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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Examination of aerosol distributions and radiative effects over the Bay of Bengal and the Arabian Sea region during ICARB using satellite data and a general circulation model" *by* R. Cherian et al.

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We would like to thank the reviewer for the assessment of our manuscript and the helpful comments. We will include the reviewer's remarks in the revised manuscript. Please see below a detailed response.

General comments:

The study presented by the authors is comprised of three parts. The first one is a comparison between estimates of aerosol optical depth (AOD) obtained with a hand-

held Sun photometer during the Integrated Campaign for Aerosols, Gases and Radiation Budget (ICARB) over the Bay of Bengal and the Arabian Sea. The second one is a comparison between AODs, aerosol size fractions, Angström exponent and aerosol absorption simulated using the European-Community Hamburg climate model ECHAM5.5 coupled to the Hamburg Aerosol Module (HAM) and those variables obtained from satellite retrievals for the two regions. The third one is a model based estimate of the top-of-atmosphere (TOA), surface, and atmospheric forcing as well as atmospheric heating rates in the regions, which then are corrected by constraining them with the AODs obtained from the satellite and Sun photometer data.

As a technical exercise, the presentation, comparisons, and applied statistics are all sound. However, I see some major problems with the study:

1. Although the statistics used in the first part of the current study are a bit more comprehensive than in Kedia and Ramachandran (2008), the previous study has already established that the data from the Sun photometer are in a good agreement with satellite data in the two regions during the campaign period, and arising differences were discussed. Other studies already presented results on the spatial and temporal patterns of aerosol properties in the regions during the campaign. Thus, what are the really new results from this validation part of the current study?

Reply: In disagreement with the reviewer's remark, we try to explain the difference from the study by Kedia and Ramachandran (2008) in a clearer way in the revised manuscript. (Please see above our response to the first reviewer's comment No. 1). Spatial distributions of aerosol optical properties and their radiative effects have largely been derived using point location observations over the region through ship cruise measurements (e.g. Kedia and Ramachandran, 2008; Kedia et al., 2010; Moorthy et al., 2008; Moorthy et al., 2009). A two-way approach in this study, described above, uses model simulations along with geographically progressing time-series measurements (sun-photometer AOD) and large-scale remote sensing estimates (from satellite AOD). Through this approach, we strongly believe that the present work not only es-

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tablishes the regional representativeness of ICARB measurements and model predictions, but importantly, contributes a robust knowledge of the aerosol radiative forcing over BoB and AS regions during pre-monsoon season.

2. In addition to that the data only cover the pre-monsoon period of one year, year 2006, i.e., it is only one data point from a distribution of AODs during the premonsoon, if more years were taken into consideration. It is not known how representative this one data point is for the pre-monsoon season in the two regions.

Reply: This is an interesting point which has been addressed fully in the revised version of the manuscript using MODIS and MISR climatology for 8years (2001-2008) and 9 years (2000-2009), respectively. We added one table (Table S4) and the following discussion in the manuscript:

"In this study, the climatology of aerosol properties from remote sensing estimates are used to examine how representative are the simulated aerosol properties for the multiyear period during the pre-monsoon season over BoB and AS regions. For this, the 9 year (2000-2008) MISR and 8 year MODIS climatology values are used. Similar seasonal-mean AOD values (0.33$\pm$ 0.05) were reported from MISR climatology (Dey and Girolamo, 2010) and MODIS climatology (0.29 $\pm$ 0.02) during pre-monsoon season over both BoB and AS regions. Model simulations also show similar AOD values (0.27 $\pm$ 0.06) over BoB and AS (0.26 $\pm$ 0.09) regions during the pre-monsoon season (March-May) of 2006, which is slightly less in AOD magnitude compared to MISR and MODIS 8 year climatology (2001-2008). Similarly, the model simulated angstrom exponent (AE) values also capture the reported MISR climatology values over both BoB and AS regions (see Table S7). Agreement between simulated aerosol properties with MISR and MODIS climatology (slightly less in AOD magnitude) implying that the AOD and AE simulated by the model well represent the pre-monsoon climatology of aerosol properties over BoB and AS regions." See manuscript (page 12, line 20-23 and page 13, line 1-10)

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3. Satheesh et al. (2006), a missing reference in the current paper, studied the seasonal cycle of the distribution of aerosols and radiative forcing in the Bay of Bengal using data from more than one set of ship based measurements and more years of satellite data.

Reply: Since the reported multiyear (2000-2004) forcing estimates are whole-sky forcing by Satheesh et al., 2006, where as the model predictions are clear-sky forcings, we added one table (see supplement) by comparing both mean clear-sky forcing and reported whole-sky forcing over these regions (see Table below). The clear-sky forcing simulated by the model is consistent with the reported whole-sky forcing values over the northern and southern BoB.

4. A seasonal climatology of AOD and Angström exponent based on multi-year satellite data was published by Dey and Di Girolamo (2010), providing more information. This study is also missing from the references in the current manuscript.

Reply: This study is now included in the manuscript. See the response of comment 2.

5. In the second part of the study, the authors compare the aerosol properties derived from satellite retrieved data with results from a model simulation with ECHAM5.5-HAM for the same time period. Model winds in the simulation were nudged using ECMWF reanalyses winds. The authors diagnose that the model simulation underestimates dust sources in the Thar Desert and dust transport from Northern India, leading to low coarse mode AOD over the Bay of Bengal in the simulation. They suspect that the deficiencies in the simulation could be due to deficiencies in the reanalyses winds. However, if the reanalyses winds used as input data in the model are deficient, then it is to be expected that the model simulation is deficient, even more if a model is highly skilled to reproduce the real world and no other model errors accidentally compensate for the deficiency in the input data. Therefore, the authors' conclusion that "the model cannot reproduce (underprediction by a factor of 3) the large AODs observed during high pollution days, especially over the BoB legs," (page 13,931, line 9 to 11) is not a

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valid one. The analysis provided by the authors is not sufficient for a real evaluation of ECHAM5.5-HAM's skills to reproduce observed aerosol properties. An evaluation providing more insight could start with the diagnosis and then systematically investigate which one of the deficiencies are actually due to insufficient model performance, and what parameters or parts in the model cause them, and which ones are due to other factors like deficient input data.

Reply: We have performed several analyses to better understand missing dust source issues with the model simulations. The model dust underprediction is now been well addressed in the manuscript (Please see manuscript page 15, line 1-15; page 16 line 5-20 and page 17 line 7-20). In order to clarify this point, we made the following changes in the conclusion section of the manuscript.

"The analysis of dust AOD along with the UV AI from OMI sensor found that the model is unable to capture high coarse mode AODs, traced back to missing dust source regions over the Thar desert (north west India). In the model too low dust emission flux over the Thar desert region caused the underestimation of coarse mode AODs over BoB regions." (See manuscript page 26, line 5-8)

See also response to comment no. 1 of Reviewer one.

6. Regarding the calculation of the radiative forcing due to the aerosols over the investigated regions, the question again is how representative are the results from the pre-monsoon period of only one year. The results from only one year don't allow any generalized conclusions about the pre-monsoon period in the region, since it is only one data point from a statistical distribution.

Reply: In response to this, we estimated multiyear (2001-2005) satellite-tied radiative forcing over BoB and AS regions. We added one table in the supplementary information (Table S9) and the following text in the manuscript:

"In this study, we examined how representative are the DARF estimates simulated

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by the model for the pre-monsoon season over the BoB and AS regions. The five year (2001-2005) model simulated pre-monsoon seasonal-mean clear-sky short-wave satellite-tied DARF is used for this analysis. The multiyear (2001-2005) seasonal-mean satellite-tied DARF is compared with satellite-tied DARF simulated by the model during ICARB over the BoB and AS regions (Table S9). The DARF during ICARB captured statistically well with the multiyear satellite-tied DARF values and with the available radiative forcing estimates from previous studies (Table S5) indicate that the regional forcing estimates from this study well represents the multiyear pre-monsoon season. The importance of the findings from this study are that (1) a robust (measurement constrained) estimates of regionally and seasonally representative aerosol radiative forcing over BoB and AS from climate models, and (2) the mean forcing efficiency of the BoB and AS is broadly agree the regional/seasonal mean values reported from previous multiyear studies, implying that aerosol forcing inter-annual variability for this oceanic region and season was low at temporal scales, and at horizontal space scales of less than 1 degree. However, the observed large spatial and temporal (episode wise) heterogeneities in aerosol properties and their radiative effects within the region/season needs to be better understood by integrating measurements with climate models." See manuscript (page 24, line 5-21)

7. It is also not clear what the new results are compared to previous studies, which estimated the radiative forcing using a larger data base (Satheesh et al., 2006; Moorthy et al., 2009).

Reply: In order to clarify the comparison of our estimates to previous studies during (Moorthy et al., 2009), we added one table in the supplementary information (Table S8). The discussion is revised in the manuscript (See manuscript page 23, line 13-18). See response to comment 3 for Satheesh et al., 2006 forcing value comparison.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 13911, 2011.