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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Increasing Arabian dust activity and the Indian Summer Monsoon" *by* F. Solmon et al.

Anonymous Referee #2

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This article makes two main points. First, it shows convincingly that dust emission perturbs Indian monsoon rainfall. The second claim is that a trend in Arabian dust emission during the previous decade accounts for a corresponding increase in Indian precipitation. The linkage of decadal trends between dust and precipitation in distant regions is imaginative and worthy of investigation, but its demonstration in the article's present form is incomplete. I would like to see more analysis and acknowledgment of uncertainty. I am recommending that the article be accepted subject to major revision.

Major points:

1. My biggest reservation concerns Figure 6 that shows interannual variations in Indian precipitation and AOD over the Arabian Peninsula (retrieved from the SeaWiFs instru-

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ment and the AERONET photometer at Solar Village). Both observed variables show general increases over the decade between 2000 and 2009. However, there is less agreement among interannual variations. For example, the Arabian dust concentration is unusually high during the last two years of the period, when Indian rainfall is trending downward. In addition, the precipitation variations show high autocorrelation, so there is the chance that some of the visual agreement may be the result of unrelated variations. The authors need to quantify this agreement, since this is central to the article (and especially the article title). They should compute correlations between the two variables for NH summer. This correlation is a key claim of the article and needs to be demonstrated. Furthermore, Figure 6 would be more effective at the beginning of the article, because it is the motivation for the calculations and analysis that follow.

The larger issue is that there are many drivers of regional precipitation, especially on interannual time scales, and it is not obvious why Arabian dust should have the dominant influence. The model's calculated trend in Arabian dust mobilization is small compared to that inferred from the observed AOD retrievals, so the authors carry out an additional experiment where they artificially increase Arabian dust. This raises the question of whether they could have reproduced the observed precipitation variations by artificially increasing the dust concentration over other sources, especially those within the Indian subcontinent itself, for example, within the Thar Desert or Indus Valley.

2. Uncertainty in dust radiative forcing: dust trends over the Arabian peninsula are inferred from retrievals of AOD either from satellite instruments or a single AERONET station at Solar Village. This retrieved AOD represents the influence of all aerosols, and not just dust. The authors attribute (line 53 and the article title) this AOD trend to dust mobilization, but without providing evidence. This is a key uncertainty that needs to be emphasized. (The authors should also check if other AERONET stations within the peninsula showed the same trends as Solar Village. This agreement would be expected if there really is a feedback between Indian monsoon anomalies and dust mobilization over the peninsula.)

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Even assuming that there is a decadal trend in dust AOD (and not just total AOD), the radiative forcing used to perturb the circulation in the regional model is highly uncertain, and this needs to be acknowledged because it can change even the sign of the precipitation anomaly, as shown in a nice article by the lead author in 2008. In summary, the perturbation to climate and precipitation depends upon the forcing which contains two different levels of uncertainty: the dust radiative properties like single scatter albedo, and the dust concentration itself that has an uncertain relation to the retrieved AOD. The authors need to give more emphasis to how this uncertainty affects their attribution of trends in Indian precipitation to Arabian dust.

3. There are many processes that potentially contribute to variations in monsoon precipitation, and the authors need to give more discussion to whether these might influence their modeled trends. For example, there are other aerosols in their model, including anthropogenic species. I don't think the prescribed emission of anthropogenic aerosols has any trend within the decade being simulated, but the authors should note this explicitly. In addition, the simulations with calculated dust mobilization (the 'dust' case) contain additional sources outside the Arabian peninsula, including within the Indian subcontinent. The authors should carry out an additional simulation that removes non-Arabian sources, or alternatively, a simulation that includes only non-Arabian sources. Otherwise, with the current experimental setup, it is impossible to attribute observed precipitation trends solely to Arabian dust.

Minor Comments:

5: replace 'implications' with 'impacts'?

12: 'has been a subject of intense study for the last decade.' Provide an example of a citation?

23: 'elevated heat pump effect' (Lau, et al., 2006)' The relevance of this mechanism to Indian precipitation has been questioned by Nigam and Bollasina, who should be cited:

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Nigam, S., and M. Bollasina (2010), “Elevated heat pump” hypothesis for the aerosolâĂŘmonsoon hydroclimate link: “Grounded” in observations?, J. Geophys. Res., 115, D16201, doi:10.1029/2009JD013800.

51: ’AOD linear trend reaching 0.014 yr-1 over the Arabian region’ How large is this trend compared to typical summertime values of AOD in this region?

63: ’Mahowald, 2007’. Yoshioka et al. 2007 should also be cited:

Yoshioka M, Mahowald NM, Conley AJ, Collins WD, Fillmore DW, Zender CS, Coleman DB (2007) Impact of desert dust radiative forcing on Sahel precipitation: relative importance of dust compared to sea surface temperature variations, vegetation changes, and greenhouse gas warming. J Clim 20:1445–1467.

91: ’(CORDEX)-India domain’. Is this domain large enough to see the effects of dust radiative heating? The length scale of influence, the Rossby radius of deformation, is especially large in the Tropics, and if the forced response extends to the model boundaries (where the circulation is prescribed via the lateral boundary condition), there may be artificial reflection. (This may be less of a problem if there is enough damping at the boundaries.) Rodwell and Jung QJRMS 2008 show that a change in Saharan dust radiative heating excites circulation changes as far downwind as India and the West Pacific.

MJ Rodwell, T Jung, 2008, Understanding the local and global impacts of model physics changes: An aerosol example. Quarterly Journal of the Royal Meteorological Society 134 (635), 1479-1497

114: ’Of particular importance for studying aerosol effects (Zhao, et al., 2011), we implemented for this study a flux corrected slab ocean parametrisation...’ In addition to citing Zhao, you should cite Miller et al who specifically considered the ocean representation and its effect upon the perturbation by Arabian dust to Indian monsoon rainfall.

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Miller, R. L., J. Perlwitz, and I. Tegen (2004), Modeling Arabian dust mobilization during the Asian summer monsoon: The effect of prescribed versus calculated SST, Geophys. Res. Lett., 31, L22214, doi:10.1029/2004GL020669.

133: 'In order to limit the effect of internal variability on our analysis of the aerosol feedbacks, we impose a small random perturbation in boundary conditions to every ensemble members during the run following (O'Brien, et al., 2011).' Please explain this in more detail. What happens if this perturbation is not added?

179: 'overestimate circulation intensity over the Bengal gulf and Indonesia.' What is the specific meaning of 'circulation intensity'?

181: 'APHRODITE data set' Was this data set introduced and described in the previous section with the other precipitation data sets. What is its resolution? Should it be preferred over the Indian subcontinent (line 188), where its indicates a lower model bias?

189: 'Comparison of Figure 2,b and 2, d,f,h shows that radiative effects of dust tends to reduce model biases over continental India southern and northwestern regions.' It should be noted, however, that dust increases the precipitation bias over the western Bay of Bengal.

Section 2.2: It should be noted explicitly that the only model quantity that can be directly compared to observations is the total AOD. This is important because the dust radiative forcing in the model depends upon additional assumptions. First of all, it depends upon the simulated dust distribution. The model may get the correct total AOD, while misestimating the contribution by dust. Are there any measurements that can be used to isolate the presence of dust in the observations? Ackerman et al 1982 provide older observations of dust radiative forcing and size resolved dust mass.

Ackerman, S. A. and S. K. Cox, The Saudi Arabian heat low: aerosol distribution and thermodynamic structure, J. Geophys. Res., $7, 8991-9002, 1982.

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Second, forcing depends upon the particle radiative properties like the single scatter albedo. The values assumed for this study needs to be specified explicitly (along with the citation from which they are derived), because this albedo is not well-constrained from observations, and models tend to use a wide variety of values, resulting in greatly varying forcing estimates given similar model AOD. The lead author here provides a good demonstration of this sensitivity for Saharan dust.

Solmon, F., M. Mallet, N.Elguindi,F.Giorgi,A.Zakey,andA.Konare ÌĄ(2008),Dust aerosol impact on regional precipitation over western Africa, mechanisms and sensitivity to absorption properties, Geophys. Res. Lett., 35, L24705, doi:10.1029/2008GL035900.

204: (Figure 3) the panels should be assigned letters to match the caption description. What is the difference of the RegGCM values in c and d? Also, satellites have trouble retrieving aerosols over bright surfaces and this can result in artificial gradients along coastal regions. How much uncertainty is there in these AOD retrievals? Wouldn't the study be improved by using the MODIS Deep Blue retrievals that are designed to detect aerosols over land?

267: 'On average, the Arabian and Indo Pakistanese dust sources appear to have a dual signature' How do you distinguish the separate effects of Arabian and local (e.g. Thar desert) sources on the perturbed circulation, given that their effects are always calculated together in the simulations?

290: 'Our work hypothesis is that, if the above mechanisms are valid, the observed increasing dust AOD trend over Arabia over the decade 2000-2010 might have been associated with a positive impact on circulation and precipitation over southern India.' Good correspondence of the (all-aerosol) AOD and precipitation time series is not obvious. For example, precipitation peaks in 2007, when the Solar Village aerosol loading is not particularly large. Moreover, AOD is higher in 2008 and (especially) 2009, when the precipitation seems to be on a downward trend. The authors should calculate the interannual correlation of summertime AOD and precipitation anomalies, and discuss

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this at the beginning of the article to motivate the experiments.

Figure 6 (caption): 'A quadratic regression fit, showing the progressive intensification of observed dust activity is superimposed (blue curve).' The Solar Village AERONET site retrieves the AOD from the combined effect of all aerosols. What is the basis for attributing the upward trend solely to dust?

Figure 6: Please explain whether the time axes of the two panels are comparable. The precipitation time series seems to stop before the AOD time series.

297 'JAS observed deseasonalized AOD are better represented by a quadratic vs linear regression' If this is true, why calculate linear trends in Figure 7?

334: 'These deficiencies are likely to be due to uncertainties in coupled convective and dynamical processes over northern Arabian Sea, Pakistan and Bengal gulf which are extremely challenging to capture properly in climate models (Turner, et al., 2012).' Alternatively, the underestimation of emission by Arabian dust sources could be due to circulation variability in the vicinity of dust sources that is not captured by the regional model?

345: 'On the JJAS AOD time series (Figure 5.a)' Figure 6a?

Figure 8: I agree with the authors that increasing Arabian dust emission creates a low over the Arabian Sea, but the onshore flow (bringing moist monsoon air onto the Indian subcontinent to supply precipitation) looks different between the regional model and the ERAI reanalyses.

379: 'Dust radiative forcing might determine a positive dynamical feedback'. This is possible, but it should be noted that the influence of the monsoon anomaly on dust mobilization is not demonstrated by the model experiments.

382 'The measured dust 2000-2009 AOD trends over Arabia and the Arabian Sea are equally if not more important as AOD trend reported for continental India and attributed to anthropogenic pollution increase (Babu, et al., 2013).' This is a key assertion of

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the article but the importance of dust needs to be demonstrated, because the Arabian peninsula AOD includes contributions from other aerosols.

Interactive comment on Atmos. Chem. Phys. Discuss., 15, 4879, 2015.