and Anonymous Reviewer #2 have raised a question about the prevalence of the double-humped coarse mode feature we observed at Lanai. As we mentioned in our reply to Anonymous Reviewer #2, we agree that the double-hump coarse mode feature at Lanai is not the norm. However, it does seem to be prevalent - especially on those days exhibiting the highest proportions of marine aerosol according to GOCART. In Fig.1 accompanying this reply, we extracted the 10 most marine aerosol dominated days at Lanai and plotted their AVSDs. The double-hump case we present in the submitted manuscript was observed at Lanai on the 21st of January 2002 (the first panel at the top-left of the above plot). Of these 10 cases, a double-hump is present in 6 of the cases. The associated GOCART data together with the optimal number of modes as found by applying the GMM method are presented in summary form in Table 4 in the revised manuscript. If one assumes that SU can be attributed to the fine mode and SS (sea salt) to the coarse mode, we would agree with Dr. Sayer that GOCART is saying that the fine mode in the case of dominant marine aerosol is mostly SU and the coarse mode is mostly SS (please see also our reply to the comment below). In a follow-up paper ready for submission we have analyzed the temporal and chemical evolution of AVSDs during aerosol incursion events and quantified the apportionment of the AVSD to chemical composition.

“As the submitted manuscript seems mostly a description of this technique applied to four different aerosol ‘type’ cases it is perhaps less important here, but as GOCART is not perfect (as indeed no dataset or model is), by picking a single case study which GOCART estimates to be the most ‘pure’ (in the sense of dominated by a single component in the model) there is a danger that the authors or readers may overgeneralise the results. In that sense it would be interesting to look at the results for, say, the top

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10 or 50 ‘pure’ cases for each site and see whether you draw the same conclusions from the ensemble as from the individual ‘top case’. This may also help mitigate the effects of the uncertainties on individual AERONET retrievals on the analysis (maybe you could see how variability on the retrievals in these cases compares with the expected level of error on the AERONET inversion). I am not an expert on the GOCART model and so cannot comment on the reliability/utility of its aerosol composition results for these specific sites investigated, but as natural sea spray aerosol is more than just sea salt (for example O’Dowd, C. D., and G. de Leeuw, 2007, Marine aerosol production: A review of the current knowledge, Philos. Trans. R. Soc. A, 365, 1753–1774, doi:10.1098/rsta.2007.2043, and de Leeuw, G., E. L Andreas, M. D. Anguelova, C. W. Fairall, E. R. Lewis, C. O’Dowd, M. Schulz, and S. E. Schwartz, 2011, Production flux of sea spray aerosol, Rev. Geophys., 49, RG2001, doi:10.1029/2010RG000349 for recent reviews) it could be that some other method of selecting case(s) for analysis could be considered for marine aerosol.”

Following this suggestion, we used the GOCART ranking approach to construct an ensemble of the top 10 daily-averaged AVSDs for each dominant aerosol type. In Fig. 2 accompanying this reply, we present the AERONET, OEV and GMM fits to the first 9 members of the ensemble of marine-dominated AVSDs as an illustration of the potentially broader application of our methods. In every case, the best fit is with 3 modes, two of which are in the coarse mode region > 1μm. A double-hump signature is clearly visible in 6 of the cases. We are grateful to Dr. Sayer for also kindly drawing our attention to some additional references on the general make-up of marine aerosol. While we believe that this is beyond the scope of the present work, it will be very interesting to study such aspects in future work. The ensemble results for the dominant aerosol types, we believe, are worth including in the revised manuscript as they suggest that the general approach adopted in the manuscript is fairly robust and general. We have added a new Table 4 (shown in Fig. 3 accompanying this reply) summarizing the contribution to the AOD from each aerosol type for each ensemble. Based on these ensemble results, in the revised manuscript we have also added the following paragraph on page 10592 line 7:

"At this point, we present a brief assessment of the representativeness of the individual dominant aerosol type AVSDs for desert dust, biomass burning, urban SU and marine (sea salt) aerosol selected by referring to GOCART chemical output data. While we do not expect the daily-averaged AVSD cases selected to echo ambient climatological aerosol conditions at these sites since for example, monthly averages are likely to be more representative, we extracted the 10 most dominant AVSDs for each case in order to place the most dominant cases in the context of a small ensemble of similar cases. Table 4 shows that the percentage contribution to the AOD from SU, BC, OC, DU and SS is consistent for each ensemble. In particular, for the dust-dominated ensemble the percentage contribution to the AOD from DU $> 97.62\%$, for the biomass burning-dominated ensemble the percentage contribution to the AOD from OC+BC $> 92.13\%$, for the urban SU-dominated ensemble the percentage contribution to the AOD from SU $> 85.22\%$, and for the marine-dominated ensemble the percentage contribution to the AOD from SS $> 48.55\%$ and includes a relatively strong SU component whose contribution is in the range: $21.76\% \leq \text{SU} \leq 39.09\%$ (not shown in Table 4). With regard to the optimal number of modes required to fit the AVSD, for the dust-dominated ensemble, the GMM method suggests that AVSDs occurring during spring-time (March and April) are best fit with 2 modes but those occurring during late autumn and early winter (November and December) have a more complex composition requiring 3 and more commonly 4 modes. For the biomass burning-dominated ensemble (all occurring in the month of August), the GMM method suggests that AVSDs are best fit with 3 or 4 modes. In the case of the urban SU-dominated ensemble, no seasonal pattern is discernible and the GMM method suggests that AVSDs are best fit with 3-4 modes (an exception is the 15th of August 2005 which presents a relatively low contribution of DU and SS and whose AVSD is best fit with a bi-lognormal). Overall, it appears that the single dominant aerosol type cases analyzed above are fairly typical of AVSD morphologies at these sites."

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“Related to the above, it is likely that in general coastal/island AERONET sites in the northern hemisphere may have a greater background ‘non-marine’ component from transported continental aerosols than those in the southern (although doubtless there are ‘pristine’ days in the northern hemisphere and so picking an appropriate day for a case study would mitigate this). We found Tahiti (17.6 S) to be a useful southern-hemisphere island AERONET site with reasonably good data record in our previous analysis on climatological properties of marine aerosol from AERONET. The authors may wish to consider this as an additional or alternate to Lanai for this or future analyses.”

We are grateful to Dr. Sayer for suggesting some alternative marine cases for study. As we described in our reply to the first point raised by Anonymous Reviewer #2, our choice of Lanai as a marine aerosol site was selected objectively according to the percentage contribution of SS emission to the total AOD as predicted by the GOCART model. While a general investigation of the marine AVSDs of varying composition is beyond the scope of the submitted manuscript, we are very interested in seeing how our methods may impact the interpretation of the size distribution at other marine sites and hope to collaborate on such studies.

“My other scientific comment/suggestion is that the present analysis focuses on reconstruction of the aerosol volume size distribution. I was wondering whether the authors have considered investigating the effects of these parametrisations on reproducing other quantities such as extinction efficiency and phase function (or asymmetry parameter)? For some applications, such as remote sensing of AOD from passive spaceborne imagers, reproduction of scattering/absorption behaviour may be more important than reproduction of size distribution.”

We would like to thank Dr. Sayer for this insightful comment. While the focus of the submitted manuscript is on parametrization of the size distribution (via the mode separation point in the OEV method and via fitting with mutliple Gaussians in the case of the GMM method), we hope that the techniques developed here can help encourage investigations into new parameterizations of the extinction efficiency, phase function and asymmetry parameter and hopefully improve interpretations of scattering and absorption behaviour. This can form the basis of interesting further studies.

Our thanks to Dr. Andrew Sayer for his helpful scientific contribution.

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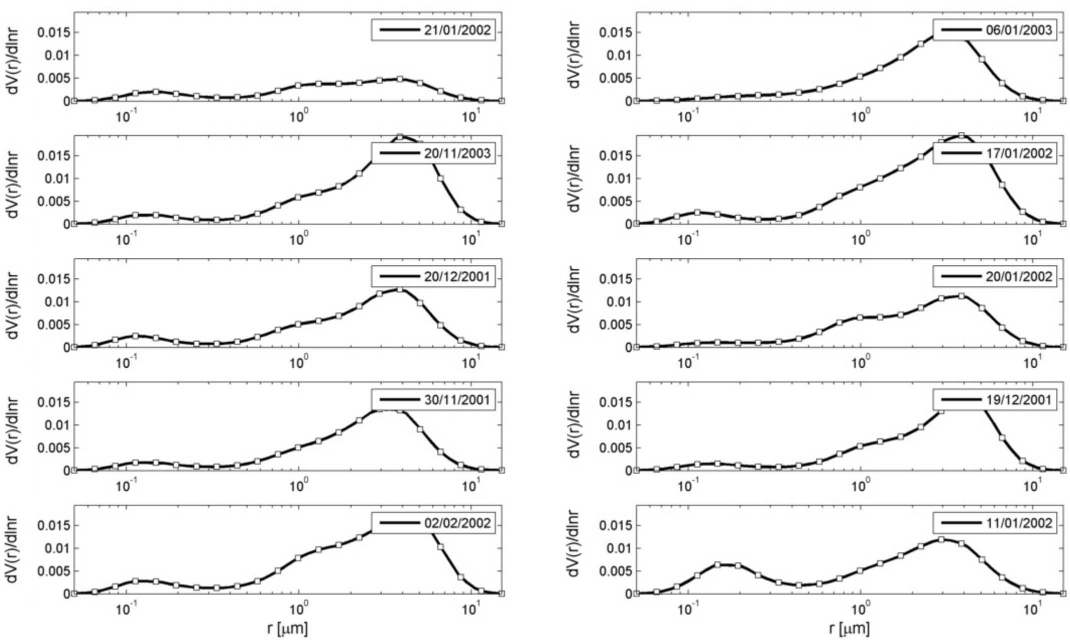

Fig. 1.

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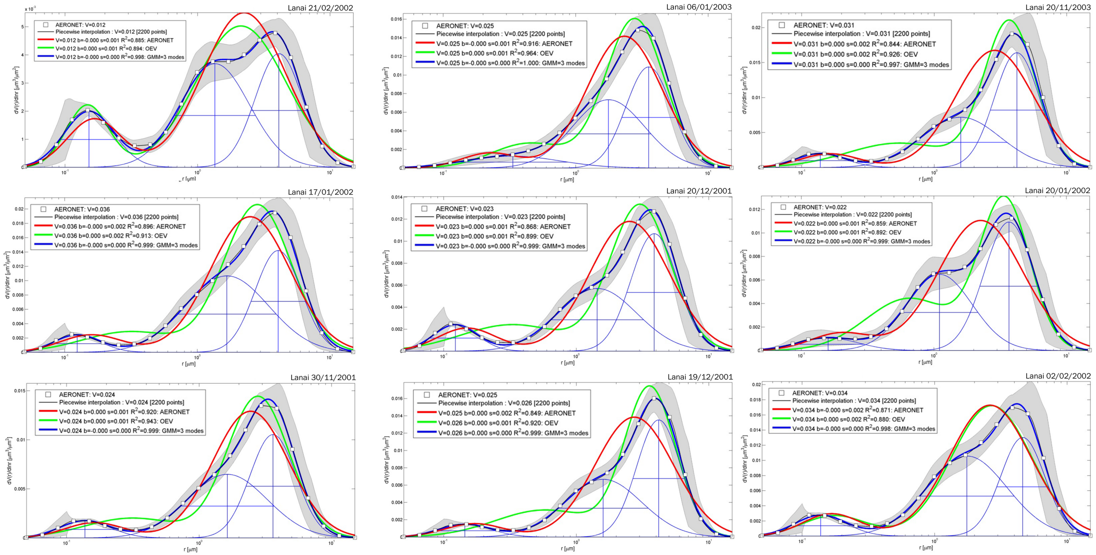

Lanai 21/02/2002
AERONET: V=0.012
Piecewise interpolation : V=0.012 [2200 points]
V=0.012 b=-0.000 s=0.001 R2=0.885: AERONET
V=0.012 b=0.000 s=0.001 R2=0.894: OEV
V=0.012 b=-0.000 s=0.000 R2=0.998: GMM=3 modes
Lanai 06/01/2003
AERONET: V=0.025
Piecewise interpolation : V=0.025 [2200 points]
V=0.025 b=-0.000 s=0.001 R2=0.916: AERONET
V=0.025 b=0.000 s=0.001 R2=0.964: OEV
V=0.025 b=-0.000 s=0.000 R2=1.000: GMM=3 modes
Lanai 20/11/2003
AERONET: V=0.031
Piecewise interpolation : V=0.031 [2200 points]
V=0.031 b=0.000 s=0.002 R2=0.844: AERONET
V=0.031 b=0.000 s=0.002 R2=0.926: OEV
V=0.031 b=0.000 s=0.000 R2=0.997: GMM=3 modes
Lanai 17/01/2002
AERONET: V=0.036
Piecewise interpolation : V=0.036 [2200 points]
V=0.036 b=-0.000 s=0.002 R2=0.896: AERONET
V=0.036 b=0.000 s=0.002 R2=0.913: OEV
V=0.036 b=-0.000 s=0.000 R2=0.999: GMM=3 modes
Lanai 20/12/2001
AERONET: V=0.023
Piecewise interpolation : V=0.023 [2200 points]
V=0.023 b=0.000 s=0.001 R2=0.868: AERONET
V=0.023 b=0.000 s=0.001 R2=0.899: OEV
V=0.023 b=-0.000 s=0.000 R2=0.999: GMM=3 modes
Lanai 20/01/2002
AERONET: V=0.022
Piecewise interpolation : V=0.022 [2200 points]
V=0.022 b=0.000 s=0.001 R2=0.859: AERONET
V=0.022 b=0.000 s=0.001 R2=0.892: OEV
V=0.022 b=-0.000 s=0.000 R2=0.999: GMM=3 modes
Lanai 30/11/2001
AERONET: V=0.024
Piecewise interpolation : V=0.024 [2200 points]
V=0.024 b=0.000 s=0.001 R2=0.920: AERONET
V=0.024 b=0.000 s=0.001 R2=0.943: OEV
V=0.024 b=-0.000 s=0.000 R2=0.999: GMM=3 modes
Lanai 19/12/2001
AERONET: V=0.025
Piecewise interpolation : V=0.026 [2200 points]
V=0.025 b=0.000 s=0.002 R2=0.849: AERONET
V=0.026 b=0.000 s=0.001 R2=0.920: OEV
V=0.026 b=0.000 s=0.000 R2=0.999: GMM=3 modes
Lanai 02/02/2002
AERONET: V=0.034
Piecewise interpolation : V=0.034 [2200 points]
V=0.034 b=-0.000 s=0.002 R2=0.871: AERONET
V=0.034 b=0.000 s=0.002 R2=0.880: OEV
V=0.034 b=-0.000 s=0.000 R2=0.998: GMM=3 modes
dV(r)/dlnr [μm3/μm2]
r [μm]

Fig. 2.

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Desert Dust	% DU	n-modes (GMM)	Biomass Burning	% OC+BC	n-modes (GMM)	Urban SO_2	% SU	n-modes (GMM)	Sea Salt	% SS	n-modes (GMM)
16/03/2005	97.91	2	14/08/2003	94.12	3	17/08/2005	87.53	3	21/01/2002	60.14	3
30/03/2005	97.84	2	13/08/2003	94.03	3	19/07/2002	87.49	4	06/01/2003	57.37	3
09/12/2005	97.75	4	12/08/2001	92.67	4	21/10/2002	87.04	4	20/11/2003	53.85	3
07/12/2005	97.74	3	20/08/2003	92.64	3	05/10/2002	86.79	3	17/01/2002	53.78	3
17/03/2005	97.74	2	15/08/2003	92.62	3	15/08/2005	86.48	2	20/12/2001	53.76	3
26/04/2005	97.74	2	22/08/2004	92.55	3	01/10/2004	86.25	4	20/01/2002	52.37	3
08/12/2005	97.72	4	26/08/2003	92.48	4	14/10/2002	85.91	3	30/11/2001	50.27	3
04/11/2005	97.69	4	11/08/2003	92.48	3	20/07/2002	85.85	3	19/12/2001	49.66	3
30/04/2005	97.64	2	07/08/2004	92.35	3	29/08/2001	85.53	3	02/02/2002	48.87	3
05/04/2005	97.62	2	23/08/2004	92.13	4	26/10/2005	85.22	3	11/01/2002	48.55	3

Fig. 3.