Comments on paper " Spatial distributions and seasonal cycles of aerosol climate effects in India seen in global climate-aerosol model" by Henriksson et al

In this paper, the authors used the ECHAM5-HAM model together with GAINS inventory of anthropogenic aerosols emissions to study the impact of aerosols on temperature and rainfall of the Indian monsoon. They first presented model results on seasonal distribution of aerosols and aerosol radiative forcing over India. Then they conducted various sensitivity experiments, to elucidate the climate effects of respectively, total aerosol, anthropogenic aerosols, absorbing aerosols, direct and indirect effects, as well as aerosol induced SST effects, to determine the relative importance of each effect in contributing to monsoon rainfall changes over India. The study should be commended as a first step towards a comprehensive understanding of aerosol-Indian monsoon interaction. It has added new perspective to the ongoing debate on the possible impacts of aerosols on monsoon. However, as is, there are major weaknesses. The authors went through a laundry list of figures, some of them with very brief discussions. The discussions were not particularly enlightening, and at times confusing. Overall, the paper lacks in-depth analyses and discussions of physical processes. Given the wealth of information in the experiments, this paper can be significantly improved, if the authors can focus on one or two key messages, and conduct more in-depth analyses to support them. I recommend publications with major revisions along the following suggested lines.

1. A main result of the paper is that decreasing the meridional SST gradient between the northern and equatorial Indian Ocean seems to have the largest impact in decreasing monsoon rainfall . The problem with this conclusion is that the aerosol SST gradient modification which followed Ramanathan et al 2005 is artificial and arbitrary. If anything, this is simply the model's response to SST cooling in the northern Indian Ocean/Arabian Sea due to any number of reasons such as increased surface wind, ocean upwelling, and others, but not necessarily aerosols. To obtained more realistic SST cooling estimate, one possibility is to estimate from mixed layer ocean, with realistic mixed layer depth, the temperature cooling caused by the model's aerosol radiative cooling over the North Indian Ocean. This has not been done. Here, the magnitude of the 20% reduction in rainfall by SST is likely to be strongly dependent on the magnitude of SST gradient which is arbitrarily set and not internally consistent with the model aerosol surface radiative forcing. The SST experiment is not in the same class as the other experiments, which are consistent internally (as far as I can tell) with the aerosol physics of the model, and hence should not be a main conclusion of this paper. If included, it should be accompanied by discussions of the caveats of such artificially modified SST.

2. Another major conclusion of this paper is that increased SDM may cause reduced evaporation, leading to reduced humidity and reduced rainfall which over compensates EHP. However, the authors did not show where and how much the reduction in evaporation occurs. Is it mainly over the NIO, due to SST cooling? Increased monsoon surface wind over the NIO from increased rainfall over India due to EHP could increase evaporation. As shown in previous studies (e.g. Lau and Kim 2006, 2010, Meehl et al, 2008), increase rainfall in northern India in late spring or early monsoon due to EHP can result in increased cloudiness, leading to surface cooling, and weakening of the monsoon in later stages. Hence the SDM effect may not be all aerosols, but amplified by cloud feedback. Including a discussion of this effect will be helpful.

3. The authors show TOA and surface aerosol radiative forcing. For EHP, strong radiative heating of the atmosphere is essential to excite the large scale circulation, moisture and latent heating feedback processes. It is more instructive to show in Fig. 3-6, the atmospheric heating , i.e., difference in TOA and surface, to indicate changes in potential for EHP initiation as a function of the season. In Fig. 7-8, the tropospheric temperature anomalies should also be shown to see if the change in rainfall is consistent with the change in the tropospheric merdional temperature gradient, which is the key to drive the monsoon and with direct linkage to EHP, more so than SST gradient. Any SST or surface thermal gradient has to be translated into tropospheric temperature gradient to drive monsoon wind and rainfall changes. Additional analyses along these lines, will greatly help the reader to understand the model results.

4. The discussions for Fig. 9 in Section 5 (P.18040) are very confusing. From Fig. 9b, it is obvious that absorbing aerosol has the largest effect in increasing rainfall in June through August, when cloud activation is included. The effect absorbing aerosol seems to be even stronger than the modified SST. According to the caption, the plot is for all-India (5-35N) rainfall. But a following statement states that total rainfall reduced by -20% in northern India due to modified SST. Is it all-India or northern India?. The next statement on the lack of statistical significance of the JJA rainfall seems to contradict or weaken the conclusion of reduced rainfall due to SDM is more important than EHHP. Then the following statement said that absorbing aerosols increases rainfall EHP with 97% significance suggesting the robustness of EHP in the model response. Yet, this result is not reflected in the conclusion or in the abstract. From observations (Lau and Kim 2010), EHP should be more effective in northern India in late spring and early summer, and over northern India. I would like to see a plot of rainfall change similar to Fig. 9b, but for northern India, i.e., (20N-35N).

5. They authors attribute the increased in aerosols and precipitation in July as a hygroscopic growth in aerosols associated with increased in humidity in July, but the increase can also be due to increase southwesterly monsoon flow, bringing more moisture and dust to northern India. These effects should be further examined from the model outputs.

6. It will be very helpful to better understand the model results, if the authors could show model AOD spatial distribution and compare with MODIS observations. For proper simulation of EHP, realistic distribution in space and time of increased aerosol in northern India piling up against the Himalayas is essential. Coarse resolution model will have problems simulating realistic distribution of AOD over India. This could be a reason of the SDM over-compensating EHP in the present model results. A discussion of the inability of coarse model resolution to resolve topography effects in transporting and trapping aerosols over the Indo-Gangetic Plain will be very useful.

William K. M. Lau