Anonymous Referee #2

General comments and recommendation

This study computes AOT and SWARE trends from multiple satellite instruments. Although no particular issues are present in the methodologies used in the study, the manuscript would benefit from a more focused presentation. The motivations for this work isn't clearly stated and it is also not clear how this work is distinct from the authors' previous papers. Relative to the authors' previous work, this study uses additional datasets, a longer time period and updates to C6 of the MODIS data products. Given this is study is essentially a repeat of previous work, I would encourage to authors to spend less time comparing every detail between this and their previous work and instead concisely present to the reader what new knowledge this study gives compared to the group's previous work. While bits and pieces of this are found throughout the paper, they are difficult to pick out in the long-winded presentation.

Response: We thank the reviewer for his/her constructive comments.

As the reviewer mentioned, in Zhang and Reid, 2010, 10-year AOT trends (2000-2010) were estimated, using C5 MODIS DT and MISR aerosol products with a focus on 10 selected regions. With the release of C6 MODIS DT products that have non-trivial changes in the retrieval process, and with the availability of a dataset with a longer study period (2000-2015), there is a need to understand the changes in AOT trends due to the above mentioned changes. In fact, we have reported a slowdown in positive AOD trends over Bay of Bengal, Arabian Sea and China. In addition, we found significant positive trends for the Red Sea and Persian Gulf regions (new regions that are not included in Zhang and Reid, 2010). Those findings warrant reporting. We have modified some discussions, as well as reorganized some sections, also per suggestions from reviewer 1 (see responses to reviewer 1 for details). Still, we felt the remaining discussions are needed to help readers who are not familiar with Zhang and Reid, 2010. Also, the reviewer notes that there is simply an "addition of new datasets." However the use of CERES fluxes is major undertaking, and it is important to show how AOD based and CERES based trends compare. Indeed, the suspected calibration drift in CERES reported in this paper sets a baseline as to how much "flux" can be compared to AOD based estimates.

Additionally, there many other studies of AOT trends outside the authors' previous work that are not cited in the manuscript which require recognition. The addition of the SWARE analysis is diminished somewhat since, in the context of the radiation budget, trends in instantaneous fluxes isn't particularly useful. Additional, although the authors appear to be surprised by this, the SWARE is largely controlled by AOT, so it is expected that trends will be highly correlated. This make the SWARE analysis somewhat redundant. Concerning the overall motivation for this study: given the large uncertainties, how do these trends help our understanding of aerosols and their role in the climate system?

Response: Firstly, as suggested, we have cited more papers as listed below:Chin, M., Diehl, T., Tan, Q., Prospero, J. M., Kahn, R. A., Remer, L. A., Yu, H., Sayer, A. M., Bian, H., Geogdzhayev, I. V., Holben, B. N., Howell, S. G., Huebert, B. J., Hsu, N. C.,

Kim, D., Kucsera, T. L., Levy, R. C., Mishchenko, M. I., Pan, X., Quinn, P. K., Schuster, G. L., Streets, D. G., Strode, S. A., Torres, O., and Zhao, X.-P.: Multi-decadal aerosol variations from 1980 to 2009: a perspective from observations and a global model, Atmos. Chem. Phys., 14, 3657-3690, https://doi.org/10.5194/acp-14-3657-2014, 2014.

- Mishchenko, M. I., Liu, L., Geogdzhayev, I. V., Li, J., Carlson, B. E., Lacis, A. A., Cairns, B., and Travis, L. D.: Aerosol retrievals from channel-1 and -2 AVHRR radiances: Longterm trends updated and revisited, J. Quant. Spectrosc. Ra., 113, 1974–1980, 2012.
- Thomas, G. E., Poulsen, C. A., Siddans, R., Sayer, A. M., Carboni, E., Marsh, S. H., Dean, S. M., Grainger, R. G., and Lawrence, B. N.: Validation of the GRAPE single view aerosol retrieval for ATSR-2 and insights into the long term global AOD trend over the ocean, Atmos. Chem. Phys., 10, 4849–4866, doi:10.5194/acp-10-4849-2010, 2010.
- Zhao, X.-P., Chan, P. K., and Heidinger, A. K.: A global survey of the effect of cloud contamination on the aerosol optical thickness and its long-term trend derived from operational AVHRR satellite observations, J. Geophys. Res., 118, 2849–2857, doi:10.1002/jgrd.50278, 2013.

We understand the existence of uncertainties in this study, but this is the first time SWARE trends have been evaluated with the use of space-borne observations alone. As suggested from Figs. 6 and 7, SWARE is a function of both AOD and aerosol type. Different aerosol species could have drastically different aerosol SW forcing efficiencies. And as the first reviewer suggested, the relationship between SWARF and AOD is rather non-linear as well. Thus, in traditional approaches for aerosol forcing studies (either models or radiative transfer calculations), detailed information about the temporal and spatial variations of aerosol properties are needed. An innovative approach is applied in this study, to direct estimate SWARE and SWARE trends from the collocated MODIS and CERES data, which doesn't not require a-priori knowledge of aerosol speciation. Thus, the results from this study can be used to inter-compare with model/radiative transfer model based SWARE analyses for evaluation and validation as well as for further estimating anthropogenic aerosol SWARE trends (e.g. Sundar et al., 2005).

Christopher, S. A., J. Zhang, Y. J. Kaufman, *and* L. A. Remer (2006), Satellite-based assessment of top of atmosphere anthropogenic aerosol radiative forcing over cloud-free oceans, Geophys. Res. Lett., 33, *L15816*, *doi*:10.1029/2005GL025535.

In the conclusion the authors state that "This study suggests that comprehensive observational systems can and should be used in future studies to gain a better understanding of any changes in atmospheric aerosol states." But what specific understanding have we gained with this study beyond a set of descriptive statistics? Given the large uncertainties, these trends are far from being climate monitoring quality, how does that limit the impact of work like this? Do we observations with lower uncertainties or is getting a few robust regional trends good enough? Given the large calibration drifts, should the goal be to develop of more advanced drift removal method than using the Remote Ocean region? More discussion on these sort of question and the broader implications of this work is needed in the introduction/conclusion.

Response: In this study, we compared aerosol trends from both passive and active-based methods (MODIS, MISR, CALIOP), over both cloud free and above cloud studies, as well as with both narrowband and broadband observations. Note that different instruments have different

sampling methods with different uncertainties under different observing conditions. Also, observations from active-based sensors can be used for reporting aerosol trends at both vertical and horizontal domains. While the above clouds aerosol studies evaluate aerosol trends from only the atmospheric columns above clouds. The broadband analysis covers the whole solar spectrum. We believe it is worth reporting the consistencies and inconsistencies we found for studies with different observing methods and with different instruments thus setting an observational baseline. We have added the following discussion in the conclusion section and revised the conclusion section.

"Note that the above mentioned studies are derived with different instruments that have different sampling methods with different uncertainties under different observing conditions. The fact that consistencies are found from those studies, adds fidelity to some of the studies that are difficult to evaluate otherwise."

Also, to avoid confusion, we removed the following discussion:

"This study suggests that comprehensive observational systems can and should be used in future studies to gain a better understanding of any changes in atmospheric aerosol states."

What is the point of keeping the seasonal cycle in some of the plots, but not others? Unless there is some particular reason for this, I would find it more instructive if all comparisons where deseasonalized.

Response: The monthly and seasonal averages of AOT and SWARE, Figs. 3a and 8a, respectively, are shown in order to illustrate the global AOD and SWARE values as well as for visual comparison to the deseasonalized time series. Due to the fact that the all-sky flux trends are not analyzed in further detail, Fig. 9 is also not deseasonalized.

The color bars on Figs. 1 and 12 make it difficult to infer any quantitative information. I suggest that the max/min range and the near-zero white portion be narrowed.

Response: We have revised the color bars as suggested as shown below. However, we still prefer to keep the original color bars to highlight significant signals in the paper, and thus no change is made to the paper.



Figure 1. Spatial distribution of trends for (a) over ocean 942 Terra MODIS DT AOT for 2000-2009, (b) over ocean Terra MODIS DT AOT for 2000-2015, (c) over ocean Aqua MODIS DT AOT for 2002-2015 and (d) over land and ocean Terra MISR AOT for 2000-2015 for every $1^{\circ}x1^{\circ}$ bin. (e) Ratios of MODIS C6 to C5 AOT trends for the study period of 2000-2009, and (f) Differences in MODIS C6 to C5 AOT trends for the study period of 2000-2009. Regions with statistically significant trends at a confidence interval of 95% are highlighted with black dots. Figs. 1e and 1f are constructed with the use of grids with AOT trends above or below ± 0.0001 AOT/year.



Figure 12. Spatial distribution of gridded AOT trends for (a) 16 year Terra (2000-2015) and (b) 14 year Aqua (2002-2015) for every 4 x 4° (Latitude/Longitude) bin derived from the collocated MODIS-CERES dataset. AOT trends are constructed using seasonally-averaged AOTs. (c) Spatial distribution of cloud-free-sky CERES ES-8 SW flux trends estimated using the collocated Terra MODIS-CERES data for the study period of 2000-2015. (d) Similar to Figure 12c, but using the collocated Aqua MODIS-CERES (ES-8) dataset for the study period of 2002-2015. (e-f) Similar to Figs. 12c and 12d, but for using CERES SSF data. Grids with statistically significant AOT/clear-sky SW flux trends at the 95 % confidence interval are shown in black dots.

Why is Eq (1) is opposite the usual sign convention?

Response: The definition of short wave aerosol radiative forcing (SWARF) is the difference in cloud-free sky short wave flux (SW) observed without (Fclear) and with (Faero) the presence of aerosol. It is typically used in the satellite based SWARE studies.

Lines 54-55: *what is meant by "detecting aerosol plumes". MODIS doesn't have an aerosol mask.*

Response: We have changed "detecting aerosol plumes" to "reporting finer scale aerosol optical properties" in the text.

Lines 60-62: Remove this sentence. The Terra/Aqua time series is not long enough to directly observe climate forcing. Additionally, the authors don't examine the SW direct forcing (i.e. radiative effect of only anthropogenic aerosols).

Response: Done.

What version of the CERES data products are being used?

Response: Edition 3A for SSF and Edition 3 for ES8. We have added that to the text.

Lines147-148: not sure what is meant by this line. What else could aerosol be classified as

Response: The CERES ES8 data set contains no information about aerosols. We have revised the sentence to: "No aerosol properties are considered in constructing ERBE ADMs"

line 175: change "Overland" to "Over land"

Response: Done.

line 186: remove "even"

Response: Done. We have revised the sentence to "Several studies have suggested that MODIS AOT retrievals may be contaminated with optically thin cirrus clouds (OTC, e.g. Kaufman et al., 2005, Huang et al., 2011, Feng et al., 2011, Toth et al., 2013).:"

lines 194-197: why is the C3M data mentioned if its never going to be used?

Response: Some readers may be familiar with the C3M products. We want to be clear on why we didn't use the C3M data.

lines 197-199: remove this sentence

Response: We prefer to keep the sentence to remind some readers of the reason that C3M data are not used.

Line 215: remove "trend paper"

Response: Done.

Line 240/251: remove "For illustrative purposes"

Response: Done.

Lines 273-274: remove "A quick comparison"

Done.

Line 293: remove interestingly.

Response: Done

line 492: remove "Surprisingly"

Response: Done.