Response to Dr. Michael Mishchenko:

We thank Dr. Mishchenko for his thoughtful comments.

Review of "A decadal regional and global trend analysis of the aerosol optical depth using a data-assimilation grade overwater MODIS and Level 2 MISR aerosol products" The manuscript can potentially become useful, but needs a significant revision before it can be considered for publication.

Question 1: *1. The manuscript implies that once an aerosol trend has started, it will continue for ever. This is a highly simplistic view. It is obvious that a decreasing AOT trend cannot continue for ever (e.g., over Europe) since one can clean the environment only so much. On the other hand, an increasing trend can be much longer as there is virtually no limit to anthropogenic pollution. The aerosol trends reported by Mishchenko et al. (2007) and Zhao et al. (2008) refer to the change between the pre-Pinatubo years and the early 2000s, and so there is no contradiction whatsoever between the new results reported in [1] (see the reference list below) and those in Mishchenko et al. (2007) and Zhao et al. (2008). In fact, Mishchenko et al. (2007) and Zhao et al. (2008) used different and totally independent radiance calibration procedures, which makes the similarity of their final conclusions significant. Also, the analyses performed in [2] and Zhao et al. (2008) show quite plausible regional trends, which gives more credibility to the two AVHRR aerosol products. The authors should give this more thought and present a more balanced account of what was reported in Mishchenko et al. (2007), Zhao et al. (2008), and [2] and whether it has much relevance to the present study.*

Answer 1: We concur that it is unphysical to assume a trend will continue forever. In fact, we were referring the trend from *Mishchenko et al.* (2007) for the period of 2000-2005 that has overlaps with this study (e.g. attached Figure 1 from *Mishchenko et al.* 2007). Figure 1 of *Mishchenko et al.* (2007) and its associated discussion suggests a decreasing trend for the period of 2000-2005 that is in their words, unlikely to be due to a calibration issue. This interpretation of the GACP dataset is renewed in the GRL paper by *Cermak et al.* currently in press, of which Dr. Mischenko is a co-author. To avoid this misunderstanding, we rephrased the text as highlighted below. We referred *Mishchenko et al.* (2009), *Zhao et al.* (2008) and *Cermak et al.,* (2010) in the text. However, calibration remains as a major issue for any trend study using satellite observations, and deserves a critical and unbiased view.

a) Removed "Contrary to some of the previous studies that showed a decreasing trend in aerosol optical depth (AOD) over global oceans, "

b) Changed from "The finding from this study, a negligible AOD trend over global oceans for the past 10 years, is in contradiction to a much larger decreasing trend as reported by *Mishchenko et al.* [2007] using the AVHRR data. Considering that MODIS has much improved spatial and spectral resolutions, and includes on-board calibration that the AVHRR visible channels lack, we suspect that the large decreasing AOD trend reported by *Mishchenko et al.* [2007] could be introduced by the uncertainties in sensor

calibration, even though some form of external calibrations using stable bright surfaces have been implemented [e.g. *Rao and Chen*, 1996]."

To: "The finding from this study, a negligible AOD trend over global oceans for the past 10 years, is inconsistent to a decreasing trend as reported by *Mishchenko et al.*, [2007] using the AVHRR data for the years of 2000-2005. Considering that MODIS has much improved spatial and spectral resolutions, and includes on-board calibration that the AVHRR visible channels lack, it is plausible that the decreasing AOD trend reported by *Mishchenko et al.*, [2007] for the period of 2000-2005 could be introduced by the uncertainties in sensor calibration, even though some form of external calibrations using stable bright surfaces have been implemented [e.g. *Rao and Chen*, 1996]. A careful analysis of calibration to the AVHRR trend is necessary for a future study."

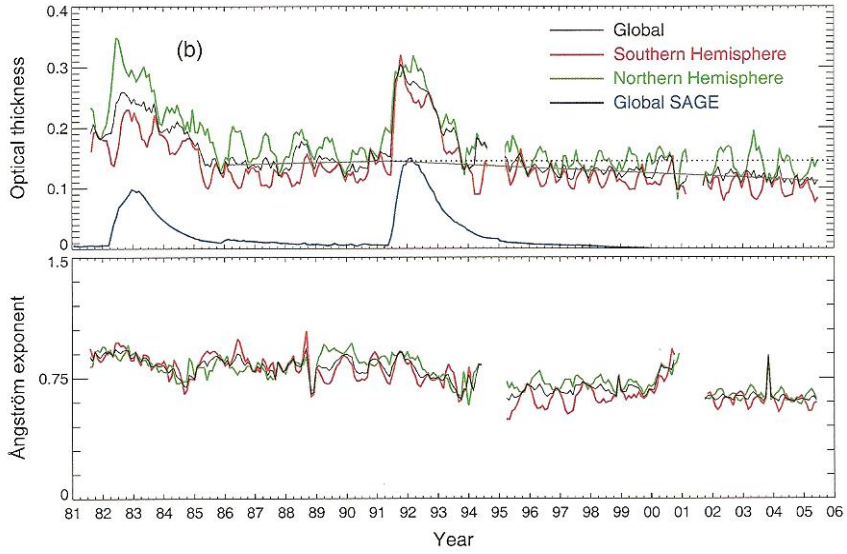

Fig. 1. Global and hemispherical monthly averages of the AOT and Ångström exponent over the oceans for the period August 1981 – June 2005 derived with (a) the old and (b) the new version of the GACP retrieval algorithm. The blue curve depicts the SAGE record of the globally averaged stratospheric AOT. The solid grey lines show pre- and post-Pinatubo linear regressions. The dotted grey line represnts the June 1991 pre-Pinatubo regression level.

Figure 1 of *Mishchenko et al.* (2007)

Question 2: *The lack of the global AOT trend over the oceans according to MODIS and MISR is the most important result of this manuscript, but it is not original. This result has been published in [1], along with maps of regional AOT trends, which the authors have failed to acknowledge and cross-analyze.*

Answer 2: Indeed, the global AOD trends from MODIS and MISR have been reported by not only *Mishchenko et al.* [2007], but also several other studies such as Li et al., [2009] and *Yu et al.*, 2009. In comparison, extensive original efforts went into this study by careful analysis of the uncertainties in the satellite products that could affect the trend analysis (see the next paragraph for detailed discussions) that most of the previous studies did not address (as far as we know), and for the first time included statistical significance analyses for both regional and global AOD trend studies. Furthermore, regions with significant trend were indentified, and reasons for the

positive trends for the last ten years were further evaluated. Lastly, to study the effect of cloud contamination to the trend analysis, a new data-assimilation quality level 3 MODIS aerosol product was used in the analysis. In short, we believe there are sufficient enough original efforts in this manuscript and as the second reviewer Dr. Lorraine Remer mentioned "This is a strong paper, well-written, conservative in approach, and contribute to the community."

To be more specific, the critical component of a trend analysis should involve serious efforts in fully understanding the uncertainties/significance of the analysis. First of all, uncertainties exist in satellite aerosol products, due to issues such as cloud contamination, surface effects, and inaccurate representation of aerosol properties in the retrieving algorithms. For example, the high aerosol optical depth (AOD) band shown from all three products, MODIS, MISR, and GACP, could not be found from the Maritime Aerosol Network (MAN) measurements over the region [Smirnov et al., AEROCOM, 2010]. The community has been long suspecting that the high AOD band is mostly introduced by cloud artifacts, especially cirrus clouds [BoCai Gao, personal communication]. For illustration purpose, we also attached one of the AOD plots from *Mishchenko et al.* [2007]. A high AOD band over the high latitude southern ocean is clearly visible. Secondly, various sampling biases and calibration drifts could indeed impact the derived trend analysis. In this study we carefully examined these issues. A revised version of MODIS aerosol products, with extensive QA and QC steps to minimize cloud artifacts, and retrieval biases, was included in the analysis. Cross comparisons between MODIS and MISR, and comparisons between satellite aerosol products and AERONET data were used for evaluating calibration drifts. Indeed, at face value, MODIS suggests a trend, whereas MISR does not-this is previously unreported. Further, different from previous studies, statistical significance of both regional and global trend analysis were discussed, and detailed regional analysis also included for the origins of the increasing aerosol events. Ultimately, not only did we report differences in trends, but through careful evaluation of data, have mostly reconciled the differences.

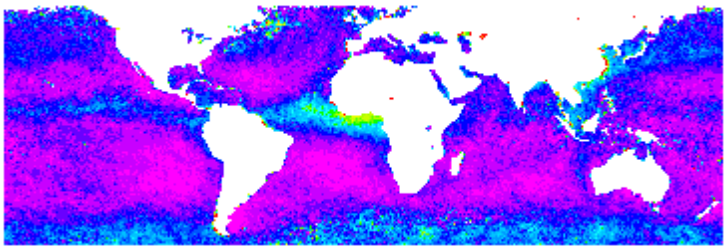

Figure 2b of *Mishchenko et al.*, [2007]. A high AOD band is clearly visible over high latitude southern oceans.

While discussion surrounds the global value, we also looked at regional differences, and in particular the statistical significance (described in Section 3) and trend validation (say against AERONET or vicarious in the remote ocean) of any regional trend, also absent from previous climatology papers. In particular, some regions in *Mishchenko et al.* [2007] which show trends we find lack statistical significance, such as the NE United States.

Lastly, without considering all the issues mentioned above, we actually found an increasing trend for the over ocean MODIS products generated by NASA for the past 5 years, not included in

these previous studies. However, most of this increasing trend could be explained by calibration issues, as suggested by this study. This, we believe, is an entirely new result useful to the community and the NASA MODIS team is currently investigating the issue.

Question 3: *The authors should parallel the comparison of MODIS and MISR AOTs with a similar comparison of Angstrom exponent results and trends (cf. [1]). This looks like an obvious thing to do, which will clearly add to or subtract from the credibility of the MODIS and MISR AOT results/trends.*

Answer 3: Thanks Mike for the suggestion. However, as we mentioned before, uncertainties exist in satellite aerosol retrievals at all channels. The Angstrom exponent (AE) can be considered as a way of measuring differences of retrieved AOD at two different wavelengths. For systematic AOD retrieval biases across the channels, we would expect they are minimized by the AE calculations. However, independent biases and noises exist in each channel, by taking the differences of the AOT values at difference channels, we expect that the uncertainties could be magnified. Therefore, it takes a solid research effort to really understand what satellite AE tells us, before we could gain insight into the trend analysis from the AE. We believe this is a whole research topic by itself, and therefore did not include in this study.

However, we do have discussion on the fine mode to total aerosol optical depth (η), which is similar to AE and in our opinion a much more robust and meaningful quantity at this point. As we said in our paper, for the most part there was no statistically significant trend in fine mode fraction, except in those few places identified in the literature.

Still, there is a risk of using a parameter that the community does not really truly understand its performance. We also added the following discussion:
"However, readers should be aware that aerosol size parameters, such as the fine mode AOD fraction and Angstrom exponent, are extremely sensitive to calibration issues, and to retrieval uncertainties at different spectral channels. Therefore, trend analyses using satellite derived aerosol size parameters could contain noise and biases that limit the significance of using such parameters for trend analysis. Future research efforts are necessary to fully understand satellite derived aerosol size parameters before we draw definite conclusions from those parameters."