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Atmospheric Chemistry and Physics
Discussions

Interactive comment on "Investigation of the "Elevated Heat Pump" hypothesis of the Asian monsoon using satellite observations" *by* M. M. Wonsick et al.

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Response to Review of Manuscript ACP-2013-44

We thank the Reviewer for his insightful comments and recommendations. First, a general comment on the key point raised in the Review.

We fully agree with the Reviewer that the "Indian monsoon is very complicated, multi-scale phenomena, and there are a lot of known strong climate factors other than aerosols". The Reviewer continues: "To filter these signals and show aerosol-induced signal we need more cases, not less". Indeed, since many scales are involved, it is not

possible to resolve all existing issues whether one uses 2 contrasting years of aerosol loading or 4 such years. In what follows, we will respond to each comment in more detail.

Reviewer Comments

1) EHP is originally established based on modeling study. Lau and Kim (2006) was the first observational evidences supporting the EHP, based on composite analysis of four high AOD years and four low AOD years over northern India. On the other hand, Wonsick et al. (2013) used only two high and low AOD years to make composite. The authors' justifications are (a) the data used in their study has higher temporal and spatial resolution, and (b) the smaller higher contrast is better because the predicted patterns should be evident during extreme aerosol years. First of all, the benefit of higher spatial, temporal resolutions is minimal when monthly mean is used for analysis. Higher temporal, spatial resolution could be beneficial if the data is used to look at EHP related patterns over high terrain area of the southern slope of the Tibetan Plateau. Second, more importantly, I cannot agree with the authors' argument that smaller, strong case provide better, clear signal. Indian monsoon is very complicated, multi-scale phenomena, and there are a lot of known strong climate factors other than aerosols. To filter these signals and show aerosol-induced signal, we need more cases, not less. LK06 used four cases, and Wonsick et al. (2013) used two cases. I do not see how composite with smaller cases can do better than that with more cases.

Authors Response

The use of a shorter record for analysis was not an arbitrary choice. Our intention was to use data of best quality and relevance to the EHP issue; these came from a later time period than the one used in the modeling study of Lau and Kim (2006) (hereafter, LK06). In principle, in a model any time period can be simulated (LK06 were also limited by the availability of the Aerosol Index (AI)). We were limited by the short period of overlap between MISR aerosol data (considered of high quality) and cloud/convection information derived from Meteosat-5 that was moved to that region in 1998 in support of INDOEX and replaced in 2006 by Meteosat-7. The processing of six years of high resolution Meteosat-5 data was a formidable effort that required inference scheme development and implementation and resulted in a wealth of unique information very relevant for addressing the EHP hypothesis. In our analysis, we looked at the behavior during individual years to see if the predicted patterns appeared under high aerosol and are absent during low aerosol conditions. We show some results for individual years and some for a composite of high aerosol years (to reduce the number of figures). We wish we had more years to analyze, but we believe there is insight to be gained from the analysis using what is available.

As to the comment: “Indian monsoon is very complicated, multi-scale phenomena, and there are a lot of known strong climate factors other than aerosols To filter these signals and show aerosol-induced signal, we need more cases, not less. LK06 used four cases, and Wonsick et al. (2013) used two cases”, it seems there is some flexibility in the interpretation of what are high and low aerosol cases. For instance, the high-aerosol years, 1988 and 1991 (LK06) have significant levels of aerosols in the IGB with an AI of 3 or more. Of the low-aerosol years, 1982 and 1983 have AI values less than 2 in the IGB. The remaining 2 years in each category are less extreme, with an average AI value between 2.25 – 2.50. Since the TOMS AI is more sensitive to aerosol loading at the upper levels than near the surface (Herman et al., 1997; Torres et al., 1998), examination of the EHP hypothesis with independent high quality aerosol information that represents the total columnar content should be welcomed.

Regarding the spatial and temporal resolution, we believe that the 0.125o convection information is advantageous for showing details in the IGB and Himalaya foothills region as compared to the 1o model resolution.

Reviewer Comment:

2) For better comparison, I would like to suggest the authors to choose the same

season/month to compare with LK06. For example, LK06 used April-May to define AOD level, but Wonsick et al used MAM. Also, Wonsick et al. did not choose same months as LK06 for rainfall map and temperature anomalies.

Authors Response:

We selected months/seasons to analyze and display based on the original paper describing the EHP hypothesis (Lau et al. 2006), rather than attempting to replicate the LK06 study with different data sources. Lau et al. (2006) make very clear statements about the behavior they expect to observe during high aerosol years as a result of the EHP mechanism. We selected four verifiable features to look for, as stated in our Methodology section. We chose MAM to define high aerosol years because this is how Lau et al. (2006) describe the aerosol build-up in the IGB when discussing the aerosol optical thickness (AOT) pattern from the GOCART model in their Figure 1. They state:

”Two branches of AOT can be identifiedâĂŤthe southern branch over the Ganges Plain of northern India, along the southern slope of the TP and a northern branch on the northern slope of the TP. In the southern branch, carbonaceous aerosol is abundant beginning in late winter, and peaks in March and April. The sources are mostly from industrial pollution, as well as biomass burning over northwestern India and Pakistan. The carbonaceous aerosol is significantly reduced during the dry-to-wet transition period (May–June), due to the reduction of biomass burning, and wet deposition of airborne aerosols during the start of the wet season. Dust aerosols begin to build up over northern India in April–May, due to the increased transport of desert dust from the Middle East by low-level westerly flow from the Arabia Sea to India. In the northern branch, the aerosol consists primarily of dust transported from the Taklamakan Desert (400 N). Here, the dust loading builds up in March–April, peaks in May–June and declines towards the fall and winter. This distribution of absorbing aerosols is in agreement with observations from satellite derived aerosol optical thickness.”

Based on this description, the aerosol build-up occurs throughout March, April, and

May. We chose to look for the upper tropospheric temperature anomaly along the slopes of the Tibetan Plateau in April because Lau et al. (2006) state:

"As the near surface air over the elevated slopes of the TP gets warmer (relative to the air above), it is forced to rise by dry convection, producing a positive upper tropospheric temperature anomaly by vertical advection and mixing in the boundary layer over the TP in April–May (Fig. 4b, c)".

Figure 4b from their model simulation shows a pronounced upper tropospheric temperature anomaly along the slopes of the Tibetan Plateau in April, so we chose to look for the same.

LK06 chose to show the composite June-July rainfall in their observational study. We looked individually at frequency of occurrence of convection for the months of May through August derived from Meteosat-5, as well as the composite JJA rainfall from GPCP. We related the analysis for each month to statements made in Lau et al. (2006) regarding the expected patterns of rainfall in each month.

Reviewer Comment:

3) The authors used the frequency of occurrence of convection to compare with rainfall shown in LK06. There are correlated, but not the same since rain rate has strong regionality.

Authors Response

Indeed, convection is only a proxy to rainfall. Therefore, we also looked at rainfall information as available from GPCP. Figure 4 compares frequency of occurrence of convection derived from Meteosat-5 to GPCP rainfall. It shows similarity in the patterns, with more detail in the higher-resolution Meteosat-5 frequency distributions. In Figure 9 we show GPCP rainfall for JJA.

Reviewer Comment:

4) In section 5.1, the authors raised questions on the accuracies of model. This is a real issue. However, the differences among three modeling studies compared in this section are not necessarily representing the inaccuracies of modeling. All three models are different each other. However, I believe there are even bigger differences in aerosol species and optics used in each models. Some model does not have dust. Some has more absorbing aerosols than others. The authors also emphasize the importance of SST gradient (10138, lines 4-5). I don't think that the SST gradient between India and Indian Ocean is important to the monsoon. That could be just results of monsoon circulation (oceanic upwelling/downwelling, and mixing) and rainfall (evaporation). It is known that mid-tropospheric temperature gradient between the Tibetan Plateau and Equatorial Indian Ocean is driving force of Indian monsoon, not local SST gradient.

Authors Response

By "inaccuracies of modeling" we simply refer to the fact that there are known deficiencies in the ability of numerical models to accurately represent and simulate the Indian monsoon. We agree that the choice of aerosol representation and treatment of SSTs will affect the results.

We do not minimize the mid-tropospheric temperature gradient between the Tibetan Plateau and Equatorial Indian Ocean as a driver of the Indian monsoon. However, previous studies have also pointed to the importance of the SST gradient. Here are some comments from Bollasina et al. (2008) regarding the impact of the SST gradient on the Indian monsoon:

o Ramanathan et al. (2005), using a coupled ocean–atmosphere model with aerosols over South Asia prescribed according to measurements, found that, while aerosol absorption of solar radiation and consequent heating of the atmosphere leads to enhanced upward motion over India during winter, it also leads to a weakening of the monsoon circulation and a reduction of rainfall over India during summer. The latter effect was attributed to the aerosol-induced decrease of the meridional SST gradient in the Indian Ocean, with a consequent cooler trend of SSTs in the northern Indian Ocean than in the southern part.

o Meehl et al. (2008) also used a coupled climate model, but with a time-evolving global distribution of BC aerosols (with all the other natural and anthropogenic forcings fixed to their preindustrial values), to investigate the effects on the Indian monsoon. A present-day distribution of BC was generated by assimilating satellite retrievals of optical depths and using a chemistry-transport model. They found that BC aerosols lead to an increase of pre-monsoon rainfall over India but to a decrease in the monsoon season, with season-averaged break monsoon conditions associated with cooler SSTs in the Arabian Sea and the Bay of Bengal and warmer SSTs to the south (i.e., a weaker latitudinal SST gradient), confirming the findings of Ramanathan et al. (2005).

Interactive comment on Atmos. Chem. Phys. Discuss., 13, 10125, 2013.