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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Spatial distributions and seasonal cycles of aerosol climate effects in India seen in global climate-aerosol model" *by* S. V. Henriksson et al.

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We thank Dr. Y. C. Sud for professional comments, encouraging positive feedback and constructive criticism. Below we present our answers to the comments as well as actions taken in revising the paper. Original comments are in italics.

This paper aims at assessing the aerosol-rainfall-climate connections due to the direct (effects) and indirect effects (DE IE) of aerosols on the vertical structure of the radiative heating, temperature profiles, and precipitation yields. The investigation relies on a suite of ECHAM5-HAM model simulations comprising of nine runs in which the

DE and IE of aerosols are turned on and off with and without the GAINS inventory of anthropogenic emissions. The SSTs are prescribed and kept identical in all the simulations except for two (one with only DE and one with both DE and IE turned on) in which SST modification entail SST-reductions (of 0.5K) as a proxy for the solar diming by aerosols over the nearby Oceans. The data are used to evaluate two recently identified aerosol impacts: i) the Elevated Heat Pump (EHP) effect enunciated by Lau and Kim (2010) and ii) the Solar Diming effect (SDM) identified by Ramanathan et al. (2001, 2007) vis-a-vis the influence of assumed SST anomalies caused by aerosols. The authors examine the rainfall changes in the 1) pre-monsoon or MAM, 2) summer monsoon or JJA, 3) monsoon withdrawal and early winter or SON, seasons. The take home message of the research is that both EHP and SDM are active and counter each other. Whereas EHP causes rainfall invigoration, SDM forces rainfall reduction, and in the balance SDM effect outweighs the EHP effect on rainfall. The authors do not discuss as to how dependant are the findings on the strengths or weaknesses of the particular model.

Further simulations and discussion have been added. The improvements we have made are explained in more detail below in response to the more detailed comments on the issues listed in the above general comments.

ECHAM5-HAM model is a world class climate model and GAINS data provides a comprehensive aerosol emission inventory. Moreover, the model's current version has been shown to produce reasonable features of aerosol-cloud-radiation forcing and hence I recognize how the simulations can be expected to provide worthwhile results. Nevertheless, the model resolution is coarse, particularly for capturing the EHP effect over Himalayan orography. Also, it may not simulate realistic aerosol number and mass density gradients to accurately develop and modulate the horizontal structures of atmospheric stability which, in turn, impacts dry and moist convection and hence the monsoon circulation over India. It is well known that model-based inferences contain a mix of GCM's biases and atmosphere's reality. Moreover, models with aerosol *physics also need good aerosol input that comprise of aerosol particle size, chemical composition, solubility, CCN activation and IN formation properties; together with a well validated parameterization of precipitation microphysics and model's ability to generate realistic juxtapositions of aerosols and clouds in the vertical. It is a tall order and one sees the need to validate the results against observations. I therefore suggest some additional diagnostics to assess the fidelity of the simulated monsoon circulation over India. These are likely to provide a stronger scientific base to the inferences outlined in the paper! Indeed, the suggested diagnostics also have a better potential for validation against real observations. Hence I urge the authors to give them due consideration.*

We thank Dr. Sud for recognizing the potential of the applied model and methods. We recognize the request for further evaluation against observations and reanalyses and a further discussion of possible biases. The limitations of the coarse resolution especially over the Himalayan orography is now further discussed in Section 2. A possible bias due to the moist physics was indeed also found by Abhik et al. (2013) and now discussed in Section 2. With the complexity of the problem at hand, not every relevant process can be discussed in detail and we refer the reader to the references, where also biases and possible error sources are further discussed. The specific validations suggested in the next comment below have, however, now been done.

Specific Suggestions and Recommendations

As to the usefulness of modeling based inferences, readers often like to know how representative are the GCM simulations over India? Do the model simulations have the key characteristics of the Indian circulation that comprise of reasonable: i) high pressure ridge in the north in MAM; ii) orientation and intensity of monsoon trough in JJA; iii) vertical temperature structure with its consequences on Intraseasonal Oscillations (ISO) with the intensity and frequency of convective events embedded into ISO; as well as iv) the onset and withdrawal of monsoon circulation and rainfall. Indeed, westerly disturbances of the winter season are also an integral part of model's characteristic, but those are not evoked in this study; so I would not bother the authors with them. If

the assessments outlined above have been published already, the authors may reference them, but a reasonable discussion of model's strengths and/or deficiencies and how those might impact the outcome of the present study would be very helpful. Indeed, if the model simulates reasonably well the key circulation features over India, the next interesting question is "how do aerosols affect these features? This will give ACP readers an invaluable insight into the intrinsic value of the aerosol effects on the Indian monsoons. On the other hand, if the monsoon characteristics of the baseline model have significant biases, the reader needs to know about them. Clearly, such diagnostic are vital for meteorology associated with the new findings. After these questions have been addressed and the paper is revised to reflect the model's ability to predict and modulate the monsoon circulation over the Indian subcontinent, the paper would be suitable for publication. However, aerosol-SST connections remain a wild card because proxy derived SST anomalies are arbitrary! A better way would be to compute SST changes consistently with a slab ocean model, but I also realize, it may be asking too much to include it in the current investigation.

We thank Dr. Sud for also recognizing the large efforts involved in studying the wide and complex topic at hand. Although it was behind a large amount of work, as recognised also by Dr. Sud, we did two 50-year slab ocean experiments: one with aerosols and another without aerosols. The resulting SST anomalies were somewhat different than we had assumed in the experiments with modified SSTs with a more uniform cooling of the north Indian Ocean. The SSTMODIF experiments are moved to the Supplementary Material as sensitivity calculations and the mixed-layer ocean results more in focus.

Also the monsoon features mentioned by Dr. Sud and some others too are now discussed in the manuscript based on ERA Interim reanalysis data, model output and literature. The comparisons i) and ii) were done using geopotential data from ERA Interim reanalysis data and the correspondence is qualitatively similar. iii) and iv) were discussed based on literature: According to Kripalani et al. (2007), ECHAM5 is a world-class model in simulating the monsoon. Rajeevan and Nanjundiah (2007) show that the MPI coupled model simulates the monsoon rain seasonal cycle and spatial patterns qualitatively correctly. According to Kemball-Cook et al. (2002) the ISO was reasonably well simulated already by the previous-generation model ECHAM4. However, also ECHAM5 suffers from a double-ITCZ problem (Lin et al., 2007), which might have to do with problems simulating ISO propagations (Rajeevan and Nanjundiah, 2007). Abhik et al. (2013) recognize a potential bias related to moist physics and convection. Thus the large-scale features of the monsoon seem to be qualitatively correct in the model, but with potential error and bias arising from convection, other smaller-scale phenomena and possible unidentified sources. It is also of course not guaranteed that the reaction of the different monsoon features to the aerosol forcing is realistic. These facts are now further emphasized in the text.

In closing, I like to state, the authors have made a laudable beginning in making an interesting series of runs with the ECHAM5 model using the best available aerosol inventories and finally ending up with the EHP and SDM comparisons. This qualifies the work for dissemination in the published literature; however, the analysis is weak on probing into changes in the monsoon circulation; the suggested diagnostics are vital for enlightening the reader about the intrinsic value of the new findings. I expect the authors to use the available data (to the extent possible) and show the success of the model in simulating the key features of the circulation over India. They may like to use the analyzed circulation fields (from somewhere ECMWF or NCEP) for model evaluation. Once these diagnostics are included, the assessment of circulation meteorology will become adequate. I would not seek to review the revised paper because my comments and authors responses will appear together and will reflect naturally on the value of the current results.

Once again we thank Dr. Sud for closing with positive comments and hope that the revisions have filled the gaps satisfactorily.

Technical Comments

Herein, I make some editorial comments. These are for the benefit of the authors; these may not be web posted.

The Technical Comments have been addressed at the respective locations in the text.

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