## Response to reviews

We thank the reviewers for their detailed review of our manuscript and we enclose point-by-point replies below. We have marked reviewer comments in italic font.

### Anonymous Referee #1

Received and published: 26 January 2015

### General comments:

*Guo et al., 2014 discuss the anthropogenic aerosol emission impacts on South Asian monsoon rainfall using climate modelling. The manuscript addresses a region of clear low bias in simulating rainfall in the models and tries to address the rainfall trends in terms of aerosol effects. The focus is on the difference in rainfall response between models parameterising direct aerosol effects and those also including indirect effects. Even though the role of aerosols on Asian summer monsoon rainfall trends are previously reported in the literature (e.g. Bollasina et al., 2011; Salzmann et al., 2014), the analysis of difference between direct vs. indirect aerosol effects could be very useful for the scientific community.*

We thank the reviewer for noting the novel aspects of our work and how useful it may be to the scientific community.

*The paper is generally well written and the findings are quite interesting. Recent studies showed that only few models are parameterized both albedo vs. lifetime aerosol indirect effects in the CMIP5 simulations. Recent studies also pointed out that convective rainfall play a dominant role in the simulated total precipitation in most of the CMIP5 models. These points need to be addressed in the manuscript. The findings from the current study are not well described in the context of several other CMIP5 studies. The following comments should be addressed before the manuscript would be satisfactory for publication in ACP.*

We address these comments in our point-by-point responses below.

### Specific comments:

*1) Authors suggested "aerosol forcing has been playing a dominant role on drying rainfall trend over South Asia". Salzmann et al., 2014 showed that the drying rainfall trend in Northern India in part be explained by internal variability. It could be useful if authors can provide some quantification aerosol forcing vs. natural/ internal variability (instead of "dominant role").*

The South Asian monsoon does undergo variations on decadal time scales, for example related to the Pacific Decadal Oscillation (i.e. long-time scale oscillations in the tropical Pacific SST). However, the design of the CMIP5 historical experiments of the 20th century (those used in our study) is such that they are not initialized to ocean conditions. Therefore any variations in the PDO (and the response of the monsoon to the same) in the CMIP5 models will not be in phase either to observations, or each other. The multi-model ensemble mean approach that we have used means that we will emphasize the variations in the monsoon common to all models (or to a particular experiment) and other variability (noise) will be smoothed out.

In an individual model or the observed system, a given phase of decadal variability can of course act to enhance (or counteract) the effects of a large-scale near-monotonic driver of change.

We note that even in Salzmann et al. (2014), consideration over the South and Southeast Asia wider domain showed the dominance of aerosols on the monsoon. A direct result of our paper is that for a small region such as northern India, averaging two distinct groups of models together results in weak signals (noise). That is, our Fig. 3 shows that where aerosol effects are weak (only direct effects are included, Fig. 3b) then the monsoon responds more to GHG increases and gets wetter. When the aerosol effects are strong (indirect effects are included, Fig. 3c) then a negative forcing is exerted on the monsoon rainfall.

We have added a relevant statement in Section 3.1, which discusses Fig. 1a.

"…We note that recent studies, e.g., Salzmann et al. (2014) have argued that the model internal variability can play as important a role as aerosol forcing over central-northern India. The South Asian monsoon does undergo variations on decadal time scales, for example related to the Pacific Decadal Oscillation (PDO). However, the design of the CMIP5 20th century historical experiments is such that they are not initialised to ocean conditions. Therefore any variations in the PDO in the CMIP5 models will not be in phase either to observations, or each other. The multi-model ensemble mean approach that we have used means that we will emphasise the variations in the monsoon common to all models and other variability will be smoothed out."

*2) Aerosol-cloud interaction processes are parameterized differently in all the indirect effects included CMIP5 models. How the inter-model differences in aerosol indirect effect parameterisation (albedo vs. lifetime) will affect the rainfall trend response over South Asia? It could be useful if authors can provide some insight into this issue over South Asia. It is not clear from the Table 1 that the whether aerosol albedo and the lifetime effects are parameterized in the indirect effect included CMIP5 models. Table1 from Salzmann et al. (2014) shows that only few models are parameterised/included both albedo and lifetime effects in the simulation. This will be useful for interpreting the findings. Also note that GISS-E2-R model included the albedo effects.*

The various different indirect effects of aerosol are interesting and may differ in the degree to which they affect the South Asian monsoon. However, as the reviewer states, aerosol indirect effects are represented in very different ways in the CMIP5 models. Some models include aerosol-cloud interactions for both warm cloud and ice clouds, but most of the CMIP5 models include aerosol-cloud interactions only for warm clouds. Similarly, though some models represent aerosol-cloud interactions with both convective cloud and stratiform cloud, aerosol-cloud interaction in other models operates on interactions with stratiform cloud only. When we embarked on our study, we did separate models with indirect effects into two subgroups: those representing the 1st indirect effect only and those parameterising both 1st & 2nd indirect effects. However, this further subdivision reduces the sample size of each group to an unacceptable level.

We are currently performing several experiments in a single-model framework to understand the role of different aerosol effects on the monsoon in a more detailed manner; the results of these new experiments will be published in a future work.

We thank the reviewer for bringing the GISS-E2-R issue to our attention. For further discussion about model inclusion, please refer to Appendix I attached at the end of this reply.

*3) Recent study showed that the CMIP5 models fail to simulate the post-1950 decreasing trend of monsoon rainfall (Saha et al., 2014). The failure of representing large-scale changes caused this issue in most of the CMIP5 models. Only 8 out off 48 CMIP5 models used is able to capture the monsoon rainfall features (Saha et al., 2014). This indicates that skill of simulating Asian summer monsoon is very poor in most of the CMIP5 models. Authors need to comment if models are poor in simulating essential features, how much reliable the model-simulated impacts of 20th century aerosol emissions on rainfall trends.*

It is by no means clear that reproducing the observed trend in a phenomenon is a suitable first-order metric of whether a model can successfully simulate that phenomenon. Contemporary studies judging the skill of models in simulating the Asian monsoon tend to focus on features more directly connected to the mechanisms involved, such as the mean rainfall pattern (its strength and distribution) and the seasonal cycle, as well as other aspects of variability (e.g., Annamalai et al., 2007; Sperber et al., 2013). This is counter to the reviewer’s suggestion that reproducing the observed trend is the first-order metric of a model’s success.

Indeed, in order to interpret any trend, we must consider its drivers, and if those drivers are being successfully simulated. There is little doubt that when we consider idealised future scenarios out to the end of the 21st century (such as doubled CO2 concentrations), or even the IPCC-style economics scenarios (such as SRES or now the RCP), then monsoon rainfall is shown to increase (e.g. see the review in Turner and Annamalai, 2012). Inherent in these scenarios is the dominance of greenhouse gas forcing and relatively low aerosol, and we also have good theoretical arguments to link warming with increased moisture supply to the monsoon. Thus, the lack of increasing monsoon rainfall towards the end of the 20th century under such global warming conditions, and indeed the presence of a weakening of the monsoon, was regarded as puzzling (Goswami et al., 2006).

Our study, and several others that we cite, in fact offers an explanation for differences in the ability of global models to simulate the trend alluded to by the reviewer. The suggestion is that anthropogenic aerosols, particularly scattering aerosols such as sulphate, are acting to counter the effects of warming over South Asia, and even override them. Their emissions and burdens over South Asia and the northern hemisphere have increased strongly since the mid-20th century. There are no other known mechanisms by which the monsoon can decrease. The point of our paper is thus that it is only the CMIP5 models that most faithfully represent aerosol processes (including both direct and indirect effects) that can capture this declining rainfall trend. Without the indirect effect, a model can thus not truly represent the full magnitude of negative radiative forcing. Our study is thus consistent with the reviewer's suggestion that only some models are able to capture this trend. In fact, our own analysis of other studies such as Ramesh and Goswami (2014) and Saberali et al. (2014) suggests that the few models that do reproduce the observed trend do contain indirect effects of aerosol.

*4) Stevens et al., 2013 mentioned that "In implementing the new-aerosol climatology to the MPI-ESM-P model, a data-formatting error led to a somewhat weaker anthropogenic aerosol forcing than was foreseen in the original data set, with the effect most pronounced over the heavily populated regions of the northern hemispheric continents." See section 3.5 in Stevens et al., 2013. It is better to avoid this model from the analysis or mention in the paper.*

We thank the reviewer for bringing this to our attention. It is MPI-ESM-LR used in our study. It was a typo in our previous manuscript. This issue, according to Stevens et al. (2013), commonly exists in MPI-ESM models. However, Stevens et al. (2013) pointed out that this formatting error only has a limited impact. Therefore, we decide to keep MPI-ESM-LR in our analysis.

For more information, please refer to our statement about CMIP5 model inclusion at the end of this reply.

*5) In the Conclusion section, authors discussed about the increases in monsoon rainfall in future CMIP5 projections. Sabeerali et al., 2013 found that most models produce too much (little) convective (stratiform) precipitation compared to observations. Is a too strong aerosol effect causing this issue? Better to add remarks on this issue in current context of the work. Whether aerosol indirect effects are enhancing the convective rainfall in the model?*

In fact, studies have shown that once aerosol-cloud interactions are included in GCMs, then both marine stratiform clouds and stratiform precipitation have been improved (Wood, 2012). This again suggests that inclusion of aerosol indirect effects leads to a more faithful representation of the physics involved. Our search of previous studies of the interaction between aerosol indirect effects and convection suggests that they are generally performed using radiative-convective equilibrium models or large-eddy models, and there have been no consistent conclusions to support the viewpoint that aerosol indirect effects are enhancing convective rainfall in models.

Looking in more detail, the representation of aerosol-cloud interactions vary from model to model. For many models, the aerosol-cloud interactions apply only to stratiform clouds in any case and not convective clouds. In theory, with more aerosols to act as cloud condensation nuclei (CCN), which reduces drizzle, stratiform precipitation can be reduced.

We also note that caution must be used in interpreting the comparison between modelled convective and “large-scale” rainfall with the convective and stratiform rainfall measured by products such as TRMM.

*6) Whether aerosol effects have any role in the reported stronger precipitable water-precipitation relationship in most CMIP5 models (Sabeerali et al., 2013)?*

We thank the reviewer for their comment, but as we mentioned in our response to comment 5, above, there is no direct evidence to support an aerosol influence on the strong relationship between precipitable water and precipitation seen in CMIP5 models.

**Technical comments:**

*(1) Page 30641, Lines 4-7: Whether the simulated aerosol distributions (aerosol optical depth, column burden) are too high over China? All the CMIP5 models are very poor in the simulating the aerosol-distributions over South Asia, especially Indian region. If the emissions are large enough, then aerosol distribution or deposition should be wrong. Rewrite the sentence.*

There is certainly large uncertainty in measurements of natural and anthropogenic aerosols over South and East Asia (especially complicated during the monsoon season when remote sensing measurements may be unreliable due to cloud cover). Thus it is very difficult at present to assess the CMIP5 model skill at simulating these distributions. However, observations do indicate that the strongest aerosol burdens in South Asia are found in the northern plains region, closest to the Himalayas. This is consistent with the common aerosol emissions used to drive the CMIP5 models, and our resultant multi-model mean of sulphate and black carbon aerosol loading shown in Fig. 5a,b.

However, regardless of the agreement with observations, the multi-model mean aerosol loadings over China are much stronger for sulphate (approximately double) as shown in Fig. S1 below (and added as Fig. 6 to the new paper). This helps inform our closing hypothesis that aerosol loadings may be large enough over China for the direct aerosol effect to act alone in weakening East Asian monsoon rainfall, and warrants further investigation

New text has been added in the conclusions and discussions, please refer to reply to technical comment (5).

*(2) Page 30642, Lines 18-19: "Maximum concentrations are found pushed up against the foothills of the Himalayas" Whether this is true in monsoon season?*

We have re-phrased the sentence. However, we note while monsoon rains are expected to reduce the aerosol burden, even during the monsoon season the strongest loadings are found there (e.g., in the MODIS and AERONET measurements of Lau et al., 2008). Irrespective of the time of year, the northern region remains the strongest emitter of anthropogenic aerosols. As we showed in Fig. 5 of the original submission, during the monsoon (JJAS) season, the strongest aerosol loads of sulphate and black carbon are present up against the Himalayas and over the northern plains of India. The sentence has been rephrased as:

"Maximum concentrations are found pushed up against the foothills of the Himalayas in the northern plains of India during pre-monsoon season (Lau et al., 2006), and remain strong during June and July (Lau et al., 2008)."

*(3) Page 30645, Lines 15-24: The MME-mean will miss out the individual ensemble run features. The ensemble members simulate rainfall trends very differently (positive vs negative) over South Asia (Salzmann et al., 2014). How well these issues are addressed in the reported mean trends?*

We thank the reviewer for their comment, but as we explained in the manuscript we have already been careful to test the robustness of the multi-model mean against noise, given the sample size involved. As we stated in the original manuscript, "To demonstrate that the signal from the MME-mean is robust, we apply permutation and binomial significance tests." Thus for the time series analysis we have used permutation tests consisting of 10,000 realisations, while for the spatial pattern-of-change maps we have used the binomial significance test. This clearly demonstrates a robust positive (negative) rainfall change over northern India when direct-effects only (indirect and direct effects) are used in models.

*(4) Page 30656, Lines 25-27: This is a broader view. Better to discuss this issue in the context of the reported dominance of convective rainfall in future CMIP5 projections (Sabeerali et al., 2013).*

As stated elsewhere in the response to reviewer comments, there is little evidence to support the role of aerosols in the dominance of convective rainfall. Thus our position stands that if aerosols emissions do not decline to the extent as prescribed in the RCPs, then future increases in monsoon rainfall related to greenhouse gas forcing may not come to fruition.

*(5) Page 30656, Lines 3-5: How well the clouds are simulated over China vs. South Asia?*

The distribution of cloud is particularly important for low cloud, since low cloud and aerosol loadings need to coincide in order for the indirect effects of aerosol to operate and exert further negative radiative forcing on the surface.

To explore this, we have added an additional figure, Fig. 6 in the paper and also reproduced as Fig. S1 in our response below. This is identical to the sulphate/black carbon aerosol loadings, low-cloud cover and cloud-droplet number change shown for South Asia in Fig. 5, but instead for the East Asia domain. A similar discussion to that below has been added to the conclusions.

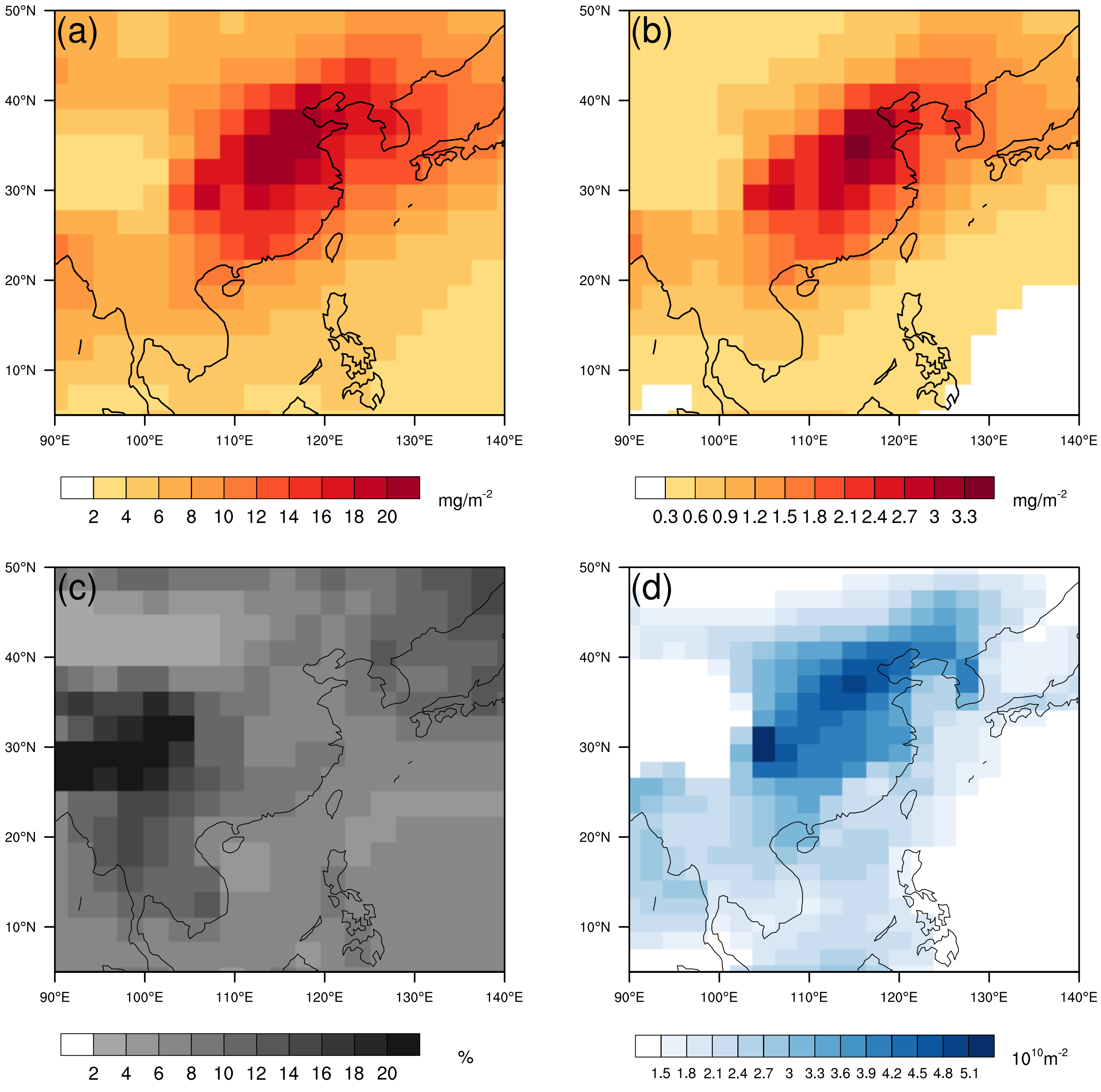
Figure S1a,b show that for both sulphate and black carbon, heavy aerosol loadings are located over eastern and southern China, consistent with large anthropogenic emissions. While the loading of black carbon is broadly the same as for South Asia (comparing Fig. S1b and Fig. 5b), the loading of sulphate aerosols over China is approximately double that of South Asia (comparing Fig. S1a and Fig. 5a). This supports the hypothesis we make in our conclusions, that the aerosol burden over China may be large enough that even including only the direct radiative effects of aerosol is enough to weaken rainfall over China during summer.

Fig. S1 reveals further interesting features. The maximum low-cloud cover during summer is situated over southwest China at the lee-side of the Tibetan Plateau (the Sichuan basin), consistent with observations. This is the region within the East Asia domain in which we note the strongest increase in cloud droplet number concentration, due to the overlap of high sulphate aerosol loads and low-cloud cover.

Over much of central and southeast China (where rainfall declines the most as in Fig. 3) there is weak low-cloud cover and thus the indirect effect is likely to make little difference (e.g. compare Fig. 3b,c). This configuration of low-cloud and aerosol loading over China is different from that over India.

Related discussion has been added to the conclusions of the new paper as:

"… Figure 6a and b show that while black carbon loading over China has a similar magnitude to that over India (comparing Fig. 6b and Fig. 5b), the sulphate loading over China is as twice large as that over India (comparing Fig. 6a and Fig. 5a). This supports the hypothesis we make here that the aerosol burden over China may be large enough that even including only the direct radiative effects of aerosol is enough to weaken rainfall over China during summer. Figure 6 reveals further interesting features. The maximum low-cloud cover during summer is situated over southwest China at the lee-side of the Tibetan Plateau (the Sichuan basin), consistent with observations. This is also the region in which we note the strongest increase in cloud droplet number concentration, due to the overlap of high sulphate aerosol loads and low-cloud cover (Fig. 6d). Over much of central and southeast China (where rainfall declines the most in Fig. 3) there is weak low-cloud cover and thus the indirect effect is likely to make little difference (e.g. compare Fig. 3b and c). This configuration of low-cloud and aerosol loading over China is different from that over India."



*(6) The following references are not cited in the manuscript.*

*Saha, A., S. Ghosh, A. S. Sahana, and E. P. Rao (2014), Failure of CMIP5 climate models in simulating post-1950 decreasing trend of Indian monsoon, Geophys. Res. Lett., 41, 7323–7330, doi:10.1002/2014GL061573.*

*Sabeerali C.T., et al (2014), Why ensemble mean projection of south Asian monsoon rainfall by CMIP5 models is not reliable?, Clim. Dyn., August 2014, DOI 10.1007/s00382-014-2269-3.*

*Salzmann, M., H. Weser, and R. Cherian (2014), Robust response of Asian summer* *monsoon to anthropogenic aerosols in CMIP5 models, J. Geophys. Res. Atmos., 119, 11,321–11,337, doi:10.1002/2014JD021783.*

We thank the reviewer for alerting us to these additional citations. These references have now been cited in this study as indicated below.

We have modified a statement in our introduction to: “However, even the current generation of state-of-the-art coupled ocean-atmosphere models participating in the Fifth Coupled Model Intercomparison project (CMIP5) suffer large biases in the region (Sperber et al., 2013) likely due to poor parametrizations and entirely missing processes, in addition to poorly representing observed trends in monsoon rainfall when taken as a whole (Saha et al., 2014; Sabeerali et al., 2014; Salzmann et al., 2014). ”

**Anonymous Referee #2**

Received and published: 2 February 2015

*The manuscript makes use of CMIP5 all forcing and individual forcing historical experiments to identify the contribution of anthropogenic aerosols and their direct/indirect effects versus greenhouse gases to the pre-industrial to present-day long-term variation of the South Asian monsoon precipitation. Anthropogenic aerosols are found to dominate the recent precipitation decline. The indirect effect is key for models to simulate the negative precipitation trend, as the direct effect would lead to increase precipitation over India.*

*The topic is of great interest, as the Indian monsoon is very important for the livelihood of a substantial fraction of the world population. The manuscript is well written and presents some interesting points on the uncertainties in the simulated precipitation trends. Yet, the decrease of monsoon precipitation has been recently discussed in numerous papers (e.g., to mention the latest, Salzmann et al., JGR, 2014; Polson et al., GRL, 2014; Saha et al., GRL, 2014; Ramesh and Goswami, Nature, 2014; Wang et al., Adv. Met., 2014). These studies have discussed potential driving mechanisms, uncertainties in the trend and among various forcing agents, comparison with observations, links with other monsoonal systems, etc.*

*Along the above point, my major concern is that, unfortunately, the manuscript does not show sufficient novel findings (compared to previous literature) that would lead to a substantial improvement of our understanding of this controversial issue. The improvement is needed before the manuscript can be acceptable for publication.*

We thank the reviewer for their thorough reading of our manuscript. The reviewer clearly acknowledges that there is great scientific interest in the topic as well as important societal impacts. Other studies have clearly examined both the trends in monsoon rainfall, the role of aerosols, and model reliability. However none of these studies look in detail at the role of aerosol. For example, Polson et al. (2014) examine only the northern hemisphere monsoons as a whole, in a smaller subset of models that run experiments for single forcings (fewer than the 8 models we use in Figure 1, since they exclude HadGEM2-ES). They also did not look at the comparison between aerosol indirect and direct effects. A key novel aspect of our study is that comparison, in addition to describing the combination of hemispheric-wide aerosol drivers (northern hemisphere negative radiative forcing and relative weakening of the NH monsoons) and local effects (particularly relevant given the strong aerosol loading local to the northern plains of India).

Other studies such as Ramesh and Goswami (2014, in Scientific Reports, not Nature) discuss the ability of models at monsoon simulation. But it is exactly our contention that CMIP-class models will be unable to reproduce observed long-term variations in the monsoon unless they faithfully represent the full breadth of aerosol effects.

We further note that the first reviewer states that the indirect-versus-direct comparison is a novel aspect of our work.

**Other comments:**

*(1) What about observations and observed precipitation trends? In this respect, what is the relationship (e.g., spatial patterns) with the changes in the recent decades?*

In our study, we try to understand the change of Indian Summer Monsoon rainfall from pre-industry period to present-day when both GHGs and anthropogenic aerosols are heavily emitted (please refer to our descriptions in the section of methodology). Therefore, there is not any gridded observation that can be used to confirm CMIP5 simulations.

The observed pattern of rainfall trend has considerable similarity with the indirect pattern of change shown in our Fig 3c. The best examples can be seen in Krishnan et al. (2013) and Bollasina et al. (2011). Reliable mapped observations are only available for India since the 1950s. Krishnan et al. (2013) compares 1-degree gridded Indian Meteorological Department data with that from the 0.5-degree APHRODITE dataset (both using only gauges). These both suggest that central-northern India has undergone a drying trend since the 1950s. Further, Bollasina et al. (2011, their supplementary material) compared spatial trends in four datasets (including the IMD), and while there is some uncertainty, all showed significant negative rainfall trends over the central/northern region (76°-87°E, 20°-28°N).

Therefore the significant rainfall decreases shown in the second half of the 20th century in our study (Fig. 1a and Fig. 2a) are consistent with these observed trends. Furthermore, our argument states that one must parametrize the full range of aerosol effects in order to capture the observed trend (i.e., in order that the monsoon responds correctly to anthropogenic aerosol forcing). This is demonstrated in our spatial map of Fig. 3c, showing particular agreement with the negative trends in northern India only when direct and indirect effects of aerosols are modelled.

*(2) The monsoon underwent multi-decadal fluctuations during the 20th century. The models also show this, though the fluctuation is not as evident as in observations. Is a century-long linear trend appropriate?*

The reviewer is quite correct that decadal monsoon variability is simulated in CMIP-class GCMs (e.g., see the variations shown for four models in Turner and Annamalai, 2012). However, an important distinction is that the model experiments used here (the 20th-century historical experiments, under all or a variety of emissions forcings) are uninitialized. That is, they were not initialized from to the observed ocean state in ~1850. This is unlike the experiment design of the CMIP5 decadal hindcast experiments, for example. Thus there is no reason to expect that 20th-century model integrations from different modelling groups, or even multiple realisations of a single model, should simulate long-term oscillations such as the PDO or AMO in phase either with observations or each other. (The PDO and AMO are both known to influence the monsoon on decadal time scales.)

It is unnecessary to consider a century-long trend since much of the anthropogenic aerosol forcing has occurred in the Asian monsoon region following rapid industrialisation since the 1950s. Our approach thus chooses two time-slices during the pre-industrial and post-industrial periods for its spatial trend analysis, representing before and after the aerosol emissions.

*(3) The importance of model biases, which likely will affect their skill in simulating precipitation changes, would need to be discussed.*

Several studies have pointed out the importance of a model being able to simulate aspects of the mean monsoon rainfall distribution, seasonal cycle, and various modes of variability (e.g., Annamalai et al., 2007; Sperber et al., 2013), and further that these aspects should be simulated in order to make reliable future projections of monsoon rainfall (Turner and Annamalai, 2012). We have already referred to the latter two of these studies in the manuscript, but we now add the additional statement in the conclusion that, "Therefore, we can have more confidence in future projections experiments obtained from model experiments if the present-day simulations perform well at simulating the mean monsoon, its seasonal cycle, and variability (Turner and Annamalai, 2012; Ramesh and Goswami, 2014; Sabeerali et al., 2014). "

However, an important major finding of our study is that models will only be able to simulate the observed drying in monsoon rainfall if they simulate both the direct and indirect effects of aerosol. Otherwise the response of the monsoon to anthropogenic aerosol will be too weak.

*Are there differences between 1st and 2nd aerosol indirect effects?*

There are likely to be differences in the response to 1st and 2nd indirect effects of aerosol, and in the relative importance of each effect in different regions. However, CMIP5 models currently simulate these effects in very different ways, or not at all. The only way to test this simply would be to split our group of CMIP5 models simulating indirect effects into further categories: those parameterising only the 1st indirect effect; and those including both effects. This would reduce our sample size even further and make results inconclusive. We are currently running a range of single-model experiments to explore these details in a future study.

We also refer the reviewer to our response to the 2nd specific comment of reviewer 1.

## Appendix I. Other changes made: Model inclusion

GISS-E2-R: Thank you to Reviewer #1 for reminding us that this model includes aerosol indirect effects. However, strictly speaking, the GISS-E2-R runs used here (p1) is not qualified as a aerosol indirect effects included run. According to Miller et al., (2014), both aerosol mass and aerosol indirect effects are prescribed in this run. We realise that it is equally inappropriate to put GISS-E2-R into the group of model that has direct-only aerosol effect. Therefore, we exclude this model from our multi-model analyses.

MPI-ESM-LR: We thank the reviewer for bringing this to our attention. However, Stevens et al. (2013) pointed out that this formatting error only has a limited impact. Therefore, we decide to keep MPI-ESM-LR in our analysis.

CESM1-CAM5: We have been contacted from the CESM team to inform us that CESM1-CAM5 includes aerosol indirect effects, though it is not indicated in the metadata of output. A correction has been listed on their errata (please refer to http://www.cesm.ucar.edu/CMIP5/errata), and therefore CESM-1-CAM5 has been move from aerosol direct-only effect group to the model group including aerosol indirect effects. This has no bearing on the outcomes of our study.

## Further references

Lau, K. M., Kim, K. M., Hsu, C. and Singh, R. P.: Seasonal Co-variability of Aerosol and Precipitation over the Indian Monsoon and adjacent deserts, GEWEX News, 18, No. 1, 2008.

Miller, R. L., et al., CMIP5 historical simulations (1850-2012) with GISS ModelE2, J. Adv. Model. Earth Syst., 6, 441-477, doi: 10.1002/2013MS000266, 2014.

Wood, R.: Stratocumulus Clouds, Mon. Wea. Rev., 140, 2373-2423, 2012.