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Interactive comment on "Satellite retrievals of dust aerosol over the Red Sea, 2005–2015" *by* Jamie R. Banks et al.

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We thank Andrew Sayer for his helpful comments. Below are our responses to his comments, and a list of relevant changes.

1) "Title/abstract: I suggest adding the Persian Gulf into here as well, since this isn't mentioned at present in either title or abstract. I'd also mention in the abstract that some differences may be related to sphericity assumptions since, as I noted above, this has not got as much attention as it perhaps should have."

We agree that the analysis over the Persian Gulf is a significant contribution to the paper, so we have added the Persian Gulf to the title. Moreover we have also included the Abu Al Bukhoosh comparison statistics in Table 1. The abstract now includes

a sentence on the consequences of the use of particle sphericity assumptions and the differences in scattering angles observed by the two satellite instruments. In the process of considering the review process we have noticed that our calculations of the SEVIRI scattering angle were not consistent with how it is calculated by MODIS: hence we now include a second panel in Figure 10 to consider the mean scattering angle in relation to the MODIS/SEVIRI AODs, which expands the analysis and provides more detail to the overall picture.

2) "General: correlation coefficients are often given to 3 decimal places; I think 2 is sufficient as 3 gives a false impression of the level of precision on an estimate of correlation."

Correlation values in various Figures and in Table 1 are now only given to two decimal places, rather than three. This is also the case in the text.

3) "Page 4, lines 4-5: It is important to make the distinction here that the Dark Target algorithm is NOT applied over land and ocean. The product is often colloquially referred to as 'Dark Target' but there is not one Dark Target algorithm. There is one algorithm over land and another algorithm over ocean. They use different wavelengths, make different aerosol assumptions, and different surface assumptions, and have very little in common. This is a common misconception in the literature and is misleading so it would be good to make the text clear. The MODIS algorithm applied in this study is the ocean algorithm. So when Deep Blue is considered as well, this makes three algorithms in the MODIS MxD04 product, not two as line 4 states."

This is a very relevant point, that there are two 'Dark Target' algorithms: we have amended the first paragraph of Section 2.2 to clarify this issue, emphasising that we are considering only the product over ocean.

4) "Page 4, line 21: I recommend using pixels with QA=1,2,3, rather than only QA=3. The QA=3 recommendation is made for Dark Target land retrievals. For ocean algorithm retrievals, the team recommend that QA=0 are discarded but QA=1,2,3 can be used. This is because the QA flags were not found to mean much over the ocean (aside from QA=0), is what prior ocean validation exercises were done with, and what is done when aggregating into the widely-used Level 3 products. Doing this will give a more realistic representation of how the product is intended to be used, and should increase data volume as well. I'm not sure whether this will quantitatively affect the conclusions much or not."

We have changed our analysis to include MODIS pixels with QA values of 1 and 2, as well as 3. Quantitatively it makes very little difference, with a relatively small number of extra pixels now included: for example, over the KAUST AERONET site there are now 595 co-locations, compared to 575 beforehand. Correspondingly there has been a very minor adjustment to many of the comparison statistics throughout the manuscript.

5) "Section 2.2: Does the study use both Terra and Aqua data? I did not see it stated, perhaps I missed it. If both are used, is there any significant difference between the two found?"

The first paragraph of Section 5 indicates that we are using both Terra and Aqua data, for clarity we now also write much earlier in the second paragraph of Section 2.2 that we are using AOD data 'from both the Terra and Aqua satellites'. Few significant differences between the satellites are found: density plots of Terra MODIS vs. SEVIRI and Aqua MODIS vs. SEVIRI (analogous to Figure 8) show much the same behaviour between Terra and Aqua MODIS. For July across the Red Sea, the Terra/Aqua correlations with SEVIRI are 0.96/0.97, the offsets are -0.068/-0.080, and the RMSDs are 0.266/0.252. However we concede that there may be smaller-scale differences of greater magnitude which may not be apparent in this analysis. In Section 5 in the first paragraph where the density plots are introduced, we include the sentence: 'Very

similar patterns are seen in comparisons between Terra-MODIS and SEVIRI, and Aqua-MODIS and SEVIRI (not shown).'

6) "Page 6 line 25: This says that the assimilation makes the model AOD fields consistent with MODIS. The implication of that wording to me is that model AOD becomes replaced with MODIS AOD, but I assume that this is not the case. I think that this last part of the sentence should be deleted since it might cause confusion and the sentence already says it is 4D-Var and gives a reference."

We agree that the wording describing the MACC assimilation process is ambiguous and potentially confusing: the last part of this sentence on line 25 has now been removed.

7) "Page 7 lines 30-32: I would state again that quality flags are applied here, just to be clear to the reader, as sometimes people don't use them (which is bad). I realise it was stated earlier in the paper that they were used for MODIS."

An extra statement has been included in the first paragraph of Section 4 to point out that we are using MODIS QA values between 1 and 3.

8) "Page 8 lines 14-15, 21: Smirnov et al (2000) should probably also be cited at one of these points as it describes the cloud screening for the level 2 data used."

We have included the Smirnov et al. (2000) reference in this paragraph, when we declare that we are using L2 data for KAUST.

9) "Page 9, lines 27-30: It's possible that this is due in part to SSA assumptions, since SSA influences the point at which the reflectance vs. AOD curve flattens out. I'm not sure what the difference between MODIS and SEVIRI assumptions is. MODIS

ocean retrievals include a green band so there will be some dust absorption at that wavelength, but the SEVIRI wavelengths (and longer MODIS wavelengths) should all be fairly nonabsorbing for dust. (Note that the MODIS ocean product also provides output AOD at 470 nm, where dust absorption would be stronger, but this band is not actually used for the inversion- a few papers are incorrect on that matter.)"

This is a good point, and we include some sentences to this effect considering this point on page 11 when we discuss possible explanations for the discrepancies between the SEVIRI and MODIS retrievals.

10) "Page 10 lines 18-19: it is good to include MISR as another point of comparison, but worth mentioning more directly that as this is another retrieval, with stated uncertainties comparable to MODIS, better agreement with MISR does not necessarily mean that a product is closer to the truth."

Where we introduce the MISR retrievals in Section 5 we include a sentence pointing out the similar quoted uncertainties of the MISR retrievals compared to the MODIS and SEVIRI retrievals, as a reminder to the reader that MISR should not be regarded as the 'truth'.

11) "General, figures: some look a bit overly digitised, not sure if this is a problem in the source files or the conversion for embedding in the manuscript but this should be checked."

The reviewer appears to be referring to Figures 8 and 10, the density plots of MODIS against SEVIRI AODs. We now use a slightly different routine to create these plots, which we believe now provides more clarity.

12) "General, figures: most font sizes could do with being increased 1-2 points as a

few scales are hard to read at 100% magnification (this could be related to the above point as well)."

We have increased some of the font sizes a couple of points, and we have given Figures 3 and 5 more page space.

13) "Figure 7: I would change the caption to read MODIS-SEVIRI offset rather than MODIS-SEVIRI bias as people often read bias to imply that the reference is truth, while offset is a more neutral word. Same with some of the text on e.g. pages 10-11."

We have amended the captions and labels in Figures 7-9 to say 'offset' instead of 'bias', and at numerous points in the text we have changed occurrences of bias to offset when we are referring to differences between the satellite retrievals.

14) "Figures 7,9: it would be good to include a short plot title rather than just a letter, for easier quick reference to what is in the plot when browsing between text and figures."

Extra information has been added to the plot titles, for ease of reference.

15) "Suggestions for extension. Both MODIS and SEVIRI over-ocean products retrieve AOD and Ångström exponent; MODIS also retrieves fine-mode AOD fraction (from which one can get fine mode AOD and coarse mode AOD). I'm not sure if it is possible to derive fine mode fraction from the SEVIRI product as well (my impression from the cited references is that it's not a direct output). It would be interesting to compare the Ångstrëxponent retrievals with AERONET and with each other, as well, since some of the effects of the MODIS spherical assumption might also manifest there (in the same way as they are seen in the AOD comparisons). This is discussed briefly on page 10 but it does not go into much detail. The MODIS product could also be broken down to give fine and coarse mode AOD, which could be compared with that from AERONET's

SDA product. This product has also not been evaluated widely for MODIS (Kleidman et al., 2005 is the main exception), and not at all to my knowledge for Collection 6. SDA is available at Level 2 for the Kaust site; it is only Level 1.5 for Abu Al Bukhoosh (because I think of the limited number of spectral channels) but that might be able to be used with caveats. Adding this to the analysis would give important information about the quality of this product, as well as perhaps indicating how the 'spherical dust' assumption affects the robustness of total AOD vs. the fine/coarse-mode split. MISR also has a 'nonspherical AOD' product which could be taken as a proxy for mineral dust AOD, and compared with MODIS-derived coarse-mode AOD in a similar way to e.g. Figure 9. Is it possible to evaluate the SEVIRI retrievals as a function of time of day (maybe comparing diurnal cycles with AERONET or just plotting bias vs. hour or something)? I understand if there might not be enough data. However temporal resolution is something that geostationary sensors have an advantage over polar-orbiters with, so I think it would be good to emphasise this aspect of the SEVIRI retrieval."

We thank the reviewer for his suggestions for extensions, and we agree that including some of this analysis adds extra value to the paper. Comparisons of MODIS and AERONET and Ångström coefficients are detailed at the end of Section 5. SEVIRI is not included in this analysis due to the fact that its Ångström coefficient derivation comes from the relationship between two independent AOD retrievals at different wavelengths, and is not itself a validated product. Because of this, we carry out all AERONET comparisons at 630 nm, scaling the MODIS and AERONET retrievals using their retrieved Ångström coefficients. The MODIS Ångström coefficients have a tendency to be biased high against AERONET, by +0.09 at KAUST and +0.16 at Abu Al Bukhoosh, implying that the MODIS retrieval assumes smaller particles than does the AERONET retrieval, and which coheres with the picture presented by the fine-/coarse-mode MODIS and AERONET comparisons.

Comparisons of MODIS and AERONET fine/coarse-mode AODs have been included at the end of Section 5, with statistics in Table 2. Consistent with Kleidman et al. (2005)

we find that MODIS-AERONET biases are actually greater for the fine-mode than for the coarse-mode, despite the coarse-mode having the greater AOD.

We like the idea of investigating the diurnal cycle of the quality of the SEVIRI retrievals, and have explored briefly the daytime cycle in the SEVIRI-AERONET biases. At KAUST the hourly-resolved biases are at a minimum at the ends of the day (-0.05 between 1300-1400 UTC, and at a maximum of +0.04 between 0800-0900 UTC). The values are however very small, so it is difficult to draw too strong a conclusion from this. Hence while this is an intriguing idea, we do not include it in the final paper.

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